International Working Group on Crater Lakes Newsletter

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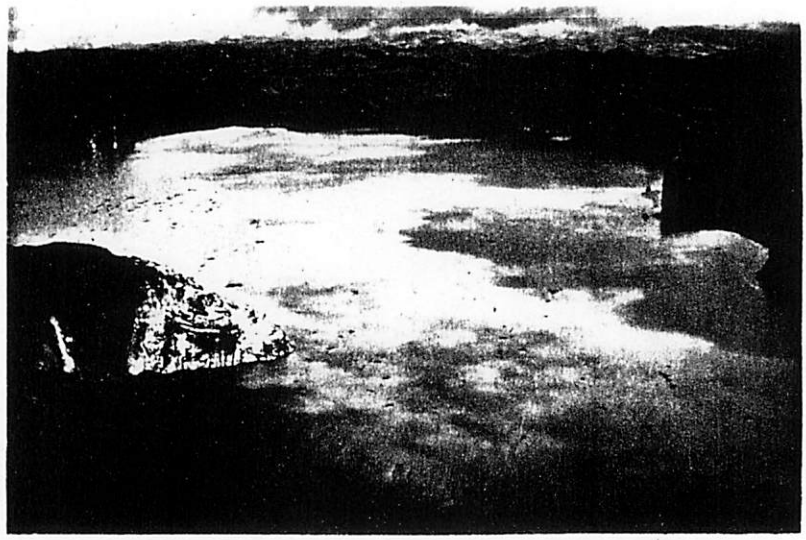
ISEI, Okayama University

Misasa, Japan

International Working Group of Crater Lakes

NEWSLETTER

No. 1 February 1989



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Editor: M. Kusakabe

Newsletter of the International Working Group of Crater Lakes

Minoru Kusakabe (ISEI, Misasa, Japan)

First of all, I apologize for a long delay of distributing this Newsletter.

Organization of International Working Group of Crater Lakes (IWGCL) was proposed soon after the 1987 Yaounde Conference on the 1986 Lake Nyos gas disaster. The main purposes of IWGCL are:

1. Communication between different researchers,
2. Organisation of international programme for the study of crater lakes including meetings,
3. Coordination of field measurements,
4. Standardization of reporting data, and
5. Joint development of instruments for crater lake survey.

This newsletter has been prepared to meet some of the above purposes, and includes (a) a preliminary list of members with addresses and subject(s) of interest, (b) a state of papers submitted to J.V.G.R. special issue related to the Lake Nyos disaster (compiled by F. Le Guern), (c) a short summary on the informal meeting of IWGCL held during the 1988 Kagoshima Volcano Conference, (d) a letter from J. Lockwood on the safety assessment of a natural dam at the northern rim of Lake Nyos, (e) a preliminary report on two Italian crater lakes by M. Martini, (f) a letter from S. Freeth on the proposal of a future international meeting on the Lake Nyos and related problems, (g) a short report on the recent visit to Cameroonian lakes by the Japanese team, and (h) application form to IWGCL.

Although the topics included in this issue of Newsletter seem to have been too much concentrated to the problems on Cemeroonian crater lakes, any other topics, notes, news and proposals on crater lake studies are welcome. Therefore, please do not hesitate to write to me anything appropriate to be circulated in the next issues of the Newsletter.

List of members of the International Working Group of Crater Lakes (as at November 1988)

Name	Institution	Subject(s) of interest
Allard, P.	Center des Faibles Radioactivites, CNRS, 91190 Gif sur Yvette, FRANCE	Stable isotopes and gas geochemistry.
Baxter, P.J.	Department of Community Medicine, University of Cambridge Fenners, Gresham Rd. Cambridge CB1 2ES, ENGLAND	Health effects, emergency planning. Medical planning for future release.
Casadevall, T.	U.S. Gelogical Survey, CVO 5400 MacArthur Blvd. Vancouver, Washington 98661 U.S.A.	Chemical evolution of crater lakes. Geological hazards associated with volcanic lakes.
Chevrier, R-M.	Conservatoire National des Art et Metiers, Chaire de Geologie Appliquee, 2, rue Conte, 75141 Paris, Cedex 03 FRANCE	Chemical evolution of lake waters.
Dietrich, V.J.	Institute for Mineralogy and Petrography Federal Institute of Technology (ETH Zurich) ETH-Zentrum, CH-8092 Zurich SWITZERLAND	Rock-gas-fluid interaction of alkalic basalts at high- and low pressures; generation of basanites and CO2 in the upper mantle.
Evans, W.C.	U.S. Geological Survey, WRD 345 Middlefield RD., M/S 434 Menlo Park, CA 94025, U.S.A.	Dissolved gases and their geochemistry.

Freeth, S.J.	Department of Earth Sciences, University College of Swansea Swansea, SA2 8PP UNITED KINGDOM	Tectonics, geophysics, geochemistry.
Giggenbach, W.F.	Chemistry Division, DSIR Private Bag, Petone NEW ZEALAND	Chemical surveillance of active volcanoes in NZ, Ruapehu Crater Lake, White Island Lake, etc.
Hall, M.L.	Instituto Geofisico, Casilla 2759, Quito, ECUADOR	
Hirabayashi, J.	Kusatsu-Shirane Volcano Observatory, Tokyo Inst. of Technology, O-okayama, Meguro-ku, Tokyo 152, JAPAN	Gas and water geochemistry of volcanic emanations. Volcanic gas hazards.
Kanari, S.	Dept. of Geophysics, Faculty of Science, Hokkaido University N10, W8, Kita-ku, Sapporo, JAPAN	
Kelts, K.	Federal Institute for Water Resources and Water Pollution Control, Associated with the Swiss Federal Institutes of Technology, CH-8600 Dubendorf-Zurich SWITZERLAND	Sedimentology and isotope geochemistry: Cameroon line; seismics and paleoclimate transect. Laachev see; siderite petrology Indonesia; paleoclimate from sediment record, stable isotopes of carbonates, gas and water.
Kling, G.W.	The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543, U.S.A.	Physical characteristics and mixing dynamics. Geochemistry of lake water and surrounding catchment. Diversity and community structure of plankton.

Kusakabe, M.	Institute for Study of the Earth's Interior, Okayama University, Misasa, Tottori-ken 682-02, JAPAN	Magmatic fluxes in crater lakes. Volatiles in volcanic rocks.
Le Guern, F.	U.G., Center Faibles Radioactivites, C.N.R.S. Bat 44, C.E.N. Saclay 91190 Gif sue Yvette, FRANCE	Geochemistry of gases and waters, Modelling of CO_2 flow on slopes Health impact of toxic gases.
Lockwood, J.P.	U.S. Geological Survey, Hawaiian Volcano Observatory, Hawaii 96718, U.S.A.	Volcanic hazards.
Maley, J.	ORSTOM Laboratoire de Palynologie Universite des Sciences du Languedoc 34060 Montpellier, Cedex FRANCE	Studies on Quaternary lacustrine deposits in crater lakes of West Cameroon and Adamaoua (Cameroon).
Martini, M.	Department of Earth Sciences University of Florence Via G. la Pira 4, 50121 Florence ITALY	Possible evidences of degassing from Beneath.
Ndzi, S.E.	Ministry of Mines and Power Department of Mines, Techniques Industrial Pollution Yaounde, CAMEROON	Geology and geochemistry.
Newhall, C.	U.S. Geological Survey, CVO 5400 MacArthur Blvd. Vancouver, Washington 98661 U.S.A.	Using crater and caldera lakes, and their sediments, as indicators of past and impending volcanic unrest.

Njine, T.	University of Yaounde Laboratory of General Biology Faculty of Science P.O. Box 812, Yaounde, CAMEROON	The lake waters: evolution of the physicochemical properties, and productivity.
Nojiri, Y.	The National Institute for Enviromental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305, JAPAN	Chemical modelling and circulation of lake water.
Punongbayan, R.S.	Phil. Inst. of Volcanology & Seismology, 6th Floor, Hizon Bldg., 29 Quezon Av., Quezon City, Metromanila, PHILLIPINES	Quaternary geology and volcanology.
Sano, Y.	Laboratory for Earthquake Chemistry, Faculty of Science, Univ. of Tokyo Bunkyo-ku, Tokyo 113, JAPAN	Rare gas isotope geochemistry
Schenker, F.	Swiss Disaster Relief Unit & GEMAG AG, Company for Geochemistry Research Dreilindenstrasse 3, CH-6045 Meggen SWITZERLAND	The lake waters as the uppermost reservoir of magmatic gaves within a hydrothermal system.
Sigurdsson, H.	Graduate School of Oceanography University of Rhode Island Kingston, RI 02881, U.S.A.	Geochemistry of lakes. Hydrothermal input.
Tanyileke, G.	Institute for Geological and Mining Research, IRGM/CRH, B.P. 4110, Yaounde CAMEROON	Gas and water chemistry.

Tietze, K.	Federal Institute for Geosciences and Natural Resources (BGR) Stilleweg 2, D-3000 Hannover 51 Federal Republic of GERMANY	Stratification and lake water dynamics. Chemistry of gassy lakes (composition, stable and radioactive isotopes) Instrumentation. Theoretical modelling.
Tuttle, M.L.	U.S. Geologlical Survey M.S. 916, Box 25046, Denver Federal Center, Colorado 80225 U.S.A.	Geochemistry and isotopes.

J.V.G.R. special issue on the CO2 : State on September 11th (by F. Le Guern)

Introduction Papers: UNESCO Meeting Yaoundé March 23 1987.

Research Report on the socio-cultural and economic Impact of Lake Nyos Disaster (Nchoji et al.)

Conclusion and recommandation of the conference(Sigvaldasson)

Papers from field observations (Research papers and Letters to the editor)

The anecdotal evidence did it help or hinder investigation of Lake Nyos disaster? (Freeth)

Exploding Lakes and Maleficient Water in Grassfields Legend and Myth. (Shanklin).

The Nyos Catastrophic event: reconstruction from interviews (Le Guern, Shanklin, Tebor).

Phenomenology of explosive event of December 1986 (Chevrier)

Gas emission and hydrothermal manifestation in Lake Nyos area, January 5 1987, January 26 1987 and June 20 1987. (Tebor).

Biology

Acute Health Impact of the gas release at Lake Nyos, Cameroon 1986 (Baxter and Kapila)

Are there biomedical criteria to assess an acute Carbon Dioxide Intoxication by a volcanic Emission? (Stupfel, Le Guern).

Clinical observations (Tirosh)

Effects of high CO2 concentrations on plants Le Guern, Lockwood etal....

Geology:

Origin and age of the Lake Nyos Maar Cameroun (Lockwood and Rubin)

Lithostratigraphy, vulcanism, paleomagnetism and palynology of quaternary lacustrine deposits from Barombi Mbo (West Cameroon) (Maley et al.)

Measurements and modeling.

The gas cloud of lake Nyos (Cameroon 1986) Results of the italian technical mission. (Barberi et al.)

Carbon dioxide burst of Lake Nyos Cameroun. Modelled as periodic supersaturation in a countercurrent reactor. (Oskarsson)

The catastrophe in Lake Nyos, a Fluid Mechanics Perspective. (Michaelides and Lasek).

An inference on the process of gas outburst from Lake Nyos, Cameroon. (Kanari).

Role of lake water in the 1986 Nyos disaster: chemical and isotopic evidence in waters and dissolved gases obtained from three Cameroonian crater lakes (Nyos, Monoum and Wum). Kusakabe et al.

Cause and Mechanism of the Disastrous Gas Burst from Lake Nyos (Cameroon 1986). (Tietze)

Water and gas chemistry of Lake Nyos and its bearing on the eruptive process. (Giggenbach).

Samples and analyses of waters taken from the site of Lake Nyos (Cameroon) A comparative study and interpretation. (Chevrier).

The Lake Nyos catastrophic event: modelisation of the carbon dioxide gas flow. (Faivre Pierret et al.)

Mechanisms of the Nyos Carbon Dioxide Disaster and of Steam (so called phreatic Eruptions. (Tazieff)

CO2 degassing process: Nyos (Cameroon), Dieng (Indonesia), Vulcano (Italy) (F. Le Guern et al.).

The significance of siderite in the sediments from lake Nyos, Cameroon (A. Bernard.R.B.. Symonds

Radiometric Studies of Lake Nyos Sediments: Evidence of strong Mixing and Excess ^{210} Pb. (Piboule et al.)

The "After catastroph":

Recent measurements in Lake Nyos (Kling)
Recent measurements in Lake Nyos (Evans)

Lake Baambulue (Cameroon) building-up the samee scenario as lake Nyos? (Pourchet et al.)

The Sénèze maar (french Massif-Central) hypothesis about a catastrophe around 1.5 M.y. (Jean Couthures).

CO2 degassing process (T.M. Gerlach)

CO2 Flowrate variation and relationship with the magma degassing and Tremors on Mt Etna Sicily (Le Guern Faivre Pierret)

Simulating gas flow: Soufrière and MAsaya (Le Guern, Faivre Pierret and Roussel)

Carbon and Helium isotopic constraints on the origin of volcanic gases emitted during phreatic eruptions at La Soufriere of Guadeloupe (Allard et al.)

Geochemistry of CO2 from the 1979 Dieng Eruption Indonesia (Allard et al.)

Informal meeting of IWGCL at Kagoshima, Japan

The Kagoshima International Conference of Volcanoes was held on 18th-24th July 1988 at Kagoshima, Japan. By making use of this occasion, an informal meeting of IWGCL was organized on the evening of 20th July, since a fairly high percentage of persons who had been involved, directly or indirectly, in the Nyos problems visited Kagoshima. The participants of the meeting were P. Allard, S. Aramaki, P.J. Baxter, W.F. Giggenbach, M.L. Hall, J. Hirabayashi, M. Kusakabe, J.P. Lockwood, M. Martini, C. Newhall, R. Punongbayan, Y. Sano, H. Shinohara, H.Sigurdsson and J. Tomblin.

The followings are the subjects discussed in the meeting.

Crater lakes in Cameroon

* Resettlement of about 2500 local people including more than 1000 children still remains forbidden in the area directly concerned with a future gas burst from Lake Nyos. They are still living in the refugee camps managed by protestant and catholic churches. It was reported that the Cameroonian government identified the lands for resettlement, although it was not clear yet (J. Tomblin, pers. commun.).
* A possible collapse of the Lake Nyos dam in the future which could endanger many lives of people living in northwest Cameroon was told by J. Lockwood. He wants to have suggestions from us what should be done to mitigate the possible flood hazard. See his letter about this subject on page 12.
* The American scientists have made extensive surveys on 37 crater lakes in Cameroon. It has been reported that no crater lakes except Nyos and Monoun contain high levels of dissolved CO_2. See a recent report by Kling et al. (Nature 337, 215, 1989).
* Continuous monitoring of CO_2 and other parameters of Lake Nyos by satellite transmission is being made by French scientists.

Crater lakes in other areas

* M. Martini reported a preliminary result of a survey on two Italian volcanic lakes L. Lucrino and L. Averno. It is given in the following pages 13 and 14.
* M. Hall stated a report that "boiling" had taken place at Lake Quicocha (180 m deep) and Lake Quilatowa (400 m deep, 3 km in diameter), Ecuador. Collection of detailed information is needed.
* R. Punonbayan reported that fishes had died in one of the crater lakes in Phillipines (172 m deep and >5 km in diameter). He wants to know the sampling techniques of deep water of crater lakes. The cause of the fish-death should be made clear, although it may have been due to upwelling of oxygen-deficient water from the depths, not a very unusual event in tropical lakes.

Sampling techniques

* The importance of collecting bottom sediments in order to obtain the sedimentary records was stressed by C. Newhall and J. Lockwood.
* Development of a simple and reliable water sampling technique for monitoring the chemistry of gassy lakes is highly important, especiallly when the target areas are remote and located in developing countries. In this respect, the sampling technique used by the Japanese Team at Lake Nyos (Niskin water sampler + a plastic bag, Kusakabe et al., JVGR special issue, 1989) is worth being considered.

Future IWGCL activities

* There was a suggestion that IWGCL should be included in one of the official working groups under IAVCEI. It is a recent tendency that a mean life-time of the IAVCEI working groups is rather short and that they deal with rather specified subjects. In this respect, IWGCL seems to meet the tendency.

* IWGCL should specify the subject(s) in order to prevent the group's activity from being diversed. Specified subjects may be (a) physics and chemistry of gassy lakes including Lake Nyos, (b) development of warning systems for gas outbursts from such lakes, (c) organization of international rescue teams, (d) suggestions and recommendations to the local governments facing to the problems.
* It was suggested to make up a catalogue of crater lakes which possess limnological and volcanological similarities to Lake Nyos and Lake Monoun. This would form a base-line data for mitigation of future gas disasters of the Lake Nyos type.

* A proposal to organize a meeting about the Lake Nyos problems sometime in mid 1990 has been made by S. Freeth, although this was not spoken at the informal meeting. For detail, see his letter on page 15.

IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

17 November, 1988

HAWAIIAN VOLCANO OBSERVATORY

HAWAII NATIONAL PARK, HAWAII 96718

Dear

The enclosed report deals with a potentially catastrophic situation which exists in northwest Cameroon. Many thousands of lives in Cameroon and eastern Nigeria are possibly threatened by the eventual failure of the Lake Nyos dam, and my co-authors and I hope that you will read this report and perhaps share our concern.

My reasons for writing you are highly personal. I spent three weeks in Colombia as part of the USGS team following the 1986 Ruiz disaster. The memories of this experience, including visions of thousands of rotting bodies in the fields below Armero, will never be erased from my mind. 25,000 innocent people needlessly died there, but why?

The blame for these deaths falls on many shoulders, but it is the lack of communication between responsible scientists and public officials that weighs most heavily on my conscience. Ruiz Volcano gave over a year of warning before disaster struck, and the international scientists who responded to the warnings did their jobs very well - they correctly described the threat and accurately predicted the nature of its consequences. An excellent hazard map was prepared by the Colombian Government a month *before* the disaster, but *not enough was done* to warn the people or to plan adequate mitigation strategies. Colombian officials did not really believe the scientists, and the scientists *did not do enough* to convince officials of the threat.

What should be done to mitigate the flood hazard presently posed by Lake Nyos? First, there is a critical need for engineering geologists with appropriate experience to further evaluate the situation. Perhaps the threat is not so grave as we have presumed. If, however, the threat does prove to be as serious as suggested in the enclosed paper, I would hope that a conference, perhaps international in scope, would be convened to plan mitigation strategies.

When lives of innocent people are at stake, I do not believe my responsibilities as a scientist end with the preparation of a report that may languish in file cabinets and libraries. If you have suggestions as to how to best respond to the Lake Nyos threat, I would appreciate hearing from you. I am presently on Sabbatical at the University of Hawaii at Manoa, where I can be reached c/o Department of Geology, Hawaii Institute of Geophysics, 2525 Correa Road, Honolulu, Hawaii 96822 [Tel. (808) 948-6488]. After Christmas I shall be back at the Hawaiian Volcano Observatory [Tel. (808) 967-7328 or 967-7414].

Sincerely,

John P. Lockwood
Geologist

SURVEILLANCE OF CHEMICAL COMPOSITION OF LAKES LUCRINO AND AVERNO (Phlegrean Fields, Italy)

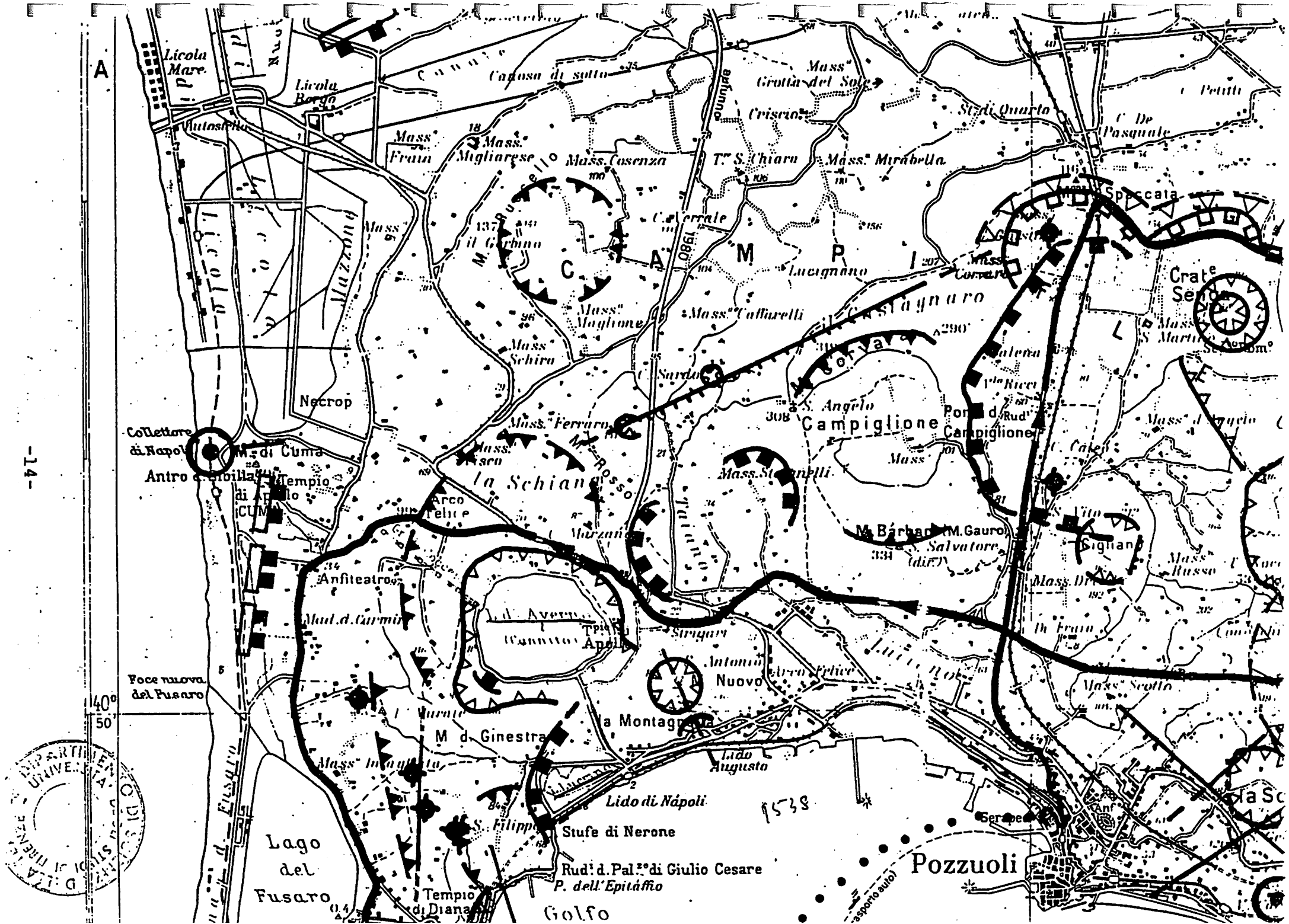
reported by M. Martini

The last volcanic event in the area of Phlegrean Fields occurred in 1538 with the building of a cone 141 m high with a diameter of 1.5 m (Monte Nuovo).
A solfataric stage followed the eruption and is represented by fumaroles, thermal waters and muds at Solfatara and Pisciarelli, and by submarine degassing mainly in the area of the harbour of Pozzuoli.
Two lakes are located in the neighboring area of Monte Nuovo (figure 1), which are supposed to receive the contribution of any degassing possibly occurring through the existing fractures.
The surveillance of the chemical composition of lake waters is in progress since early 1984, in order to verify any significant change which can be correlated to an increased gas output from beneath.
Table I gives the mean composition recorded in 1987, which is not substantially different in comparison to previous years.
Seasonal changes are observed as well, which do not affect the bulk composition.

TABLE I

	Lucrino	Averno
Temperature	21 °C	19 °C
pH	7.65	8.75
Sodium	10560 ppm	639 ppm
Potassium	394	56
Calcium	432	29
Magnesium	1085	12
Bicarbonate	238	348
Chloride	19653	746
Sulphate	2540	202
Lithium	0.42	0.49
Boron	5.6	1.7
Ammonium	0.97	1.6
Bromine	75	1.8
Carbon dioxide	0.90 mmoles/L	0.26 mmoles/L

DIPARTIMENTO DI SCIENZE DELLA TERRA
UNIVERSITA' DEGLI STUDI DI FIRENZE



DIPARTIMENTO DI STORIA DELL'ARCHITETTURA UNIVERSITÀ DI NAPOLI

SPECIAL SESSION ON THE LAKE NYOS DISASTER

During the Yaoundé Meeting (March 1987) there were many aspects of the Lake Nyos disaster about which scientists who had been involved in the initial investigation were finding it difficult if not impossible to agree. In general the differences were differences in interpretation, though in a few instances there were clear conflicts between the "facts" as observed by different teams. Many of us thought, at the time, that it might be helpful if a further meeting were held in about two years (Spring and Summer 1989). Two years should have been about right to give all of us time to consider the implications of other people's ideas, time to complete laboratory studies and time to absorb the contents of papers from the Yaounde meeting which were to be published in J. Volcanol. Geotherm. Res.

About this time last year I noticed that there was to be an IAVCEI General Assembly in Santa Fe in June 1989, which would include a symposium on "active volcanism and volcano hazards." Since nobody else seemed to me to be over anxious to organise a Lake Nyos meeting, I wrote to the symposium organiser (Dr. D.A. Swanson) and suggested that a Special Session on Lake Nyos might be included within the overall frame work of his symposium. Don Swanson's response was most encouraging and he suggested that I wrote around to those of you who might contribute to such a symposium to see how many of you would be interested. This I did and I was very pleased that all the replies which I received supported the idea of a meeting though some people were not sure that they would be able to obtain appropriate financial support. With such a clear level of support Don Swanson and I decided to go ahead and organise a Special Session on Lake Nyos. In order to help matters along, I arranged to visit Don Swanson at the Cascades Volcano Observatory in early December. Whilst I was there we drew up a list of invited speakers which was to have been as follows; Baxter, Kusakabe, Le Guern, Lockwood, Shanklin, Tchoua, Tietze and myself. And I agreed to prepare a circular which could be sent to anyone else who might be interested to encourage them to attend the meeting and if possible to present "posters" to the main meeting. I also intended to organise one or more Working Group meeting so that we could present the results of our recent work, argue amongst ourselves and hopefully co-ordinate future research.

Sadly, all my plans have come to nothing. When I got back to Britain in mid-December I found a letter from Dan Swanson waiting to inform me that he had put our proposal to the Organising Committee (Lipman and Dungan) only to be told that "none of the symposium convenors should solicit invited talks, owing to the format of the meeting, which will emphasise posters" and that "only after all of the abstracts are in and the general program arranged will it be possible to assign a very few of the abstracts to oral presentation." Clearly given these conditions there is absolutely no way in which I or anyone else could organise a special session. For most of us to obtain sufficient financial support to attend a meeting in the United States it would be necessary to have a specific invitation from the meeting organisers. And for those of you who, like myself, do not consider yourselves to be volcanologists (sensu stricto) there would be little point in offering an abstract to the Santa Fe meeting unless you could be assured in advance not only that there would be a viable Lake Nyos session but also that many of the main contributors to the Yaoundé meeting would be present.

Despite this abject failure, I am now more than ever convinced that a Lake Nyos session (preferably tacked on to a significant scientific meeting) could be of value to all concerned. Clearly it is now too late to put together an alternative venue for summer 1989 and as far as I am aware there are no appropriate meetings later this year. So how about a Lake Nyos meeting in Europe in mid 1990? Having gone so far I would be happy to try to organise such a meeting but I would be pleased to receive any advice or encouragement which any of you might have to offer.

Dr. S.J. Freeth,
Department of Earth Sciences,
University College of Swansea,
Swansea, SA2 8PP, U.K.

Preliminary Report of the Geochemical and Limnological Survey on Lake Nyos and Lake Bambuluwe in December 1988 by the Joint Japanese-Cameroonian Team

M. Kusakabe, J. Hirabayashi, H. Sato, Y. Sano,
Y. Nojiri, H. Shinohara, T. Njine, F. Tchoua and G. Tanyileke

During December 1988, a geochemical and limnological survey of Lake Nyos and Lake Bambuluwe was carried out as the Japan-Cameroon joint programme. A preliminary report of the mission activity is given below.

The purposes of the survey can be summarized as follows;
(1) distribution of dissolved chemical species in the lakes,
(2) temperature distribution and its temporal variation,
(3) mineralogical examination of the sediments, and
(4) regional survey of mineral springs and volcanic rocks.

Lake Nyos

1. CTD Survey

CTD (conductivity/temperature/depth profiler) measurements were carried out at 4 points. The profiles obtained are very similar to each other, and have remained essentially unchanged from those obtained in Octover 1986 (Kusakabe et al., 1988) and in 1987 (Kling and Evans, pers. commun.). However, both conductivity and temperature rise steeply towards the bottom, indicating a supply of high-temperature, high-salinity water at the bottom. Temperature as high as 24.7 °C was recorded at the deepest point, and it appears that bottom temperatures continue to rise gradually since the 1986 event.

2. Collection of Water and Gas Samples

Lake water was collected with a Niskin water sampler from 12 different depths (0, 10, 20, 30, 50, 75, 100, 125, 150, 175, 190 and 200 m) at the center of the lake. By using a newly developed sampling technique, the total CO_2 was fixed in-situ by introducing water into a plastic syring which had been partially

charged with a concentrated alkaline solution (Kusakabe and Nojiri, in preparation). Chemical and isotopic analyses of the samples are in progress.

3. Continuous monitoring of lake water temperature

Two temperature data loggers have been moored at the center of the lake. The instrument is programmed to record the temperature data at every 2 hour interval for at least 1 and half year. The results available after this period would clarify the heat low from the lake bottom, possibly in the form of a thermal spring, and might be able to contribute to evaluation of the accurate prediction of the cyclic gas release from the bottom. Therefore, it is highly important to recover the instrument from Lake Nyos after an appropriate period of time.

4. Collection of Bottom Sediments

Bottom sediments have been collected with an Eckmann-type surface sediment sampler. The sediments were dark-gray to black, and CO_2 was continuously degassing when the sediments were brought to the surface. There was no smell of H_2S. The sample will be examined for the mineralogical composition in relation to the water chemistry.

Lake Bambuluwe

The CTD profiling, water collection from 8 different depths, and collection of bottom sediments were carried out at Lake Bambuluwe (Awing). This lake was visited because of a strong request by the Cameroonian counterparts. In contrast to Lake Nyos, the temperature and CTD profiles indicate that there is no indication of existence of high-temperature, high-salinity water at the bottom. CO_2 level was found to be very low.

Regional Survey of Mineral Spring Waters

Mineral spring waters and the associated gases have been collected in order to better understant the geochemical characteristics of volatile materials outgassing in the North-West Province. Their chemistry and helium isotopic composition will be compared with those of Lake Nyos.

Geochemical Study of Volcanic Rocks in the NW Province

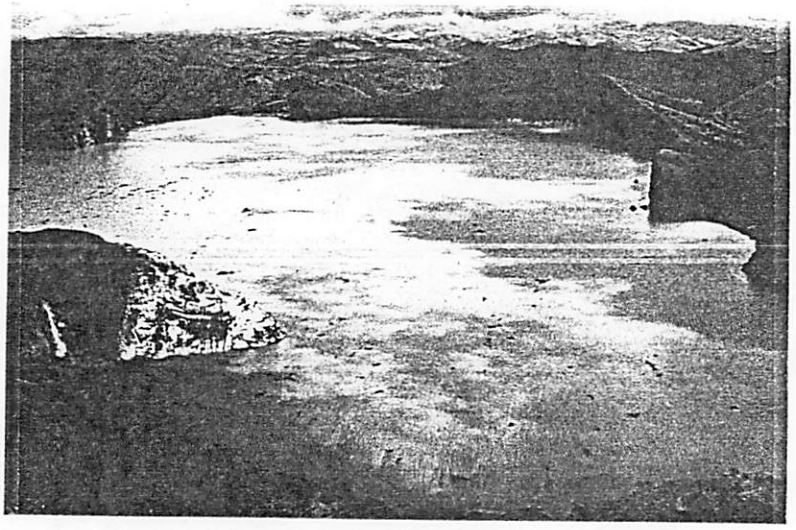
Specimens of basaltic rocks along the Cameroon Volcanic Line including those from the recent eruptions of Mt. Cameroon have been collected to characterize the Quaternary basaltic volcanism in relation to that of Lake Nyos.

International Working Group on Crater Lakes

NEWSLETTER

No. 2

February 1990



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Editor: M. Kusakabe

A Letter from the Editor

The second issue of the Newsletter of the International Working Group on Crater Lakes (IWGCL) has now been sent to you as promised previously.

It seems inevitable that the IWGCL Newsletter tends to be filled with news and information related to the 1986 Lake Nyos gas disaster and its aftermath, although the Editor has expected the materials on the other subjects to reach him. This is because IWGCL was born in Yaounde where the International Conference on the Lake Nyos gas disaster was held in March 1987 and also many of the group members are still, or even more, interested in this unusual event and gassy lakes. However, the materials on any subject related to the studies of crater lakes are welcomed by the IWGCL Newsletter, and the editor is waiting for your contribution to the Newsletter on any news, proposals and communication which you think it worthwhile to circulate.

An important notice included in this Newsletter is the call for contributions to the Symposium on the Lake Nyos Disaster and Inaugural Meeting of IWGCL as a part of the 15th Colloquium on African Geology which will be held at Nancy, France, during 10th-13th, September, 1990. The symposium will be convened by Dr. S.J. Freeth, Department of Earth Sciences, University College of Swansea, U.K. The deadline for registration and submission of abstracts is set at 31st March 1990. The compiled abstracts will be distributed to the IWGCL members as the Newsletter No. 3 sometime in coming July-August.

Here is a favor to ask you: the Editor would very much appreciate your donation to support the cost that is necessary to print and distribute the Newsletter. If you agree with this proposal, please send $US10.00 to the Editor with the address given below together with a sheet of paper attached to this issue. The payment should be by cheque in $US to the order of Minoru Kusakabe, The Editor, IWGCL Newsletter, payable at the Bank of Tokyo Ltd., Osaka Branch.

M. Kusakabe
The Editor of IWGCL Newsletter
ISEI, Okayama University
Misasa, Tottori-ken 682-02, Japan

Lake Nyos Victims Resettled

Dear colleagues,

It is slightly over two and half years today since a catastrophic voluminous release of carbon dioxide gas killed 1746 people, 3952 cows, 337 sheep, 552 goats, 3404 fowls, dogs and cats in the villages of Cha, Nyos and Subum in the northwest province of Cameroon; with the subsequent evacuation of the survivors. An appeal for material and financial aid from friendly countries and organizations resulted in about 1.3 millards francs CFA and several tons of material aid (food, tents, medicines, clothes etc.) collected.

For two and half years, the national committee created to manage the aid on behalf of the victims ensured them of their daily bread, temporary lodging, health care and schooling for their children while waiting for permanent resettlement. For this, the Government initially banked on scientists for delineation of disaster zones and choice of appropriate sites for the new villages. After two and half years of waiting and indecision, the Government finally assumed its responsibilities and ordered the immediate resettlement of the victims.

Bua-Bua, Iparim, Yemgeh, Kumfutu, Kimbi, Waindo (Ukpwa) and Esu are the new villages which are today the centres of considerable attraction and envy. Tents, general inactivity and boredom are today a thing of the past and by next harvest season, they will no longer entirely depend on the authorities for their livelihood. This project was completed within two months, thanks to the collective action of the civil authorities and the victims themselves.

Each village consists of access roads, family houses (function of family size), a school, churches, a market etc. Bua-Bua the largest of these villages already has tap borne water and work is in progress for the water supply of the other villages. The exact resettlement situation is shown in the table below.

Village	No. of Families	No. of Houses	Head count
Bua-Bua	115	125	617
Iparim	47	49	176
Yemgeh	42	48	228
Esu	13	20	72
Kimbi I*	47	50	315
Kimbi II**	23	27	80
Kumfutu I*	13	13	52
Kumfutu II**	12	18	70
Waindo (Ukpwa)	44	62	259
Total	356	412	1870

* farmers

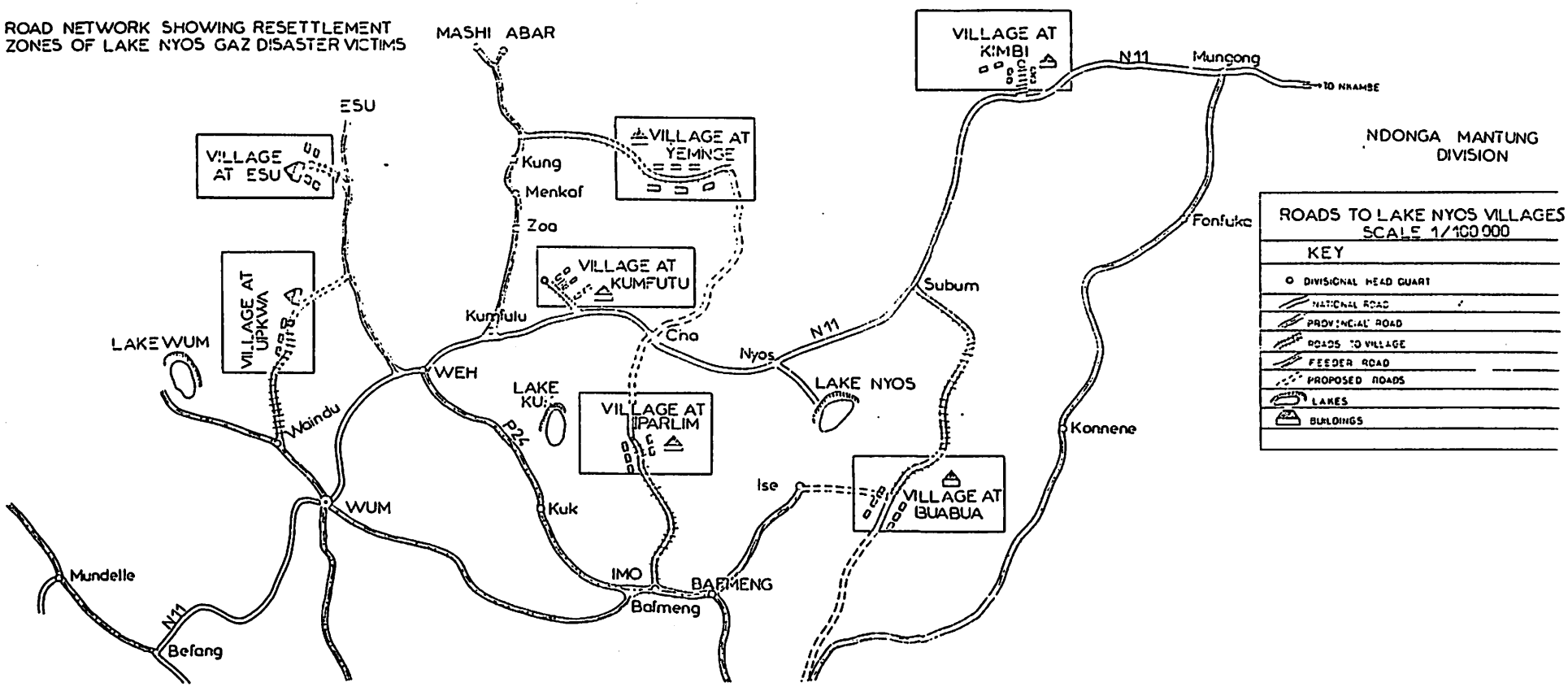
** grazers

source: Cameroon Tribune No. 4348

The road network is shown in the map below. Lake Nyos is TODAY within 10 minutes walking distance and plans to take the road to the Lake have been completed and work is in progress. It is indeed the end of a nightmare, not only for the victims but also for us the scientists. The much needed data required for a better understanding of the Lake Nyos event and gassy lakes in general will henceforth be collected with relatively much ease and I look forward to seeing many of you back here soon.

Permit me use this opportunity to thank those of you who initiated this Newsletter and hope we will keep it alive.

G. Tanyileke
IRGM/CRH
BP. 4110 Yaounde
Cameroon


ROAD NETWORK SHOWING RESETTLEMENT ZONES OF LAKE NYOS GAZ DISASTER VICTIMS
MASHI ABAR
ESU
VILLAGE AT ESU
VILLAGE AT UPKWA
LAKE WUM
Waindu
WUM
Mundelle
N11
Befang
WEH
Kumfutu
Kung
Menkaf
Zoa
VILLAGE AT YEMINGE
VILLAGE AT KUMFUTU
Cha
Nyos
LAKE KU
VILLAGE AT PARLIM
Kuk
IMO
BAFMENG
Bafmeng
VILLAGE AT KIMBI
N11
Mungong
TO NKAMBE
Subum
LAKE NYOS
Ise
VILLAGE AT BUABUA
Konnene
Fonfuka
NDONGA MANTUNG DIVISION
ROADS TO LAKE NYOS VILLAGES
SCALE 1/100 000
KEY
DIVISIONAL HEAD QUART
NATIONAL ROAD
PROVINCIAL ROAD
ROADS TO VILLAGE
FEEDER ROAD
PROPOSED ROADS
LAKES
BUILDINGS

INVESTIGATIONS ON CRATER LAKES OF ITALY

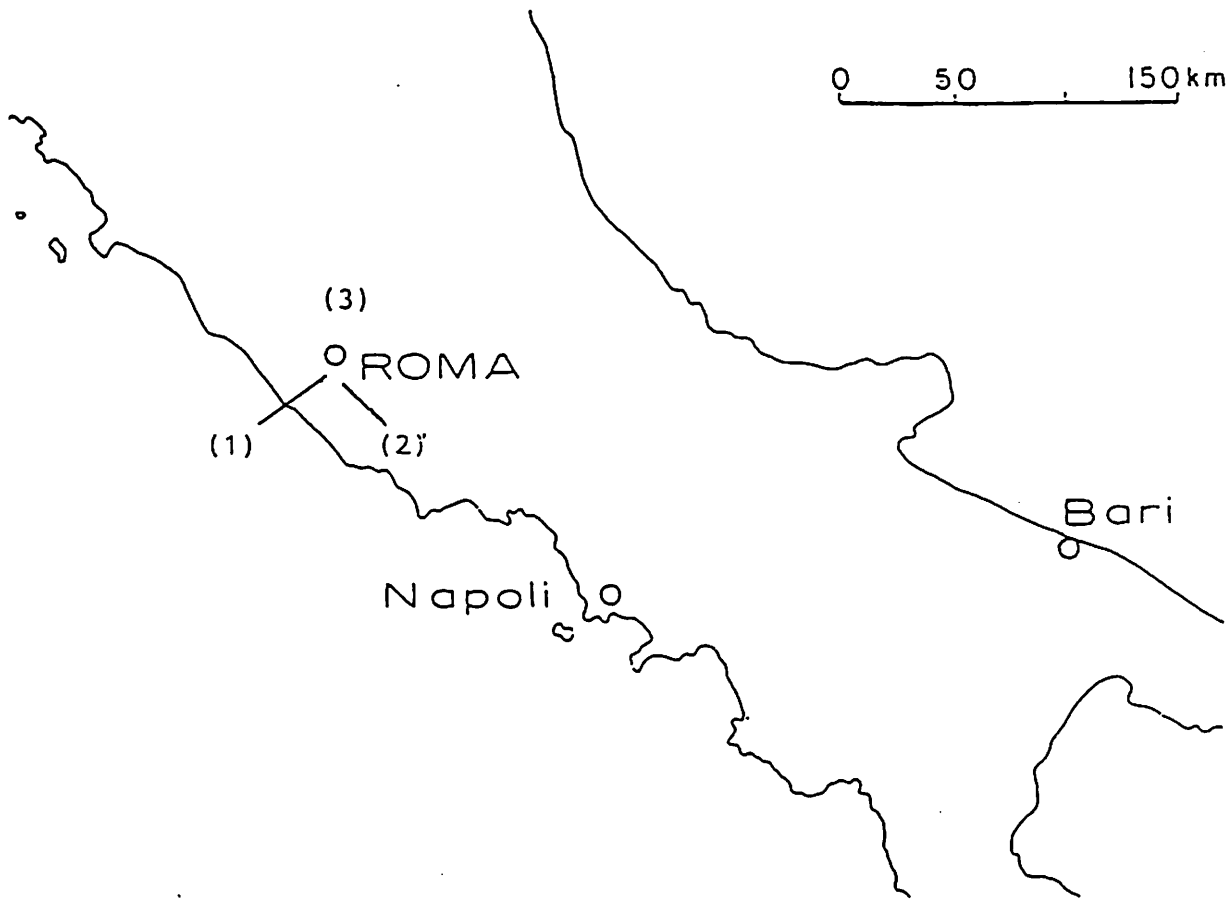
MARINO MARTINI

DEPARTMENT OF EARTH SCIENCES, UNIVERSITY OF FLORENCE, ITALY

Besides the periodical survey of lakes Averno and Lucrino in the area of Phlegrean Fields, as reported in Newsletter no. 1, a systematic study of other crater lakes of Italy is in progress since 1988.

In particular, bathymetric profiles and samplings at different depths have been carried out at lakes Albano (1), Nemi (2), and Vico (3), pertaining to the roman volcanic province.

The analytical program includes major, minor and trace constituents of waters, as well as the determination of dissolved gases.



1989 French - Camerounian Field Work

In a previous work concerning natural and artificial radioisotopes profiles from Camerounian lake sediments, we observed anomalies in 2 lakes: Nyos and Bambuluwe. In the case of lake Nyos, we concluded that the sediments has been mixed for several meters in depth (1).
In lake Bambuluwe the 210 Pb radioactivity along the upper 15 cm exhibits a constant value. As in lake Nyos, this activity is unusually strong (2,3).
We consider these radiometric measurements as an opportunity for evaluation and prevision of gas eruption.
In collaboration with Camerounian scientists, and with the financial supply of Ministère de l'Environnement (Délégation aux Risques Majeurs), ORSTOM and CNRS, we conducted, in april 1989 a new collect of sediments in 19 lakes of Cameroon.
For each lake we sampled a 1 meter long sediment core, and we measured physical parameters (bathymetric and temperature profils).
Concerning Bambuluwe lake, our new measurements confirm the 210 Pb excess as previously measured and don't show evolution of this excess during the last two years.
For the others lakes, including Monoun, we are determining the radioisotopic profils and about one year will be necessary for this work.

1- M.PIBOULE et al. Radiometric studies of lake Nyos sediments: evidence of strong mixing and excess 210 Pb. J. of Volc. and Geoth. Res. in press
2- M.POURCHET et al. Another gas burst in a Cameroon lake? -Nature Vol. 334; 1988
3- M.POURCHET et al. Lake Bambuluwe (Cameroon): Building-up the same scenario as lake Nyos? - J. of Volc. and Geoth. Res. in press.

M. POURCHET and J.F. PINGLOT
L.G.G.E. CNRS Grenoble France
E. NAAH
C.R.H. IRGM Yaounde Cameroon

SCIENTIFIC INVESTIGATION OF LAKES NYOS AND MONOUN, DECEMBER 1989

PRELIMINARY RESULTS

Evans, William, U.S. Geological Survey, Menlo Park CA 94025
Kling, George, Marine Biological Laboratory, Woods Hole MA 02543
Tanyileke, Greg, IRGM, BP 4110, Yaounde, Cameroon
Tuttle, Michele, U.S. Geological Survey, Denver CO 80225

INTRODUCTION

This report presents the preliminary results of an investigation that began on 9 December and ended on 22 December 1989. We were accompanied during segments of our field studies by Greg Tanyileke and Emmanuel Naah (Institute for Geological and Mining Research, MESRES), and assisted by Soba Djallo (Director, IRGM), Gamnje Ngala (Provincial Delegate, Mines, Water, and Energy, Bamenda), and Francis Fai-Yengo (Senior District Officer, Wum). Financial and logistical support was provided by IRGM-MESRES, USAID, the U.S. Embassy, the U.S. Geological Survey, the Marine Biological Laboratory in Woods Hole, and a grant from the National Geographic Society.

RESULTS and DISCUSSION

LAKES

Water temperature

The temperature of the deepest waters in Lakes Nyos (208 m) and Monoun (90 m) has increased slightly since our last measurements made in May 1987, from 24.17 to 24.83°C and from 22.56 to 23.07°C respectively. These increases are small and amount to a rate of change of about 0.02°C per month. In Lake Nyos the rate of temperature increase has slowed somewhat from 0.07°C per month measured during the first nine months following the event. There have been significant changes in thermocline depth in Lake Nyos as well. Thermocline depth has increased from 7 m in January 1987 to 11 m in May 1987 and finally to 18 m in December 1989. Changes in thermocline depth in Monoun are small and are related to normal seasonal mixing.

Water chemistry

Chemical measurements made in the field include alkalinity, pH, dissolved oxygen, and conductivity. Most chemical analyses will be performed later in the laboratory. The field measurements are compared to

previous results in Table 1. Alkalinity concentrations (as HCO_3^-) in both lakes are generally similar to those from May 1987, except in the surface water of Nyos where alkalinity has decreased. Surface water pH, dissolved oxygen, and conductivity have also decreased at Nyos. These changes in surface water chemistry mainly result from dilution of lake water by precipitation inputs and expansion of the epilimnion since the degassing event. The chemistry of surface waters in Lake Nyos is becoming more similar to surface water chemistry measured in 1985 before the event.

Gas chemistry

As long as the lakes contain large quantities of dissolved gas they could potentially release lethal amounts of gas without warning. A key factor in estimating the likelihood of a gas burst is the degree of gas saturation (the ratio of gas pressure to hydrostatic pressure) in the hypolimnion. In January 1987 we started a program to monitor changes in dissolved gas content over time. Pressurized sample cylinders were filled at discrete depths several times during the ensuing months. Subsequent laboratory analyses provided a measure of gas content in the lakes. At the time of the last sampling in June 1988, no detectable changes in gas content had occurred. However, these discrete samples do not provide an adequate number of data points to separate spatial variations in gas content from time-dependent trends. We therefore designed and built a gas probe which could be lowered into the lakes to provide an immediate, direct measurement of gas pressure. This probe allows us to make more measurements than is possible with the cylinders alone.

The difference between the two sampling methods is that the probe measures total gas pressure whereas the cylinder samples can be analyzed for individual gas species such as CO_2 and methane. Using the probe we measured higher gas pressures on this field trip than had been calculated from previous analyses of cylinder samples. At Nyos, the highest pressure measured with the probe, 9.5 bars, occurred just off the bottom (below 200 m depth). Based on an ambient hydrostatic pressure of 21 bars at this depth, gas saturation is 45%. Near 160 m, gas saturation was about 30%. In Lake Monoun gas pressure at 96 m is about 5.7 bars. Gas saturation at this depth is approximately 55%. The fact that present day gas saturation is less than 100% does not indicate that the lakes are safe. Mechanical disturbance of the water column could trigger a release of the gas remaining in these lakes.

Before any significance can be attached to the apparent increase in gas pressure, the simultaneously collected cylinders must be analyzed and compared to the probe measurements and to the results of previous cylinder analyses. This will occur in the next few months. Very preliminary results from a few of the cylinders indicate that in Nyos, there have been significant increases in methane as well as CO_2. Although methane makes up a very small fraction (<0.5%) of the gas, its contribution to the total gas pressure is significant because of its low solubility in water, 25 times

less soluble than CO_2. Stable and radioactive isotopes will be run to determine if any of the added methane and CO_2 has come from the breakdown of the plant matter that was swept into the lake during the 1986 gas burst. Although a detailed interpretation of the gas probe data will take some time, the field measurements strongly suggest that horizontal variations in gas pressure are very small in the deep waters of Nyos.

SPRINGS

There is good evidence that the CO_2 in Lakes Nyos and Monoun has a common origin with the CO_2 discharged from soda springs along the Cameroon Volcanic Line. We located and sampled such a soda spring 0.5 km from Lake Nyos. The spring opening is about 2.5 m across and the spring visibly discharges gas to the atmosphere. Water temperature of the spring was 19°C, the pH was 4.49, and the alkalinity was 126 mg/L. This spring has apparently existed and discharged gas for a least several decades (local report), and is therefore not a result of the recent gas burst (as appears to be the case with the stream northeast of Nyos). The existence of this spring is consistent with our hypothesis that CO_2-charged groundwater exists in the immediate vicinity of Lake Nyos.

In addition we sampled three freshwater springs in the Lake Nyos area. Laboratory analyses of these springs will provide information on the chemical evolution of groundwater in the Lake Nyos basin.

FUTURE MONITORING

In an effort to characterize the changes over time in Lakes Nyos and Monoun we installed a self-contained climate station on each lake (Figure 3). These stations will monitor air temperature, relative humidity, solar radiation, rainfall, and wind speed. In addition each station operates an array of nine thermistors placed at various depths to measure water temperature. Changes in water temperature may then be related to climatic variability. Through our collaboration with IRGM we will sample Lakes Nyos and Monoun twice in the coming year.

TABLE 1. Chemical data for Lakes Nyos and Monoun in May 1987 and in December 1989. Conducitivity is in uS/cm, HCO_3^- is in mg/L, dissolved oxygen (DO) is in mg/L, and temperature is in ^oC.

Lake Nyos	pH	Conductivity	HCO_3^-	DO	Temp
surface 1987	7.76	251	163	9.0	27.0
surface 1989	6.75	104	55	7.6	22.9
bottom 1987	-	-	964	0	24.17
bottom 1989	-	-	896	0	24.83
Lake Monoun					
surface 1987	7.15	125	73	7.6	25.5
surface 1989	6.78	137	70	5.6	21.2
bottom 1987	-	-	1870	0	22.56
bottom 1989	-	-	1903	0	23.07

A SIMPLE PLASTIC SYRINGE SAMPLER FOR IN SITU FIXING OF THE TOTAL CO_2 DISSOLVED IN LAKE WATER

M. KUSAKABE[(1)], Y. NOJIRI[(2)] and M. NARITA[(3)]

(1) Institute for Study of the Earth's Interior, Okayama University, Misasa, Tottori-ken 682-02, Japan
(2) National Institute for Environmental Studies, Tsukuba, Ibaraki 305, Japan
(3) Rigosha Co. Ltd, Hongo, Bunkyo-ku, Tokyo 113, Japan

Introduction

One of the most important requirements in a study of the gassy lakes such as Lakes Nyos and Monoun is to obtain the exact distribution in time and space of $CO_{2(aq)}$ concentration within the lakes. As the partial pressure of CO_2 in deep waters of these lakes exceeds 1 atmosphere pressure, effervescence of CO_2 takes place when the deep waters are brought to the surface. To collect the deep waters, it is necessary to use a pressure bottle (Tietze 1987, Kling et al. 1989) or a Niskin water sampler attached with a plastic bag to accommodate the exsolved gases (Kusakabe et al. 1989). Such situation hinders us from a frequent observation of water chemistry of the lakes. In order to solve these problems, we have developed a simple plastic syringe sampler with which the total dissolved CO_2 can be fixed in situ in an alkaline solution.

Sampler

A schematic diagram of the sampler is shown in Fig. 1. The sampler consists of a plastic syringe with a capacity of 50 ml (A), a metal rod (B) which pulls down the stem of the syringe by shrinkage of a spring when a catch (C) is released by action of a falling messenger, and a metal frame (D) to support the syringe, spring and rod.

The amount and concentration of an alkaline solution that should be filled in the syringe before use can be changed depending on the total CO_2 concentration of the water to be sampled. About 40 ml (max.) of sample water can be sucked into the syringe. After retrieval of the sampler, the syringe

is detached from the frame and fitted with a sealing cap. The total CO_2 concentration is determined in the laboratory by a classical micro-diffusion analysis on an aliquot of the alkaline solution. The $CO_{2(aq)}$ concentration is given by the difference between the total CO_2 concentration thus determined and the HCO_3^- concentration.

Results

In our last survey of Lake Nyos in December 1988, we used 10 ml of 5 N NaOH solution which can fix 25 mM of the total dissolved CO_2 theoretically. This amount of CO_2 corresponds to the concentration of 625 mM/kg, slightly higher than the saturated CO_2 concentration at the bottom. The total CO_2 concentration in Lake Nyos water with a depth deeper than 50 m is plotted in Fig. 2 as a function of the total dissolved solids (TDS) content which is obtained from the chemical analysis of water. A linear correlation can be recognized for the samples with depths of 50 m, 75 m, 100 m, 125 m and 150 m. The $CO_{2(aq)}$ concentrations calculated from these data are in good agreement with those given in Tietze (1987), Kling et al. (1989) and Kusakabe et al. (1989), indicating that our syringe sampler works well at these depths.

The data points for water deeper than 175 m are apparently something wrong, since the sampler did not work properly for deep waters. However, we have been able to estimate the $CO_{2(aq)}$ concentrations of these waters based on the volume of the CO_2 exsolved from the Niskin water sampler, the HCO_3^- concentration and the conductivity profile (Nojiri et al., 1990). There are two reasons that are conceivable for the cause of the discrepancy: (1) malfunctioning of the syringe during recovery due to effervescence of CO_2 from water remaining in the volume within the "closed-face" rubber O-ring (E in Fig. 1) of the syringe (this really caused deformation of some of the syringes used for deep water sampling), and (2) insufficient time of CO_2 fixation for the deep samples containing progressively higher $CO_{2(aq)}$ concentrations than the shallow samples. These problems can be solved by (1) making holes on the stem top to let the exsolved gas in E of Fig. 1 escape outside, and (2) adjusting the time for CO_2 fixation and the volume of water to be sampled.

Application

We believe that the total CO_2 concentration of the gassy lakes can be

easily determined by utilizing the syringe CO_2 sampler described here. More important is that development of a simple, inexpensive sampling devices such as those described here would make the frequent monitoring of the gassy lakes possible by the local scientist(s) and would contribute to forecasting a possible gas event in the future.

Reference

Kling, G.W., Tuttle, M.L. and Evans, W.C. The evolution of thermal structure and water chemistry in Lake Nyos. J. Volcanol. Geotherm. Res. 39, 151-165, 1989.

Kusakabe, M., Ohsumi, T. and Aramaki, S. The Lake Nyos gas disaster: chemical and isotopic evidence in waters and gases from three Cameroonian crater lakes, Nyos, Monoun and Wum. J. Volcanol. Geotherm. Res. 39, 167-185, 1989.

Nojiri, Y., Kusakabe, M., Hirabayashi, J., Sato, H., Sano, Y., Shinohara, H., Njine, T. and Tanyileke, G. An estimate of CO_2 flux in Lake Nyos, Cameroon. Submitted to Nature. 1990.

Tietze, K. Results of the German-Cameroon research expedition to Lake Nyos - October/November 1986-, Bundesanstalt fur Geowissenschafften und Rohstoffe, Hannover, pp. 84, 1987.

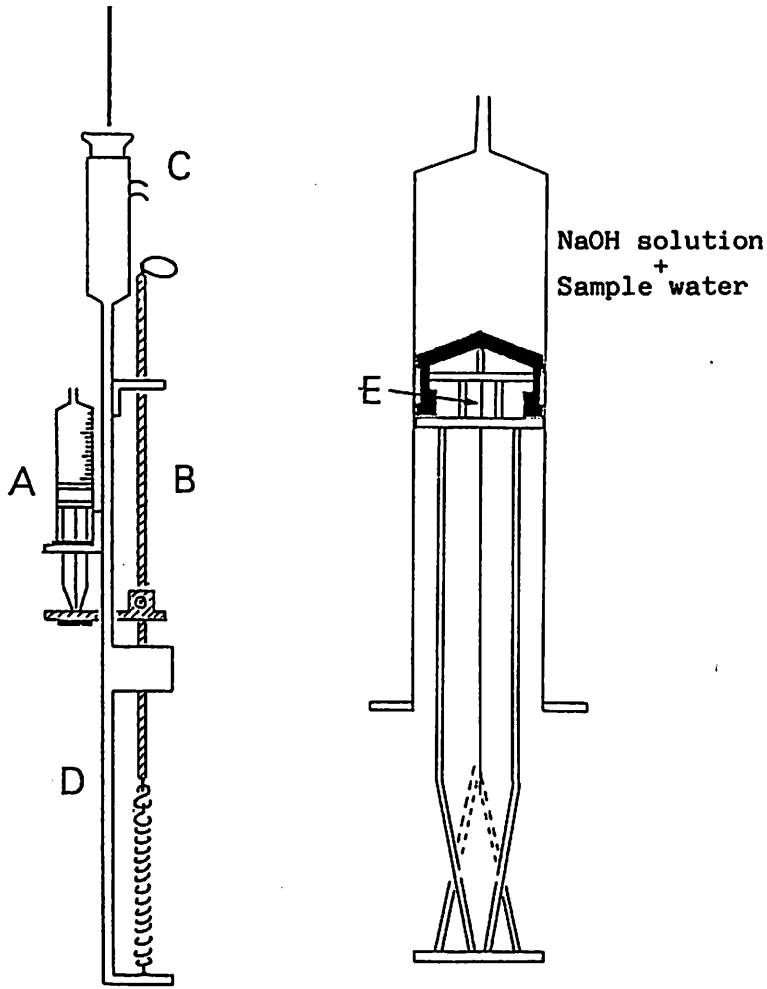


Fig. 1 A schematic presentation of the sampler. A:syringe, B:actuating rod, C:catch, D:frame, E:void

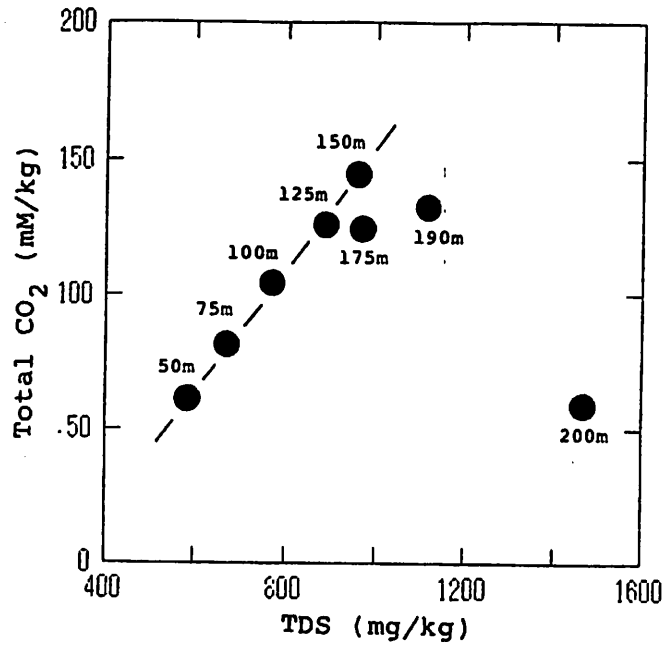


Fig. 2 A plot of the measured total CO_2 versus total dissolved solids (TDS) concentrations at Lake Nyos.

15th Colloquium on African Geology
Nancy, France 10-13 Sept. 1990
Symposium on the Lake Nyos Disaster

and

Inaugural Meeting of the International Working Group on Volcanic Crater Lakes

Convenor: Dr.S.J.Freeth, Department of Earth Sciences,

University College of Swansea, Swansea SA2 8PP, UK

Telephone: 44-792-295522 (direct line) 44-792-295618 (fax)

Call for contributions

The provisional programme for the Lake Nyos Symposium, as outlined below, contains space for a limited number of additional contributions.

1. Broad reviews
   S.J. Freeth (Swansea) Review of the geological evidence.
   P.J. Baxter (Cambridge) Review of the medical evidence.
   Eugenia Shanklin (Trenton) Review of the ethnographic evidence.

2. Latest results from the investigating teams
   F.M. Tchoua (Yaounde) Recent work in Cameroon
   M. Kusakabe (Okayama) Report on work by the Japanese Team
   K. Tietze (Hannover) Report on work by the German Team
   W.C. Evans (Menlo Park) Report on work by the American Team

3. Other contributors
   Offers of appropriate contributions should be sent to Dr. Freeth as soon as possible but not later than 28th February, 1990.

Participants who may wish to do so or who cannot be accommodated in the time available for oral contributions are encouraged to present their results as "posters".

Arrangements will be made for a Working Group Meeting during which there can be brief presentations and extended (though hopefully structured) discussion. There will also be time set aside to inaugurate the International Working Group on [Volcanic] Crater Lakes and decide how such a group can best serve our common scientific interests.

The official languages of the Colloquium are French and English, contributions to the Seminar in either language will be equally acceptable.

All participants in the Symposium must register with the Colloquium organisers. The deadline for registration and submission of abstracts is 31st March, 1990. Further information including copies of the "second circular and registration form" can be obtained from: Dr. Marc Deschamps (Colloquium Secretary), Laboratoire de Petrologie, Université de Nancy 1, B.P. 239, 54506 Vandoevres-lès-Nancy Cedex, France.

List of new members of the International Working Group of Crater Lakes (as at February 1990)

Name	Institution	Subject(s) of interest
Fazlullin, S.	Institute of Volcanology Petropavlovsk-Kamchatskii 683006, USSR	Investigations on the crater lakes of Kamchatska, Kuril Islands and New Zealand.
Halbwachs,M.	Laboratoire d'Instrumentation Geophysique Universite de Savoie B.P. 1104, 73011 Chambery Cedex FRANCE	Temp. and acoustic noise monitoring at Lake Nyos by NYOSSONDE buoy via ARGOS. Similar measurements at the Kelut crater lake (Indonesia).
Livingstone, D.A.	Department of Zoology, Duck University Durham, N.C., 27706 U.S.A.	Mixing dynamics, water chemistry and biological production in existing crater lakes; sampling dissolved gases; sampling sediments; use of sediments to understand limnology, vegetational and climatic change.
Olade, M.A.	Geology Department University of Ibadan NIGERIA	Water geochemistry and geological hazards of crater lakes.
Pourchet, H.	Laboratoire de Glaciologie et Geophysique de L'environnement B.P. 96 -38402 Saint-Martin-D'Heres Cedex FRANCE	Sampling of sediments and radiochemistry of this sediments: measurement of natural or artificial radioelements for dating
Vandemeulebrouck, J.	Laboratoire d'Instrumentation Geophysique Universite de Savoie B.P. 1104, 73011 Chambery Cedex FRANCE	Temp. and acoustic noise monitoring at at Lake Nyos by NYOSSONDE bouy via ARGOS Similar measurements at the Kelut crater lake (Indonesia).

The full list of the members is retained by the IWGCL Editor and is available upon request.

Application Form to

International Working Group on Crater Lakes

I want to join the International Working Group on Crater Lakes.

Name:

Institution:

Address:

Country:

My main subjects of interest on crater lakes are:

I propose the following(s) for the activity of the working group:

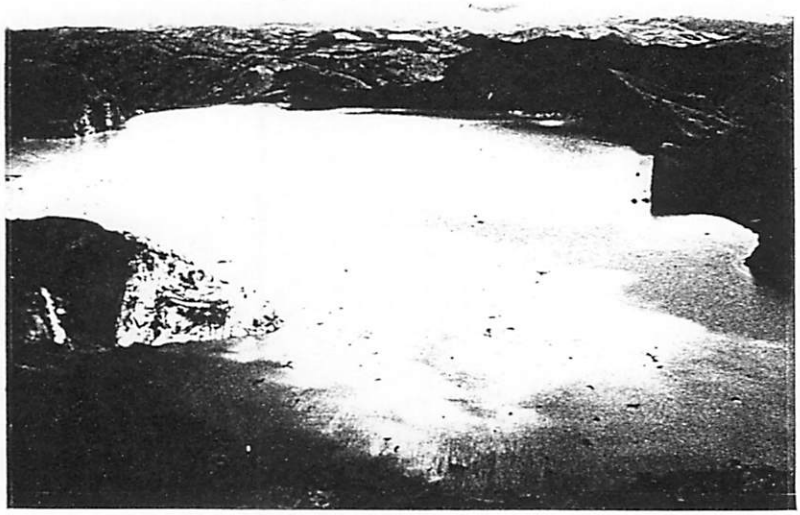
Return to:
M. Kusakabe
Institute for Study of the Earth's Interior
Okayama University
Misasa, Tottori-ken 682-02, Japan

International Working Group on Crater Lakes

NEWSLETTER

No. 3

July 1990



Special Issue

Abstracts: Symposium on Lake Nyos Disaster

Editor: M. Kusakabe

Preface

The Newsletter No. 3 of the International Working Group on Crater Lakes (IWGCL) is devoted to a special issue in which all the abstracts of the papers submitted to the Symposium on the Lake Nyos Disaster have been included. Convened by Dr. S.J. Freeth (Swansea), the Symposium will be held as a part of 15th Colloquium on African Geology at the University of Nancy 1, Nancy, France, from 10th to 13th September 1990. The Symposium programme will be finalized after the time allocation to the Symposium is given by the Organising Committee of the Colloquium.

Inaugural Meeting of IWGCL will take place during the Symposium. The main purposes of IWGCL are, as given in Newsletter No. 1, (1) mutual communication of the Group members, (2) organization of international programmes including meetings, (3) coordination of field survey, (4) standardization of reporting data, (5) joint development of instruments for crater lake survey, etc. The purposes have been only partially fulfilled so far, and at the Inaugural Meeting we should discuss what IWGCL should do in the future, what the members of the Group want to IWGCL, possible renaming of the Group, and so on. The editor should be pleased to receive the opinions from those who cannot attend the Meeting by mail or facsimile given below. He will bring with him the opinions to the Meeting.

The editor should like to express his thanks to those who responded to his favour given in the Newsletter No. 2 that $10 donation would be appreciated to cover the cost for print and distribution of our Newsletter. He will report the balance at the Meeting.

M. Kusakabe
The Editor of IWGCL Newsletter
ISEI, Okayama University
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Facsimile 81 858 43 2184

15th Colloquium on African Geology
Nancy, France, 10-13 September 1990

Symposium on the Lake Nyos Disaster
Convened by Dr. S. J. Freeth

List of Papers Accepted for Presentation

Baxter, P.J. (Cambridge) ..... Lake Nyos : review of the medical evidence

Evans, W.C. (Menlo Park) ..... Ongoing research activities at Lakes Nyos and Monoun, Cameroon, by the U.S. Scientific Team

Freeth, S.J. (Swansea) ..... The Lake Nyos disaster

Freeth, S.J. (Swansea) .....Potentially hazardous lakes in West Africa

Halbwachs, M. (Savoie), Vandemeulebrouck, J. (Savoie), Sabroux, J.C. (Gif sur Yvette) and Naah, E. (Yaounde) ..... Artificial priming of gas-lift on Lake Nyos and Monoun and its application to CO_2 release prevention

Kusakabe, M. (Misasa) ..... Water and gas chemistry of Lake Nyos in December 1988 : an estimate of thermal and CO_2 fluxes

Kwende-Mbanwi, T.W., Manguelle-Dicoum, E., Bokosah, A., Leenhardt, O., Nouayou, R. and Temdjim, R. (Yaounde) ..... Magnetotelluric investigations of the subsurface around lakes Nyos and Monoun

Leenhardt, O. (Yaounde) .... Age of the Lake Nyos

Leenhardt, O. (Yaounde), Morin, S. (Pau) and Temdjim, R. (Yaounde).....Water temperature of the lake Nyos after the disaster

Leenhardt, O. (Yaounde) .....Was the phreato-magmatic blow-out observable on lake Nyos floor with the techiniques used?

Leenhardt, O., Menard, J.J. and Temdjim, R. (Yaounde) ..... Inventory of maar lakes of the Cameroon line

Maley, J. (Montpellier) and 14 others.....West Cameroon quaternary lacustrine deposits from Barombi Mbo Sedimentology, volcanism, paleomagnetism and palynology

Martini, M. (Florence) .....Chemical characters of crater lakes in areas of recent volcanism: Albano, Nemi, Vico, Averno, Lucrino (Italy) and Sete Ciudades, Congro, Fogo, Furnas (Azores)

Njilah, I.K. and Wilson, M. (Leeds) ..... Volcanology of the Oku massif, Cameroon

Pourchet, M. (Grenoble), Pinglot, J.F. (Grenoble), Maley, J. (Montpelier) and Naah, E. (Yaounde) ..... Radioanalytical results of 19 Cameroonian lake sediment

Tabod, C., Fairhead, T.D. and Stewart, G. (Leeds) ..... Seismological studies of the Lake Nyos region and the seismicity of Cameroon

Tchoua, F. (Yaounde) ..... Recent research on Lake Nyos

Tietze, K. (Hannover) .....The Lake Nyos disaster: report on work by the German Team

Walker, A.B., Redmayne, D.W. and Browitt, C.W.A. (Edinburgh) .....Seismic monitoring at Lake Nyos

Inaugural Meeting of the International Working Group on Crater Lakes

Lake Nyos: Review of the medical evidence

Baxter, P. J. (Department of Community Medicine, University of Cambridge Clinical School, Addenbrooke's Hospital, Hills Rd, Cambridge CB2 2QQ, UK)

The results of the medical investigations at Lake Nyos were inconclusive on the type of gas released, the main problem being the limited pathological and toxicological information that could be obtained at the time of the emergency. In addition language and cultural factors militated against the use of epidemiological surveys in the survivors. Instead, reliance was placed upon the observations of rescue workers, photographic evidence and an analysis of the hospital clinical records, all of which suggested that the exposure had been to an asphyxiant gas. Any hypothesis for the mechanism of the gas release has to account for at least the following medical findings: coma-states lasting hours; blistering, ulceration or redness of the skin in 19% of survivors and an unknown proportion of the dead; and the rapid recovery of most of the survivors together with the absence of chronic neurological problems in those who had been comatose. Large-scale human exposure to carbon dioxide has not been reported before but further insight into the nature of the release and its effects may be possible using gas dispersion models that take account of the local topography and human exposure thresholds for carbon dioxide-in-air mixtures. The Lake Nyos event has shown the need for collaborative studies between geologists and medical scientists in elucidating future disasters of this kind, and the importance of a multidisciplinary approach for advising decision makers during the emergency and in the post disaster phase.

Ongoing research activities at Lakes Nyos and Monoun, Cameroon, by the U.S. Scientific Team
Recherches en cours par le Groupe Américain aux Lacs Nyos et Monoun

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Kling, G. W. (The Ecosystems Center, Woods Hole, MA 02543, USA)
Tuttle, M. L. (U.S. Geological Survey, Denver, CO 80225, USA)

Our most recent measurements at Lakes Nyos and Monoun, Cameroon, were made in December 1989. We obtained depth profiles of temperature, water and gas chemistry, and, using a newly-designed probe, dissolved gas pressure. The gas pressure measurements are, to our knowledge, the first such measurements made in-situ at these lakes. Although temperature and chemistry profiles at both lakes are generally similar to previously reported profiles, some significant changes have occurred, particularly in surface and bottom zones.

Bottom temperatures at both lakes have increased by about 0.02°C/month in the in the 31-month period before December 1989, from 24.17 to 24.83°C in Nyos (at 208 m) and from 22.56 to 23.07°C in Monoun (at 90 m). At Nyos, the rate of temperature increase has slowed markedly from the 0.07°C/month rate in the first 9 months following the 1986 gas burst. Surface temperatures at both lakes show the expected seasonal variations, but at Nyos, some long-term changes are occurring as well. Thermocline depth has increased from 7 m in January 1987 to 11 m in May 1987 and to 18 m in December 1989. Some downward mixing of cool, dilute surface water has reached depths of nearly 70 m, as shown by decreases in both temperature and ionic strength.

In the deeper waters of both lakes, the divalent Fe, Mg, and Ca still dominate the cations, and HCO_3 remains the dominant anion. The highest alkalinity values (as HCO_3) measured were 1900 mg/L in Monoun at 95 m and 1270 mg/L in Nyos at 206 m, near previous values. The increase in alkalinity with time, noted in previous samplings of the deepest waters in Nyos, may have slowed or stopped after May 1987.

Pressurized samples collected in stainless steel cylinders from various depths in both lakes show that CO_2 still makes up >98% of the dissolved gas. In Nyos, CO_2 concentrations are similar to previous values at depths between 75 m and 170 m but show an increase at 198 m, from 193 mmol/kg to 244 mmol/kg. A flux of $2x10^8$ mol/yr of CO_2 into the lake bottom is required to explain this change. The highest CO_2 concentration measured was 281 mmol/kg at 206 m. Concentrations of CH_4 appear to have increased at all depths samples in Nyos. This may derive from organic debris washed into the lake during the gas burst.

The newly-designed gas probe was used in both lakes. Dissolved gas pressures near lake bottom were 9.5 bars in Nyos (at 202 m) and 5.7 bars in Monoun (at 94 m). Probe measurements confirmed that a high percentage of the stainless steel cylinders were reliable. In Nyos, where the probe was used at 3 different anchored stations, we found that horizontal variability in gas pressure was small. Therefore, precise location on the lake is not as critical as precise depth control for investigation of time-based trends.

Nous avons fait des mesures récentes (Décembre 1989) de la température et de la composition chimique des eaux et des gaz aux lacs Nyos et Monoun. Des mesures de la pression gazeuse, obtenues avec une nouvelle sonde, suggèrent un flux de CO_2 de $2x10^8$ moles/année au fond du lac Nyos.

The Lake Nyos disaster/Le sinistre du lac Nyos

Freeth, S. J. (Department of Earth Sciences, University College of Swansea, Swansea, SA2 8PP, U.K.)

Late on the evening of 21st August 1986 a cold heavy cloud of toxic gas, released from the waters of Lake Nyos, swept down the valleys to the north leaving more than 1250 dead and dying people in its wake. Two years previously, early in the morning of 15th August 1984, gas from Lake Monoun hung as a low cloud over a swampy area and killed 37 people who walked into it. In both cases, the deaths were caused by carbon dioxide poisoning. At concentrations greater than 30% carbon dioxide starves the body of oxygen, causing loss of consciousness and subsequent death.

From studies conducted immediately after he disaster we know that at that time the deep waters of Lake Nyos were highly charged with carbon dioxide and we know from subsequent isotopic studies that this gas had originally come from deep within the earth. At surface temperatures and pressures, water can absorb almost its own volume of carbon dioxide but at higher pressures (and pressure increases with depth in a lake) the amount of carbon dioxide which can be absorbed increases. Lake Nyos is 208 metres deep and at that depth water can absorb fifteen times its own volume of carbon dioxide. One consequence of this is that if water from depth containing excess carbon dioxide is stirred up and brought towards the surface, it will rapidly release much of the dissolved carbon dioxide. The released carbon dioxide will rise as bubbles towards the surface dragging up more bottom water with it. The effect is much the same as you get when you shake a bottle of Fanta and then take the top off - an explosive release of gas.

It can be calculated that the waters of Lake Nyos ***could*** absorb 970 million cubic metres of carbon dioxide. We know from studies by Dr. Klaus Tietze and his team that in October 1986 the lake contained about 270 million cubic metres of carbon dioxide. So, had the lake been saturated prior to the disaster, it must have released about 700 million cubic metres of carbon dioxide. However, we know that Lake Nyos took only four days to refill after the disaster and that water flows into the lake, during the wet season, at a rate of about 50 thousand cubic metres per day. So, during the disaster, the volume of water in Lake Nyos must have decreased by about 200 thousand cubic metres. When carbon dioxide is absorbed by water, the volume of the water expands (ever so slightly) and so when it is released, the volume decreases. From the known volume decrease, we can calculate that Lake Nyos cannot have released more than 80 million cubic metres of carbon dioxide. We also know that the cloud contained finely dispersed droplets of water (which came from the lake) so the actual volume of carbon dioxide released must have been less than 80 million cubic metres. From the locations of compounds in which people survived we can calculate that at least 20 million cubic meters of carbon dioxide must have been released but that no more than 40 million cubic metres could have been released. Therefore, the amount of carbon dioxide left in the lake is only 10% less than the amount which was in the lake before the disaster.

The implication of this is that Lake Nyos may be as dangerous now as it was in 1986 before the disaster which cost 1250 lives.

Potentially hazardous lakes in West Africa
Les lacs qui pourraient être dangereux en Afrique de l'Ouest

Freeth, S. J. (Department of Earth Sciences, University College of Swansea, Swansea, SA2 8PP, U.K.)

Within the last few years, two volcanic lakes, both of which lie close to the main axis of the Cameroon Volcanic Line, have released lethal clouds of toxic gas. In August 1986, a toxic aerosol of water and carbon dioxide was released from Lake Nyos killing more than 1250 people and two years previously, in August 1984, a similar toxic aerosol was released from Lake Monoun killing 37 people. There are more than 40 large lakes in West Africa, any one of which might pose a potential hazard to people living in its vicinity. Since two lakes released toxic gas within two years of each other, it would be surprising if all the other lakes were entirely safe.

Ideally, all the deeper lakes should be checked for excess carbon dioxide but, given that the available resources are limited, a list of priorities should be established so that the most potentially dangerous lakes are checked first. The amount of gas which can dissolve in a given volume of fluid at a given temperature is proportional to pressure (Henry's Law). At surface temperatures and pressures one volume of lake water could dissolve approximately one volume of carbon dioxide and the amount of carbon dioxide which could be dissolved increases with depth at a rate of about one volume for each ten metres. Although it is not possible to say that even a shallow lake is totally safe, under all circumstances, there are certain limits which can be offered as a general guideline. It would seem most unlikely that any lake which is less than 40 m deep could pose a significant threat or that any lake less than about 60 m deep could cause a major disaster.

In Cameroon, there are only 14 lakes which are about 60 m or more deep. Of these, two (Nyos and Monoun) have recently released clouds of toxic gas and may do so again. Three (Wum, Barombi Mbo and Bambuluwe) have been checked and found to contain no excess carbon dioxide. Three (the Manengouba lakes and Enep) are set in basins which would probably contain any gas which they might release. Three (Nefo, Ngaoundaba and Mfou) though all about 60 m deep, are small in area and hence in volume. This leaves only three deep lakes which, as far as I am aware, have not yet been adequately investigated. I should however emphasize that there is no evidence to suggest that any of these three lakes is any more dangerous than any of the lakes which have been checked and found to contain no excess carbon dioxide.

There are also three large caldera lakes of unknown depth, one in northern Nigeria and two on the islands of Bioko, any one of which could pose a potential hazard to people living near them.

Artificial priming of gas-lift on Lakes Nyos and Monoun and its application to CO_2 release prevention
Expérience d'auto-siphon sur les lacs Nyos et Monoun et application a la prévention du risque de dégagement de CO_2

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Sabroux, J. C. (Centre des Faibles Radioactivites, Gif sur Yvette, France)
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GENERAL POINTS: During a one week field campaign on Cameroon lakes (March 1990), artificial gas lift was triggered, using simple and light equipment. Four lakes have been investigated, namely Nyos, Monoun, Bambuluwe and Wum. The gas lift priming was successful on Lakes Nyos and Monoun whereas no gas was exsoluted in Bambuluwe and Wum. This original method allows a simple and precise in situ determination of the content of dissolved gas in relation to depth. Associated with temperature measurements, the level of saturation can be inferred at any depth in the lake in order to monitor catastrophic CO_2 release.

EXPERIMENTAL: A 9 mm diameter plastic pipe is plunged vertically, its bottom opening being located at a measured depth. The water at the upper mouth of the pipe is slowly pumped using a manual pump, causing a rising of the water column into the pipe. When the hydrostatic pressure equals the gas saturation pressure, bubbles begin to form. Then a natural ascending process is initiated called gas lift or self-siphon. When the permanent rate of flow become established, the respective liquid and gas outflow can be easily measured, using a calibrated test tube. A vertical diagraphy of the dissolved carbon dioxide has been gained on Lakes Nyos and Monoun and the total amount of CO_2 still remaining inside those lakes has been calculated. One can note that when the gas lift is primed, it operates automatically and can be let, permanently spouting water and exsoluted on the site.

FUTURE DEVELOPMENT: Our future efforts will concentrate on two main directions: On the one hand we intend to begin a CO_2 flushing out procedure on Lakes Nyos and Monoun to prevent possible new catastrophic events. We will apply the gas lift method on a large scale, using some 10 cms diameter pipes. Lake Monoun will be emptied first as it contains, at least one order of magnitude lower content of carbon dioxide than Nyos. On the other, and indissociable from our first action, we will instal automatic surveillance stations on both lakes to monitor continuously CO_2 concentration (taking advantage of the gas lift device), temperatures and some other parameters. Those data will be gathered in Yaounde and France using the Argos satellite transmitting system.

Un tube a été immergé verticalement à différentes profondeurs dans les lacs Nyos et Monoun. L'eau est aspirée dans la partie supérieure du tube à l'aide d'une pompe à main. L'ascension de la colonne d'eau provoque par baisse de pression l'exsolution des bulles de CO_2 à saturation et entretient un régime autonome d'auto-siphon. Ce procédé très simple permet un dosage précis des proportions d'eau et de gaz dissous a différentes profondeurs et donc une évaluation de la quantité totale de CO_2 total dissous dans le lac. Une méthode réaliste de purge de ces lacs par ce mécanisme est proposée.

Water and gas chemistry of Lake Nyos in December 1988: an estimate of thermal and CO_2 fluxes
Chimie de l'eau et des gaz du lac Nyos en Décembre 1988: estimation du flux thermique et de celui du CO_2

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Outburst of a large amount of CO_2 dissolved in Lake Nyos, Cameroon, killed more than 1700 people on 21 August 1986. The surveys made soon after the disaster indicate that the CO_2 is magmatic in origin and that the lake is chemically stratified. We revisited the lake in December 1988. Our bottom sounding study revised the bathymetric map by Hassert (1912). The conductivity-temperature-depth profiller (CTD) measurements and chemical analysis of the lake water revealed that temperature, total dissolved solids (TDS) and CO_2 content of water below 160 m increased considerably over the last 25 months. This supports the view that CO_2 is being supplied to the lake bottom in the form of warm, CO_2-charged, mineralized water. Fluxes of heat and CO_2 were estimated to be 0.36 MW and 515-560x10^6 mol/y, respectively, by multiplying the increments of temperature, TDS and CO_2 contents with the lake volume below 160 m. The CO_2 flux is consistent with that estimated from the T-^{3}He-CO_2 relationship. The estimated CO_2 flux is large enough to saturate the lake's hypolimnion below 30 m within 50 y. Using the CO_2-TDS-Si relationship and temperature dependence of amorphous silica solubility, chemical composition of the warm mineralized water was estimated. Existence of a CO_2 saturated fluid below the sedimentary cover is suggested.

Après la catastrophe du 1986, il a été observé que la température ainsi que les concentrations du CO_2 et des autres composants dissouts augmentent aux profondeurs au-delà de 160 m. Ainsi le flux thermique et celui du CO_2 ont été évalués.

Magnetotelluric investigations of the subsurface around Lakes Nyos and Monoun

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Introduction: Magnetotelluric soundings (MTS) can be used to study the variations of apparent resistivity with depth at a given station thus determining the geoelectric section of the subsurface. Magnetotelluric profilings (MTP) lead to a determination of lateral variations at a constant horizon in the earth through a series of apparent resistivity measurements at regular intervals along a profile.

Aim: Assuming that the Lakes Nyos and Monoun gas catastrophies were due to volcanic phenomena, it should be possible to detect fractured zones and magma chambers.

Work done: The Geophysics Group of the University of Yaounde in collaboration with the Centre de Recherches Geophysiques de Garchy (CRG, France) received in 1988, a CAMPUS Grant from the French Ministry of Cooperation to carry out audiomagnetotelluric (AMT) and deep MT investigations around Lakes Nyos and Monoun. AMT measurements at sixty sites around the lakes have been completed within a first phase. Interpretations of the results are near completion and a report containing 1D and 2D interpretations should announce the preliminary conclusions. The second phase of the project will begin once the report of the first phase is completed. Mr. A. Dupis of CRG should bring the Centre's heavy MT equipment to Cameroon for the deep investigations.

Des mesures audio-magnétotelluriques sur 60 stations ont été effectuées autour des lacs Nyos et Monoun pour mettre en évidence d'éventuelles chambres magmatiques. Nous présenterons au colloque les premiers résultats.

Age of Lake Nyos/Datation du lac Nyos

Leenhardt, O. (Faculté des Sciences, Univ. Yaoundé, BP. 812, Yaoundé, Cameroun)

Samples in the alluvial plain on the south of Lake Nyos would assure a minimum age for the creation of the lake, then of the dam.

Au vu de la controverse opposant J.P. Lockwood à S. Freeth sur l'âge du barrage du lac Nyos, nous sommes revenus au schéma géologique donné par K. Hassert: on peut chercher à dater le lac par le C^{14} de sédiments organiques prélevés dans la plaine alluviale lacustre en amont du lac.

Dans ce but, 2 échantillons ont été prélevés dans la plaine alluviale en amont du lac, à la tarière, après creusement d'un trou et nettoyage de la tarière, samedi 4 pour le premier et dimanche 5 novembre 1989 pour le second. Le premier a été pris au ras de l'eau, dans le sens horizontal, dans un trou de l'ordre de 30 cm de longueur, l'eau étant alors au niveau du déversoir (1091 m), en un point 10,75 et 41,50 du carroyage rectangulaire de la carte US Nyos au 1/50000 (soit environ 6°25'45" N et 10°17'50" E). Ce point est à 350 m de la rive. Le second a été pris verticalement dans un trou nettoyé, à 2 m sous le niveau de l'eau, en un point plus proche de la rive, à environ 200 m d'elle, de coordonnées rectangulaires 10,80 et 43,70 et géographiques 6°25'48" et 10°17'55".

Ils ont été expédiés à Marseille, au laboratoire du Professeur Taieb; les résultats ne sont pas encore disponibles.

Suite aux remarques de S. Freeth (in lit.), concernant la "pollution" possible du gaz carbonique du lac par un gaz d'origine volcanique plus ancien, une nouvelle campagne de prélèvements est envisagée, en collaboration avec S. Freeth. Elle aurait lieu sous les hospices de la Délégation au Cameroun des Communautés européennes. Les datations seront faites par l'organisme spécialisé anglais.

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Water temperature of Lake Nyos after the disaster
La température de l'eau du lac Nyos après la catastrophe

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Morin, S. (Université de Pau et des pays de l'Adour, France)

An inquiry on what was the temperature of lake Nyos after the disaster confirms the Marinelli-Tazieff explanation of a magmato-phreatic eruption

Lors de la Conférence internationale sur la catastrophe du lac Nyos, se sont opposées les tenants de la thèse du renversement du lac et ceux de l'éruption phréato-magmatique. Les deux phénomènes sont endothermiques, mais le second met en jeu un gaz dont la température initiale est de quelques centaines de degrés: la température du lac peu après la catastrophe, au lieu d'être inférieure à la température de l'eau proche de la surface en saison humide (et froide, 23°C environ) doit être supérieure à la normale.

Quelques mesures de température de l'eau du lac ont été effectuées immédiatement après la catastrophe. Marinelli (in Tazieff) a mesuré au deversoir une température de 30°C le 26 aout. L'équipe Tazieff a mesuré au deversoir 26°C le 31 aout et 25°C la semaine suivante. Le 3 septembre, Sigurdsson (1987) a mesuré une verticale de températures toutes inférieures a 24°C.

Au moins un auteur de langue anglaise n'a pas hésité à dire en séance que l'on ne pouvait s'appuyer sur une seule mesure! Il faisait allusion à celle de Marinelli, ignorant les autres. Voici des témoignages et observations complémentaires.

Outre les témoignages cités par Tazieff, un autre rescapé, M. Tem (1986), survivant d'Upper Nyos, se trouvait sur les hauteurs au moment de la catastrophe; il rapporte une explosion à 9 heures, puis un vent violent et un gaz très chaud. Le Dr. Tegah (1987) signale deux fois la température de l'eau à 30°C. Le rapport medical de Kaptue a relevé les causes de brûlures indiquées par les blessés: 1 de l'hopital de Wum et 2 de l'hopital de Nkambe ont été brûlés par l'eau du ruisseau. Enfin, P. Nzeuguem, (in Shei, 1987) a mesuré le 28 août 23°C en surface, après des pluies torrentielles, mais 30°C a 2 m de profondeur.

Ces témoignages confirment l'explication "franco-italienne" d'une éruption phréatique d'origine magmatique.

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Was the phreato-magmatic blow-out observable on Lake Nyos floor with the techniques used?
L'explosion phréato-magmatique pouvait-elle laisser sur le fond du lac Nyos une trace visible avec les moyens utilisés?

Leenhardt, O. (Faculté des sciences, Univ. Yaoundé, BP. 812, Yaoundé, Cameroun)

To support its conclusions, the US team at lake Nyos argued that it did not observe any trace of a vent on the lake floor.

The technique used to survey the lake Nyos was unable to detect a vent because of the lack of precision, frequency and directivity of the sounder, the configuration of the lake and the density of the profiles surveyed.

Un des arguments apporté par la mission américaine contre l'hypothèse phréato-magmatique est que les levés du fond du lac à l'écho-sondeur n'ont pas montré la trace d'un orifice de sortie des gaz.

Etant donne:

- la précision d'écho-sondeur utilisé, sa fréquence d'émission et sa directivité,
- la configuration des fonds lacustres et
- la couverture de profils effectués,

il n'était pas physiquement possible de détecter une telle trace.

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Inventory of maar lakes of the Cameroon line
Inventaire des lacs maar de la ligne du Cameroun

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As there is no inventory of the Cameroonian lakes indicating their origins, we are closing this gap.

Le risque de voir d'autres lacs maar provoquer le même type de catastrophe que celle de Nyos conduit à dresser l'inventaire des lacs maar. Aucun document n'existe à ce sujet. La liste, incomplète, des lacs volcaniques du Cameroun donnée par Kling ne distingue pas d'entre les types de lacs.

Grâce à un crédit de la Mission française d'action culturelle et de coopération à Yaoundé, un inventaire des lacs maar du Cameroun est en cours. MM. Tchoua, Morin & Nanaa, connaisseurs des maar a différents titres, ont été consultés, ainsi que les indications bibliographiques de Hassert.

Lés resultats de cette étude seront disponibles lors du séminaire de Nancy.

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West Cameroon quaternary lacustrine deposits from Barombi Mbo: Sedimentology, volcanism, paleomagnetism and palynology. A Nyos type event ca. 21,000 years BP ?
Sédiments lacustres Quaternaires de l'Ouest - Cameroun: Sédimentologie, volcanisme, paléomagnetisme et palynologie

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Giresse, P. (Laboratoire de Sédimentologie Marine, Université de Perpignan, 66025 Perpignan, France)
Livingstone, D. A., Kling, G. and Stager, C. (Zoology Department, Duke University, Durham, NC 27706, U.S.A.)
Thouveny, N. and Williamson, D. (Laboratoire de Géologie du Quaternaire, CNRS, Faculté des Sciences de Luminy, 13288 Marseille Cedex 09, France)
Kelts, K. and Haag M. (Geology & Geophysic Section, EAWAG/ETH, Zurich, 8600 Dubendorf, Switzerland)
Pourchet, M. and Pinglot, J. F. (Laboratoire de Glaciologie et Géophysique de l'Environnement, CNRS, BP. 96 - 38402 St. Martin d'Heres Cedex, France)
Fournier, M. (ORSTOM, UR A3, Laboratoire de Géochronologie, 70 Route d'Aulnay, 93143 Bondy, France)
Bandet, Y. (Laboratoire de Geochronologie, Universite Paul Sabatier, 31062, Toulouse, France)
Zogning, A. (Centre Géographique National, MESIRES, BP. 157, Yaoundé, Cameroun.)

Une carotte de 23.5 m a été prélevée dans le Barombi-Mbo, lac situé dans la partie méridionale de la Dorsale Volcanique Camerounaise (Ouest-Cameroun). Cette carotte couvre approximativement les derniers 25.000 ans (1). Ce lac se situe dans un cratère d'explosion formé entre 1 et 5 Ma (6 datations K-Ar sur basalte), mais vu la fraicheur des parois du cratère, l'âge le plus récent parait le plus probable.

La carotte étudiée ici a été prélevée au centre du lac, sous environ 110m d'eau. Les sédiments sont très laminés et composés principalement d'argile, avec 5 à 10% de carbone organique. Les lamines sont determinées par la répétition de séquences sédimentaires épaisses en moyenne de 2 à 3 cm et caracterisées par:
- une unité inférieure grossière, associant des silts quartzeux et feldspathiques, des débris végétaux grossiers et des spicules d'éponge,
- une unité supérieure fine, plus argileuse, avec souvent des cristallisations de sidérite. Les 16 datations au radiocarbone montrent en particulier que chaque séquence a duré en moyenne 15 ans. L'unité inférieure correspond au maximum des apports détritiques, lors des fortes crues du tributaire principal qui draine un petit bassin versant, tandis que l'unité supérieure correspond à des conditions plus calmes durant lesquelles les particules plus fines se sédimentaient. La sidérite resulte de la concentration de carbonate a l'interface eau-sediment.

Les laminations sont limitées aux couches déposées dans le fond du lac, au-delà d'environ 90m de fond. De ce fait, l'observation du redressement à la verticale des couches laminées vers la base de la carotte, entre 22.5 m et 21 m sous une discontinuité se situant vers 21.000 ans BP, ne peut pas correspondre a un slumping venant de la pente du cratère, mais doit résulter probablement d'une émission brutale et localisée de gaz, comparable à ce qui s'est passé récemment à Nyos où les sédiments lacustres ont été perturbés dans leur partie supérieure par une injection brutale de CO_2 (2).

De minces couches de cendres volcaniques, généralement de quelques millimètres d'épaisseur, se rencontrent fréquemment dans les sédiments carottes; la plus forte concentration se situe entre les couches datées de 18.000 à 10.000 ans BP environ. Ces cendres ont une composition similaire à celle de scories basaltiques prévelées sur un des nombreux puys, d'apparence tres fraiche, qui parsement surtout une région située entre 20 et 30 km à l'est du lac.

L'étude du paléomagnétisme a mis en évidence des oscillations de haute fréquence, appelées variations séculaires du champ magnétique. Ce premier profil des variations séculaires obtenu sur le continent africain, se compare étroitement à la courbe type enregistrée en Europe occidentale.

Les résultats des analyses polliniques font conclure à la présence de refuges forestiers dans l'Ouest Cameroun durant la dernière grande phase aride et froide, datée entre 20.000 et 15.000 ans BP. La présence d'élements montagnards a basse altitude implique un abaissement de la température compris entre 3° et 6°C.

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Chemical characters of crater lakes in areas of recent volcanism: Albano, Nemi, Vico, Averno, Lucrino (Italy) and Sete Cidades, Congro, Fogo, Furnas (Azores)

Martini, M. (Department of Earth Sciences, University of Florence, Italy)

Systematic investigations of crater lakes pertaining to recently active volcanic systems have been carried out in order to detect possible residual influences of past activities. Such influences, mainly consisting in thermal and compositional anomalies related to convective flows of varying intensities from deep-seated magma chambers, is possibly of great importance in determining catastrophes similar to those occurred at Monoun and Nyos (Cameroon) in 1984 and 1986, respectively; an exhaustive knowledge of the actual composition of lake waters appears accordingly as an important tool to mitigate possible consequences of future similar events.

The results of bathymetric profiles of crater lakes here considered point out general shallow depths, produced by undisturbed gradual replenishment as the result of weathering of the surrounding slopes. Lake Albano only still keeps a funnel-shaped profile, so that some kind of different post-eruptive history can be derived.

From the point of view of chemical composition, not negligible quantities of free CO_2 can be observed at Sete Cidades and Furnas (Azores), Albano and Lucrino (Italy). This character, possibly related to gaseous input at depth, can act as an indicator of residual volcanic activity and seems to deserve cautious consideration.

Volcanology and geochemistry of the Oku massif, Cameroon

Njilah, I. K. and Wilson, M. (Department of Earth Sciences, Leeds University, Leeds LS2 9JT, UK)

The Oku massif is a large (3011 m high) composite volcano, situated 300 km NE of Mount Cameroon, within the central part of the continental sector of the Cameroon Volcanic Line. Volcanic activity commenced approximately 23 Ma ago with the eruption of basaltic lava flows on to a basement of Pan-African granite gneiss. These flows are overlain by a sequence of more acidic flows (trachytes and rhyolites) intercalated with block and ash flows and rhyolitic ash flows, erupted during the period 23-15 Ma. Evidence for much more recent volcanic activity is provided by numerous, morphologically young, cinder cones and volcanic craters across the greater part of the massif. A basaltic lava flow breaching one of the cinder cones has given a K-Ar whole rock age of 0.89 Ma. One of the largest craters is a circular maar now occupied by Lake Oku, which from local folklore appears to have been formed very recently (<500 years BP). This is of the same age as that proposed by some workers for Lake Nyos, further to the north.

Since December 1988 detailed sampling and geological mapping on a 1:50,000 scale has been undertaken on the Oku massif, covering an area of 900 km^2. 110 rock samples, ranging from basalt to rhyolite in composition have been petrographically studied and analysed for major and trace elements (including REE). The samples form a bimodal alkali basalt /trachyte-rhyolite suite with a marked Daly gap between 52-58% SiO_2. Trace and REE element geochemistry suggests derivation of the parental magmas from an enriched mantle source, which may be hot spot related. K-Ar age determinations on selected whole rock samples have established the age range for the volcanic activity from 23 to <1 Ma. Selected samples have also been analysed for Sr-Nd-Pb isotopes at the University of Michigan by A. N. Halliday and G. R. Davies.

Radioanalytical results of 19 Camerounian lake sediments
Analyses radiochimiques des sédiments de 19 lacs Camerounnais

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Maley, J. (Laboratoire de Palynologie, ORSTOM, UR A3, 34060 - Montpelier Cedex - France)
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La distribution verticale, dans les sédiments lacustres des radioéléments naturels et artificiels est liée aux processus de sédimentation. Lorsque des événements violents, tels que ceux de Nyos ou de Monoun se produisent, ils perturbent cette sédimentation et induisent des anomalies radiochimiques dans les profils sedimentaires.

Nous avons observé dans les sédiments de ces 2 lacs, une déformation des profils en radioisotopes ainsi qu'une augmentation du bilan en ^{210}Pb non supporté par des parents à vie longue.

La deformation des profils s'explique par le mixage qui a affecte les sédiments au moment de la phase violente. La variation du bilan en ^{210}Pb est liée à une augmentation du flux de $^{222}Radon$ qui, par filiation radioactive donne du ^{210}Pb.

Le decriptage de ces informations radiochimiques donne des indications sur les mécanismes responsables des catastrophes de Nyos (1) ou de Monoun.

Par cette méthode, nous avons cherché des paléoévénements similaires dans 19 lacs de la dorsale Camerounnaise, en particulier au lac Bambuluwe ou un nouvel echantillonnage confirme et complète nos précédentes observations (2, 3).

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Seismological studies in the Lake Nyos region and the seismicity of Cameroon
Etudes sismologiques dans la région du lac Nyos et la sismicité du Cameroun

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Cameroon, like most of West Africa, is by world standards aseismic although felt earth tremors have been reported over a wide range of Cameroon since 1852. In 1982 a seismic station was established in Yaounde followed in 1984 by a seismic network to monitor Mount Cameroon. In 1987 a further seismic network was established in the lake Nyos region by the British Geological Survey following the 21 August 1986 gas emission from the lake killing 1700 people. This network has been kept in operation by the University of Leeds to monitor the seismicity of the region. The network has been supplemented by temporary networks in 1988 and 1989.

Seven felt earthquakes have occurred in Cameroon since 1983. The two largest events occurred on the Foumban Shear Zone at Magba (1983) and Tibati (1987) in central Cameroon. The latter with mb=4.8 causing minor damage. Other events have been restricted to the Mount Cameroon region, the most recent of which occurred in March 1989, and Kribi south east of Douala.

The seismicity for the lake Nyos region is low with no obvious pattern of seismic activity. Mount Cameroon by comparison is active with instrument recorded earthquakes occurring at a rate of 2 every 3 days.

Regional earthquakes recorded by the network around lake Nyos have been used to estimate the crustal structure and upper mantle velocity in this area. Delay times from teleseismic events recorded by this network and the Mount Cameroon network have been used to investigate the deeper seismic velocity structure of the region. The results of these studies will be presented.

Après une période d'observation sismologique de trois ans (depuis 1987), la région du lac Nyos ne présente pas une sismicité importante. La structure de la croûte et la vitesse sismique du manteau externe sont estimées à partir des données régionales et les téléseismes ont été analysés en vue d'en déduire un modèle de vitesse sismique dans cette region et celle du Mont Cameroun.

Recent research on Lake Nyos/Travaux recents sur le lac Nyos

Tchoua, F. M. (Universite de Yaoundé, Cameroun)

Le Lac Lwui, plus généralement connu sous l'appellation Lac Nyos depuis la catastrophe de 1986, fait partie de la quarantaine de lacs camerounais d'origine volcanique. Situé a 25 kilomètres à vol d'oiseau à l'Est de la ville de Wum dans le Nord-Ouest du pays, le lac Nyos occupe un maar typique. De forme approximativement rectangulaire et profond de 208 metres, il mesure, en période de hautes eaux, 1925 mètres dans le sens Nord-Sud et 1180 mètres suivant Est-Ouest pour une superficie qui peut être évaluée à 227 hectares environ.

Survenant deux ans (1984) après l'explosion gazeuse du Lac Monoun situé a une centaine de kilomètres au Sud-Est et qui fit 36 victimes parmi les populations de la region, la catastrophe du Lac Nyos se traduisit, dans la nuit du 21 Aout 1986, par une décharge de dioxyde de carbone à une concentration lethale qui décima 1746 vies humaines, 3952 zebus, 337 moutons, 552 chèvres, 3404 volailles, des chiens, des chats et autres animaux sauvages dans les villages de Nyos, Subum, Cha, Bwabwa, Koskin, Mishion, etc.

Ce phénomène surprit la communaute scientifique internationale par son ampleur et surtout par sa nouveauté car, à notre connaissance et de mémoire de volcanologue, il s'est agi d'une premiere dans les manifestations volcaniques.

L'effet de surprise passe et après les observations sur le site du sinistre et les premières données analytiques, il fallait maintenant tenter de trouver une explication plausible au phénomène aprés avoir répondu a un certain nombre de questions : quelle était la nature du gaz mortel? Se trouvait-il dans les eaux du lac ou dans le substratum de celui-ci? S'est-il agi d'une manifestation volcanique de type phréatomagmatique ou d'un phénomène d'origine anthropique? etc... et plus récemment un autre probleme s'est greffé sur les précédents, celui de la résistance du barrage de pyroclastites naturel qui retient les eaux du lac.

Pour tenter de répondre aux nombreuses interrogations soulevées par la catastrophe du lac Nyos, une conférence scientifique internationale fut organisée du 16 au 20 mars 1987 à Yaounde. Au cours de cette rencontre des sommités scientifiques mondiales, deux hypotheses émergèrent parmi tant d'autres.

_ l'une, dite volcanologique, soutint qu'il s'est agi d'une manifestation phréatomagmatique classique; malheureusement aucune observation de terrain ne permit de justifier cette théorie;

- l'autre, dite limnologique, prétendit que le gaz mortel se trouvait dissous dans les eaux du lac au moment de l'éruption et qu'il s'est agi d'un simple processus de retournement des eaux dû à la différence de température entre les eaux de surface et celles de profondeur en cette période de l'année (la plus froide). Et les participants se séparèrent sur l'affrontement entre ces deux thèses, le problème restant entier.

Depuis cette date, et indépendamment des travaux effectués par des équipes scientifiques étrangères, les chercheurs camerounais ou sur place ont porté leurs efforts sur l'étude géologique, volcanologique et pétrologique du lac Nyos et de ses environs, sur la genèse et l'évolution du maar Nyos, la datation des sédiments et, partant, du cratère, la concentration de CO_2 dans les eaux du Lac; ils se sont également attaqués, avec les homologues nigérians, au problème de la résistance du barrage naturel du Lac. Ils s'intéressent au lac Monoun ainsi qu'aux autres lacs camerounais, notamment ceux de la region de Wum: Wum, Enep, Elum, Kuk, Benakuma, etc.

Pour ce faire, les méthodes classiques de géologie de terrain ont été utilisées; l'interprétation photogéologique, les méthodes géophysiques, (électrique, gravimétrique, magnétométrique, sismique) ont été mises en oeuvre. La variation de la concentration de CO_2 dans les eaux des lacs est suivie régulièrement; la datation par la méthode de ^{14}C a été entreprise. Et les résultats déjà obtenus ainsi que ceux qui sont espérés sont à la fois intéressants et encourageants.

The Lake Nyos disaster: Report on work by the German Team
Le disastre du Lac Nyos: Rapport du travail de l'equipe allemande

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On 21 August 1986 a catastrophic gas burst occurred in Lake Nyos in Cameroon. In October/November 1986 a German-Cameroon research expedition was conducted to investigate this tragic natural event and to obtain data for preventive measures against further eruptions.

Considerable physical, chemical and isotopic data on Lake Nyos water, gas and sediment were obtained. The gas released was dissolved in the stratified waters of the lake before the event. The post-event gas content of Lake Nyos of about (0.272±0.03) km^3 (STP) consists of around 99.5 % carbon dioxide with small quantities of other gases.

Data from gas analysis, carbon-14 dating and stable isotope analysis for carbon dioxide and helium suggests that the bulk of these gases is of magmatic origin. They migrated slowly upwards from the earth's mantle and dissolved in the groundwater which continuously recharges the lake. The lake water shows a significant density stratification which traps and accumulates the gases within the lake. A special physical stratification effect was found. This effect is considered to be strong enough, in the case of Lake Nyos, to lead per se to a "potential zonal dynamic oversaturation" of the lake water with CO_2 in a zone within and below the first gradient layer (metalimnion), and thus to potential instability. This finally resulted in the gas burst, even before the deep water reached high saturation levels.

The continuance of the stratification, its shape and stability, the vertical distribution of tritium in the lake and other facts argue against "Overturn Limnic Eruption", "Convection Limnic Eruption", "Gas Pocket Eruption", "Liquid Gas Eruption", and "Phreatic Eruption". The theories for these eruptions assume that the gas burst originated in the deep water of the lake or below the lake. The theory developed here, a special form of limnic eruption, which can explain the measurements and observations, is called "Fountain Limnic Eruption Theory". It assumes that the gas burst originated relatively near the surface.

The mechanism of the gas burst can be described as follows: An internal or external event, e.g. a major storm causing high internal waves and thus momentary oversaturation, triggered a massive exsolution of bubbles from the "potential dynamic oversaturated zone". These bubbles led to a local density reduction and thus to currents from deeper parts of the lake into this zone. This resulted, in a particular area, in a high, selfsustaining fountain of explosively degassing oversaturated water. The total amount of gas which escaped from the lake during the gas burst is estimated to have been (0.2±0.1) km^3 (STP), consisting mainly of CO_2.

The Lake Nyos disaster and a similar event with fatalities in Lake Monoun in 1984, drastically demonstrate the need for preventive research on gas-bearing lakes throughout the world and for practical measures against similar hazards.

Avec l'aide des dormées obtenues des mesures diverses au Lac Nyos une "Théorie de l'Eruption Fontaine Limnique" a été développée. Après l'incident, 0.27 km^3 de CO_2 se trouvaient à l'état dissout. Estimation de la quantité échappée: 0.2 km^3 de CO_2.

Seismic monitoring at Lake Nyos

Walker, A. B., Redmayne, D. W. and Browitt, C. W. A. (Global Seismology Research Group, British Geological Survey, West Mains Road, Edinburgh, UK.)

During February 1987, a network of hydrophones and geophones were installed in and around Lake Nyos. The intention was to monitor any activity of a seismic nature which may have been related to the gas release of 21 August 1986 and a possible second event on 30 December 1986. It was also important to monitor for signs of volcanic activity, or its absence, in order to assess the risk of eruption.

During the six months monitoring period, 30 regional earthquakes and a number of small local events, interpreted as rockfalls, were detected but no significant crustal earthquakes were found beneath or close to the lake.

No clear evidence of magma movement or other signs of volcanic activity were found, suggesting that direct volcanic activity was not involved in triggering the Nyos gas release although some localized noise outbursts were detected and may have represented small scale gas emissions.

Les enregistrements sismiques faits par le BGS au Lac Nyos durant une période de six mois après le désastre de 1986 ne montrèrent que peu d'évidence d'activité volcanique. De petits tremblements de terre furent enregistrés dans la province volcanique en général, mais aucun ne survint dans le voisinage du Lac.

M. Kusakabe

International Working Group on Crater Lakes

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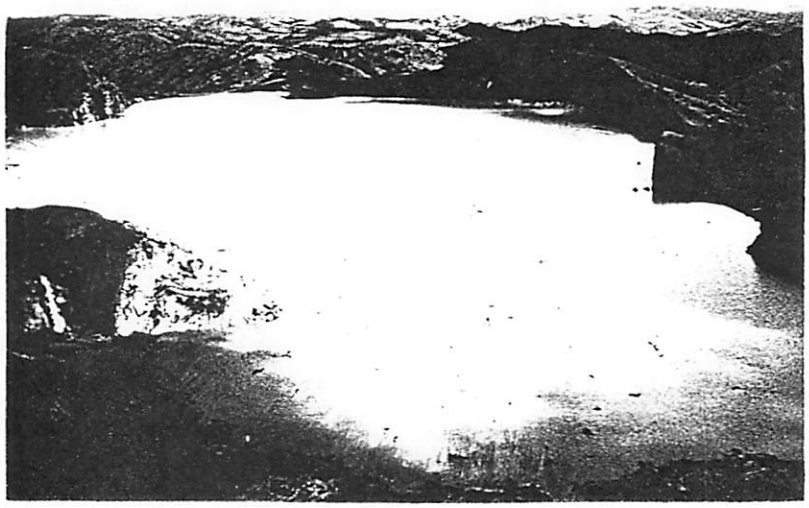

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Editor: M. Kusakabe

A letter from the Editor

Crater lakes are usually located on top of the volcanic conduit through which the materials constituting volcanoes were released. Even after an eruptive activity has ceased, it is expected that heat and volatile materials from a magma are supplied to the crater lakes. In other words, the crater lakes can be regarded as a trap for the materials and thermal energy coming out of the magma sitting at depths. It may be possible to estimate what is going on beneath the volcano through analysis of material and energy balance of the crater lakes. The present issue of IWGCL Newsletter contains not only the Lake Nyos-related subjects but also more general aspects of active crater lake studies. The editor is pleased to have such contributions which certainly widen the scope of the *Newsletter*.

The inaugural meeting of IWGCL was held as a part of "Symposium on the Lake Nyos disaster (10-13 September 1990)" during the 15th Colloquium of African Geology, University of Nancy 1, Nancy, France. At the meeting, S.J. Freeth (U.K.), M. Kusakabe (Japan) G.W, Kling (U.S.A.), J. Maley (France), F.M. Thcoua (Cameroon) and K. Tietze (Germany) were elected to form a steering committee, and M. Kusakabe was asked to act as secretary of IWGCL. During the meeting it was discussed that IWGCL should have a more firm basis rather than staying as a private group of scientists who are interested in crater lakes. The secretary proposed that IWGCL could affiliate with the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) as one of its commissions with the name "**Commission on Crater Lakes**". For present structure and activities of IAVCEI, see *Bull. Volcanol.* 52, 494-506 (1990). Having had an agreement from a majority of the steering committee members, the secretary has sent a letter to Prof. S. Aramaki, President of IAVCEI, to have our proposal approved at the IAVCEI General Assembly which will be held in August 1991 in Vienna.

There would be no demerit in affiliation with IAVCEI, and the merits would be that (1) we could use the "official" name of IAVCEI for our activities, and (2) we could use the *IAVCEI News* in *Bull. Volcanol.* as a clipboard for regular and wider communication, although funding from IAVCEI is basically unexpected. The important thing is that there will be no change at all in the purposes and activities of our group by affiliating with IAVCEI. Needless to say, joining IAVCEI as a Commission does not mean to exclude non-volcanologists from the new Commission.

During the Nancy meeting discussion was also made on the next meeting of our group and it was desired to be held in Japan in two years time. M. Kusakabe has started looking for a possible source of funding, and hopes that the next issue of *IWGCL Newsletter* will contain more detailed information on the next meeting.

In the previous communication (Newsletter No. 2) the editor asked you a favor to donate $(US)10 for support of IWGCL's activity including publication of the Newsletter. The following persons are acknowledged for the donation; P.J. Baxter, W.C. Evans, S.J. Freeth, S. Kanari, K. Kelts, G.W. Kling, M. Kusakabe, O. Leenhardt, D.A. Livingstone, Y. Nojiri, H. Pourchet, F. Schenker, G. Tanyileke, F.M. Tchoua, K. Tietze and M.L. Tuttle. The editor would be pleased to have the donation from the people who have not contributed yet. Those who are willing to donate are kindly requested to send a cheque ($US10) to the editor with the address given below.

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Volcanic lakes in Indonesia: Geological or natural resources?

Casadevall, T. J. (U. S. Geological Survey, Denver, CO 80225, U.S.A.)

The Indonesian region contains more than 130 volcanoes of Holocene age together with more than 500 volcanic centers of Pleistocene age. Rainfall throughout Indonesia, a tropical region, ranges between 1 and 5m per year with a national average of more than 2m. Lakes occur at more than 60 Indonesian volcanoes. Lakes vary in size from ephemeral ponds of a few thousand cubic meters volume up to large caldera-filling lakes found at Toba, Maninjau, Bratan, and Batur calderas with volumes exceeding tens of cubic kilometers. Volcanic lakes occur within craters and calderas as well as through impoundment of drainages on the flanks of volcanoes. Many crater lakes have elevated temperatures and low pH reflecting the effects of shallow hydrothermal systems; examples are Sibayak, Kelut, Ijen, Kelimotu, Mahawu, and Lokon. Others show no detectable chemical or thermal affects from underlying vent systems (Galunggung).

Volcanic lakes present a number of unique volcanic hazards. Eruptions of lava through saturated lake sediments and lake water may range from passive, non-explosive (Lawu) to highly explosive (Kelut-1966) activity of phreato-magmatic character. Maars are common for volcanoes erupting near sealevel (Grati) and in regions of shallow groundwater (Lamongan, Pematang Bata). Frequently such maars develop into lakes. Impoundments of surface drainages by volcanic deposits (Lava flows, mudflows, pyroclastic flows) may be susceptible to failure owing to the weakness and erodeability of the impounding rocks. Mudflows and floods are significant hazards related to failure of such impoundments. For volcanic lakes with thermal, acidified waters, leakage of lake waters may harm cultivated areas and down-stream surface water supplies used for drinking and sanitation. No deep, pressurized volcanic lakes of the Cameroon-type have been identified in Indonesia. A significant secondary hazard is failure of steep crater walls and landslide of material into crater lakes to produce splashover and secondary mudflows and floods.

During the 20th century, the presence of a crater lake (1.2 million cubic meters) in Kelut volcano in East Java has been responsible for the most deadly 20th century eruption in Indonesia. Sudden eruption and

catastrophic emptying of the Kelut crater lake has produced large-volume mudflows. Efforts to mitigate this hazard included a series of tunnel works to partially drain Kelut lake. At Ijen volcano, also in East Java, a hot, highly acid crater lake (37 mcm) occasionally spills over its outlet to produce fatal mudflows and to damage land under cultivation. A sluiceway, constructed in 1923, currently controls the level of the lake. Ijen is under surveillance by the VSI as well as by the Regional Irrigation Service. No effort has been directed at draining Ijen lake. At Galunggung volcano, West Java, a crater lake (7.5 mcm) has formed within the 1982-1983 crater. Efforts are currently underway to evaluate the feasibility of draining this lake through a tunnel leading into the Cibanjaran drainage.

A number of volcanic lakes feature prominently as tourist attractions in various parts of Indonesia. The water from many volcanic lakes is used for irrigation, sanitation, and drinking. Utilizing the volcanic lakes for their social and tourist value requires that careful surveillance be maintained and consideration be given to safety of those using the resource. Efforts to prevent disasters and mitigate the hazards from volcanic lakes must balance the benefits derived from recreational and human uses of the lake against the potentially deleterious effects of volcanic activity.

The crateric lake of Maly Semyachik volcano in Kamchatka

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At the Maly Semyachik volcano an ultra-acid lake is located in the Troitsky crater. Here complex geochemical and hydrological studies were carried out in the period from July 31 to August 16, 1990. These studies included sampling of water, bottom sediments, free and dissolved gas, as well as limnological surveys. Figure 1 shows the distribution of depths and the points of location of hydrological stations. Powerful gas bubble emission occurs in the deepest part of the lake (max h=141 m). At this site, because of gaslift a hydrodynamically active zone with high horizontal velocities (~10 cm/sec) is formed in the area of over 1000 m^2. This zone is well seen on aerial photographs; it is outlined by bright yellow sulfur foam. In addition its colour differs from the other part of the lake: against a turquoise background it has a brown tint and uneven but distinct boundary. Based on the dynamics of patch spreading one can suggest that the source at the floor of the lake is characterized by pulsing regime.

At present the lake is gradually cooling down. In the period from 1986 to 1990 its temperature decreased from 32.5 to 16.4 °C. The vertical distribution of temperature during the survey was even (the maximum difference at stations reached 0.5 °C). The distribution of water density in the lake indicated the presence of a powerful convective intermixing.

pH of water in the lake is somewhat lower at the surface which is due to sulfur oxidation at the boundary with the atmosphere. The range of pH values is from 0.66 at the surface to 1.16 at the floor. The values of E Pt/AgCl of the medium are distributed rather evenly. Their values lie within the ranges (330-365 mV). The reduction reactions occur under the influence of volcanic gases and large amounts of Fe (II) available in the solution.

Free and dissolved gas is almost entirely of volcanic origin. A high concentration of H_2 is noted. In water the concentration of dissolved H_2 and CO_2 increases with depth and that of N_2 and O_2 decreases (Table 1).

The water of the lake has a high mineralization. Noticeable concentrations of some metals are found in the solution due to absorption

of a part of the material which is supplied from the volcano depths and due to leaching of elements from rocks of the lake bowl (Table 2).

The bottom sediments of the lake are represented by sulfur ooze with admixture of authigenic clay minerals and fine-sand varieties. In the zone of gas lift, the areas with melted sulfur are noted. Those are caused by heat flow. Probably, the formation of hollow sulfur balls is associated just with these areas at the floor of the lake. Unfortunately, no intact balls are encountered because of high difference of gas pressure (compared to the surface of the lake) during their formation (ΔP=12 to 14 atm).

The water in the lake is nontransparent because of high content of fine-dispersed suspension.

Since 1969 hydrochemical and hydrological studies are being conducted on the lake. However, no indications for the forthcoming eruption have been found yet.

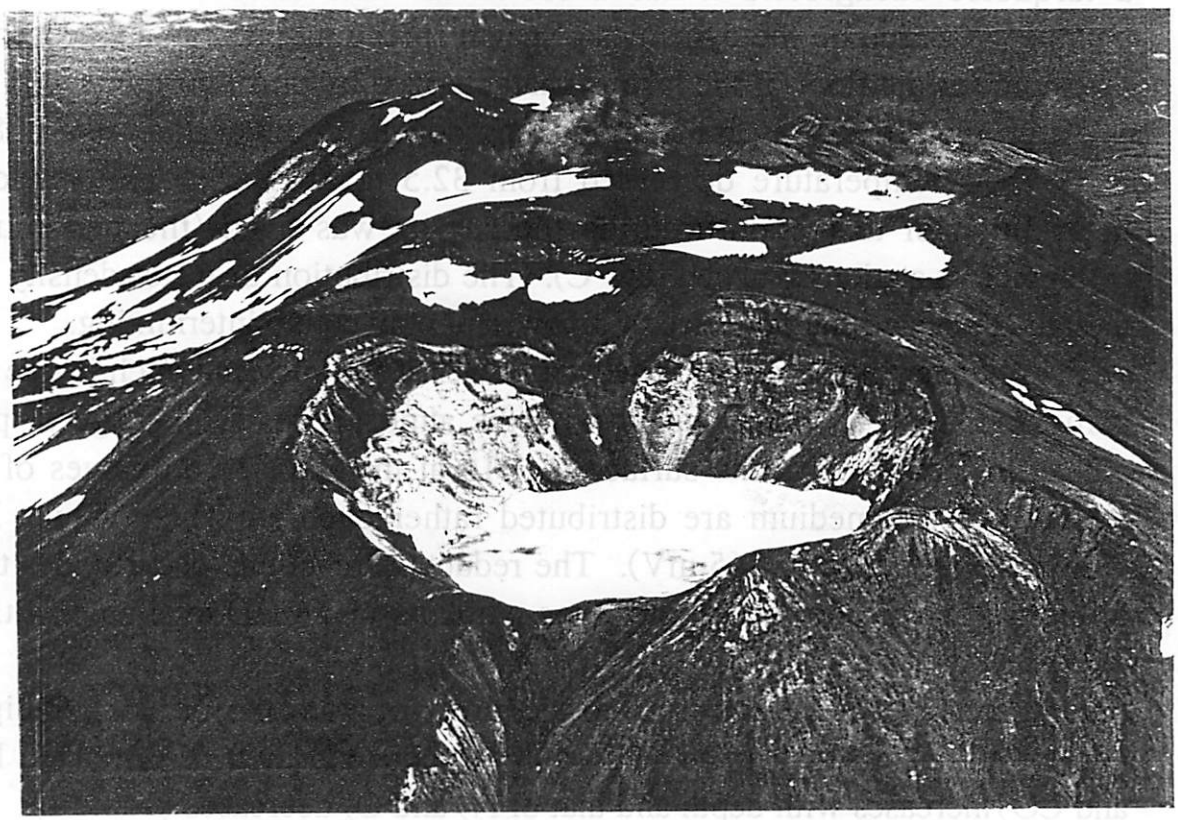

Fig. 1. The crater lake of Maly Semyachik volcano, Kamchatka

Table 1 Gas compositions of the Maly Semyachik crater lake

Species	Free gas	Dissolved gas					
	h=0m	h=0m		h=40m		h=120m	
	C, %	C, %	C, ml/l	C, %	C, ml/l	C, %	C, ml/l
He	0.015	-	-	-	-	-	-
H_2	3.390	0.285	0.213	0.485	0.3448	1.0304	0.7735
CO	0.004	-	-	-	-	-	-
CH_4	0.017	0.136	0.1015	0.0034	0.0024	0.0169	0.0127
Ar	0.581	0.440	0.329	0.443	0.315	0.401	0.301
O_2	7.518	2.257	1.686	1.914	1.362	1.544	1.159
N_2	85.265	24.210	18.090	22.39	15.930	20.300	15.240
CO_2	3.210	72.640	54.290	74.770	53.200	76.710	57.580

Table 2 Concentration of dissolved elements (mg/l)

Component	Concentration	Component	Concentration
Temp.(°C)	16.2	Mn	9.2
pH	0.75	As	0.72
Na	200.3	Cu	0.12
K	45.4	Sc	0.32
Ca	521.0	Co	0.5
Mg	244.2	Cd	0.1
Fe	591.8	Pb	0.2
Al	745.2	Cr	0.4
Cl	5248.0	Zn	1.1
SO_4	471.7	Ni	0.1
HSO_4	13452.9	U	3.2
S_4O_6	1594.9	H_4SiO_4	95
F	253.6	HBO_3	19.3

The Crater Lake of Poás Volcano (Costa Rica): Measurements, Modeling and Interpretations.

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Introduction

Poás is an active andesitic stratovolcano of the Central American chain, with a total volume of ~100 km^3, and an age estimated at between 100,000 and 200,000 years (Prosser and Carr, 1983). The active crater is located at 2300 m altitude, is ~800 m in diameter, and ~150 m deep. Historically, Poás has been in a state of near continuous mild activity, characterised by fumarole emissions and a hot, acid lake, which exhibits occasional phreatic/phreatomagmatic eruptions. The most recent phase of major activity was during 1952-55. Phreatomagmatic eruptions removed the old crater lake and built up a cinder cone; this cone was subsequently largely destroyed by explosions, producing a pit crater at the northern end of the main crater. A new lake formed within this pit crater in 1965.

Measurements

Approximately monthly measurements of lake and fumarole temperatures have been made by Costa Rican vulcanologist Jorge Barquero (Universidad Nacional, Heredia) since 1978. These data have been supplemented by ~monthly measurements of lakewater SO_4^{2-}, Cl^-, and F^- contents since 1983 (Jorge Barquero, personal communication; Rowe et al., 1991). Former lake levels have been estimated from photographs; these levels have been converted to lake volumes and surface areas using a survey of the lake basin carried out in March 1989. In addition, monthly rainfall data exist for Poás National Park visitors centre, ~1km from the active crater. Windspeed, air temperature and humidity were monitored on the crater floor over 8 weeks in March/April 1989, revealing an average windspeed of 2.3 m s^{-1} at 1m height, an average air temperature of 15°C, and an average humidity of 80%.

Modeling

(i) Mass and Energy Balance

A mass and energy balance model has been developed and applied to Poás crater lake for the period 1978-89. The mass and energy flows between each temperature measurement are considered. Mass is added to the lake by steam (at a rate M_{st}), and rainfall (rate M_{rn}). Mass is lost through evaporation from the lake's surface (rate M_{ev}), and through seepage (M_{sc}). The rate of change of lake mass (ΔM) is therefore given by:

$$\Delta M = M_{st} + M_{rn} - M_{ev} - M_{se} \qquad (1).$$

Each mass flow (M_x) has an energy content or enthalpy, H_x (where x = st, rn, ev, se). Thus each term in the mass balance (M_x) has an equivalent term in the energy balance (E_x) equal to the product of mass flow and enthalpy ($E_x = M_x \,.\, H_x$). Values for enthalpies can be estimated using steam/water tables (e.g Rogers and Mayhew, 1980). In addition to evaporation, there are two other energy losses from the lakes surface: sensible heat (E_{sh}), and radiation (E_{ra}), neither of which remove mass. Sensible heat is the loss due to conduction of heat from hot water to cold air; once heated, the air convects upwards. The rate of change of energy stored within the lake (ΔE) can therefore be written:

$$\Delta E = E_{st} + E_{rn} - E_{ev} - E_{se} - E_{sh} - E_{ra} \qquad (2).$$

ΔM and ΔE can be estimated from lake temperature and volume data. M_{rn} can be approximated by estimating a catchment area for the lake, and using the nearby rainfall data. Evaporative losses (M_{ev}, E_{ev}) can be estimated using the semi-empirical model of Sill (1983). This model requires the input of lake temperature and area, and ambient weather conditions (windspeed at a given height, air temperature and humidity). Weather conditions used in the model are those measured in March/April 1989. Sensible heat losses (E_{sh}) are related to evaporative losses, because the same convection mechanism governs both losses. Net radiative losses (E_{ra}) can be estimated using Stefan's law for

Lake T / °C	Air T / °C	Wind / m s^{-1}	ϕ_{ev} / W m^{-2}	ϕ_{sh} / W m^{-2}	ϕ_{ra} / W m^{-2}
30	10	0	233	77	11
		2.5	398	132	11
		5	535	178	11
	20	0	121	31	-35
		2.5	211	53	-35
		5	317	80	-35
50	10	0	1117	197	147
		2.5	1834	324	147
		5	2163	383	147
	20	0	937	135	101
		2.5	1577	227	101
		5	1872	269	101

Table 1. *Surface losses calculated for two lake temperatures, two air temperatures, and three windspeeds. Windspeeds at 2m height, humidity 100%. An incoming solar radiation of 140 W m^{-2} is assumed for the net radiation term. ($E_x = \phi_x \,.\, Area$).*

longwave radiation (incoming atmospheric and outgoing back-radiation), and a simple approximation for the incoming solar shortwave radiation. Rigourous equations for surface losses are given in Stevenson (1991), and some typical values are given in table 1. Results for the rate of steam input to the lake over the period 1978-89 are shown in figure 1.

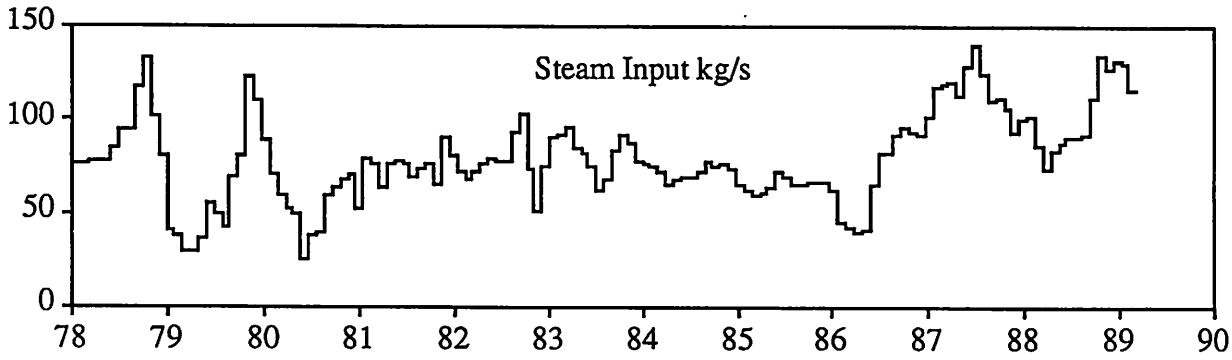

Figure 1. *Calculated steam input rate (M_{st}) for Poás crater lake over the period 1978-89. Values are smoothed to 30-day averages.*

(ii) Chloride Ion Balance

Chloride ions in the lake are thought to be primarily derived from the addition of HCl gas from the lake-floor fumarole vents. Making the assumption that negligible amounts of HCl are lost by volatilisation at the lake's surface, the only loss of chloride ions will be through lake seepage. A chloride ion balance can therefore be written:

$$\Delta[Cl] = M_{st}\,[Cl]_{st} - M_{se}\,[Cl]_{lake} \qquad (3),$$

where $\Delta[Cl]$ is the rate of change of total chloride ions within the lake, and $[Cl]_{st}$ and $[Cl]_{lake}$ are the chloride concentrations in the steam and the lake respectively. $\Delta[Cl]$ can be found by using the regular measurements of lakewater chloride concentration, and calculations of lake volume. Values of M_{st} and M_{se} have already been calculated using the mass and energy balance, and an average value of $[Cl]_{lake}$ can be assumed. Thus $[Cl]_{st}$ can be calculated for each time interval. Figure 2 shows

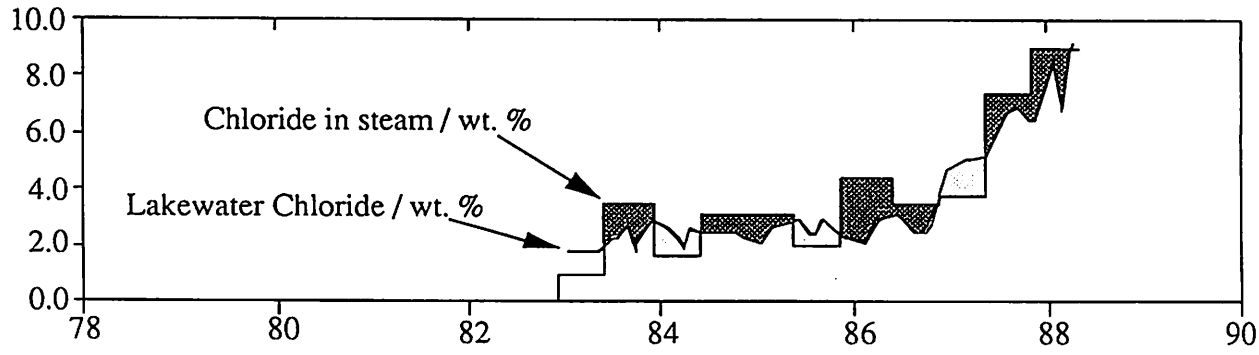

Figure 2. *Chloride concentrations in steam (calculated six-month averages) and lakewater (measurements). Heavy shading indicates periods when $[Cl]_{st}$ exceeds $[Cl]_{lake}$, and the light shading vice-versa.*

calculated values of $[Cl]_{st}$ with measured values of $[Cl]_{lake}$ superimposed.

Interpretations

The steam input graph (fig. 1) shows that the steam flux has varied considerably with time. Peaks in 1978 and 1979 correspond to periods of phreatic activity in the lake. The sharp rise in mid-1980, sustained through 1984, corresponds to the numerous A-type seismic events that occurred during July 1980 (Casertano et al., 1985). These events were followed by a dramatic rise in fumarole temperatures (95 to 960°C) on the cone adjacent to the lake, the first signs of which were observed in January 1981 (Barquero, 1989). These fumaroles declined in temperature until mid-1986, when, once again, increased seismicity was observed (Fernandez, 1990), and a new area of high temperature (~600°C) fumaroles formed. This also corresponds to a sharp increase in steam input to the lake (fig. 1). At this time, the lake started to fall in level, and by mid-1987, phreatic eruptions recommenced, presumably due to the increased steam influx, and reduced lake-floor pressures. The lake continued to reduce in volume, and had effectively disappeared by the end of April 1989, when large lakes of liquid sulphur formed around some lake bed vents (Oppenheimer and Stevenson, 1989). In the situation where gas is passing directly through the lake, the mass and energy balance model becomes inaccurate, and results for mid-1987 onwards are unreliable.

The question of whether the steam has a magmatic or hydrothermal source can be addressed by comparing lake chloride concentrations with those of the steam itself (see fig. 2). If the steam is simply recycled lakewater, then the two concentrations should be broadly similar, because any HCl in lake seepage waters will be vaporised and returned to the lake with the steam. This is generally the case for the period 1983-88 (fig. 2), indicating that the major form of heat transfer is through the downwards percolation of lake water, which is heated, then returned to the lake as steam. The heat is thought to be derived from conduction through a thin boundary layer above a magma body. Some heat is also thought to be transferred through direct magmatic degassing. The most likely period for a major input of magmatic gas to the lake is in early 1986, when $[Cl]_{st}$ values of ~4 wt.% have been calculated, compared to $[Cl]_{lake}$ values of ~2.5 wt.%. This also corresponds to the period of increased seismicity and the appearance of new, high temperature fumaroles on the cone. The results suggest that magmatic gas in 1986 had a HCl content of over 4 wt.%, compared to 0.9 wt.% HCl measured in high temperature 'magmatic' gases in 1982 (Casadevall et al., 1984). This possibly indicates a new, volatile rich magmatic source was being tapped. A new magmatic intrusion has been

suggested by Rymer and Brown (1989) on the basis of observed increases in gravity at crater floor stations. However, the gravity increases can also be modeled by invading a steam zone beneath the cone with water, over the period when fumarole temperatures fell from 600°C to 95°C (1986-89).

In conclusion, the major form of heat transfer at Poás for the period 1983-88 is thought to be through the recycling of lakewater. Seepage is vaporised at depth, by heat supplied across a conductive boundary layer above a magma body, then returned to the lake as steam. Some additional heat is transferred directly by magmatic degassing. Abrupt increases in steam input to the lake are thought most likely to represent bursts of magmatic gas, as opposed to a sudden increase in the vigour of the recycling system. The mechanism of magmatic degassing and its interaction with the hydrothermal system is currently being investigated.

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EVALUATION OF VOLCANIC ACTIVITY AT CRATER LAKES USING AQUEOUS SULFUR SPECIATION

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1. Introduction

Two major sulfur-containing gases in volcanic exhalations are sulfur dioxide (SO2) and hydrogen sulfide (H2S). If such gas mixtures are injected into a water reservoir , these sulfur gases react each other, resulting in various sulfur species in the water. Active crater lakes are the cases for such gas reactions at ambient temperature (Takano, 1987; Takano and Watanuki, 1990).

SO2/H2S ratios in volcanic gases are closely related with volcanic activity; they generally rise with increasing temperature and volcanic activity (cf. Giggenbach, 1987; Ossaka et al., 1980; Ossaka et al., 1983). On the other hand, the distribution of aqueous sulfur species in the lake water is expected to vary with the SO2/H2S ratio of volcanic gases discharged into the water. Then we may presume that the change in volcanic activity at the crater lake give rise or cause to a variation in distribution of sulfur compounds in the lake.

This short note presents our recent research developments in aqueous sulfur speciation and its relationship with volcanic activity at active crater lakes.

2. A working hypothesis

When SO2 and H2S gases are injected into water, H2SxO6 (x=4, 5, 6,・・・) and colloidal sulfur are produced. This solution has long been known as the Wackenroder liquid in inorganic chemistry. There still remains some ambiguities in its reaction mechanism which may proceed in the solution (cf.Chitani, 1959; Kimura, 1913). Stoi-

chiometries for the formation of polythionates, however, are written as follows (Ohsawa, 1989):

$$3SO_2(aq) + H_2S(aq) \rightarrow H_2S_4O_6 \quad (1)$$

$$10SO_2(aq) + 5H_2S(aq) \rightarrow 3H_2S_5O_6 + 2H_2O \quad (2)$$

$$11SO_2(aq) + 7H_2S(aq) \rightarrow 3H_2S_6O_6 + 4H_2O \quad (3)$$

Equations (1)-(2) suggest that polythionates are produced most efficiently when a SO2/H2S ratio in water is about 1-3. Under this condition, neither SO2 nor H2S remains in the water, or at most very slightly. In the case of the SO2/H2S ratio greater than 1-3, SO2 or H2S remains in large excess and the efficiency in polythionate formation will decrease. Consequently, we may predict that when the SO2/H2S ratio shifts with an increase in volcanic activity at a crater lake, the distribution of H2S , H2SxO6 and SO2 in water will change as shown in Table 1. SO2 gas dissolves about fifteen times as much as H2S gas in the water of about pH 1 at 20°C (Chronological Scientific Table, 1985; at 0°C ,Handbook of Chemistry and Physics, 1988-1989). Therefore, if the SO2/H2S ratio in lake water is X, the ratio of the volcanic exhalations discharged into a crater lake at 20°C will be close to X/15 (Ohsawa,1989).

3. Experimental

Fujiwara (1989) conducted an experiment to prove the working hypothesis described above reasonable for active crater lakes. The reaction between SO2(aq) and H2S(aq) was commenced by adding sodium bisulfite (NaHSO3) and sodium bisulfide (NaHS) to a bisulfate-sulfate buffer solution (pH;1.5, ionic strength;0.15 ; Ohsawa, 1989). The SO2/H2S ratio in the water was changed from 0.1 to 50. Polythionates were determined using reversed phase HPLC (Takano and Watanuki, 1988). SO2(aq) and H2S(aq) were determined by ion chromatography (Dasgupta et al., 1980) and the modified detection tube method (Togano and Ochiai, 1987), respectively. The experimental results are shown in Fig. 1. The SO2/H2S ratio at which polythionates are produced most efficiently is from 1-3 and efficiency in polythionate formation decreases as the ratio deviates from 1 ~ 3. When the SO2/H2S ratio is above 1, excess SO2 remains in the water and no H2S is detected. At the ratio less than 1, H2S remains in the

water but no SO2 is detected. These results strongly suggest that the working hypothesis described above can be applied reasonably as far as the experimental conditions are closer to the crater lake environments.

4. Application to active crater lakes

We started the surveillance of Yugama crater lake, Kusatsu-Shirane volcano, Japan, in 1984. Since then this volcano has been decreasing activity except for sporadic seismic activity. In order to obtain more data of sulfur chemistry at active crater lakes, we analyzed the sample waters from two more volcanoes: Poas (Costa Rica) and Ruapehu (New Zealand). These volcanoes are thought more active than Kusatsu-Shirane volcano at present and contain active crater lakes of the size:

Poas volcano; Laguna-Kaliente (diameter;250m, depth;40m, pH; ~0)
Ruapehu volcano; Crater Lake (diameter;480m, depth;135m, pH;0-1)
ref. Kusatsu-Shirane volcano; Yugama (diameter;280m, depth;23m, pH;~1)

A. *Kusatsu-Shirane volcano*

Variation of polythionates from 1960 to 1988 are shown in Fig. 2 (Takano and Watanuki, 1990). Recent eruptions were recorded at Kusatsu-Shirane volcano in 1982 and 1983. Concentrations of polythionates quickly decreased two months before the first eruption and were maintained under detection limit (about 0.n ppm) during the eruption period *. The SO2/H2S ratio of a subaerial fumarolic gas sampled at a newly-opened vent at the lake shore at this period was about 3 (Hirabayashi, 1984). Accordingly, it may be reasonable to consider that subaqueous fumarolic gases at the lake floor had quite a similar gas compositions to that of the observed. Under this condition, the SO2/H2S ratio in the lake water should be about 45 (refer to the section 2: a working hypothesis). Therefore, when volcanic activity is so enhanced as to erupt, polythionates could not be detected and SO2 should be found in the lake water.

Polythionates quickly returned to a high concentration level once more after the 1983 eruption, but from 1985 till 1988, began to de-

crease again to a low concentration level. Since then, H_2S(aq) has been at about 5-20 ppm and SO_2(aq) has not been detected in the crater lake water. Consequently, the SO_2/H_2S ratios of the subaqueous fumarolic gases at this period would be quite low, probably much lower than 0.07. This value strongly indicates that the volcanic activity at Yugama crater lake during this period was relatively quiescent. This conclusion is in good accord with a recent trend in variation of sulfur isotope ratios of sulfate in the lake water (Ohsawa et al., 1990).

On the other hand, when polythionates existed at a high concentration level, for example, in 1968, only trace amounts of H_2S(aq) was detected (Kurasawa, 1975) in the water. Then the SO_2/H_2S ratio of the crater lake water is likely to have been slightly less than 1 (cf. Fig. 1).

* Quite a small eruption occured in 1976. But no variation of polythionates in Yugama crater lake water was observed. This may be due to the lack of sampling covering this eruptive period.

B. *Poas volcano*

Polythionates were determined for about 80 waters which were sampled from 1984 to 1990 (Ohsawa et al., 1990; Rowe et al., submitted for publication in JVGR). At this volcano, two eruption periods were recorded from June 1987 to December 1988 and from April 1989 to mid-1989. A rapid decrease in polythionate concentration was observed before both eruption periods (Fig. 3).

During the eruptive periods (including just before eruption), enhanced volcanic activity yellow-colored strongly the crater lake water (Ohsawa et al., manuscript in preparation). The reason for this coloration will be attributable to formation of ferric chlorocomplexes. On the other hand, during quiescent periods, the lake water was colorless probably because iron in the water is present as ferrous. In a strongly acidic solution as the pH about zero, H_2S(aq) rapidly reduce ferric ion to ferrous , while SO_2(aq) does it quite slowly (Ohsawa et al., manuscript in preparation). Therefore, the rapid decrease in polythionates before the eruption and their dis-

appearance during the eruption period are correlated to enhanced SO2/H2S ratios of subaqueous fumarolic gases (Ohsawa et al., manuscript in preparation).

C. *Ruapehu volcano*

Polythionates were determined for about 180 waters which were sampled from 1968 to 1990 (Takano et al., manuscript in preparation). Polythionate concentrations also decreased just before eruptions and held at a low level through the eruptive periods.

Unfortunately, data of dissolved SO2 and H2S have been lacking so far. But recently, Ohsawa and Takano determined both SO2(aq) and polythionates at Crater Lake, Ruapehu volcano (February 9, 1991). Polythionates existed at a high concentration level (S406: 174, S506 : 163, S606: 88.4 ppm). SO2(aq) was present at about 4 to 11 ppm and H2S(aq) was just above the detection limit (~0.1 ppm). Recent report by DSIR (New Zealand) shows H2S(aq) at 0.05 ppm (Private communication from Dr. Bruce Christenson). These results indicate that activity at the crater lake is now in calm but still active state as that at Yugama from 1960 - mid 1982.

5. Summary

From the discussion described above, it was demonstrated that the sulfur species (SO2(aq), H2SxO6, H2S(aq)) in active crater lakes strongly reflect volcanic activity at the craters. We summarized our conclusion in Table 2. When SO2 is detected and polythionates are at a high concentration level, activity of volcanoes would be relatively high. When polythionates begin to decrease with increasing SO2(aq), we have to be cautious of impending erutions.

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Table 1. Relation of SO2/H2S ratio in lake water and volcanic gas to distribution of aqueous sulfur species: H2S(aq), H2SxO6, SO2(aq).

VOLCANIC ACTIVITY	:	Low ←		→ High
SO2/H2S (volcanic gas)	:	←	0.07~0.2	→
SO2/H2S (lake water)	:	←	1~3	→

H2S(aq)	exist	none or trace	none
H2SxO6	none or trace	exist	none or trace
SO2(aq)	none	none or trace	exist

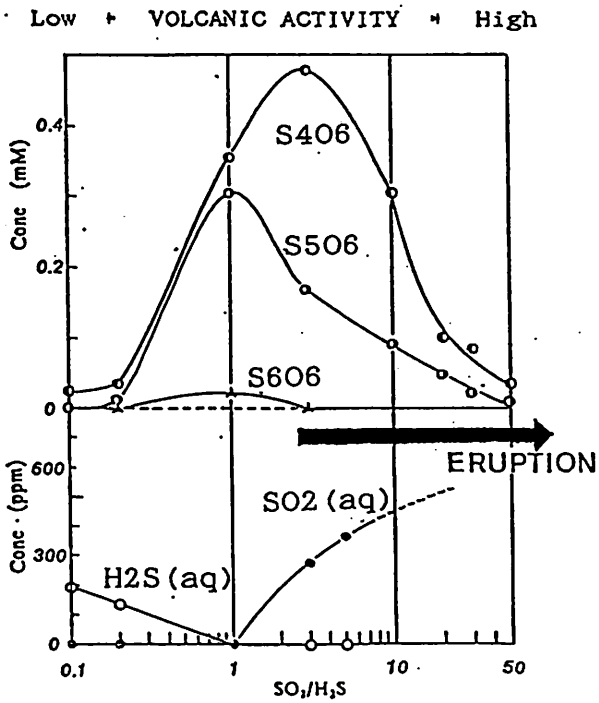

Fig. 1 Experimental results on the reaction between sulfur dioxide and hydrogen sulfide in water.

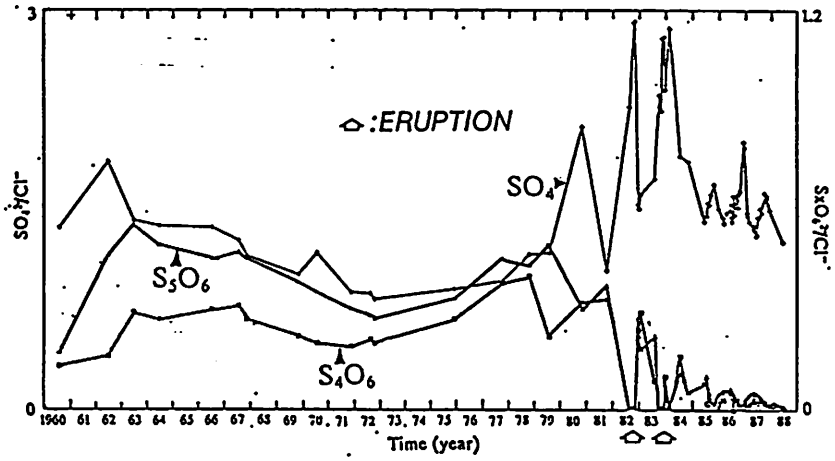

Fig. 2 Variation of polythionate concentration normalized by chloride at Yugama crater lake, Kusatsu-Shirane volcano.

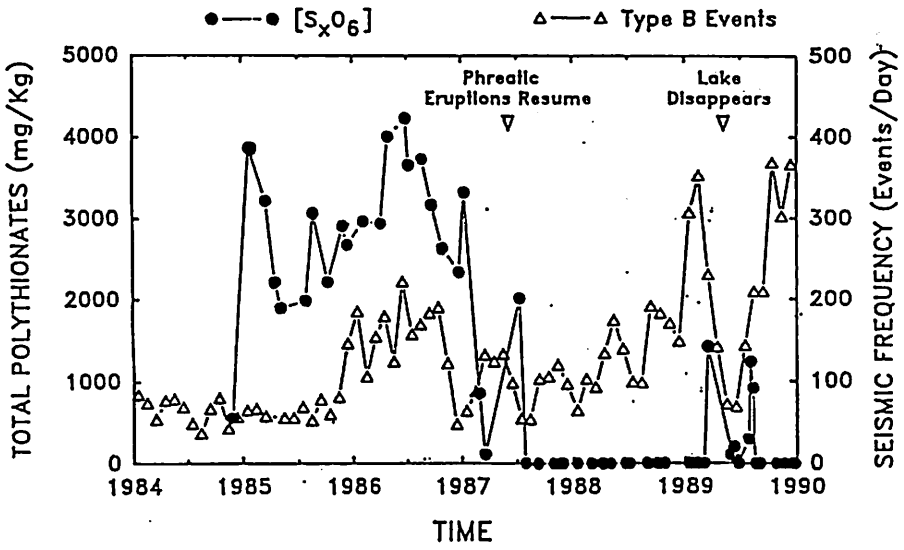

Fig. 3 Variation of polythionate concentration at Laguna-Kaliente, Poas volcano.

Table 2. Relationship between volcanic activity and distribution of aqueous sulfur species (summary).

ACTIVITY	MOST ACTIVE (A)	ACTIVE (B)	RELATIVELY CALM (C)	CALM (D)
HSO_3^-	Y	L*	N	N
SxO_6^{2-}	N	Y	L	N
H_2S	N	L*	Y	N
pH	Low(<1.5)	←	→	High(>2) **

Y:Present,N:None,L:Low Level

*These sulfur species do not coexist in acid solution.
** pH values of H_2S- and CO_2-saturated solution are about 4.0 and 5:6, respectively.

Clearing Centre for Gas-Disaster Prevention Research

Klaus TIETZE

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In the past various research efforts have been made in the important field of gas-bearing lakes (e.g.: Schmitz and Kufferath 1955; Tietze 1978-1981) and ocean basins (e.g.: Degens and Ross 1969; Sackett et al. 1979). As a response to the disastrous gas bursts from lakes Monoun and Nyos in Cameroon, these early efforts have been intensified (e.g.: Kling et al. 1989; Nojiri et al. 1990; Tietze 1987-1991).

In the meantime the literature on research concerning gas-bearing lakes has grown rapidly. Further, it is now clear, that the gas bursts from lakes Monoun and Nyos may not have been the only ones, but rather they may only be the "tip of an iceberg". From the physical standpoint it is logical that in lakes like Nyos cyclic limnic gas bursts, disastrous or not, must inevitably occur (Tietze 1991a) if we consider a long enough time scale.

I believe that it is now high time to intensify international cooperation (Sigvaldason 1989;Freeth et al. 1990) in the field of gas-bearing lakes to prevent future gas disasters of the Nyos type. Therefore I have established a centre to

- collect information on gas bursts of all kinds which occur in lakes and ocean basins,
- collect information on any gas-bearing lakes or ocean basins having a possible burst potential,
- make initial assessments and
- make this information available to scientists and other interested parties.

To this end may I ask my collegues for help by providing the centre with all the information they have on gas bursts other than those of lakes Nyos and Monoun as well as on lakes and ocean basins with a gas burst potential. Furthermore I would like to invite all interested persons to send copies of their work on gas-bearing lakes and ocean basins, both publications and reports, including those on lakes Monoun and Nyos, for inclusion in the centres literature archives. The centre will cooperate intensively with the IWGCL. In the future the centre intends to expand its activities to cover also other types of gas disasters.

To give a preliminary example for the possible information which will be available in about one year (see planned information in IWCL newsletter 5 in 1992) a short list of the known gas bursts in lakes, including selected references is given below.

A more comprehensive list, based on this preliminary table will be followed by a "complete" list of references and by a list of other gas-bearing lakes which may have a high gas burst potential (including references).

Many thanks in advance to all those who help to consolidate the clearing centre.

I would like to point out that this is a private initiative and that letters may be sent only to my private address as on the title page!

Preliminary abbreviated list of gas-eruptions from gas-bearing lakes with rounded mean data:

name of lake	date of erupt.	number of victims	surmised type of eruption	main gases inv.	max. gas concentr. m^3 (STP) / ($m^3 H_2O$)	gas volume in place km^3 (STP)	surmised gas origin	main sources of information	ref. on rec.	next likely burst (a)
paleo-lake, Sénèze depression, France	$1.5 \cdot 10^6$ years BP (repet.)	?	?	CO_2?	?	?	?	Couthures (1989)	1	?
Barom-bi-Mbo, Came-roon	$21 \cdot 10^3$ years BP	?	?	CO_2?	?	?	?	Maley et al. (1990)	1	?
some lakes, Came-roon	historic time (repet.)	?	?	CO_2?	?	?	?	Shanklin (1989) (legends and myths)	1	?
Monoun, Came-roon	15 Aug. 1984	37	overturn limnic eruption	CO_2	?	?	magm.	Sigurdsson et al. (1987)	5	?
Nyos, Came-roon	21 Aug. 1986	1746	fountain limnic eruption	CO_2	4.5	0.27 ±0.03 (1986, post event)	magm.	Kling et al. (1989); Kusakabe et al. (1989); Tietze (1987-1991)	150	0.3
Nyos, Came-roon	30 Dez. 1986	0	- " -	CO_2	- " -	- " -	- " -	Chevrier (1989)	1	0-50?
land-fall lake in Bad Pyrmont, Germany	18 Aug. 1988	0	fountain limnic eruption	CO_2 H_2S	?	?	magm. bact.	Tietze (1991b)	2	?

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The 1990 Nancy Meeting of IWGCL: Conclusions and Recommendations

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Institute for Study of the Earth's Interior, Okayama University
Misasa, Tottori-ken 682-01, Japan

A symposium on the Lake Nyos gas disaster, convened by S.J. Freeth, was successfully held on 11-12 September 1990 at the University of Nancy 1, Nancy, France, with the total number of participants in excess of 50. The abstracts of the papers presented were given in the last issue of the *IWGCL Newsletter* (No. 3). During the symposium a broad consensus was reached by the participants concerning the cause of the disaster and it was discussed that the remedial measures were urgently needed to prevent a further disaster and therefore decided that a document should be prepared which summarizes the conclusions and recommendations of the symposium, by the International Working Group on Crater Lakes. After rather lengthy discussions the conclusions and recommendations, which are given below, were unanimously accepted by the participants of the IWGCL meeting.

Conclusions:

(1) The 1986 gas disaster in Cameroon was caused by a massive release of CO_2 from Lake Nyos.
(2) Lake Nyos now contains about 300 million cubic meters of carbon dioxide and therefore remains dangerous.
(3) This danger is increasing because carbon dioxide is currently being added to Lake Nyos at a rate of at least 5 million cubic meters per year.

Recommendations:

(1) Another gas disaster could occur at any time. Therefore the amount of carbon dioxide in Lake Nyos should be reduced as a matter of urgency,
(2) Prior to controlled degassing, equipment should be installed for continuous monitoring of the stability of the lake.
(3) Pipes should be installed to remove gas-rich water from the bottom of the lake.
(4) Degassed water should be discharged outside the lake basin to avoid disturbing the natural stratification of the lake.
(5) The rate of water extraction should not exceed the natural water recharge rate. Lowering the lake level would increase the risk of gas release from beneath the lake.
(6) Any system for gas extraction should be tested on Lake Monoun.
(7) The stability of the natural dam at the exit to Lake Nyos and the possibility of lowering the lake level should be further investigated.

It was agreed in the meeting that the above conclusions and recommendations should be sent to the governments of Cameroon and Nigeria. As a convener and chairman of the meeting, S.J. Freeth prepared a communique which is almost the same as above and sent it to the relevant government bodies. It was also agreed that the above materials should be sent to *Nature* for publication. Freeth summarized the conclusions and recommendations except the recommendation (7) with explanatory wordings on the background and logical sequences. It was published in *Nature* by the members of the IWGCL steering committee [1]. However omission of the recommendation (7) from the Nature article was felt problematic by the people who believe that the Nyos dam may collapse due to its instability giving rise to another disaster by flooding downstream. For this reason, a complete set of the conclusions and recommendations drawn up at the meeting was published in the *GVN Bull.* [2] together with a summary of the results recently obtained by the U.S. team.

[1] S.J. Freeth, G.W. Kling, M. Kusakabe, J. Maley, F.M. Tchoua and K. Tietze. Conclusions from Lake Nyos disaster. *Nature* 348, 201 (1990)
[2] *Bulletin of the Global Volcanism Network* (formerly *SEAN Bulletin*), 15 (11),7-8 (1990), contributed by W.C. Evans.

Report on the "Workshop on the Lake Nyos Disaster", Lagos, December 1990

S.J.Freeth
Geological Hazards Research Unit, University College of Swansea,
Swansea SA2 8PP, U.K.

The workshop in Lagos, organised by the Nigerian Federal Ministry of Science and Technology, concentrated on problems associated with the natural dam which blocks the exit from Lake Nyos. Should this dam fail then it may release up to 57 million tonnes of water which would sweep down the valleys to the north, into the Katsina Ala, across the frontier into Nigeria, down the River Benue and into the Niger Delta.

The age of the Lake Nyos dam is of practical importance; if the dam is very young and eroding rapidly, then there is considerable cause for concern, whilst if it is old and eroding slowly, there is far less cause for concern. Two estimates of the age of the dam have been offered; a sample of carbon collected from the downstream face of the dam has yielded a ^{14}C age of 400 years (Lockwood & Rubin 1989) whilst a lava flow which post-dates the dam has yielded a K-Ar age of over 100,000 years (Freeth 1988). It was generally agreed, by the participants in the workshop, that the observed erosion rate probably precluded an age of less than a few thousand years.

A number of studies, aimed at evaluating the structure and stability of the dam, were discussed at the meeting.

Although it is now firmly established that there is bedrock, at a depth of 38 metres below lake level, at the downstream face of the dam there is, as yet, no hard evidence concerning the nature of the bedrock surface beneath the dam. It is certainly possible that the bedrock surface may rise beneath the dam and there is some evidence to suggest that there may be resistant rocks at a depth of as little as 10 metres immediatly upstream from the dam. It was therefore generally accepted that even if the dam were to fail it might release only 15 million tonnes of water rather than the full 57 million tonnes which would be released if the dam were ripped out to a depth of 38 m.

The properties of the rocks which form the dam are currently being studied by a team of Nigerian geotechnical engineers. Their preliminary results, which were presented at the meeting, suggest that, even on a worst case scenario concerning the structure and configuration of the upstream face, the dam currently has a safety factor of at least two. It should be emphasised that this is a preliminary result and that a far larger safety factor would be required for the design of a man-made dam. However, their result does suggest that the dam may pose less of an immediate threat than that posed by the gas (Freeth et al. 1990). Clearly more detailed studies on which a full stability analysis can be based should be a matter of high priority, but the long term hazard posed by the dam should not be allowed to distract attention from the immediate hazard posed by the present level of gas in Lake Nyos.

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List of new members of the International Working Group of Crater Lakes (as of March 1991)

Name	Institution	Subject(s) of interest
Leenhardt, O.	Department of Physics Faculty of Sciences, Univ. Yaounde B.P. 812, Yaounde, Cameroon	Seismics, sounding, profiling
Hurst, A.W.	Geology and Geophysics, D.S.I.R. Salamance Rd., Kelburn P.O. Box 1320, Wellington, New Zealand	
Varekamp, J.C.	Department of Earth and Environmental Sciences, Wesleyan University Middletown, CT 06457, U.S.A.	

The full list of the members is retained by the IWCCL Editor and is available upon request.

Application Form to

International Working Group on Crater Lakes

I want to join the International Working Group on Crater Lakes.

Name:

Institution:

Address:

Country:

My main subjects of interest on crater lakes are:

I propose the following(s) for the activity of the working group:

Return to:
M. Kusakabe
Institute for Study of the Earth's Interior
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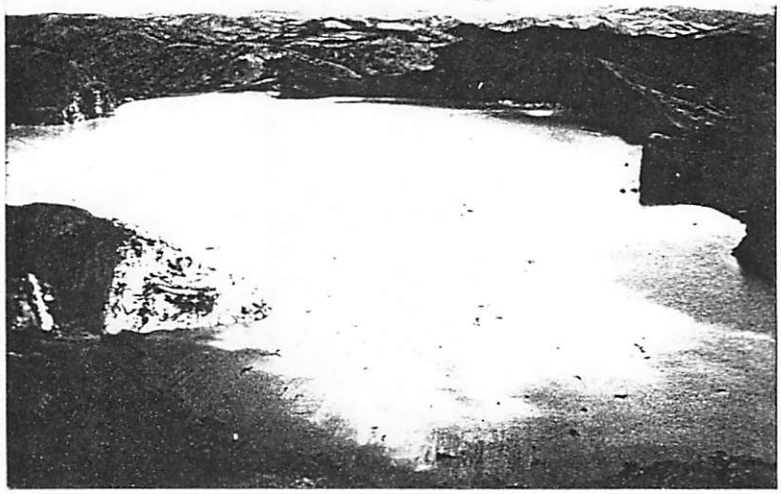
International Working Group on Crater Lakes and Commission on Crater Lakes, IAVCEI

NEWSLETTER

No. 5

March 1992



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Editor: M. Kusakabe

A letter from the Editor

As written in the IWGCL Newsletter No. 4, the steering committee of the IWGCL (S.J. Freeth, G.W, Kling, M. Kusakabe, J. Maley, F.M. Tchoua and K. Tietze) agreed that the IWGCL should have more structure rather than remaining as an informal group of scientists who are interested in crater lakes. Along this line the secretary (M. Kusakabe) proposed to the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) that the IWGCL should affiliate with the IAVCEI as one of its commissions with the name "**Commission on Crater Lakes.**" The secretary sent a letter to the President of IAVCEI to have our proposal approved at the IAVCEI General Assembly in August 1991 in Vienna. Although not 100 % affirmative, the reaction of the Executive Committee (EC) of the IAVCEI was positive as shown in the following EC's minutes which was sent to the secretary after the IAVCEI's General Assembly:

"The International Working Group on Crater Lakes (IWGCL) has submitted a proposal to IAVCEI to be established as a new IAVCEI commission. The EC is enthusiastic about the proposal but recommends to the IWGCL to approach the International Association of Hydrological Sciences (IASH) to form an inter-association commission because of the obvious key role to be played by hydrology and hydrologists."

To form an inter-association commission may be a good idea considering that the members of the IWGCL consist of people working in various fields including limnology and hydrology. In our capacity as the IWGCL's steering committee members, G.W. Kling and myself started negotiation with the key persons of the IAHS to realize the "inter-association" commission. Obviously these kind of procedures need a long time to be finalized. We hope that we can report any progress on this matter in the next Newsletter. The editor would appreciate it if you could express your opinion about this in the next issue of the Newsletter or directly write to him.

IMPORTANT! I am very glad to inform you that my government has decided to support me in organizing the second IWGCL or the first CCL meeting in Japan, as suggested in the Newsletter No. 4. The meeting will take place from 19th to 22nd of October, 1992 in Misasa, Japan. I would enthusiastically like to ask you to prepare for the meeting. For more information on the meeting, please look at "Call for Papers" (p. 17) in this issue.

Minoru Kusakabe
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CHEMICAL SURVEILLANCE OF TWO DEEP CRATER LAKES IN ECUADOR

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DSIR Chemistry, Petone, New Zealand

B Beate and L Lemarie
Escuela Politecnica Nacional, Quito, Ecuador

In order to assess the potential danger posed by deep volcanic crater lakes, a chemical survey was carried out for Lakes Cuicocho and Quilotoa, both are potentially active volcanoes located on the Western Cordillera of the Ecuadorean Andes. Samples were collected of deep and shallow waters and of gas discharges on the shores of the lakes. The sampler used to collect both deep water and gas samples is a modified version of the "syringe sampler" described by Kusakabe et al. (1990), but holding two syringes thus allowing the simultaneous collection of both water and dissolved gases.

Lake Cuicocha (78^{o} 21.6' W, O^{o} 18.3' N) occupies a very recent, roughly circular caldera on the southern flank of the Pleistocene andesitic volcano Cotacachi. It is deeply eroded by glaciers, the basement rocks are late Creataceous to early Tertiary accreted calc-alkaline volcanites and associated minor sediments. The city of Cotachi lies some 10 km to the east above a gently dipping apron of extensive pyroclastic flows. The steeply walled caldera is 3 km in diamter with its highest point at 3400 m, the lake has a diameter of 2 km at an elevation of 3064 m, its maximum reported depth is 180 m.

Some 3100±150 years ago, a large dacite dome started to grow on the S flanks of Cotacachi volcano followed by explosive activity, the destruction of the dome's W side and the extrusion of 4.2 km^3 of pyroclastic flows covering an area of 180 km^2 (Hillebrandt, 1989). Subsequent collapse formed the Cuicocha caldera. More recent activity (2990±300 a BP) was dominated by smaller explosive eruptions and the growth of four dacite domes within the caldera. The predominant rock type is plag-hbd rich dacite wity little mag-qtz-px. Active NE trending faults cross the Cuicocha area, a 3.9 magnitude tectonic earthquake was recorded in October 1990 by the IG/EPN network.

Present thermal activity consists of the gentle discharges of streams of gas bubbles over an area 10 by 10 m along the NW shores of Isla Yerovi, one the recent dacite domes. Vigorous discharges of CO_2 rich gases occur from soda springs on the outer flanks of the structure some 11.5 km to the east. Analyses of waters collected on 20 November 1990 from a depth of 149m, LC-1, and the surface, LC-2, are given in Table 1. Both deep and surface waters are very little mineralised and virtually identical. There was no free gas in the water samples collected at the lake bottom when brought to the surface.

The compositions of the gases discharged along the NW shore of Isla Yerovi are shown in Table 2. They are essentially mixtures of CO_2 and atmospheric gases. H_2S, H_2 and CH_4 are very low suggesting any associated high temperature hydrothermal system to be at considerable depth. The similarity in the composition of surface and deep waters suggest that the Lake Cuicocha waters are well mixed. Together with the lack of dissolved gases in the waters, the survey shows that there is no hazard of the Lake Nyos type.

Table 1.- Chemical composition of waters from crater lakes and springs in Ecuador, in mg/kg.

No	°C	pH	Li	Na	K	Rb	Cs	Mg	Ca	Ba	B	HCO_3	SiO_2	NH_3	SO_4	Cl
LC-1	17.6	8.2	.21	67	4.4	.013	.001	36	45	.030	5.2	264	49	<.1	<2	75
LC-2	16.8	8.3	.17	65	4.0	.004	<.001	36	109	.030	5.1	252	47	<.1	<2	71
LQ-0	14.6	7.8	3.7	2285	196	.44	.043	900	229	.004	156	392	116	0.7	2570	4200
LQ-1	12.8	7.8	3.5	2255	195	.44	.040	831	308	.009	155	415	118	0.2	2530	4156
LQ-2	13.0	7.8	3.5	2270	196	.44	.042	838	328	.009	156	420	116	9.0	2560	4145
LQ-3	22.8	7.7	3.5	2250	197	.43	.042	784	574	.010	159	430	106	0.2	2620	4146
TU-1	44.7	8.0	.73	523	82	.12	.008	897	327	.019	5.4	620	175	0.5	2960	796
TU-2	54.0	8.3	.72	522	82	.12	.009	499	205	.022	6.0	980	201	0.5	1680	428

Table 2. - Chemical composition of gases discharged from thermal systems in Ecuador, in mmol/mol of dry gas.

No	°C	CO_2	H_2S	NH_3	He	Ne	Ar	H_2	O_2	N_2	CH_4
LC-A	24.6	743	<.6	.021	.0077	.0029	2.34	<.004	23.2	226	4.72
LC-B	24.6	834	-	-	.0104	.0016	1.36	<.008	2.9	162	0.48
LQ-A	22.5	974	0.5	.011	.0005	.0002	-	<.0002	4.2	21	0.09
LQ-B	14.6	773	-	-	<.008	.0053	4.39	<.040	71.2	152	<.04
TU	44.7	998	<.2	.0018	.0002	.0004	0.03	<.001	0.2	1.1	0.002
LN	23.0	990	<.1	-	.0360	.00005	0.05	<.002	0	5.2	1.00
ASW	-	15	-	-	.0024	.0098	16.4	.0005	336	633	0.004

Lake Quilotoa (78° 54'W, 0° 51'S) occupies an almost perfectly circular, central caldera with near vertical walls and a diameter of 3 km. The lake is about 2 km in diameter at an elevation of 3520 m, with a reported, but unconfirmed depth of >360 m. Quilotoa volcano is a truncated strato volcano reaching a height of 3914 m with a base 5 to 7 km wide at 3500 m.

Andesitic lavas and tephra make up the early strato cone, it overlies mid-Tertiary fractured wackes. Four main periods of explosive activity can be distinguished two >16000,the other 14000 and 850 a ago. Conspicuous and well developed paleosoils separate deposits from these periods. The dominant rock type is a porphyritic bio-hbd-plag dacite. Domes and voluminous pyroclastic flows are the main manifestations of volcanic avctivity. The domes were intruded into the old andesitic edifice while the pyroclastic deposits ponded into the headwater valleys of Rio Toachi forming a large well preserved flat topography deeply dissected by recent erosion gullies. The formation of he present caldera possibly commenced during the first eruptive period, later eruptions contributed to its enlargement and present shape. A small dacitic dome (<300 m in diameter) grew inside the caldera at the SSW lake shore to a height of ~20 m above the present lake level. The resulting peninsula is mantled by by a few m of phreatomagmatic surge deposits, also plastered against the S and W crater wall, probably from the most recent magmatic - eruptive event.

Quilotoa volcano lies some 33 km WNW of the city of Latacunga. A telemetered seismograph of the EPN/IG network monitors volcanic activity with no recent significant recent changes from normal behaviour.

Most of the known discharge of gas occurs from vigorous near shore and underwater vents at the tip of the peninsula, they are related to NE dome fractures. Water samples were collected on 21 and 22 November 1990 in the center of the lake at a depth of 0.3 m (LO), from two widely spaced points at the lake bottom at a uniform depth of close to 240 m (LQ-1, LQ-2) and from a spring at the lake shore (LQ-3). The lake waters are highly mineralised, but of close to uniform composition and temperature pointing to the absence of both salinity and temperature stratifications within the lake. The deep water samples did not contain any free gas when brought to the surface. Again, the lake is obviously well mixed and does not contain excess dissolved gas and therefore poses no Lake Nyos type hazard.

The composition of the spring water associated with the vigorous gas discharge is virtually identical with the lake waters, its temperature is somewhat higher. The spring waters emanate only some 5 to 10 cm above the lake surface and therefore may only represent recycled lake water, "gas lifted" by the stream of rising gas.

Sample LQ-A represents gas discharged at the lake edge, LQ-B gas dissolved in the lake water at depth of some 30 cm. In most aspects they are very similar to the Lake Cuicocha gas. As there, they are largely mixtures of CO_2 with atmospheric gases. The CO_2 content of the dissolved gas, however, is much higher than that expected for air saturated water (15 mmol/mol, Table 2). For comparison, Table 2 also contains data for another CO_2 rich spring in Ecuador, one associated with Tungurahua volcano (TU), for the gas dissolved in Lake Nyos (LN), and that of water saturated with air at 20°C (ASW). It appears that all these CO_2 rich gases are chemically quite similar.

According to theoretical considerations, at these low temperatures, CO_2 should both be converted virtually completely to CH_4 or be incorporated into a carbonate (calcite). The gases as discharged are obviously far from equilibrium with crustal rock. In a recent study Giggenbach (1991) made an attempt to reconcile the occurrence of this type of gas with their theoretical instability within the crust at low temperatures and suggested that they may be derived from high temperature magmatic gases to be stored underground in gas pockets allowing only limited acces to crustal rock. The surface gas discharges represent some leakage of gas from these pockets. The main requirement for formation and preservation of low temperature CO_2 rich gases is cooling from magmatic temperatures without extensive interaction with rock. The environment for such interaction is generally provided by geothermal systems. The occurrence of low temperature CO_2 rich gases therefore may suggest that extensive hydrothermal systems are absent.

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INVESTIGATION ON CRATER LAKES IN AREAS OF RECENT AND ACTIVE VOLCANISM OF ITALY

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B. CAPACCIONI Inst. Mineral. Petrol. University of Urbino

Crater lakes pertaining to active volcanic systems have been investigated with reference to changes occurring in water chemistry in response to different stages of activity, and interesting information is available about Ruapehu (Giggenbach, 1974), Kusatsu-Shirane (Ossaka et al.,1980), and Poas (Casertano et al., 1985).

Lakes Averno and Lucrino, located in the Phlegrean Fields (figure 1),where a quiescent volcanic stage characterized by solfataric activity and vertical ground movements is lasting since the eruption of 1538, are also sistematically investigated under a program of geochemical surveillance of the area (Martini et al., 1991); any kind of increased activity in the deep system is expected to produce changes in the surface environment, for which crater lakes can be preferential sites.

Volcanic activity can obviously occur in a surrounding area without disturbing crater lakes, but significant changes observed in crater lakes can be interpreted as related to some kind of resumed activity.

Several other lakes can be found inside quaternary volcanoes from

central Italy; in particular, lakes Vico, Nemi, and Albano, located in the surroundings of Rome (figure 1) can be referred to a relatively recent activity, and their investigation has been undertaken during the last years.

Careful depth profiles, obtained by means of Video Scan Sounder (Ray-Jefferson), allowed to reproduce the shapes of the ancient craters where the water bodies are hosted. From figures 2-4 it is possible to observe that Vico and Nemi display almost flat bottoms, while Albano still keeps a funnel shape.

Lake Averno (figure 5) appears similar to Vico and Nemi, while the very shallow lake Lucrino, continuously reworked since Roman times for nursery purposes, can hardly provide the evidence of its shape.

The shallow depths and the flat bottoms can be interpreted as produced by the continuous sedimentary refilling in quiet basins; the funnel shape of Albano seems on the contrary to point out a possible "cleaning" because of circulating fluids.

With reference to the chemical composition of lake waters, salinities of about 200 ppm and calcium bicarbonate character pertain to Nemi, Vico, and Albano, reflecting equilibrium with country rocks; salinity values of 2050 and 25500 ppm displayed by Averno and Lucrino, respectively, as well as their sodium chloride character appear related to different extents of seawater influence.

No thermal anomaly has been detected in any crater (figure 6), while interesting details arise from the vertical profiles of figures 7 and

8. The relatively significant decrease of pH and increase of dissolved CO2 at constant temperature, observed at Albano, appear as an indication that gaseous species are released at depth; even if the extent of degassing may be not very important, this appears to strengthen the above mentioned hypothesis of "cleaning" fluids which prevent from a quiet sedimentation and from a progressive refilling of the lake.

This circumstance probably represents a rather common behaviour for crater lakes pertaining to areas of recent volcanism; degassing and lack of refilling, however, can be considered as evidences that a local anomaly is still alive in the area.

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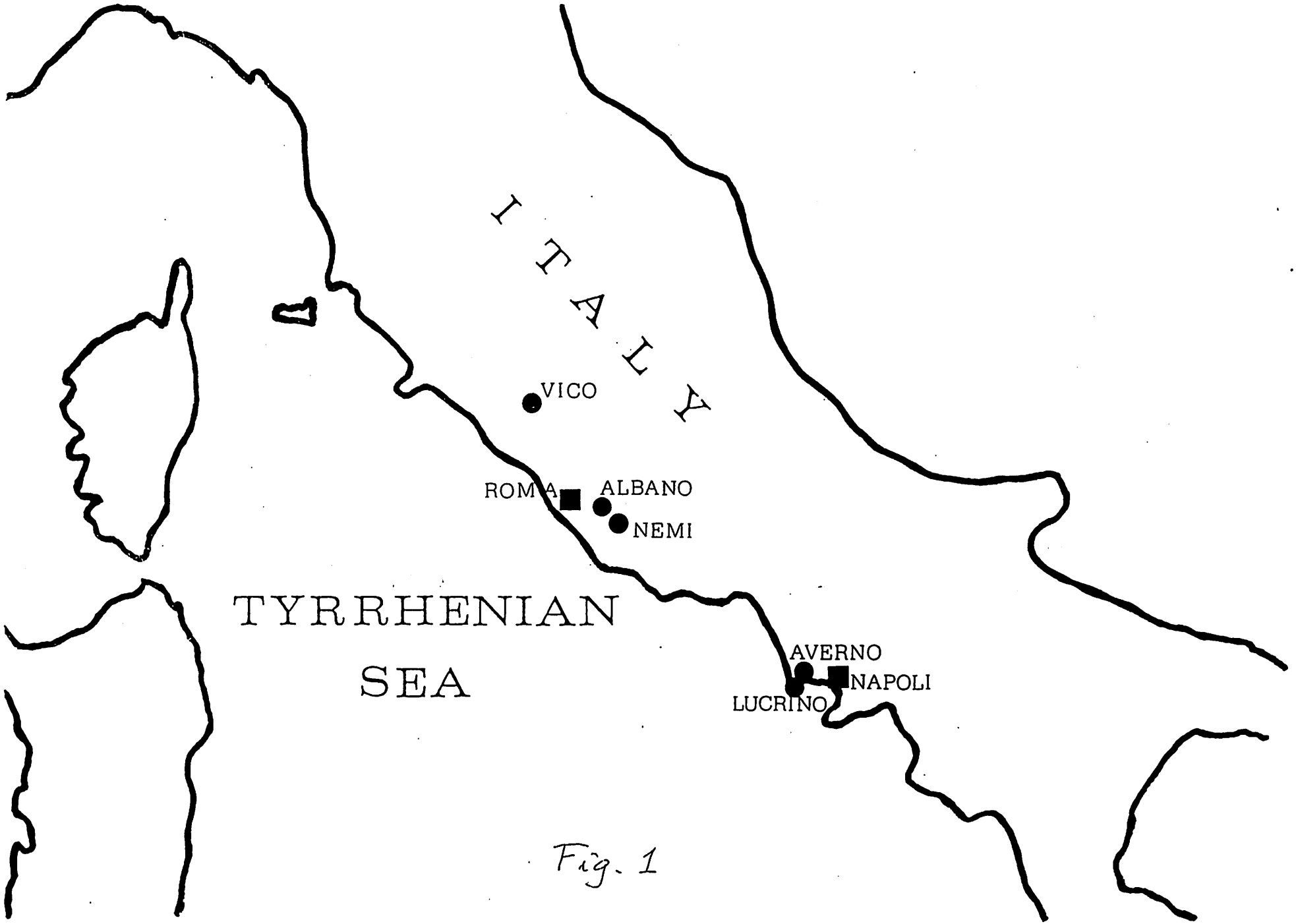
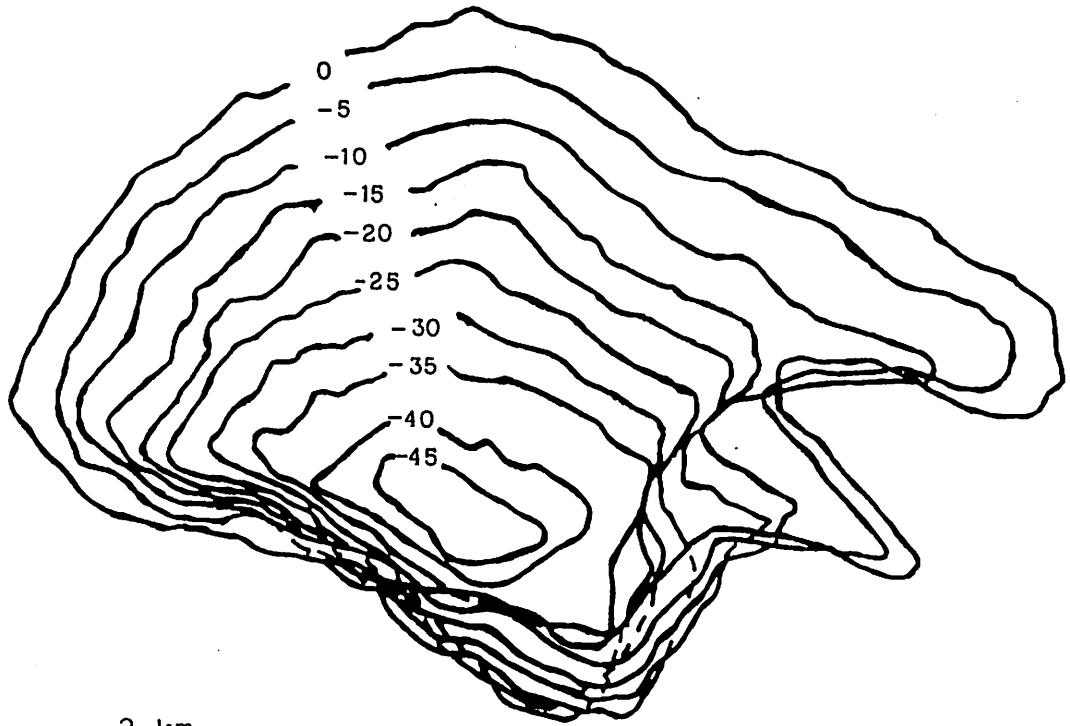

ITALY
VICO
ROMA
ALBANO
NEMI
TYRRHENIAN
SEA
AVERNO
NAPOLI
LUCRINO

Fig. 1

VICO LAKE

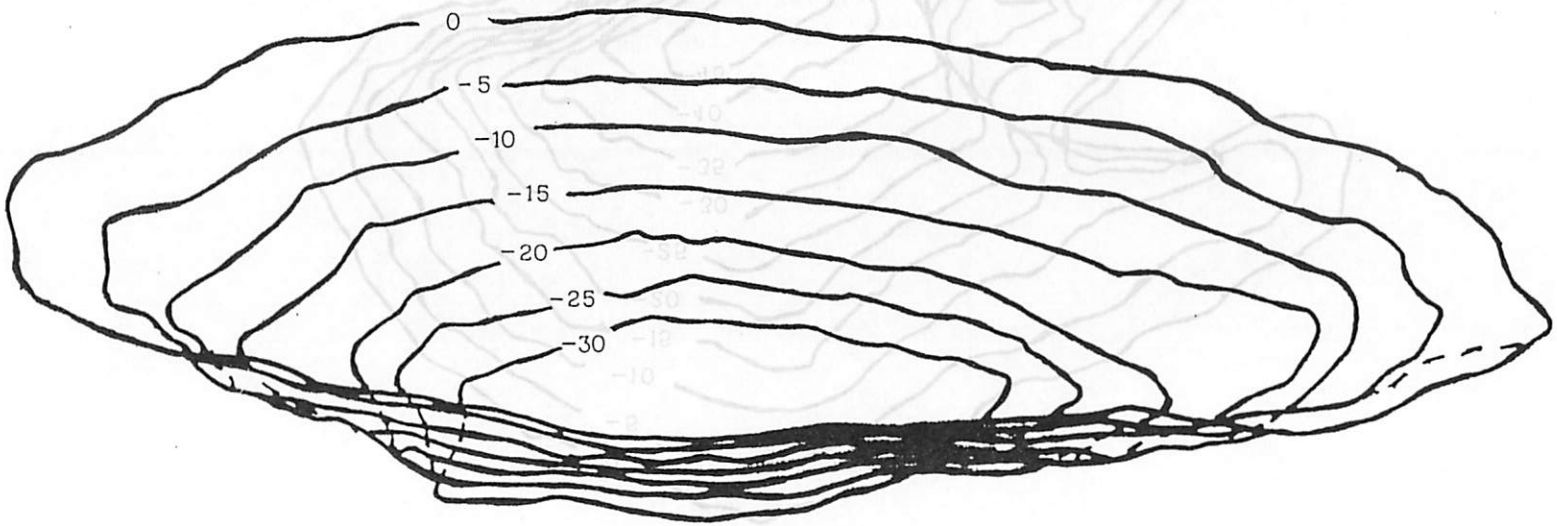


0 1 2 km

Exaggerated vertical scale: maximum depth 45 m

Fig. 2

NEMI LAKE

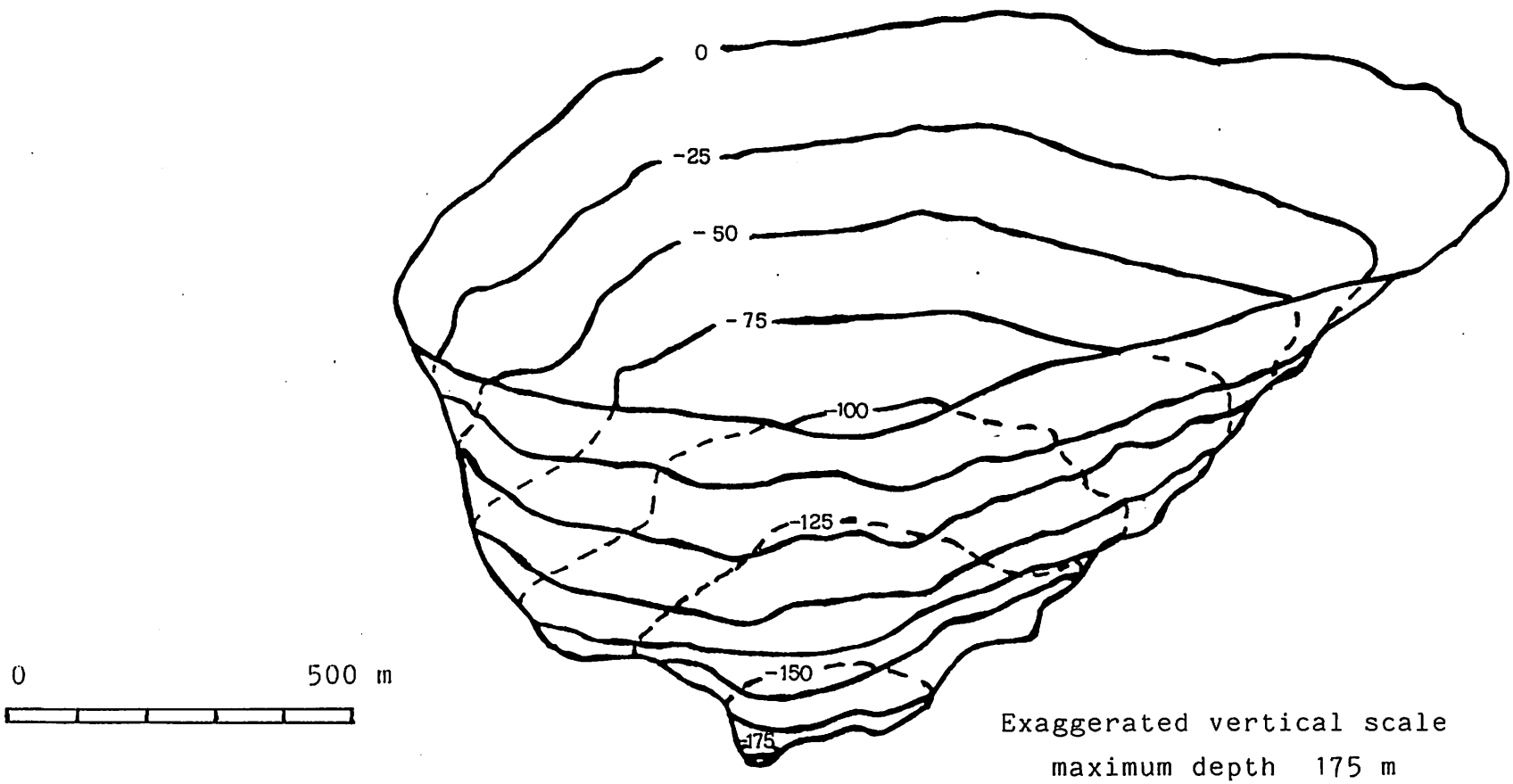


0 500 m

Exaggerated vertical scale: maximum depth 30m

Fig. 3

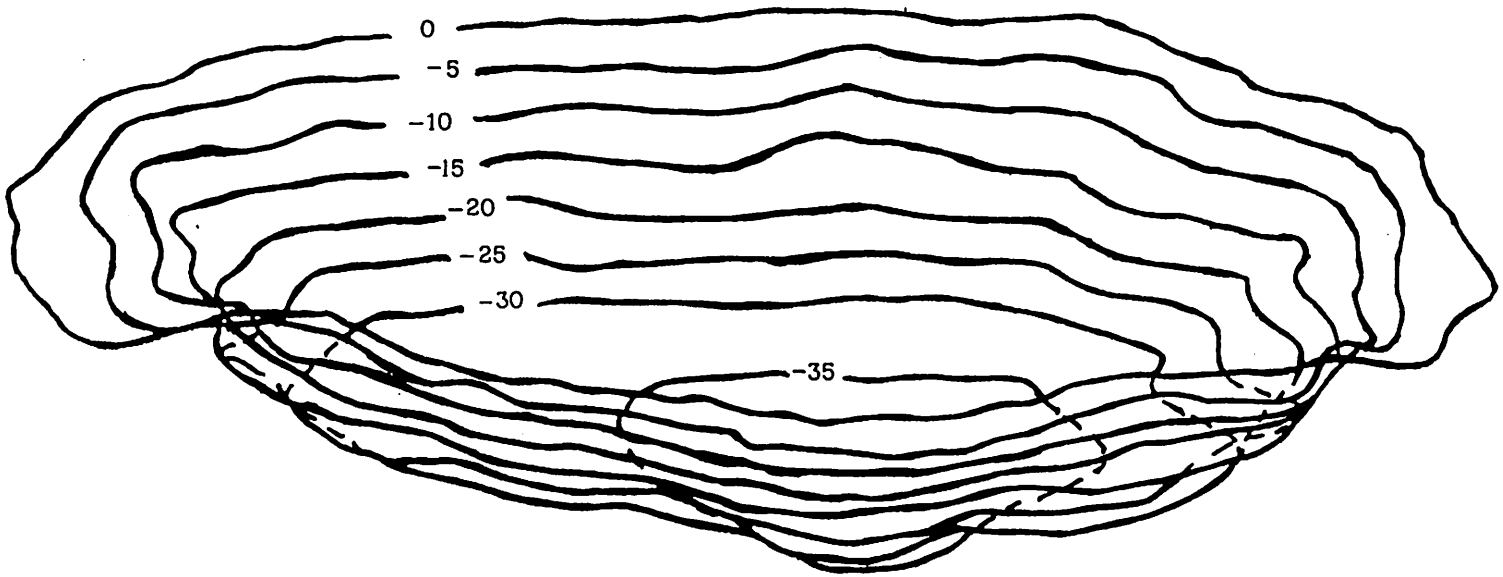
ALBANO LAKE



Exaggerated vertical scale
maximum depth 175 m

Fig. 4

AVERNO LAKE



0 250 m

Exaggerated vertical scale: maximum depth 35 m

Fig. 5

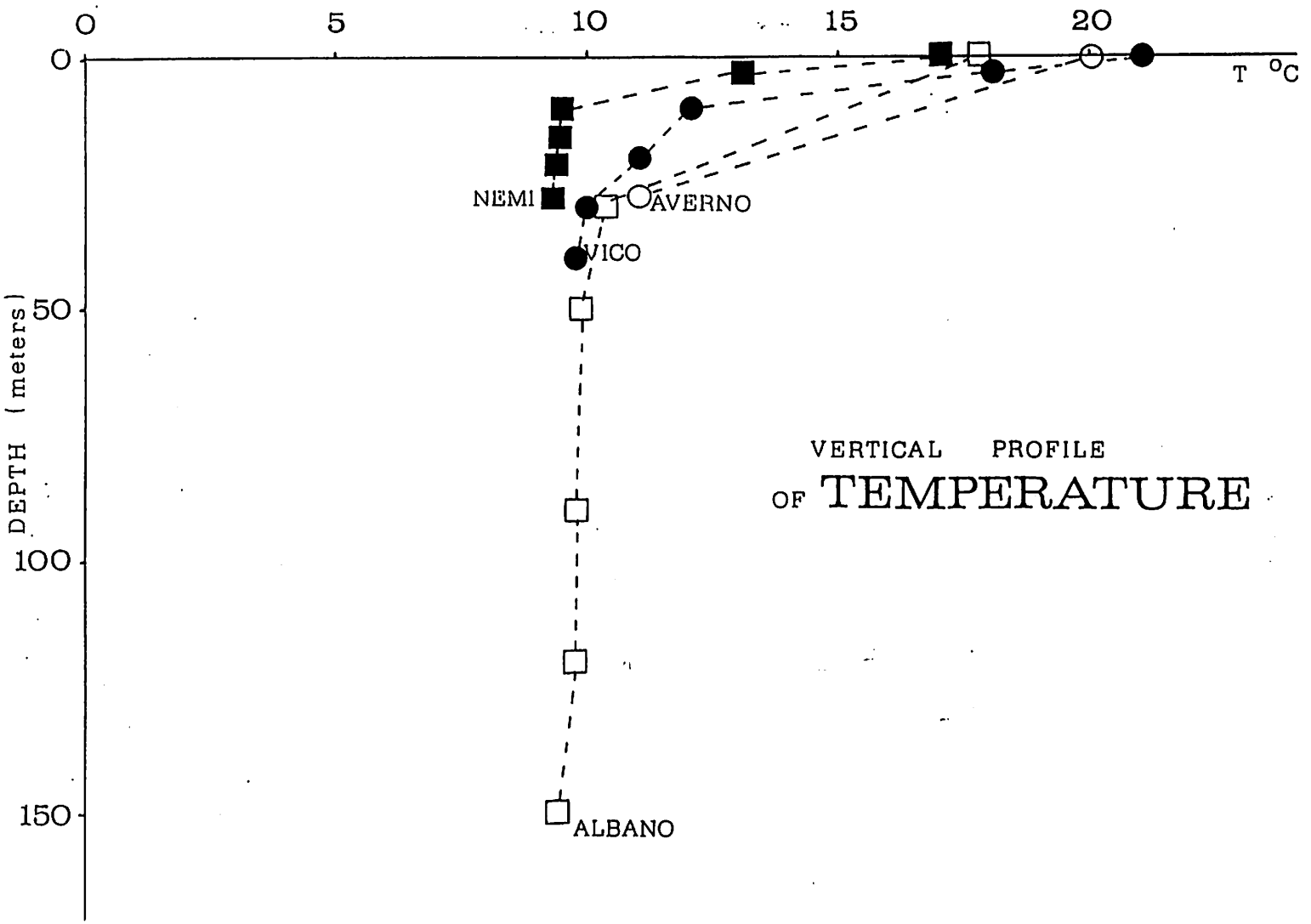

0
5
10
15
20
0
T °C
NEMI
AVERNO
VICO
50
100
150
DEPTH (meters)
ALBANO
VERTICAL PROFILE
OF TEMPERATURE

Fig. 6

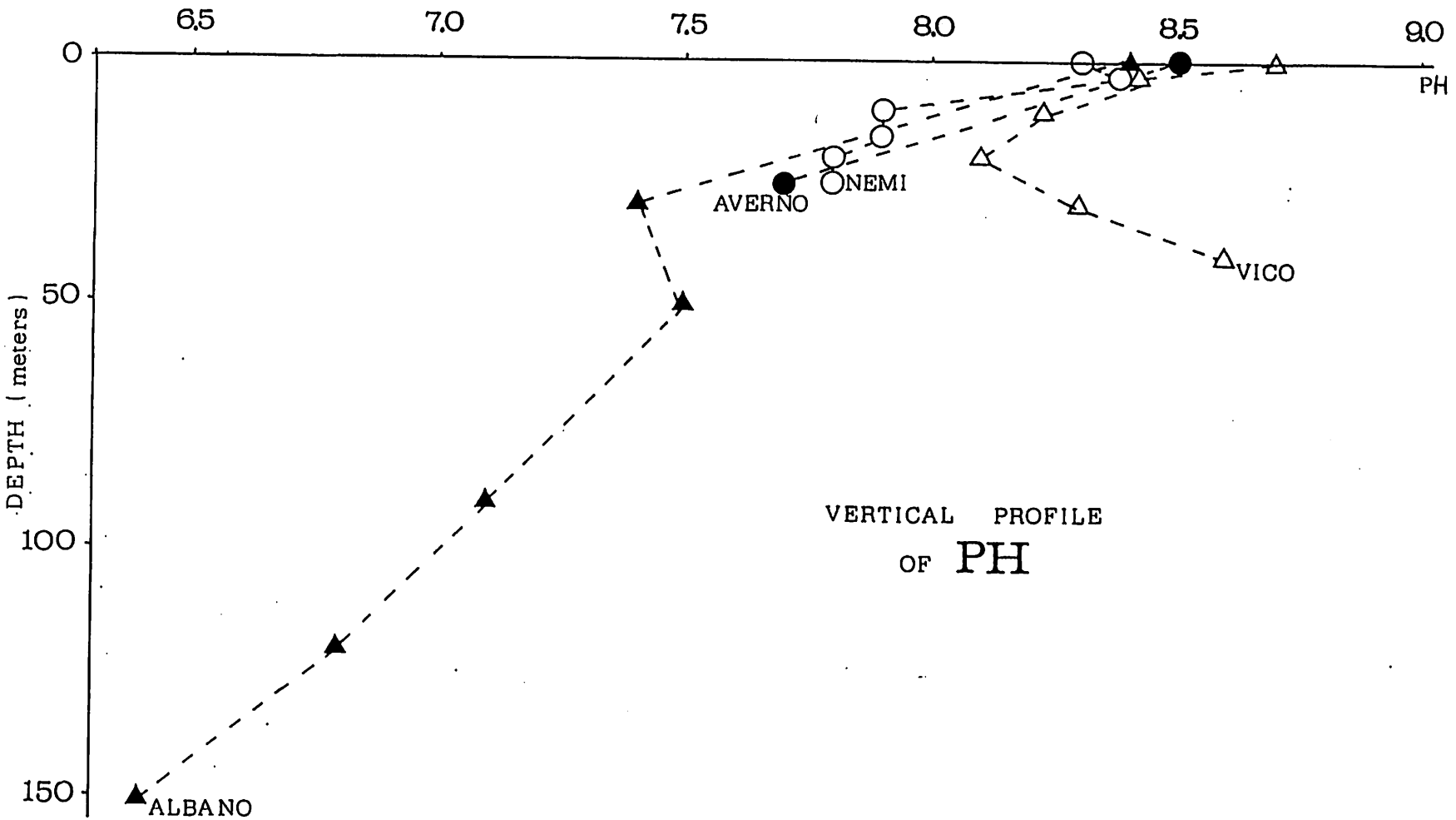

6.5
7.0
7.5
8.0
8.5
9.0
PH
0
50
100
150
DEPTH (meters)
AVERNO
NEMI
VICO
ALBANO
VERTICAL PROFILE
OF PH

Fig. 7

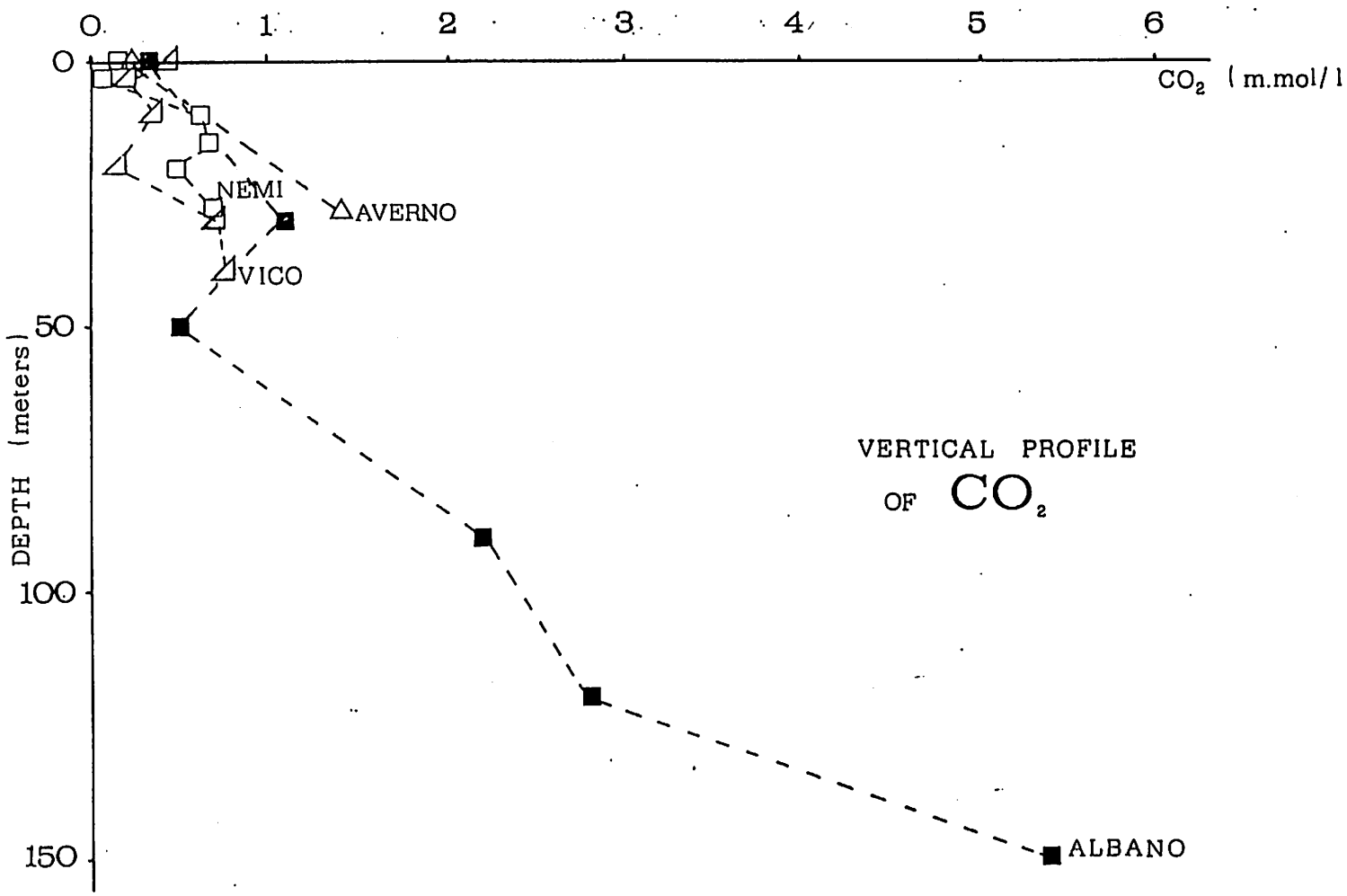

0
1
2
3
4
5
6
0
CO_2 (m.mol/l)
NEMI
AVERNO
VICO
50
DEPTH (meters)
100
150
ALBANO
VERTICAL PROFILE
OF CO_2

Fig. 8

Call for Papers

The Second Meeting of
The International Working Group on Crater Lakes
and
The Inaugural Meeting of the Commission on Crater Lakes,
IAVCEI

International Symposium on Hazardous Crater Lakes
Misasa, Japan 19-24 October 1992

Invitation

The Organizing Committee is pleased to announce that the second meeting of the International Working Group on Crater Lakes (IWGCL) will be held this coming October in Japan. This meeting will also be the inaugural meeting of the Commission on Crater Lakes, IAVCEI (see IWGCL Newsletter No. 5).

An active crater lake is usually located on top of the volcanic conduit through which volatile materials in the magma are released. Even after eruptive activity has ceased, it is expected that heat and volatile materials from the magma are supplied to the crater lake. Excessive accumulation of carbon dioxide in the crater lake can lead to outburst of the gas as demonstrated by recent gas disasters at Lakes Nyos and Monoun in Cameroon. The crater lake can thus be regarded as a trap for the materials and thermal energy coming out of the earth's interior. It may be possible to estimate what is occurring beneath the crater lake through analysis of its material and energy balance.

The present symposium aims at gathering scientists concerned with volcanological, geochemical, biological and limnological aspects of hazardous crater lakes and those of active crater lakes, with the goal of exchanging information on the latest achievements. Through discussion on the above topics, it is hoped that we can reach a better understanding of processes occurring in and beneath crater lakes and that we can find ways to mitigate natural disasters related to hazardous crater lakes.

The Organizing Committee cordially invites those who are actively working on crater lakes to attend the 1992 IWGCL Meeting at Misasa;

Place:	Seminar Hall, Misasa Onsen Kaikan Hotel Misasa, Tottori-ken, Japan
Dates:	Registration and Get-together, 19 (Mon.) October 1992 Scientific Session, 20 (Tue) - 22 (Thu) October 1992 Field Excursion, 22(Thu)-24(Sat) October 1992
Language:	English

Venue

The symposium consists of a $2\frac{1}{2}$ day scientific session and a $2\frac{1}{2}$ day field excursion. The scientific sessions will be held at Seminar Hall in Misasa Onsen Kaikan Hotel. The meeting place is about a 20 minute walk from the Institute for Study of the Earth's Interior, Okayama University. Misasa is a small town on the Japan Sea side of western Honshu, about 200 km northwest of Osaka. See the attached map for the location of Misasa. Following the scientific session, a field excursion consisting of a $2\frac{1}{2}$ day field trip to an extinct crater lake at Tateyama volcano in central Honshu, will allow you to observe banded sulfur sediments and low temperature fumarolic activity.

Abstract

Abstracts should be written in English and should contain title, author(s), institution, address, and text in that order. Abstracts should be typed preferably as single or double spaced on a maximum of 2 clear white sheets of A4 size (21 x 29.5 cm) or letter size (8 x 11 in) paper. All abstracts submitted will be printed and distributed to all of the participants at the registration desk. The deadline for the receipt of the abstract by the Organizing Committee is 15 August 1992.

Registration

Participants are requested to return the attached registration form to the Organizing Committee no later than 15 June 1992. On arrival at the meeting place, registration will occur at the registration desk in the Misasa Onsen Kaikan Hotel on the afternoon of 19 October and on the morning of 20 October. Registration fee of 10,000 yen (5,000 yen for students) covers the abstract volume and other necessary expenses for the $2\frac{1}{2}$-day scientific sessions at Misasa Town. Those who wish to participate in the $2\frac{1}{2}$-day field excursion are requested to pay additional fees for lodging at Tateyama volcano. Details of the field excursion will be sent to those who expressed interest in the registration form.

Scientific Sessions

Scientific sessions will be held at Seminar Hall in the Misasa Onsen Kaikan Hotel between the 20th and 22nd October. Only oral presentation is acceptable. At this time no preparations have been made for poster sessions. For the oral presentation, a 35 mm-side projector and an overhead projector (OHP) are available. A video tape recorder (VHS only) may be used by making prior arrangements with the Organizing Committee.

Publications

Your paper presented at the Symposium can be published in a special issue ("Crater Lakes") of *Geochemical Journal*, an official journal of the Geochemical Society of Japan. Manuscripts submitted to the journal will receive usual review procedures. Please consider to submit your paper to the journal.

Social Events

All symposium participants and accompanying persons are invited to attend the following social events free of charge.

Welcome Party:	Evening of the 19th(Mon) October 1992 at Misasa Onsen Kaikan Hotel
Banquet:	Evening of the 21st(Wed) October 1992 Details will be given in the final announcement.

Accompanying Persons

A program for accompanying persons can be organized if such requests are numerous. A possible program may include a microbus tour of Misasa and the vicinity.

Visas

For scientists and accompanying persons from some countries, a valid visa is needed to come to Japan. Please inquire at Japanese embassy, consulate or your foreign affairs office. If you need an official letter of invitation other than this circular for obtaining a visa and for other purposes, please write to the Organizing Committee.

Accommodations

Rooms for participants will be reserved at Onsen Kaikan Hotel. Reservations will be confirmed upon receipt of the attached registration form by the Organizing Committee. All the rooms in the Onsen Kaikan Hotel are Japanese style. Usually, a room is shared with two or more persons. Since Misasa is a famous spa in southwestern Japan, guests at the Onsen Kaikan Hotel can enjoy a hotspring bath every day. Exact prices for accommodation are not available at present, but charges will not exceed 10,000 yen per day per person including three meals, tax and service charge. One US dollar is equivalent to about 130 Japanese yen in March 1992.

Field Excursion

A $2\frac{1}{2}$ day bus tour will be arranged for the excursion to an extinct crater lake and fumarolic areas of Tateyama volcano, Toyama, central Honshu (see the attached map). The excursion site is located at a fairly high altitude, so the temperature may be below 0°C and you may encounter a snowfall. At the excursion site you will be guided by Profs. Y. Mizutani, T. Kobayashi (both Toyama Univ.) and M. Kusakabe (ISEI, Okayama Univ.).

The official activity of the symposium will be finished after the excursion. You can fly directly back to Tokyo, or visit Kyoto on the way back to Tokyo by train at your own expense. Please write to the Organizing Committee for additional information concerning these activities.

Sponsors

Institute for Study of the Earth's Interior, Okayama University
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Organizing Committee of the 2nd IWGCL + 1st CCL meeting

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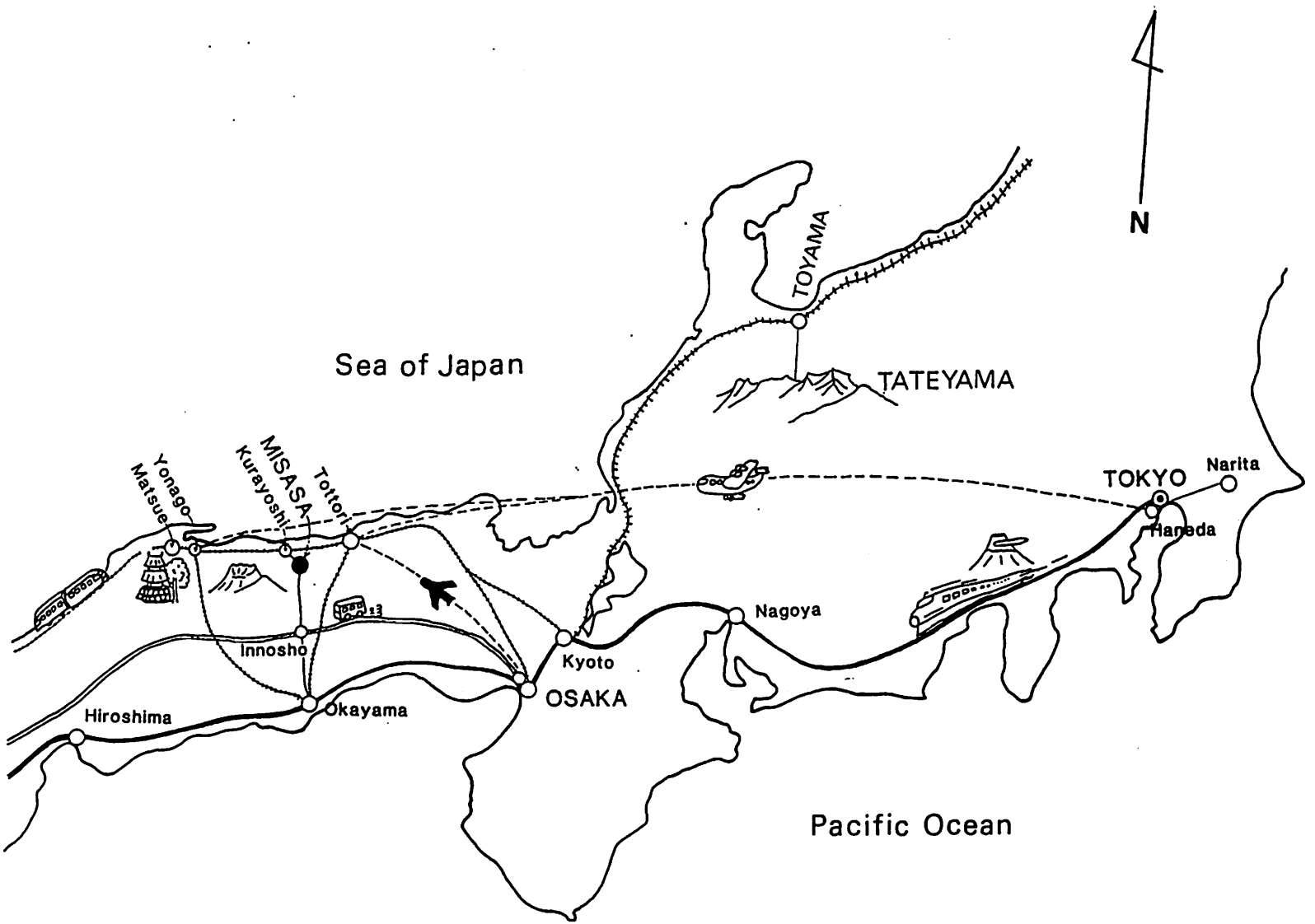
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Application Form to

International Working Group on Crater Lakes and Commission on Crater Lakes, IAVCEI

I want to join the International Working Group on Crater Lakes and Commission on Crater Lakes, IAVCEI.

Name:

Institution:

Address:

My main subjects of interest on crater lakes are:

I propose the following activity(s) for the IWGCL/CCL:

I enclose a $US 10.00 note or equivalent to support the IWGCL/CCL activities. (Please do not enclose a personal check.)

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M.K.

International Working Group on Crater Lakes

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Editorial

The news that six volcanologists had died when Galaras volcano erupted in January must have come as a terrible shock to any volcanologist who had ever visited a seemingly quiescent volcano but particularly so to many of our members who knew one or more of the victims. Those who died were Geoff Brown, who was Head of the Department of Earth Sciences at The Open University, Igor Menyailov from the Russian Institute of Volcanology at Petropavlovsk and four Colombian volcanologists: Carlos Trujillo, Hernando Cuenca, Nestor Garcia and Jose Arlès Zapata. On behalf of the members of the IWGCL I would like to express our collective sorrow to the friends and relatives of those who died.

I first met Geoff Brown in the late 1960's, when he was a research student at the University of Manchester working on the petrogenesis of granitic rocks, and since than our paths have frequently crossed. He was someone whom I liked immensely as a person and for whose academic work I had great respect. His death left me with a profound sense of loss and I realise how much worse it must be for those who were working more closely with him. In his recent work on Poas and other crater lakes Geoff was ably assisted by Hazel Rymer, who has writen an orbituary which is printed immediately after this editorial. It is followed by a tribute to Geoff, writen by Gary Rowe who has been working on Poas since 1988.

Igor Menyailov was a gas chemist whose work on active volcanoes had, over the last 20 years and more, taken him to many parts of the 'ring of fire' around the Pacific. Many of our members worked with Igor, either as colleagues within the Institute at Petropavlovsk or as part of the international community of volcanologists, and his loss will be keenly felt.

I have received, from Marino Martini, the following tribute to two of the Colombians who perished, both of whom had accompanied him on a visit to the Galeras crater on 26 November 1986:

"Nestor Garcia lived and worked in Manizales, and on the occasion of the Nevado del Ruiz crisis participated in several expeditions to the volcano's crater. After our joint sampling of fumeroles on the crater bottom, on 19 October 1985, and despite strict warnings to keep well away from the volcano he returned to the top on 12 November, to make further observations, just escaping the disaster the following day.

Jose Arlès Zapata lived and worked in Pasto, at the very foot of Galeras, and was completely devoted to the geochemical study of the volcano. His main interest being the investigation of volcanic activity so as to minimise risk to the population."

In many ways the best tribute to those who died will be for those of us who remain to continue to seek ways of better understanding and predicting volcanic activity so as to minimise future losses. However, I think that some more tangible memorial to our colleagues would also be appropriate. Since our next meeting will be in the Americas and will no doubt attract a number of contributions concerned with South American volcanoes and crater lakes could I suggest that a lecture dedicated to the memory of those who died, or perhaps a dedicated volume of papers presented, might be appropriate?

Prior to the recent IWGCL Meeting in Misasa, Minoru Kusakabe let it be known that he felt that the time had come for him to hand on responsibility for editing our Newsletter. I was pleased to be able to offer my services since I feel that a regular newsletter is of great importance at this stage in the development of the IWGCL.

My first responsibility, as Editor, must be to thank Minoru for everything which he has done over the last five years. Not only did he act as founding editor for the Newsletter and prepare subsequent issues at regular, yearly, intervals but he also printed a special issue containing abstracts for the Inaugural Meeting of the IWGCL in 1990 and organised the very successful 2nd Meeting of the IWGCL in Misasa.

I do not plan to make any major changes as far as the style and content of the Newsletter are concerned. But I would like to draw attention to a minor change; I have instituted a calander of events which is intended to draw the attention to meetings (or any other event) which might be of interest - members are encouraged to send me information on future events which might be included in subsequent Newsletters. And on the subject of meetings I would like to draw particular attention to the next IWGCL meeting which will be organised by Joop Varekamp who is "shooting for a date in October 1994, and a possible location at Crater Lake, Oregon" although "an East Coast [of the U.S.A.] meeting has not been ruled out". I am sure that we would all like to wish him 'good hunting'.

The Newsletter grew from 19 pages in no.1 to 26 pages in no.5 but with this issue its size has increased to 64 pages! Although size of itself is not a problem it may become a problem if the Newsletter continues to grow at the present rate. There are implications in terms of cost - at the present time the average distribution cost is about £1.00 ($1.40) per copy and the cost of reproduction is about £2.00 ($2.80) per copy. Obviously distribution costs are only loosely related to size but production costs are directly related to the number of pages. And there are implications in terms of editorial time which relate to the number of contributors. As far as cost is concerned - I have made a suggestion elsewhere (see p.30) as to how the subscription might be more efficiently collected. But even if an annual subscription of $10 is collected from every member there would still be a problem in covering the direct costs of producing this Newsletter. I have therefore looked for other ways of raising finance. One possibility would be to to raise money from publishing companies by offering to distribute information on books which would be of specific interest to our members - targeted information (niche marketing) is more effective than an indiscriminate 'mail shot'. A number of publishing companies have expressed interest but such matters take time and the only specific deal which I have been able to finalise is with Vieweg Verlag, to distribute information on "Natural Hazards in West and Central Africa". If any members do not like this idea or if they can suggest other ways of raising money for the Newsletter I would be pleased to hear from them.

There is also another consequence which may accompany increasing size and an increasing number of interesting contributions. This is an 'informal' Newsletter and information in it should not be quoted without specific permission from the author and, strictly speaking, such information should be quoted as a 'personal communication'. However, it is not possible to enforce such a convention and I.W.G.C.L. Newsletter (or similar) has already appeared four or five times in Science Citation Index! If this Newsletter is being quoted then it should be in an agreed form. And what will happen if and when it becomes the 'Newsletter of the Joint IAVCEI-IAHS Commission on Crater Lakes'! An unmanagable and unquotable title. Could I suggest that we adopt a 'short title' - ideas please - and relegate Newsletter of the etc to a sub-title??

S.J.F.

Obituary for Prof Geoff Brown

Geoff Brown was one of two British delegates at a workshop in Colombia designed to establish a comprehensive geophysical and geochemical monitoring programme at Galeras volcano, Colombia. The meeting was funded by the US National Science Foundation, and Galeras had been identified as one of the most important volcanoes to study in this International Decade of Natural Disaster Reduction because of its high level of activity and proximity to large towns such as Pasto. Geoff was killed instantly as the cone inside the crater on which he was installing a monitoring station erupted sending rock fragments hundreds of metres into the air at over 1000^{0} C.

Geoff was an active and productive researcher in several fields, from experimental studies on granites, to geothermal energy evaluation, to physical volcanology. I worked closely with him on the latter project over the last ten years developing techniques to firstly map out the sub-surface structure of active volcanoes and then to monitor and model changes within them. The objective of the research is to understand how volcanoes work and what processes operate within them before and during eruption. We use gravity and ground deformation measurements to do this and it was while setting up a network of observations within the active crater of Galeras volcano that Geoff was so tragically killed. Geoff's untimely death is a tremendous loss to volcanology - his insight into the relationships between geophysics, geochemistry and geology and their applications inspired his colleagues and enthused everyone he met.

Volcanology was only one aspect of Geoff's busy life. He was the Head of the Earth Science department at the Open University since 1983, responsible for teaching the equivalent of 1000 undergraduate students. A gifted teacher and communicator, he wrote several undergraduate teaching texts and presented TV and radio programmes both for the OU and BBC including an 'Horizon' documentory. He also co-authored and co-edited respectively the much praised text-books "Understanding the Earth" and "The Inaccesible Earth". As if this wasn't enough, he somehow found time to chair the Research Committee, coordinating research enterprises throughout the Open University.

Geoff's philosophy of life was to live life to the full and he threw himself whole-heartedly into everything he did. The University Grants Council identified Geoff's department as one of the top seven in the UK in 1989, but the unique funding situation of the Open University meant that no funds for further expansion were forthcoming. He therefore actively sought external and internal monies and a new laboratory wing partly funded by the Wolfson Foundation will be opened by the Secretary of State for the Environment on February 1st. This is the first building on the campus to be financed in this way and to be devoted entirely to research activities; it is tragic that Geoff who worked so hard for this moment will not be there in person.

A talented leader, teacher, researcher and family man, Geoff will be sorely missed by the scientific community. For those of us priviliged to have known him well, there is a deep sense of gratitude that we have benefitted from his caring and enthusiastic presence.

Dr Hazel Rymer
Open University

A NOTE REGARDING THE CONTRIBUTIONS OF GEOFF BROWN

I first met Geoff Brown in January of 1988 on the floor of Poas Volcano, in Costa Rica. Geoff and Hazel Rymer were making their annual set of gravity measurements in the active crater whereas I was observing phreatic eruptions in the rapidly declining crater lake. Geoff had been working at Poas since 1978 and had been making detailed microgravity studies of the summit and active crater area of Poas. At Poas, Geoff and Hazel's microgravity measurements showed no remarkable changes until 1985 when sharp increases in the microgravity signal were noted. The area of marked increases were concentrated over the remains of a partially collapsed cinder cone adjacent to the lake. This increasing trend continued through 1989 and was parallelled by the rapid decline in lake level and an apparent increase in the summit power output over the period 1987-1988. Geoff and his coworker Hazel Rymer monitored these changes and interpreted the changes in terms of density increases caused by the ascenscion of a small volume of new magma. They produced several important and thought-provoking papers on the relationship between the observed microgravity increases, thermal power output variations at Poas, and the decline and disappearance of the crater lake.

In the last set of papers Geoff became increasingly attentive to the role of the crater lake in maintaining a stable cooling front in the shallow magma body and how the presence of the lake could potentially moderate volcanic activity at Poas. He had plans to continue geophysical and geochemical monitoring of Poas and I sincerely hope that such plans are carried forth by his friends and colleagues at the Open University. When I last saw Geoff at the October 1992 Penrose Conference on Fluid-Volcano Interactions, we agreed that our overall views of recent events at Poas were converging towards a common theme. As one of Geoff's professional colleagues, I would note here that his death represents a great scientific and human loss, not only to IWGCL, but to the entire volcanological and scientific community as well. His scientific knowledge will be sorely missed by all.

<u>A Selected Bibliography of Geoff Brown's Work at Poas Volcano:</u>

Brown, G.C., Rymer, H., and Thorpe, R.S., 1987, Gravity fields and the interpretation of volcanic structure: Earth and Planetary Science Letters, v. 82, p. 323-334.

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Rymer, H., and Brown, G.C., 1987, Causes of microgravity changes at Poas Volcano, an active but non-erupting system: Bulletin of Volcanology, v. 49, p. 389-398.

Rymer, H., and Brown, G.C., 1989, Gravity changes as a precursor to volcanic eruption at Poas Volcano, Costa Rica: Nature, v. 342, p. 902-905.

IGOR A. MENYAILOV
(To the memory of a friend)

On January 14, 1993 when collecting gas samples in the crater of the Columbian Galeras volcano together with eight other colleagues a Russian scientist Igor A. Menyailov was killed during an explosion. Igor worked at the Institute of Volcanology, Far East Division, Russian Academy of Sciences in a small city in the Far East of Russia Petropavlovsk-Kamchatsky and lately was the Chief of the Lab of Active Volcanism. His parents, famous Russian volcanologists Sofia I. Naboko and Aleksandr A.Menyailov lived in a small village of Klyuchi in Kamchatka located close to many volcanoes and worked at the Volcanological Observatory when on March 14, 1937 their son Igor was born. Sofia once said that even before birth Igor climbed the Highest in Kamchatka Klyuchevskoy volcano.

In 1962 Igor Menyailov graduated from the Moscow Historical Archival Institute but even when he was a student he took part in the field work of the geologic teams of Geologic Institute in Moscow thus gradually turning from an archaeologist into a geologist. After leaving the Institute he went to work to Kamchatka where he got a position as a senior technician at the Volcanology Institute. His wife, Lyudmila N. Nikitina, a professional chemist-geologist encouraged Igor to undertake the profession of volcanologist and to study the chemistry of volcanic gases. Working at volcanoes one has to know geology and Igor started to read books and study geology without assistance. In 1972 Igor Menyailov completed his PhD in Geology. His Thesis was entitled "The Differentiation of Magma Volatiles in the Process of Active Volcanism (on the Example of the Eruption of Bezymianny Volcano, Kamchatka)".

And new field seasons at volcanoes, new meetings, new friends. In 1982 to 1985 Igor A. Menyailov was the Leader of the Complex Volcanologic Expedition in Nicaragua responsible for the geochemical part of work at Momotombo volcano.

The major interest in scientific life of Igor Menyailov was geochemistry of volcanic gases, their origin, evolution in the process of eruption and their role as precursors of volcanic eruptions. The period from 1975 to 1985 was highly productive in Igor's work.He studied active volcanoes of Kamchatka Bezymianny, Shiveluch, Klchevskoy, goes to the Kuriles where investigates Alaid and Ebeko. Of particular interest was the work at the one of the largest earthly eruption of Tolbachik volcano in 1975-1976. The group led by I.Menyailov revealed the features of chemical composition, isotopic ratios of elements and estimated the peculiarities of deep magmatic gases issued during eruptions of basaltic and andesitic volcanoes. As a result of this work Igor proved the existence of the mantle ore-bearing gases as well as got the idea on the evolution of composition of the eruptive gases in the process of eruption. Also scientists demonstrated the leading role of crustal contamination of the gases of high-temperature fumaroles (400-850 degrees C) and suppressing effect of crustal, meteoric and aerial components of low-temperature fumaroles (300-100 degrees C). The group managed to find

out geochemical precursors for paroxysmal eruptions at andesitic volcanoes.

Published in 1980 book by Igor Menyailov with co-authors L.P. Nikitina and V.A. Shapar "Geochemical Features of the Exhalatives of the Large Tolbachik Fissure Eruption" was a considerable tribute to the scientific world. The authors showed that different character of eruptions at different vents is due to differences in the volatile contents in the magmatic melt (high in magnesian basalts of the Northern vent and low in the subalkaline basalts of the Southern vent. Investigations at the Tolbachik volcano eruption allowed Igor Menyailov to work out quantitative estimates of evacuated deep material and in particular on the amount of ore elements in volcanic gases. These data were frequently referred to by many scientist of Russia and abroad.

Twice, in 1988 and 1990 Igor A. Menyailov was the Head of the marine expeditions aboard R/V VULKANOLOG. In these cruises the scientists studied submarine and terrestrial volcanoes in the southern latitudes of the Pacific.

In more recent time of closer attention and higher interest became the issue of the impact of volcanic eruptions upon environment. Together with his american colleagues he introduced remote sensing equipment COSPEC to study gas components in volcanic outbursts and issues.

Dr.Menyailov was the member of the Workshop "Volcanic Gases" at IAVCEI and "Volcanic Monitoring at Active Volcanoes" at the International Organization CODATA. He presented interesting reports at numerous in-country meetings as well as abroad, such as "Island-Arc Volcanism" in Japan in 1981, "Rock-Water Interaction" in Prague in 1983, "Geochemistry of Natural Gases" in Moscow in 1983, "Potassic Magmatism-Etna volcano" in Italy in 1985 and many other. Also he took part in the joint scientific programs with american, mexican and italian colleagues.

Igor Menyailov wrote over 150 scientific papers, more than 20 were published abroad.

Igor A. Menyailov tragically left us in the prime of his life, full of great plans for further work. His Doctoral Dissertation was nearly ready and many articles stayed unfinished. We will keep the memory of Igor through the years and may God help us.

Dr Gennady Karpov
(translated by Sergei Kasyanov)
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*(Communications with Petropavlovsk are problematic, at the best of times. This tribute to Igor Menyailov was sent by Alexey Osipenko but arrived after the Newsletter had been printed. It has therefore been inserted at an appropriate place. - S.J.F.)

Report

on the

Second Meeting

of the

International Working Group on Crater Lakes:

International Symposium

on

Hazardous Crater Lakes

(Misasa and Tateyama, Japan, 19-24 October 1992)

Klaus Tietze

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Abstract

From 19 to 24 October 1992 an International Symposium on Hazardous Crater Lakes took place at the Institute for Study of the Earth's Interior (ISEI) of the Okayama University in Misasa, Japan. This Symposium was simultaneously the Second Meeting of the International Working Group on Crater Lakes (IWGCL), which was founded during the International Conference on the Lake Nyos Disaster in Yaounde in March 1987. During the scientific meeting of 36 scientists from 11 countries in Misasa, 28 papers were presented. They consisted of several papers covering a wide range over themes, from cold degassing of volcanoes through their flanks to special intrumentation which uses lakes as early warning systems for hot volcanic eruptions. Some other papers treated in particular the hazardous lakes Monoun and Nyos, with themes like bathymetry, eruption models, monitoring and disaster prevention by degassing, and investigations of the Lake Nyos dam. The largest number of papers dealt with many different lakes, their behaviour, eruption potential, whether cold limnic from the lake, or hot volcanic from the underground, as well as the possibility of early warning and disaster prevention. The symposium was closed by a visit to the ISEI, a very pleasant banquet, a visit to the historically valuable Sanbutsuji Temple in Misasa, as well as a field excursion to the majestic Tateyama Volcano in the Japanese Alps. In conclusion, the symposium was a very successful attempt to put together the research on different kinds of crater lakes with the potential for cold limnic eruptions from the lake water to those with the potential of hot volcanic eruptions from the lake's underground. The second aim of the conference was to further develop the IWGCL to a more official status. This was put forward by several contacts of the IWGCL steering committee in advance of the meeting to the International Association of Volcanism and Chemistry of the Earth's Interior (IAVCEI) and the International Association of Hydrological Sciences (IAHS), where the IWGCL was invited to become an inter-association task group with the short term perspective of becoming an inter-association "Commission on Crater Lakes". The appropriate decisions were made during the meeting as well as a reorganization of the steering committee of the IWGCL.

1 Introduction

The Second Meeting of the International Working Group on Crater lakes (IWGCL) took place at the Institute for Study of the Earth's Interior (ISEI) of the Okayama University in Misasa, Japan, between October 19 and 24, 1992. It was held as an International Symposium on Hazardous Crater Lakes.

The business and scientific meetings held in Misasa were followed by a field trip to the aweinspiring Tateyama Volcano. Misasa (see Photo 1) is a lively, beautiful small town with 8700 inhabitants. It is situated on the northern edge of the Chugoku Mountains (see Fig. 1) and covers 233 km², some 90% of which is mountainous. The area is divided by four major rivers, which cut deeply into the mountains, forming large valleys. The marvellous landscape and the warm atmosphere of the town created by its people were the ideal platform for the successful meeting of the IWGCL.

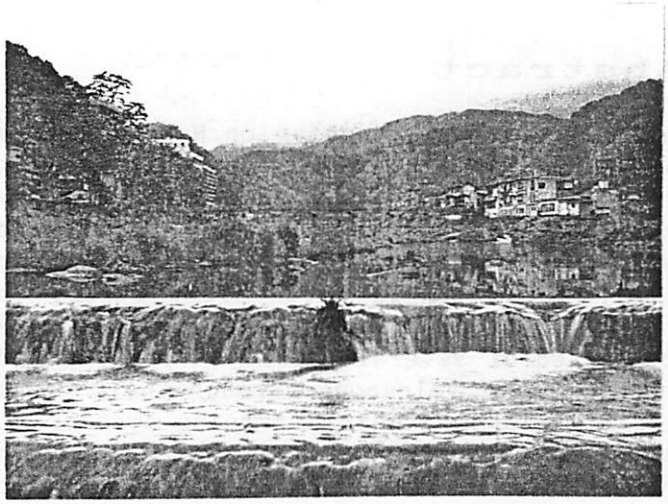

Photo 1: Misasa, a charming town with hotsprings and mountains
Figure 1: Map of Japan, showing the location of the meeting places Misasa and Tateyama
(Photo and figure taken from a brochure of Misasa town)

2 History of the IWGCL

The International Working Group on Crater Lakes (IWGCL) was founded in Yaounde in March 1987 during the International Conference on the Lake Nyos Gas Catastrophe (see Kusakabe 1989). The aim was to create a platform for international scientific cooperation and planning concerning prevention of gas disasters of the Nyos type. At this time no structure was created, except the nomination of Minoru Kusakabe as first secretary of the IWGCL.

In 1989 the first IWGCL-Newsletter was distributed, which has since than been circulated annually and made a significant contribution in increasing the membership to 59 by the Misasa-Conference. At the 15th Colloquium on African Geology in Nancy 1990, Samuel Freeth organized the First (Inaugural) Meeting of the IWGCL. Around 40 scientists met there during a one day session within which 19 papers on the lakes Nyos and Monoun disasters were presented (see IWGCL-Newsletter No. 3, 1990). During this session the need for a structurization of the working group was established. Thus a steering committee was elected consisting of

- Samuel Freeth (Great Britain),
- George Kling (United States of America),
- Minoru Kusakabe (Japan),
- Jean Maley (France),
- Felix Tchoua (Cameroon) and
- Klaus Tietze (Germany).

Additionally Minoru Kusakabe was confirmed as secretary and editor of the IWGCL-Newsletter.

The discussions of the Nancy meeting were summarized in a resolution of the steering committee which was approved at a meeting of the whole group. This resolution, which underscored the necessity and urgency for degassing the Nyos and Monoun lakes and which also gave a plan on how to proceed with the degassing, was sent to the Cameroon and Nigerian governments and published later in Nature (Freeth et al. 1990).

Further, from the foundation of the IWGCL until the Misasa-Conference the intensity of cooperation between the group-members increased more and more, which means joint field and laboratory work as well as joint publications.

3 Business meeting

One important point which was discussed during the meeting was, how to give the IWGCL a more official status. Therefore it was necessary to find some important decisions for the future of the IWGCL.

3.1 Decisions made during the Second IWCL-Meeting

During the Misasa-meeting several decisions were made:

a) The steering committee was reorganized. Jean Maley and Felix Tchoua were replaced by three new scientsits, with many thanks for the work they did for the IWGCL. The four other committee members were confirmed, so that the steering committee now consists of

- Alain Bernard (Belgium),
- Samuel Freeth (Great Britain),
- John Fonji (Cameroon),
- George W. Kling (United States of America),
- Minoru Kusakabe (Japan),
- Marino Martini (Italy),
- Klaus Tietze (Germany).

b) Minoru Kusakabe was asked to continue as secretary of the IWGCL. Following his wish to give up the editorship of the IWGCL-Newsletter he was released from this duty with special thanks expressing the gratitude of the whole group. Samuel Freeth offered to take over as editor and that offer was accepted.

c) In advance of the Misasa-meeting, the steering committee had several contacts with the International Association of Volcanism and Chemistry of the Earth's Interior (IAVCEI) and the International Association of Hydrological Research (IAHS). The aim was to develop the IWGCL into an inter-association "Commission on Crater Lakes" parallel to the IAVCEI and the IAHS. The principel agreement of the IAVCEI and the IAHS was received prior to the start of the symposium. After the new steering committee was formed, it recommended the plenum to approve the transfer of the IWGCL into commissions in the IAVCEI and the IAHS. This was accepted. This implies the development of a new organising structure at the next general meeting which should take place in about two years (for further details see Kusakabe & Kling 1993).

3.2 Plans for future IWGCL-activities

Following the aim of the foundation of the IWGCL, the main activities of the group are:

a) An increase in cooperation between the IWGCL members among one another and scientists outside the group is being strived for, especially with regard to joint laboratory and field work.

b) The "tradition" of holding general meetings of the group about every two years will be continued. The next meeting will be organized by Johan C. Varekamp of the Wesleyan University in Middletown, Connecticut, USA in 1994. This was very much appreciated by the whole group.

c) Additionally, all possibilities for organizing informal meetings between steering committee members together with smaller or larger groups of other members during international conferences is being looked at. The next possibility for this could be the IAVCEI-Conference in Canberra in 1993 and the Water-Rock Interaction Meeting in Petropavlovsk in 1995.

4 Scientific Meeting in Misasa

In contrast to the First IWGCL-Meeting in Nancy, the Second IWGCL-Meeting in Misasa did not focus only on lakes Nyos and Monoun. Papers on all kinds of hazardous crater lakes were presented. They showed the wide interest and working capability of interdiscipinary cooperation within the IWGCL.

During the symposium in Misasa 28 paper were presented (see reprint of the programme, this issue and Kusakabe 1993). They consist of 3 more general papers, 7 papers concerning lakes Monoun and Nyos and 18 papers reporting conditions in different other lakes and their connection to the respective volcanoes. Many papers also provided a generalization of the results reported. In the following the most important points from the various papers are briefly discussed.

4.1 Short review of general papers

The paper "Diffuse emanations of carbon dioxide at active volcanoes: features and implications" by Allard & Baubron pointed out that invisible diffuse emissions of volcanic gases where "more reactive species (S, HCL, H), typical of hot magmatic gases, are lacking", "can supply about as much CO_2 (or He) as crater emissions (e.g. Etna, Vulcano) or even be the dominant process of gas release at dormant volcanoes (e.g. at Vesuvius)". This general fact underscores the standpoint of the majority of the scientists who investigated the Lake Monoun and Lake Nyos disasters, that the gas bursts were cold limnic eruptions from the stratified waters of the lakes, which acted as traps for those diffuse gas emanations.

Martini gave an overview on "Chemical characters of crater lakes" and Ossaka, Ozwa, Yoshida, Matsubaya, Sakamoto, Yamamoto & Kusakabe discussed "Volcanic gas hazards in Japan and their mitigation". Volcanic gas accidents in Japan are mainly due to H_2S. More than ten gas accidents with loss of human life have happened since the beginning of this century. Preventive measures since 1983 have successfully suppressed the further loss of human life due to gas emanations, for example:

- hazard maps (derived from measured H_2S concentrations),
- generation of "off limit" zones and
- automatic H_2S measuring and warning systems as well as
- automatic air pumping systems.

Even at lakes Monoun and Nyos CO_2 and not H_2S was the problem: this is an important fact, acting as model for supporting those scientists searching for warning systems to be installed near the dangerous Cameroon lakes.

4.2 Short review of papers concerning lakes Nyos and Monoun

Results of repeated investigations on lakes Nyos and Monoun were reported in the two papers of Evans, Tuttle, Kling, Tanyileke & Michel "Six years of change at Lake Nyos, Cameroon, yield clues to the past and cautions for the future" and Kling, Evans, Tuttle and Tanyileke "Forecasting the endpoints of chemical evolution in gas-rich lakes: recharge, gas bursts, or controlled degassing". They led to the assessment that a new gas burst is likely with increasing probability in Lake Nyos within the next 20 years and in lake Monoun within the next 6 years. Thus a technical degassing must be initiated without delay.

Because the bathymetric maps published up to now by several groups are insufficiently accurate due to lack of data within anyone group, Tietze, Sato, Sauthoff, Kusakabe, Buziek, Hirabayashi, Kruse & Ngando tried to generate an improved bathymetric map by combining first all German and Japanese bathymetric data and later all available data of this kind. An improved bathymetric map is important

- for a better estimate of the time of the next gas burst,
- with respect to problems concerning the dam, and
- for simplifying the installation of future degassing systems at the lake.

Tietze reported "A special physical stratification effect: the last link in the chain of causes leading to the disastrous fountain limnic gas eruption from Lake Nyos in 1986". This effect, first mentioned soon after the disaster (Tietze 1987), was given now in more detail. It leads to a "paradoxical" situation. Even though the lake is fed through the bottom with gas in dissolved form, the exchange conditions within the stratified lake lead to relatively increased accumulation of the dissolved gases below strong density gradient layers. Therefore the "gas concentration stratification" follows the density stratification. Gradient layers are normally much steeper than the shape of the 100%-saturation curve of water for gas, which is mainly a function of pressure and temperature. Therefore saturation peaks can first reach the saturation curve at a depth near a steep gradient, that means relatively far from the bottom. Thus the trigger depth of the disastrous gas burst in Lake Nyos of 1986 was estimated at either between 20-50 m or 120-150 m, depending on the pre-event stratification.

The new temperature-conductivity-gas-concentration profiles from 1988 of Nojiiri et al. (1993) and from 1990 of Evans et al. (1993) are interpreted in such a manner, that a new special stratification is developing, depending on heat and mass influx from the bottom as well as from forces at the surface. From this it can be predicted that saturation peaks developing near the newly built up density gradients will reach the 100%-saturation curve in either about 50 m or 120-

150 m depth, if the influx conditions do not dramatically change. The chances of the next serious gas bursts being triggered in this manner will climb over the next 20 years.

Good evidence for this model is the situation in Lake Monoun (due to simple stratification conditions, this is a trivial case of the effect). Based on this effect it is estimated from gas concentration profiles measured in 1990 (Halbwachs, personal note) and 1992 (Halbwachs et al. 1993), that the next gas burst will be triggered within several years in a depth of about 60 m in this around 100 m deep lake.

The paper of Halbwachs, Grangeon, Sabroux, Villevielle & Naah "Gas lift flushing of dissolved carbon dioxide out of Lake Monoun and implications for Lake Nyos degassing project" describes the first self-acting siphon test in Lake Monoun carried out in March-April 1992, following the recommendations given by the steering committy of the IWGCL in 1990 (Freeth et al. 1990). The resulting jet exiting from a 50 mm diameter pipe reached a height of 4 m, that of a 140 mm pipe a hight of 8 m. The calculated flow rates of CO_2 at STP are 14 dm^3/s and 146 dm^3/s, respectively. The degassing of Lake Monoun with two 140 mm diameter pipes would need roughly one year. A similar degassing procedure could be applied to Lake Nyos, taking several years for total degassing. A degassing test in Lake Nyos is planned at the end of 1993/beginning of 1994. It may be pointed out here, that simply allowing the degassed water to fall back into the lakes would result in a relatively high risk of a serious gas burst triggered by the degassing procedure. The risk would be lower when mixing the degassed water with surface water and rejecting it in a depth with similar density, but the minimum risk method would be to pipe the degassed deep water at a similar rate out of the lake to the inflow rate into the lake (Tietze 1992). These and similar problems were discussed at a special workshop "Orgues de Nyos" held in Paris in September 1992 (see Villevieille 1992).

The papers of Fonji, Mbogning & Tanyileke "A study of the internal structure and configuration of the Lake Nyos natural dam by resistivity methods" and of Freeth "Constraints on the age and stability of Lake Nyos dam" are a continuation of the dispute on the stability of the dam at the outlet of Lake Nyos between Freeth and Lockwood (1988). A failure of this dam could generate not only a new gas burst out of the lake and additionally of the sediment, but also a catastrophic flooding downstream of Lake Nyos in Cameroon and Nigeria. This could cost more than 10000 lives. Therefore it is a very important point whether "there is no reason to suspect that it (the dam) poses an immediate threat" (Freeth) or if "reconnaissance geological mapping of the dam indicates that it is composed of purely consolidated pyroclastic surge deposits which are being eroded at a geologically alarming rate" (Fonji, Mbonging, Tanyileke).

4.3 Short review of papers concerning other lakes

In his paper "The Lake Manengouba 'event' of January 1992", Freeth concluded: the fact, that this Cameroonian lake turned brown in 1992 the first time since 1949 "is no cause for serious alarm" but a reason for a proper investigation.

In the other papers the conditions in several lakes of Japan, Indonesia, New Zealand, Russia, Costa Rica and Zaire/ Rwanda were discussed. They are summarized in Table 1.

TABLE 1: Properties of lakes discussed during the meeting

Authors and title	Outline of important features
JAPANESE LAKES	
Nojiri, Kawai & Otsuki "Fluxes of heat and chemical components in Lake Mashu Caldera, Hokkaido, Japan" / Igarashi, Ozima, Ishibashi, Gamo, Sakai, Nojiri & Kawai "Mantle Helium flux from the bottom of lake Mashu, Japan"	Lake Mashu: 210 m deep; heat flow ($\approx$900 mW/m^2) $\approx$ 15 times larger than Japanese average; bottom spring; residence time for CO_2 $\approx$ 1 year; $R = {}^3He/{}^4He$ (deep water) $\approx 4.6 \cdot R_{air}$; estimation of R of injected mantle helium is close to the highest values reported in Japan; res. time for He $\approx$ 2-4 years;
Ohba & Hirabayashi "Chloride content of crater lake at Kusatsu-Shirane Volcano" / Ritchie & Hirabayashi "The hydrothermal system associated with Kusatsu-Shirane Volcano and Yugama Crater Lake, Japan"	Lake Yugama: six steam explosions in the 1980s; significant increase in Cl^- following volcanic gas influx, coincidental with seismic activity $\Rightarrow$ danger of eruptions; 18 eruptions since 1805; deep fracture system and elevation/stratigraphic controls; periodic chemical pulses; spatial variation in fluid composition;
Abiko "Geochemistry of O-Yunuma explosion crater lake at Noboribetsu Spa, Japan"	Lake O-Yunuma: hot lake (26 m depth), 132 °C; other explosion crater: Jigiku-dani ("Valley of Hell"); 90000 t of hot water; strong chemocline in about 12 m; increase in temperature with depth from 50 °C to 132 °C and in chemical constituents;
Kusakabe & Muzutani "Volcanic gases, and sulfur sediments of an extinct crater lake at Tateyama volcano, central Japan"	Jigokudani Valley: Active fumarole temperature $\approx$ 120 °C ; fumarolic gas, rich in $CO_2 + H_2S$; sulfur deposits; deep seated high temperature source, contribution of mantle helium;
INDONESIAN LAKES	
Badrudin "Geochemistry of Kelut Crater Lake East Java, Indonesia" / Vandemeulebrouck & Halbwachs "Acoustic analysis in volcanic crater lakes as a new method for eruption monitoring: the case of Kelut, 1990"	Kelut Crater lake: covers the most active area of the volcano; changes of chemistry in the lake reflect directly changes in volcanic activity; eruption lahars; degree of danger = function of water level; after the 1919 eruption construction of a system of tunnels to drain the lake; automatic experimental acoustic station

	measured since July 1988 until the eruption in Feb. 1990; the hydrophones (ranges 1-50 Hz, 200-5000 Hz, > 20 kHz) and temp. sensors collected data in front of the eruption, which are a powerful key to understand and predict volcanic activity;
Varekamp, Kreulen & Sriwana "The Keli Mutu Crater lakes, Flores, Indonesia"	Three vividly coloured crater lakes exist for more than a century; they contain varying acid-sulfate brines, saturated in some species which explains the sometimes dramatic change in colour; high temperature water-rock interaction, possibly related to subaquaous magma intrusion. The authors speculate that these lakes are in some sense modern analogs of the early precambrian oceans;
Delmelle & Bernard "A thermodynamic modeling study of the acid crater lake of Ijen volcano in Indonesia"	Crater lake of Kawah Ijen Volcano: passive degassing of volcano since 1900,except two small hydrothermal eruptions observed within the lake in 1936 and 1953; it contains probably the largest accumulation of strongly acid waters in the world, obtained mainly by injection/dissolution of SO_2, H_2S and HCl; liquid sulfur predicted at the bottom;
Christenson, Crump & Glover "Ruapehu Crater Lake bathymetry, temperature profile and water column chemistry: February, 1991"	Lake first observed in 1879; replaced only briefly in 1945 by a lava tholoid; chemical composition typical for crater lakes in active volcanoes;mixture of sulphuric and hydrochloric acids, composition and concentrations vary with volcanic activity; sulfur pool at the bottom;
RUSSIAN LAKES Fazlullin "Limnological studies in the Ksudach caldera, Kamchatka"	Lakes Stubel (2.5 km^2) and Klyuchevoe (5.4 km^2): last explosive eruption in 1907; hot spring (68 °C); energy release 10 kcal/s; free gas collected has deep genesis; organic matter in sediments <1%;
Opisenko "Features of mineralogy of recent bottom sediments from the hydrothermal lakes of Uzon caldera (Kamchatka)"	15 Uzon Caldera Lakes: 4 different types of hydrothermal lakes, but an active process of silicea mineral generation such as quartz, cristobatite and amorphous segregation in all lake sediments;
COSTA RICAN LAKES Rowe "Fluid volcano interactions at an active stratovolcano: the crater lake system Poás Volcano, Costa Rica"	Crater lake system is characterised by a steady release of heat (baseline ≈200 MW) and episodic hydrofracturing / magma of ascent events (≈ 600 MW); seepage of acidic brine back into the volcanic edifice (cyclic period 1 year); growth of underground permeability by extremely corrosive lake brines / reduced by filling of

	pores with native sulfur; recent disappearance of the crater lake; a major volcanic eruption at Poás is unlikely in the near future.
LAKES FROM DIFFERENT STATES Takano, Saitoh, Takano "Molten sulfur lake as a platform for measuring fumarolic activity at crater lakes"	Yugama, Kusatsu-shirane Volcano (Japan); Crater lake, Mt. Ruapehu (Newzealand); Laguna Caliente, Poás Volcano (Costa Rica); Bannoe Lake, Uzon Caldera, Kamchatska (Russia); solfataric areas (Japan): This intensive examination of molten sulfur pools at the bottom of crater lakes is expected to lead to an alternative explanation for the role of molten sulfur pools in transferring heat and masses from deeply seated magma within crater lakes; the previous assumption is that oscillation of lake temperature and repeated blockage and opening of the passage of steam is triggered by the sulfur pool which shows a strongly temperature-dependent viscosity at 159 °C and/or that H_2S reduces the viscosity of molten sulfur from 255 to 1.25 poise at 187 °C;
LAKE IN ZAIRE/RWANDA Maekawa, Nakai, Wakita & Nakao "Helium isotope ratio of dissolved gas in Lake Kivu, Africa"	Last but not least the only non-volcanic lake considered here: Lake Kivu is a large rift lake in East-Central Africa: R = $^3He/^4He$-ratios increase with depth from 1.3 to 3.3 R_{air} in the multilayer waters. A sample of hot spring gas near the shore of the lake contains helium with $R=7R_{air}$; this points to a contamination of the hydrothermal discharge at the lake bottom by helium of crustal origin;

5. Social events, cultural program and field excursion

The meeting did not consist only of intensive work, but some time was left to visit the Institute for Study of the Earth's Interior (ISEI), the historically valuable Sanbutsuji Temple, to celebrate a splendid banquet as well as to visit and examine the impressive Tateyama volcano mountains.

5.1 Visit to the Institute for Study of the Earth's Interior (ISEI)

During the visit to ISEI the participants of the meeting got an overview of its wide range of scientific activity, covering geological-geochemical problems, as well as over its good high-tech instrumentation, ranging from high-pressure apparatus to normal and special mass spectrometers.

5.2 Banquet and cultural program

The participants visited the Sanbutsuji Temple at Mount Mitoku which consists of several "dōs". It is the oldest building in the Tottori Prefecture and an architectural National Treasure. One of the "dōs" is called "Nageire-dō". This 1000-year-old building, situated in a cave above a precipitous cliff, is in perfect harmony with nature. Unfortunately the day of the visit was the only day of the meeting with hard rain, which encumbered the total enjoyment of these cultural monuments somewhat. But the walk through the temple area was exeptional, so that despite this difficulty the participants took with them a lasting impression of Japanese history and culture.

A very enjoyable banquet was celebrated at the Onsen Kaiken Hotel:

- honorable officials of Misasa town welcomed the participants,
- an artistically decorated and delicious buffet was most inviting,
- the female participants were a feast for the eyes in their lovely Kimonos and
- a group of traditional drummers demonstrated their virtuosity. This was the absolute highlight of the evening's entertainment.

Altogether it was a most pleasurable evening to partake in the Japanese way of celebrating such events. It will remain in the minds of the participants for a long time.

5.3 Field excursion to the Tateyama Volcano

The symposium was closed with a spectacular visit to the about 3000 m high Tateyama Volcano in the Japanese Alps. Fumaroles, mud eruptions, fine layered sediments, cold and hot springs with gas flow, pure sulfur pillars, steep walls, and bright snow were all shrouded in a misty atmosphere. The sun's rays added diffuse lighting to the scene, helping make this trip unforgettable for the group of scientists and friends (see pictures 2-4).

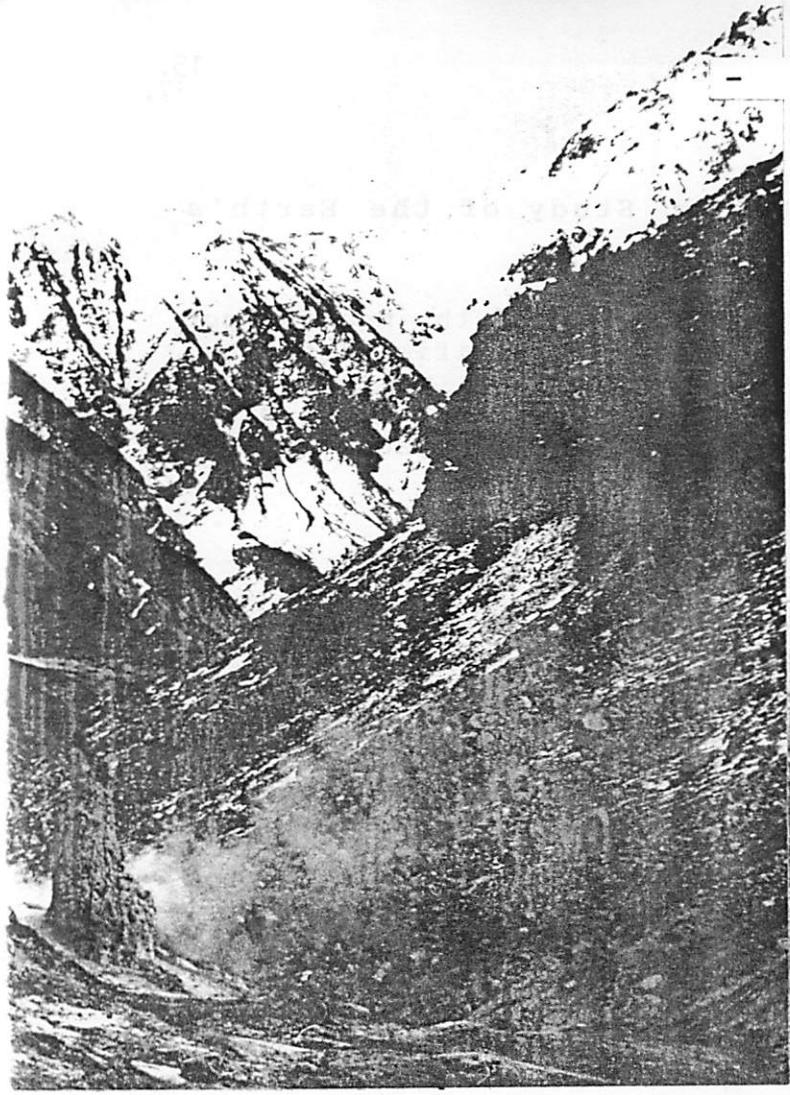

Photo 2: Majestic Tateyama mountains, seen from the "active" area of the volcano (left: pillar of "pure sulfur" in front of a fumarole)

Photo 3: Participants at the meeting examine the pillar of "pure sulfur"

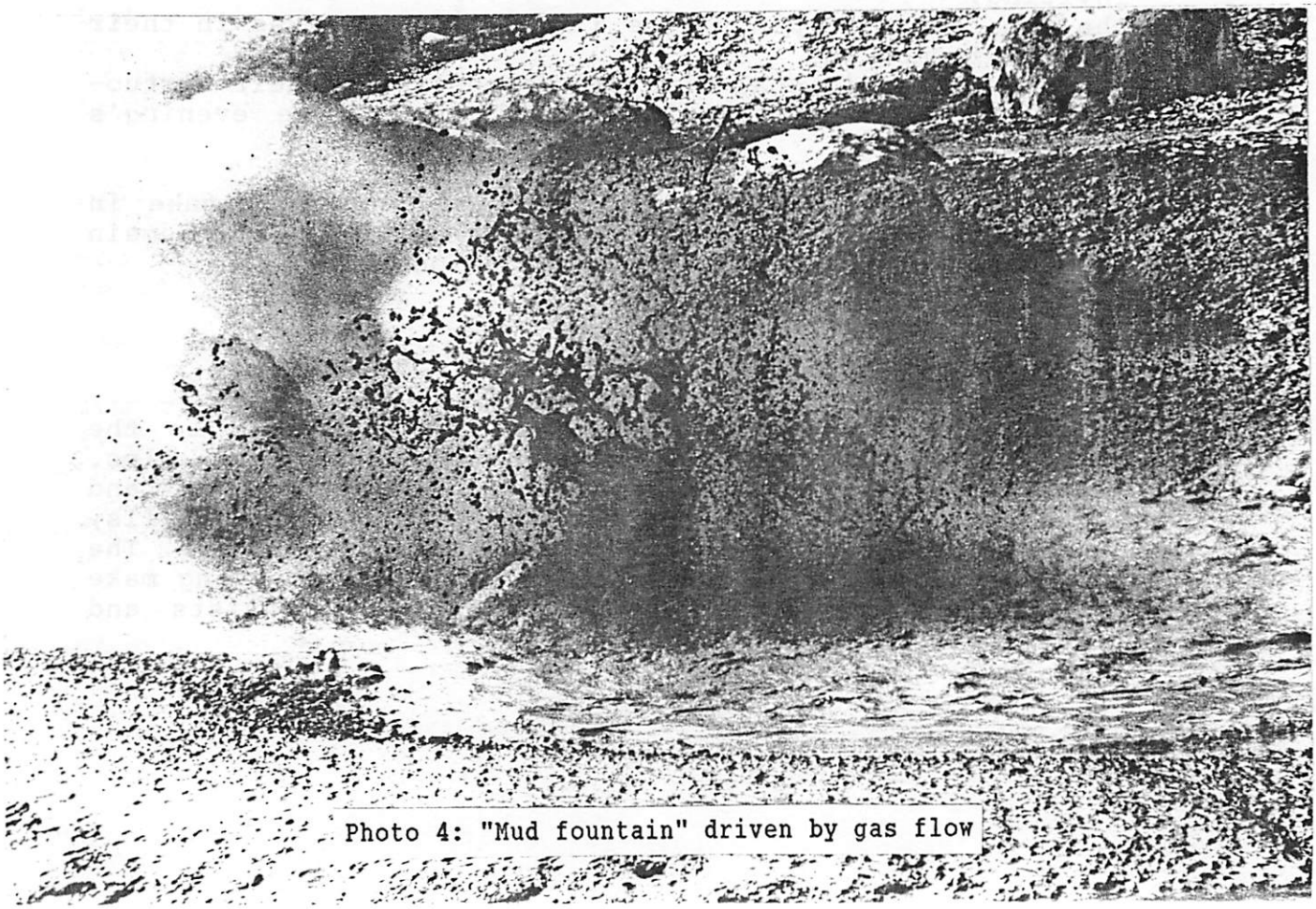

Photo 4: "Mud fountain" driven by gas flow

6. Conclusions and Recommendations

The Second Meeting of the IWGCL, held in Japan in October 1992, was simultaneously an International Symposium on Hazardous Crater Lakes. Both the business meeting as well as the scientific meeting were very successful.

With the decisions of the business meeting and the reorganisation of the steering committee the points were set for the future development of the IWGCL into an inter-association "Commission on Crater Lakes" of the IAVCEI and the IAHS.

The 28 papers presented by scientists from 11 countries covered a wide range of themes concerning crater lakes:

- their behaviour,
- the connection to "their" volcanoes, whether dormant with cold degassing or active with considerably greater hot eruption potential,
- cold limnic eruption models from the water as well as searching for hot eruption mechanisms from the underground,
- early warning systems for both cases as well as development of special instrumentation,
- disaster prevention by degassing lakes Nyos/Monoun as well as monitoring of lakes on dormant and active volcanoes.

The papers and discussions gave the following picture:

Even if dormant volcanoes show no spectacular activity, their invisible "cold degassing" can lead to a hazardous situation in the presence of crater lakes. When stratified crater lakes are charged with gas, they can erupt out of the water as happened in the cases of lakes Monoun (1984) and Nyos (1986). In both cases the danger of new disastrous gas eruptions is rapidly increasing and will eventually lead to new catastrophes within the next years if no preventive measures are taken. Therefore:

- a technical degassing and monitoring of lakes Nyos and Monoun in the near future is absolutely necessary,
- an expansion of research in crater lakes at dormant volcanoes for disaster prevention is urgently required, together with the development of special equipment, and
- the problem with the suspect Lake Nyos dam must be solved,

Crater lakes can also be an early warning system for hot volcanic eruptions at active volcanoes. Additionally they themselves pose a serious danger. Therefore:

- an expansion of research in crater lakes in active volcanic areas is very urgent, too, even when settlements are not far from the volcanoes and
- due to acidic water chemistry and continuous/discontinuous gas discharges, very special intruments must be developed,
- monitoring of those lakes and their volcanoes is required; this will lead to an enhanced understanding and better possibilities for prediction of volcanic eruptions.

The prevention of disasters connected with crater lakes and thus the saving of lives is the ultimate task of the IWGCL. The fruitful symposium in Misasa has shown that this group is prepared and willing to overcome this challenge.

7. Acknowledgments

I am sure that I reflect the sentiments of all participants of the meeting when expressing my heartfelt thanks to Prof. Kusakabe and his team for the superb organisation of the meeting, which involved great personal effort from them all.

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Minutes of the IWGCL Business Meeting held on 21 October 1992 in Misasa, Japan.

1. Kusababe asked for comments on the proposal for the IWGCL to become a joint commission of IAVCEI and IAHS. The proposal was supported and no additional comments were made.

2. Uri Shamir, President of IAHS, suggested that the IWGCL steering committee should have a member belonging to IAHS. Kusakabe asked who should be appointed to the stearing committee as a representative of IAHS. It was suggested that we allow IAHS to appoint a member of their choice, but it was decided that we should retain control over appointment of steering committee members. Michele Meybeck was nominated as a stearing committee member because of his activity in the field of surface-water biogeochemistry, and because he has shown an interest in the IWGCL. It was decided that we would wait until the end of the meeting for suggestions besides Meybeck, and at that time Kusakabe would draft a letter of invitation to the proposed member to join the steering committee.

3. Wally Johnson, General Secretary of IAVCEI, suggested that the IWGCL steering committee contain better representation from volcanologists. Kusakabe recommended that Marino Martini and Alain Bernard join the committee, and he asked for discussion from the floor. It was suggested that because Martini is currently the president of an IAVCEI commission, Johnson would look favourably on the addition of a third volcanologist who was not already heavily committed with duties within the IAVCEI. The idea of a third volcanologist was supported, although it was decided that such an appointment could wait until an appropriate person was nominated.

4. Kusakabe proposed that current steering committee members Tchoua and Maley be replaced by Martini and Bernard and asked for discussion. It was also proposed that Cameroon should be represented on the committee. This was agreed and Greg Tanyileke proposed that John Fonji, Sub-director of Geology at the Ministry of Mines and Power, should be that representative. This proposal was seconded and agreed. A proposal was made that an Indonesian representative also be included in the committee, a short discussion followed on the general criteria for committee membership and adequate representation of various countries or interests. It was suggested that in the future national representatives could be appointed as a way to address this concern. The other members of the steering committee will remain the same (Tietze and Kling), and Kusakabe agreed to continue as Secretary.

5. Kusakabe made a plea for those at the meeting who were not currently members of IWGCL to join, and asked that the current members solicit new members.

6. There are at present about 10 to 12 papers committed to a special issue of the Geochemical Journal concerning this conference. Papers are due to Kusakabe by March 1993, and the issue will be published in October 1993.

A second meeting was held during the conference field trip on 23 October 1992.

1. Johan Varekamp confirmed his offer to organise the next meeting. The meeting will be held in the U.S. within several months after July 1994.

2. Sergei Fazlullin and Alexy Osipenko will proceed with arrangements to have a special meeting of the IWGCL during the Kamchatka field trip of water-rock interactions no.8, to be held in Russia in 1995.

3. It was decided that dues for membership in IWGCL would be $20 (U.S. dollars) and would be collected every two years at the time of the group meeting. This money will be used to defray costs of publishing the Newsletter and of organising the meetings. Additional gifts to IWGCL to help with such cost can be given to Kusakabe.

These minutes were prepared by George Kling and approved by Minoru Kusakabe who presided over the meetings.

A History of Efforts of IWGCL to form an Inter-association Commission of IAVCEI and IAHS

M. Kusakabe (ISEI, Okayama Univ., Japan) and
G.W. Kling (Dept. of Biology, Univ. Michigan, USA)

At the inaugural meeting of the IWGCL at Nancy, France in September 1990, the agreement was reached that the IWGCL should have a more formal basis rather than staying as a private group of scientists who are interested in studies of crater lakes. Considering that the group was formed after the 1987 Yaounde Conference on the Lake Nyos disaster, and that scientific studies on crater lakes are often related to volcanism, it was attempted to affiliate our group with the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) as one of its commissions. Our desire for affiliation was first sent to the IAVCEI's Executive Committee (EC) meeting held in Vienna in August 1991 through Prof. S. Aramaki, President of IAVCEI at that time (see Appendix 1). The proposal given to the IAVCEI's EC. was discussed favorably, and the following recommendation was made (extracted from the minutes of their EC meeting):

> "The International Working Group on Crater Lakes (IWGCL) has submitted proposal to IAVCEI to be established as a new IAVCEI commission. The EC is enthusiastic about the proposal but recommends to the IWGCL to approach the International Association of Hydrological Sciences (IAHS) to form an inter-association commission because of the obvious key role played by hydrology and hydrologists."

Accepting the above recommendation, G. Kling and M. Kusakabe have prepared a proposal to form an inter-association commission on crater lakes, and the proposal was sent to the new officers of IAVCEI, Dr. P. Gasparini (President) and Dr. R.W. Johnson (Secretary General). In addition the proposal was sent to Dr. Uri Shamir (President of IAHS) as well as Drs. Colenbrander, Golubev, Gorelick, Higuchi, Meybeck, Todini, and Van de Ven, who are the leaders of the IAHS's commissions (proposal given in Appendix 2). We received mostly positive replies about our proposal, although Dr. Higuchi pointed out that because there is no existing "inter-association" commission, formalization of such a commission would require closer examination of the related regulations and by-laws.

The IAVCEI's EC met again in Kyoto in August 1992 during the 29th IGC. M. Kusakabe, as Secretary of IWGCL, met Dr. Johnson during the conference and explained in detail our desire to become a commission, the background and history of IWGCL, and the potential difficulty of forming an inter-association commission due to the lack of a previous administrative model. During this conversation Dr. Johnson expressed his personal view that the status of a task group of IAVCEI should be immediately given to us if we increase the number of volcanologists on our steering committee.

During the second IWGCL meeting held 10-24 October 1992 at Misasa, Japan, it was agreed by the meeting participants that two volcanologists, Dr. Marino Martini and Dr. Allain Bernard should be invited as new steering committee members replacing Dr. J. Maley and Dr. F. M. Tchoua, (see the minutes of the Misasa business meeting in this issue). It was also agreed to include a hydrologist representing IAHS, and Kusakabe sent an invitation letter to Dr. M. Meybeck to become a member of the IWGCL's steering committee. He is interested in crater lakes and has high reputation in the field of surface water biogeochemistry. In November, Kusakabe sent a copy of the minutes and the abstract volume of the Misasa meeting to Dr. Johnson. In his reply letter dated 30 November 1992 to Kusakabe, he states;

> "I can see no reason now why the IAVCEI Executive Committee will not accept IWGCL as an IAVCEI Task Group. I will contact Committee members making such a recommendation and proposing that full Commission status be considered at its meetings in September next year during the 1993 IAVCEI General Assembly here in Canberra. May I suggest that aims of your steering committee should include the expansion and consolidation of the list of members who receive your newsletter, and devising a schedule of activities for the next two or three years. An overall objective before September 1993 should be to demonstrate that the Task Group has active members who are committed to a vigorous and on-going program of activities that have international scope".

Given the foregoing, it is highly probable that the IWGCL will be approved as an IAVCEI's task group or commission in September 1993 when the General Assembly of IAVCEI is held at Canberra, Australia. It is clearly essential for us to keep the scientific activity of our group at a high level, and to expand it in the future with increased participation of all the IWGCL members.

Appendix 1

INSTITUTE FOR STUDY OF THE EARTH'S INTERIOR
OKAYAMA UNIVERSITY
MISASA, TOTTORI-KEN 682-02, JAPAN

Prof. Shigeo Aramaki
President of IAVCEI
Earthquake Research Institute
University of Tokyo
Yayoi 1-1-1, Bunkyo-ku, Tokyo 113
Japan

Re: Application for a new IAVCEI Commission, "Commission on Crater Lakes"

Dear Prof. Aramaki,

The International Working Group on Crater Lakes (IWGCL) was set up, as an informal group, during the International Conference on the Lake Nyos disaster held in Yaounde in March 1987 with the primary objectives:

1. Communication between different researchers,
2. Organization of international programs for the study of crater lakes including meetings,
3. Coordination of field measurements,
4. Standardization of reporting data, and
5. Joint development of instruments for crater lake surveys.

The inaugural scientific meeting of IWGCL was successfully organized by S.J. Freeth (U.K.) and M. Kusakabe (Japan) as a part of "Symposium on the Lake Nyos Disaster (10-13 September 1990)" during the 15th Colloquium of African Geology, University of Nancy 1, Nancy, France, although an informal business meeting had been held during the 1988 Kagoshima Conference on Volcanoes. The total number of the IWGCL members is 51 as of February 1991, and the Newsletter is distributed among the members on a once-a-year basis.

At the Nancy meeting, S.J. Freeth (U.K.), G.W. Kling (U.S.A.), M. Kusakabe (Japan), J. Maley (France), F.M. Tchoua (Cameroon) and K. Tietze (Germany) were elected to form a steering committee and they agreed that IWGCL should have a more firm basis rather than staying as a private group of scientists who are interested in crater lakes, and that IWGCL should affiliate with IAVCEI as one of its commissions. Therefore, I, as Secretary of IWGCL, would like to express our desire that IAVCEI approves us as a "Commission on Crater Lakes". The Commission, if approved, will last for 10 years.

The copies of the IWGCL Newsletter Nos. 1 to 3 are enclosed for your reference. The Newsletter No. 4 will be distibuted shortly.

11 March 1991

Yours sincerely,

Minoru Kusakabe

Minoru Kusakabe
Secretary of IWGCL

cc: Dr. H.-U. Schmincke

Appendix 2

The University of Michigan

DEPARTMENT OF BIOLOGY

Natural Science Building
Ann Arbor, MI 48109-1048

Department Telephone (313) 764-1440
FAX (313) 747-0884

12 June 1992

Dr. R. W. Johnson
Secretary General of IAVCEI
Bureau of Mineral Resources, Geology and Geophysics
GPO Box 378
Canberra
ACT 2601, Australia

Dear Dr. Johnson:

On behalf of the members of the International Working Group on Crater Lakes (IWGCL) please accept the following proposal to form an inter-association IAVCEI Commission with IAHS, to be called the International Commission on Crater Lakes (ICCL). Our contact with Dr. Uri Shamir, President of IAHS, and members of the appropriate IAHS bodies has been favorably received, and is detailed in the enclosed correspondence. Here we describe the history, structure, rationale, and objectives of the ICCL for your consideration.

The proposed International Commission on Crater Lakes

(I) History

The International Working Group on Crater Lakes (IWGCL) was initially organized during the International Conference on the Lake Nyos Disaster held in Yaounde, Cameroon in March 1987. A business meeting was held during the 1988 Kagoshima Conference on Volcanoes in Japan. During this meeting the proposal to publish a Newsletter was accepted, and the first Newsletter was distributed to group members in February 1989. The latest Newsletter issue was dispatched in March 1992.

The inaugural scientific meeting of the IWGCL was held in conjunction with the "Symposium on the Lake Nyos Disaster" during the 15th Colloquium of African Geology, University of Nancy, Nancy, France in September 1990. At this meeting a steering committee was elected, and a resolution was passed that IWGCL should solidify its structure through affiliation with IAVCEI. In March 1991 a proposal was drafted to IAVCEI that the working group be accepted as the International Commission on Crater Lakes (ICCL).

In August 1991 the IAVCEI Executive Committee showed enthusiasm for this new commission, but recommended that the ICCL be established as an inter-association commission with the International Association of Hydrological Sciences (IAHS). Our proposal to IAHS to form an inter-association commission was positively received, and has resulted in the document presented here outlining the structure and objectives of the joint ICCL.

The second scientific meeting of the IWGCL will be held in Misasa, Japan, 19-22 October 1992. Hopefully at that time we will formalize the structure of the proposed ICCL.

(II) Structure

Currently the IWGCL is composed of 51 members paying regular dues. Minoru Kusakabe serves as the editor of a Newsletter that is distributed annually. Kusakabe is also the Secretary of the group, and the elected Steering Committee consists of:

S. J. Freeth (University College of Swannsea, UK; geochemistry and neotectonics)
G. W. Kling (University of Michigan, USA; limnology and biogeochemistry)
M. Kusakabe (Okayama University, Japan; geochemistry and volcanology)
J. Maley (University of Sciences and Techniques of Languedos, France; palynology)
F.M. Tchoua (University of Yaounde, Cameroon; volcanology)
K. Tietze (BGR, Germany; physical limnology, geophysics)

The current structure will serve the proposed ICCL on an interim basis, awaiting a reorganization under the guidelines of IAVCEI and IAHS.

(III) Rationale

Crater lakes lie in the terminus of a volcanic conduit through which volatile materials and/or magma are released to the earth's surface. The resulting surface expressions and formations serve as our investigative windows into the earth's interior. Long after eruptive activity has ceased, heat and volatiles from magma may be supplied to a crater lake. The lakes act as integrators and traps for thermal energy and gases, and thus function as recorders of geological and chemical processes in the earth below. Excessive accumulation of gases in crater lakes may even lead to violent gas bursts, as demonstrated by the recent disasters at Lakes Nyos and Monoun in Cameroon.

For the limnologist, crater lakes encompass the entire range of diversity in physical, chemical, and biological properties of lakes, and they present invaluable opportunities for comparative studies on the surface and groundwaters that fill them. In fact many of the formative principles in limnology were discovered and developed through studies in crater lake districts.

We believe that for the further development of crater lake studies, it is essential to integrate research on the geological formation and physico-chemico structure of crater lakes with the broader aspects of hydrological sciences. For example, most of the environmental problems facing society today will be solved only through the interdisciplinary efforts of our scientific community. We believe that a joint affiliation between IAHS and IAVCEI, through the ICCL, would be beneficial to both organizations, and would lead to greater scientific understanding and the increased communication required by interdisciplinary problem solving.

(IV) Objectives

The main goal of the ICCL will be to foster communication between scientists concerned with volcanological, geochemical, and limnological aspects of crater lakes. Through the exchange of ideas and the establishment of interdisciplinary contacts, we will reach a better understanding of the processes occurring in and beneath these lakes. This knowledge will provide new approaches to mitigate current and future environmental concerns as well as the natural disasters related to hazardous crater lakes. We will accomplish this goal through three major efforts:

(1) **To increase communication between researchers** - The Newsletter is a forum for members to present scientific results or articles and news items of general interest, and its annual distribution will continue. A complete Directory of members and their scientific interests will be developed. In addition we propose to conduct a scientific meeting with themes of particular interest to the ICCL every two years, in conjunction with meetings organized by IAHS or IAVCEI. These efforts will facilitate the education and transfer of information between our members, and promote the awareness of new research ideas and directions in various disciplines.

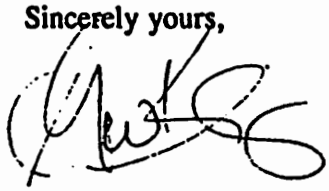
(2) **To serve as a repository of scientific information** - We will develop a multi-faceted database on crater lakes of the world. The database will include basic geological and limnological information, and will contain bibliographic references and specific scientific contacts for those interested in collaborative research. Standard geographical information will be included to allow for the future incorporation of the database into a Geographical Information System. As a repository of scientific information and expertise, the ICCL will also be able to represent its members with a unified voice on various scientific or manangement issues to governments and international agencies.

(3) **To coordinate research activities on crater lakes** - The ICCL will also function to assist the coordination of international field measurement programs, and help in the development and standardization of new instruments and methods used in crater lake research.

Some of these goals have been reached by the IWGCL in the last several years, such as the development of international collaboration on crater lake research in Cameroon and

the facilitation of remediation efforts sanctioned by the Cameroonian, French, and American governments. We hope to continue and intensify these efforts through the establishment of the ICCL, and we look forward to your response to our proposal.

Sincerely yours,



George W. Kling
Steering Committee, IWGCL
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encl/correspondence
cc/ Higuchi, Golubev, Todini, Colenbrander

Towards a constitution for the IWGCL

S.J.Freeth,
Geolgical Hazards Research Unit, University College of Swansea.

Introduction

The International Working Group on Crater Lakes is now 6 years old, we have more than 60 'members' (or more accurately the distribution list for the Newsletter has more than 60 names on it), but no constitution. Perhaps the lack of a written constitution is no bad thing and it may well be that the 'members' would prefer to continue without one. However, if the group continues to grow I suspect that the 'committee' will need to take at least some policy decisions between meetings and I feel that it would be helpful if some guidelines were set down as to how such decisions should be taken. In my view there are problems with an International Group (at the present time we have 'members' from 15 countries) which would not arise within a National Group. Aside from the obvious problems of communication and language it has been my experience that different styles of organisation have developed in different countries. The problems for a group like ours, lie not in these differences, but in many peoples inate assumpions based on experience of their own National way of organising matters. I therefore think it important that the 'members' should decide how the 'committee' is chosen and to what extent decisions should be taken without reference to the membership as a whole. My purpose in writing these comments is not to offer suggestions of my own but to open a debate in the pages of this Newsletter to which I would hope many members might contribute.

Background

The possibility of setting up an International Working Group was first discussed by a group of interested scientists during the International Conference on the Lake Nyos Disaster which was held in Yaounde in March 1987. During that meeting it became clear that there were many aspects of the 1986 disaster about which the scientists who had been involved in the initial investigation were finding it difficult, if not impossible, to agree. Many of us felt that it might be a good idea if we were to circulate a Newsletter to facilitate the rapid circulation of new information and ideas, between the various National groups. There was also a general feeling that it might be of value to convene a further meeting in a couple of years, by which time there would be far more data from the samples which had already been collected and we would all have had time to give more careful consideration to the competing hypotheses which were being argued over during the Yaounde meeting. Minoru Kusakabe agreed to compile and circulate a Newsletter - and thus the (as yet unnamed) Working Group was formed

An 'informal' meeting of members of the Group was organised by Minoru Kusakabe, during the Kogashima International Conference on Volcanoes, in July 1988 - during which the possibility of setting up a more formal group which might seek affiliation with international bodies (such as IAVCEI) was discussed.

A formal "Inaugural Meeting" was organised, by myself, and took place alongside a Symposiun on the Lake Nyos disaster which was part of the 15th Colloquiun on African Geology in Nancy, in September 1990 - at this meeting a "steering committee" was selected and the proposal to seek affiliation with IAVCEI and other International bodies was endorsed.

The 2nd. Meeting of the I.W.G.C.L. was organised, in Misasa, by Minoru Kusakabe in October 1992 - at this meeting the Group was firmly established and we are now able to look to the future with confidence.

Objectives

The main objectives of the Group, as set out by Minoru Kusakabe in his editorial to the 1st Newsletter were:

1. Communication between different researchers,
2. Organisation of [an] international programme for the study of crater lakes including meetings,
3. Coordination of field measurements,
4. Standardisation of reporting data, and
5. Joint development of instruments for crater lake survey.

To these objectives the Kogashima meeting added:

6. To prepare a catalogue of crater lakes which possess limnological and volcanological similarities to Lake Nyos and Lake Monoun.

In Newsletter no.3, which was circulated prior to the Inaugural Meeting in Nancy, Minoru Kusakabe drew attention to the fact that the objectives as set out in the first Newsletter were being only partially fulfilled and suggested that the Nancy meeting would be an appropriate occasion to discuss the future of the Group.

Although informal discussions took place during the Nancy meeting, and again during the recent meeting in Misasa, no formal resolutions have been adopted concerning the objectives of the Group.

An alternative version of the Group's objectives has been drawn up by George Kling and Minoru Kusakabe as part of a continuing effort by the Group to seek affiliation with IAVCEI and IAHS. These are set out in a letter which is printed in full on pages 23 to 26 of this issue - rather than repeat what is written elsewhere I suggest that the reader turns to page 23. - - - - - - - - -. It seems to me that this is an admirable statement of ideal objectives but that, as with the previous set of objectives, it proposes more than the Group can dispose.

I suggest that at its next meeting the Group should adopt a formal set of objectives but that these should be limited to those which we can realistically hope to achieve. And to this end I suggest that we limit ourselves to the following:

1. To encourage international and inter-disciplinary collaboration between scientists with an interest in crater lakes.
2. To facilitate rapid communication, of results and ideas, between members.
3. To prepare [and distribute] a definitive catalogue of lakes in volcanically active areas.

The first of these objectives is a little pious since experience suggests that scientists collaborate when it suits their own perceived interests - but as an objective it is a laudable one. Rapid communication would cover the production of this Newsletter and the organisation of meetings at regular intervals. And a definitive catalogue, which included the type of information suggested elsewhere in this Newsletter by Rowe and Varekamp, could be of considerable value.

Members

When the Working Group was first set up, as far as I am aware, there was no intention that it should have a formal membership. The general idea being that any scientist who was interested in volcanic lakes would be a 'member'. The idea that 'members' should make a financial contribution was

introduced, by Minoru Kusakabe in 1990, to help support the cost of producing and distributing the Newsletter. His request for a 10 $US "contibution" was repeated in subsequent Newsletters and accepted as a "membership fee" at the recent meeting in Misasa.

On reflection I am far from sure that a compulsory membership fee was an entirely good idea. Particularly since very few 'members' have paid it and the amount of money collected therefore covers only a small part of the production and distribution costs of this Newsletter. I myself offered to to take over the editing of this Newsletter because I thought that the Newsletter was making a valuable contribution, but since only part of the production cost and none of the distribution cost is being met by the IWGCL I would object if I was told that I could only send copies to paid up members. I also feel very uneasy at the idea of setting a flat rate fee expressed in $US. The problem being that the real value of a $10 bill varies from country to country. Perhaps I could illustrate this point with reference to a common commodity - in the United States $10 would purchase about 3 litres of beer, and in Britain or most Western European countries it would purchase a similar amount, but at the recent meeting in Misasa it would have purchased only 1 litre whilst in Lagos it would purchase nearly 20 litres! Thus in terms of purchasing power we are asking those who can least afford it to pay the most. I am not suggesting that the Newsletter should be paid for in Beer (though the idea does have a certain appeal) but that we should not make the presumption that what is small change to one member is necessarily small change to another.

I would like to suggest an alternative way of funding the production cost of the Newsletter. Why not charge a small amount extra as part of the registration fee for the next IWGCL meeting?? Of say $10 since the next meeting is scheduled for the United States and 'members' who attend that meeting would then be entitled to a free copy of the next two Newsletters. The Newsletter could carry a cover price (of say 10 ECU's) and members who did not attend the meeting could be asked to make an appropriate donation.

Committee

The idea of an elected committee was first discussed at the meeting in Nancy but since at that time we had no constitution which would offer guidance as to how such a committee should be elected it was agreed to 'appoint' a steering committee. And since it is an International Working Group each of the National groups which were present at the meeting were asked to nominate one member. During negotiations to become a commission of IAVCEI their Secretary suggested that there were insufficient volcanologists on our committee and our Secretary therefore co-opted a volcanologist. At the recent meeting in Misasa the 'steering committee' met and discussed, at some length, how to renew itself. It was generally agreed that if we wished to maintain a balance of Nationalities and interests then a simple election would be inappropriate. The committee therefore proposed a 'slate' which was accepted (with one addition) by a general meeting.

Although this is not an ideal way of 'electing' a committee it seems to me to be the best available. But perhaps someone might be able to suggest a better way?

I would also like to draw attention to what I feel to be a major anomaly which has arisen, at least in part, because the decision concerning the venue for the next meeting took place after the committee's 'slate' was endorsed. It would seem to me that those who contribute most to organising the Group should be members of the committee - thus the Secretary, the Organiser of our next Meeting (and perhaps the Editor of the Newsletter -though it is hardly for me to suggest this) should all have automatic seats on the Committee. I would therefore suggest that we should have a

constitution which specifies certain 'officers' such as Secretary, [Editor] and Meeting Organiser (and any others which might be added to the list) as automatic members of the Committee, together with a number (perhaps specified) of Members all of whom would be nominated, by the retiring committee and then put before a meeting of members for endorsement (or rejection).

Some decisions need to be taken by the Committee between Meetings (otherwise there would be no point in having a committee) and I think it important that we should specify whether decisions should be taken by a simple majority or by a qualified majority. I myself think that a simple majority would not be appropriate, since the committee should seek general agreement before taking any decisions. But we also have to take into account the fact that from time to time some members of the Committee may be difficult to contact. I would suggest that decisions should require the consent of two-thirds of the Committee - given that the committee currently has 7 members that would then require the consent of 5 members.

The suggestions, which I have set out above, were written with the intention that they would open a debate to which I hope many members will feel impelled to contribute.

Recent Geochemical Survey of Crater lake waters in West-Cameroon.

A. Bernard[1], G. Tanyileke[2], P. Delmelle[1], G. Setche[3] and Nono[4].

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2: Institute for Geological and Mining Research, IRGM/CRH, BP 4110, Yaounde, Cameroon.
3: Laboratoires Associés de Géologie, 160/02,Université Libre de Bruxelles, 50 Ave. Roosevelt, 1050 Brussels, Belgium.
4: Département des Sciences de base. Centre Universitaire de Dschang, Cameroon.

This report describes the preliminary results obtained during a geochemical survey carried out on three crater lakes in West-Cameroon in May 1992.

Lake Monoun and lake Nyos were both the sites of a catastrophic gas (CO_2) burst respectively in 1984 and 1986. These lakes are unique examples where a catastrophic gas release has been observed and scientifically documented. Both lakes still contain huge amounts of CO_2 gas dissolved in their deep waters. Since the gas disaster, the CO_2 contents of the bottom waters have increased in both lakes due to a slow recharge in CO_2 at depth. Detailed studies of this CO_2 recharge processes can be useful to identify the nature of the feeding mechanism of CO_2 in these lakes. These studies can also help our understanding of how the lake is readjusting its overall chemistry in response to the CO_2 fluxes into the lake reservoir. This could give some insights on the chemical compositions that prevailed in these lakes before the catastrophic gas bursts. An estimate of the recharge rates in CO_2 is also essential before to proceed to an artificially controlled degassing of these lakes. To achieve these goals, a continuous chemical monitoring of these lakes should be maintained.

This report is a contribution to this chemical monitoring. The data presented here are in a very preliminary form, but we hope they can be of use for those currently working with these gassy lakes.

Methods:

The lake waters have been collected during a two weeks survey May 10-25, 1992. Water samples were filtered in the field and acidified to pH=1. Alkalinity (acid titration) and pH were measured in the field. Cations were analyzed by DCP-AES and Atomic Absorption.

Results:

The chemical compositions of the lake waters are listed in Table 1.

For lake Nyos, depth profiles of the concentrations of HCO_3^- and Fe^{++} are plotted on Figure 1. These two species are thought to be the most sensitive to a CO_2 gas increase into the lake reservoir. The compositions measured shortly after the catastrophic gas burst in September 1986 (Tuttle et al, 1987) and October 1986 (Kusakabe et al., 1989) are also plotted as references. The most significant changes observed since the gas disaster are:

- a decrease in the alkalinity for the surface waters probably resulting from a reequilibration with the atmosphere and/or dilution and mixing with meteoric waters as suggested by Kling et al. 1992;

- a significant increase in the HCO_3^- and Fe^{++} for the bottom waters. The simultaneous increase in both iron and alkalinity confirms the influence of CO_2 on the solubility of Fe. For these anoxic waters, the solubility of iron is controlled by the equilibrium reaction with solid siderite ($FeCO_3$). After the 1986 gas disaster, deep lake waters (> 40m) were close to the equilibrium with siderite (Kling et al., 1989; Kusakabe et al., 1989; Bernard and Symonds, 1989).

For lake Mounoun, similar depth profiles are plotted on Figure 2. These data show also a parallel increase in both alkalinity and iron contents of the bottom waters for depths > 60m.

Lake Manengouba:

Two crater lakes are present in the summit caldera of the Manengouba volcanic complex (Southwest province, Bangem): the so called female lake (lac de la femme) and male lake (lac de l'homme). The female lake is the largest and the deepest (168m).

On the 4th of January 1992, a change in the color of the surface waters of the Female lake was observed by local people. The death of about one hundred fishes was also reported. See Freeth (1992) for a complete summary of this event.

A preliminary report made by Cameroonian investigators concluded to a possible emission of CO_2 gas similar to the Nyos event as the origin of the phenomenon and recommended that a proper geochemical survey of the deep waters was undertaken (Ntep and Edimo, 1992).

Surface and bottom waters were collected on May 20, 1992. The compositions listed in Table 1 show no enrichment in HCO_3^- or iron. The alkalinity data reported here are very close to those reported in 1987 for this lake by Kling and Evans (1987). In conclusion, it seems

unlikely that the waters of lake Manengouba have recently stored a significant amount of carbon dioxide.

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Kusakabe, M., Oshumi, T. and Aramaki, S. 1989. The lake Nyos gas disaster: chemical and isotopic evidence in waters and dissolved gases from three Cameroonian lakes, Nyos, Monoun and Wum. J. Volcanol. Geotherm. Res. 39: 167-185.

Ntep, G. P. and Edimo, A. M. 1992. Changement de couleur et mort subite des poissons dans le lac Manengouba (Bangem). Rapport de Mission. Ministère des Mines, de l'eau et de l'énergie, République du Cameroun, 13pp.

Tuttle, M. L., Clark, M. A., Compton, H. R., Devine, J. D., Evans, W. C., Humphrey, A. M., Kling, G. W., Koenigsberg, E. J., Lockwood, J. P. and Wagner, G. N. 1987. The 21 August 1986 Lake Nyos gas disaster, Cameroon. U. S. Geol. Survey, Open File Rep. 87-97, 58pp.

Table 1: Water chemistry of Lake Nyos, Monoun and Manengouba and thermal springs.
(All values in mg/l)

	pH	Si	Al	Fe	Mn	Mg	Ca	Na	K	Ba	Sr	B	HCO3
15-17 May 92													
Nyos 0m	8.41	7.4	<0.01	<0.1	<0.1	4.1	4.0	3.3	1.3	<0.01	0.03	<0.02	47
Nyos 20m	6.45	7.1	<0.01	<0.1	<0.1	4.5	4.4	3.4	1.5	<0.01	0.03	<0.02	49
Nyos 50m	5.54	15.5	0.06	41.7	1.1	34.6	27.0	11.4	3.9	0.06	0.10	<0.02	395
Nyos 100m	5.59	17.6	0.11	53.0	1.2	45.9	35.1	27.7	11.0	0.09	0.13	<0.02	542
Nyos 170m	-	24.4	0.15	74.3	1.5	59.1	42.9	-	-	-	-	0.02	-
Nyos 200m	-	33.3	0.07	100.7	1.7	93.7	64.1	24.5	7.4	0.09	0.23	0.03	1037
Nyos 203m	-	34.7	0.07	108.7	1.8	99.4	67.4	25.6	7.9	0.09	0.24	0.03	1130
19-May-92													
Monoun 0m	7.2	7.6	<0.01	0.4	0.1	4.6	7.3	90.5	3.5	0.03	0.09	<0.02	73
Monoun 65m	-	55.2	0.29	629	5.0	29.2	47.1	23.2	0.6	0.62	0.88	0.14	1818
Monoun 96m	-	59.9	0.40	779	5.7	30.2	49.9	25.4	0.6	0.73	0.93	0.16	1904
20-May-92													
Manengouba 0m	8.47	4.6	<0.01	<0.1	<0.1	1.5	2.3	1.5	1.4	<0.01	<0.032	<0.02	22
Manengouba 164m	-	4.4	<0.01	1.6	<0.1	1.7	3.2	1.6	1.8	<0.01	0.05	<0.02	36
Lobé spring	6.2	25.4	0.11	0.6	<0.1	43.6	155.3	1669	76.0	0.91	11.01	1.51	1534
Ndibsi spring	6.4	52.2	0.09	0.1	0.2	63.6	84.7	738	58.1	1.00	0.98	1.80	2049
Baré spring	5.81	59.5	0.13	6.9	0.4	33.5	101.4	180	38.0	0.44	0.63	0.04	1021

-: not analyzed

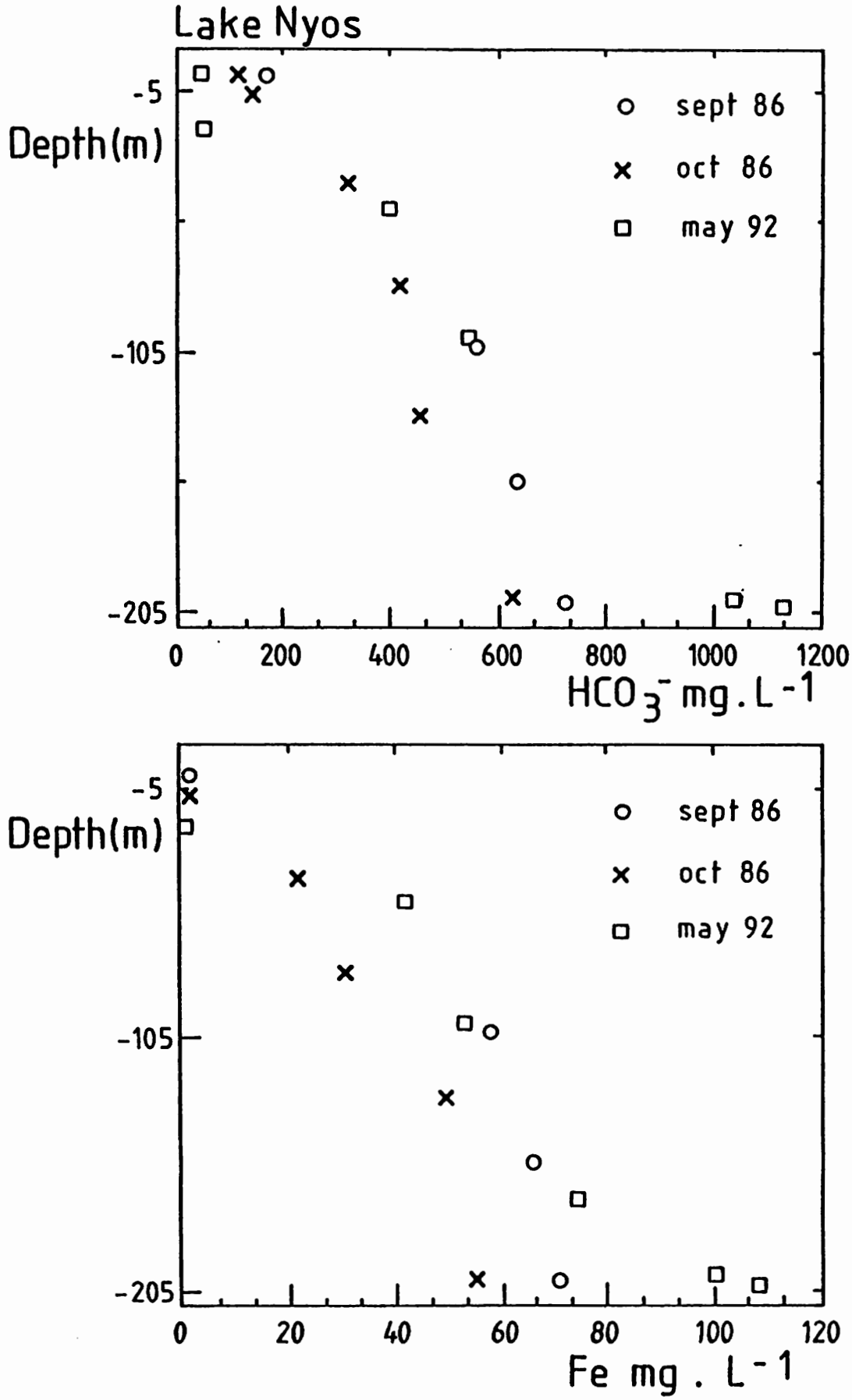

Figure 1: Lake Nyos. Profiles of HCO_3^- and Fe^{++} as a function of depth.

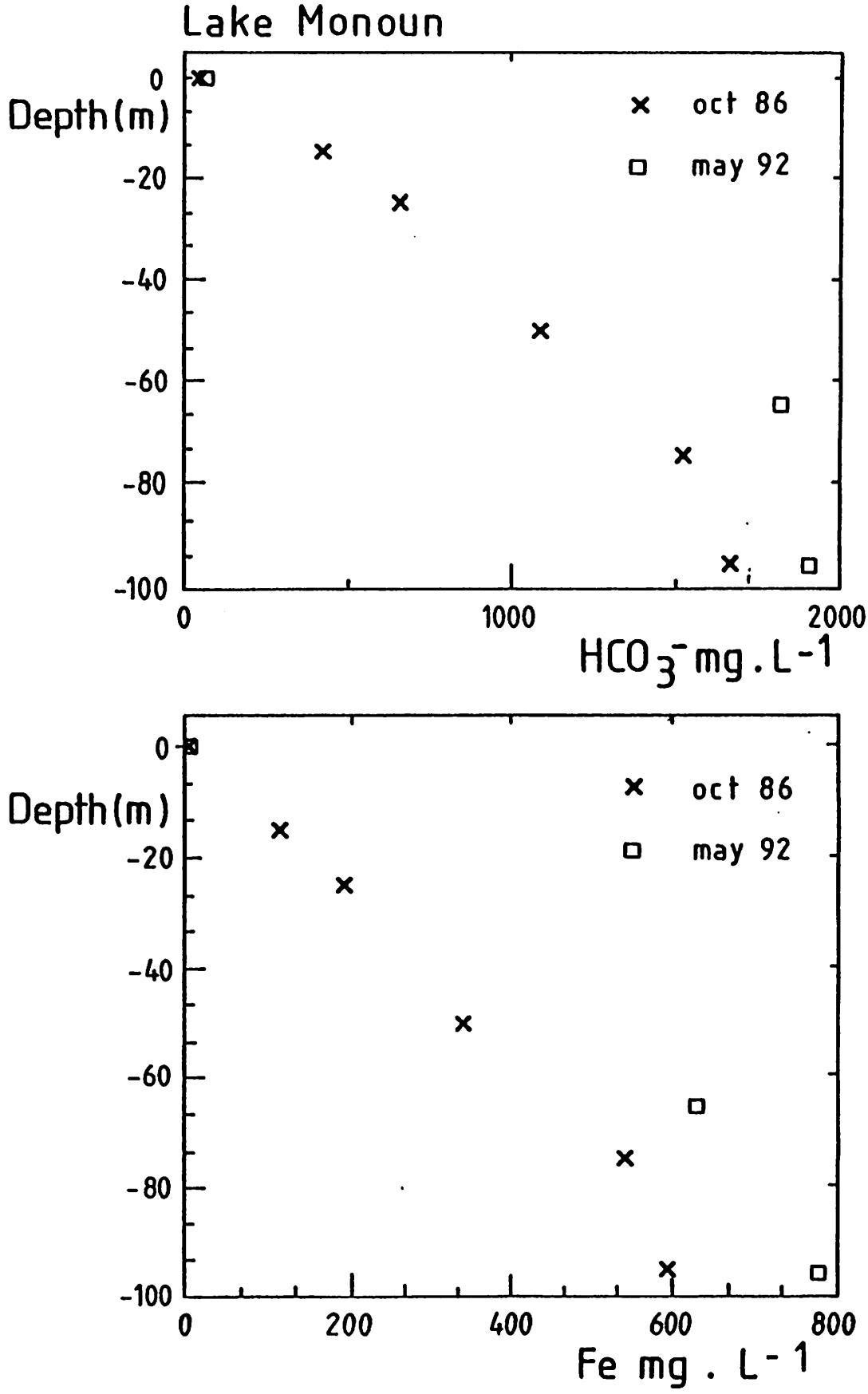

Figure 2: Lake Monoun. Profiles of HCO_3^- and Fe^{++} as a function of depth.

THE SCIENTIFIC INVESTIGATIONS OF LAKE NYOS DAM THREATS TO CAMEROON AND NIGERIA - SUMMARY.

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This report emanates from the work of a joint team of Nigerian and Cameroonian experts, set up by the Governments of both countries, to examine the validity of a claim by a section of the international scientific community that the natural dam impounding the waters of Lake Nyos is in danger of collapse. If the dam failed, it is estimated that fifty five million cubic meters of water would be released and cause flooding in downstream areas within Cameroon and the agricultural low lands of the Katsina Ala Valley in Nigeria.

To accurately assess the stability of the dam, it was necessary to carry out an engineering and geotechnical evaluation. Detailed topographic, geological and geophysical mapping of the dam and its environs were undertaken in late April and early May 1990. A study of the hydrology of the lake and the downstream valley system, to determine the water balance of the lake catchment area and deliniate areas likely to be affected by floods in the event of a dam collapse, was also carried out.

RESULTS - The results of these studies showed the following:

1. LAKE CONDITION

(i) About 98 per cent of the gas dissolved in the lake is carbon dioxide, of magmatic origin. Its concentration has continued to build up since the gas outburst of 1986 and could achieve complete saturation within 50-100 years, although saturation is not necessarily a prerequisite for another gas outburst.

(ii) Water temperatures are higher near the bottom than at the mid-depth range.

(iii) Pyroclastic and basement rocks on the lake periphery are cracked, jointed and faulted, hence the danger of substantial rock falls into the lake are quite real. Such rock falls could precipitate another gas outburst and/or spillage over the dam. These observations are clear indicators of a substantially unstable lake likely to overturn, explode or release its gas due to any measurable disturbance caused, for example, by a rock fall, a density current within the lake, and earthquake or an unusual heat flux or surge from the lake bottom.

2. DAM CONDITION

(i) The dam is seated on weathered, faulted and fractured basement.

(ii) The dam was formed by the deposition of tuff and lapilli tuff in beds of non-uniform composition. The upper unit consists of fairly consolidated

pyroclasts, which are severely jointed. These break off in blocks along vertical planes of weakness on both the upstream and downstream faces of the dam. The lower rock unit is formed of unconsolidated pyroclasts, demonstrably weaker than the upper unit, and further weakened by caves and soda springs.

(iii) The continuing erosion of the dam crest along the spillway is a result of both water spillage from the lake, and the resultant vibration within the layer of water passing over the spillway, and abrasion/corrosion along joints and in potholes on the spillway surface.

(iv) There is an abundance of potholes, numerous unweathered ultramafic xenoliths in the pyroclastic rocks and parallel joints occuring on the dam surface.

(v) There is internal leaching and erosion of the dam material.

(vi) The dam rocks' compressive and shear strength, bulk density and specific gravity, slaked durability and modulus of elasticity were quite low, giving an overall Rock Mass Rating (RMR) that varies from poor for the upper unit to very poor for the underlying pyroclastic rocks.

(vii) Sliding failure of the dam is of greater concern than overturning, from the first-order stability analysis.

Considering all the above, and the fact that the dam is located alond the Cameroon Volcanic Line, which is known to be a seismically active area, it is concluded that the lake Nyos dam is unstable and could fail at any time.

MITIGATING OPTIONS - With the instability of both the lake and the dam established, the following mitigating options were identified:

(i) Elimination of the threat of a dam break by degassing of the lake, drainage of the lake to a level below the base of the dam and removal of the dam.

(ii) Reduction of the probability of the occurence of a dam break by reinforcement, reduction of seepage through the dam and rempval or control of potential rock falls from the rim of the lake.

(iii) Preparation of the downstream areas to absorb threat by delimiting zones likely to be flooded, early prediction of events and the development of an emergency preparedness programme.

(iv) Construction of a downstream containment dam, and the development of plans for evacuation from threatened areas.

RECOMMENDATIONS - Given all the above, it is recommended as follows:

1. LAKE NYOS

(i) A detailed bathymetric survey of the submerged upstream face of the dam, using seismic or other suitable means must be undertaken right away, not only to map the dam face / lake bottom topography, but also to determine the composition of the dam material.

(ii) In response to the rapidly changing physico-chemical condition of the lake, monitoring of its geochemical and thermal parameters should be intensified. In addition to the weather station on the lake, the Nyossonde should be reactivated to telemeter measured data to Yaounde and other suitable off-site stations for instantaneous analysis and early warning of an impending catastrophe.

(iii) It is imperative that a permanent lake level monitor be installed for continuous recording of lake water level. The measured data should also be telemetered to a central processing station for imediate analysis and utilisation.

(iv) The full participation of indigenous personel in the installation, operation and maintainence of all hydrometeorological instrumentation should be mandetory. In time, qualified indigenes should take over full responsibility for the operation of these stations.

(v) Limnological records should be processed immediately upon acquisioion to ascertain the level of changes within the lake, check out unusual events and determine the necessity for emergency action.

2. LAKE NYOS DAM

(i) More detailed geotechnical investigation of the dam including core drilling and additional sampling of dam and parent materials.

(ii) Frequent surveys, and additional instrumentation and geodetic definition, of the dam crest to determine dam movements, shifts and deformation.

(iii) Shallow seismic and other geophysical surveys, to check previous results and further map voids and bedrock topography.

(iv) Measurement and continuous monitoring of spillway joints and fractures.

(v) Detailed stratigraphic, petrographic and structural studies of the dam using core samples.

(vi) Detailed geological mapping of the downstrream face of the dam and its foundations.

(vii) Dam stability analysis, considering in detail such failure mechanisms as internal erosion, piping and chemical deterioration.

(viii) Finite element analysis for determination of dam stability.

3. OTHER ACTIONS

(i) Installation of permanent stream gauging stations on Nyos and neighbouring streams (Rock, Kam Njupi), as well as on the Kumbi River.

(ii) A helicopter reconnaissance survey of the Nyos, Kumbi and Katsina Ala valleys.

(iii) Mathematical simulation of the failure of the dam and the development of inundation maps of downstream areas likely to be flooded in the event of a dam break.

(iv) Conduction of demographic and land use surveys over the areas threatened by the lake and its dam.

(v) Maintainance of close contact and liason between Nigeria and Cameroon in matters relating to the Lake Nyos dam problem.

Copies of the full report are available, on request, from either of the authors whose addresses are given above (ed.).

Report on a visit to Lakes Nyos and Bambuluwe and to the Manengouba lakes in March 1992

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Introduction

In August 1986 Lake Nyos released a toxic aerosol of water and carbon dioxide which killed an estimated 1700 people. In the aftermath of the disaster teams of scientists were sent by many countries (including one from Britain) to assist in the investigation of the disaster. This was the second gas disaster in Cameroon within a period of only two years (the previous one being at Lake Monoun in August 1984) and there was therefore concern not only that Lake Nyos might release more gas but that other lakes in the area might also be dangerous.

There are now very few questions, concerning the cause of the 1986 disaster, which have yet to be answered to the satisfaction of most of the scientists involved in the investigation. And no other lakes have been found to contain excess gas. However, the investigation has thrown up a number of important questions relevant to the future safety of the area. Foremost amongst the questions which require urgent answers are, on the one hand those concerning the rate at which the gas concentration at depth is building up and ways in which some of this gas might safely be removed and on the other hand those concerning the stability of the natural dam which confines the upper 40 metres of Lake Nyos.

During previous visits to Lake Nyos (in September 1986 and March 1987) I collected samples which on subsequent analysis yielded radiometric ages which indicate that the Lake Nyos dam is more than a hundred thousand years old. If the dam is indeed many thousands of years old then it is eroding very slowly and does not pose an immediate threat. However, if it is very much younger, as some have suggested, then there may be cause for serious concern.

Objectives

The primary objectives of my visit were: (1) to collect samples which would allow a more precise determination of the age of the Lake Nyos dam, and thus the rate at which erosion has reduced its width, (2) to see whether or not there had been any detectable changes since 1987 and (3) to determine the rate at which water was flowing through the dam and through the pyroclastic deposits to the north-east of the lake.

As a secondary objective it was my intention to obtain information on, and where possible arrange to visit, other lakes which might possibly contain high concentrations of gas and thus pose a potential hazard. Any information which might help reduce the anxiety felt by people living in the vicinity of such lakes would be of considerable benefit to those areas.

Shortly before leaving Britain, I was asked (by the O.D.A. in response to a request from the Ministry of Mines, Water and Power, Yaounde) to extend my visit so that I could investigate reports of an 'event', at the larger of the Manengouba lakes, which had turned the water brown and killed a large number of fish in January 1992.

Outline programme

My visit to Cameroon was very interesting and most of my main objectives were achieved. I visited the Ministry of Mines, Water and Power in Yaounde, the Ministry's Provincial Office in Bamenda and the Sub-Divisional Office in Wum. I also visited the Manengouba lakes, Lake Bambuluwe and made three visits to Lake Nyos.

I had been advised, by the British Embassy, that the road to the Manengouba lakes was not good and that I would need a 4 wheel drive vehicle, as it turned out this was fortunate advice given the state of the Nyos road. On previous visits the trip from Bamenda to Nyos had taken about four and a half hours but I had been assured that the Bamenda-Wum and Wum-Nyos roads are now in a rather better state than they were in 1986. Sadly this was not the case and they are in fact in a very bad state of repair. In reality it is now about a six hour drive from Bamenda to Nyos and the last 7km takes the best part of an hour - even with a (new) Toyota Runner it was only just possible to get through and in one place we had to stop to rebuild the road each time we wanted to pass! By staying with the Catholic Fathers in Wum and by leaving at first light and returning after dark I managed to achieve most of what I set out to achieve but it was exhausting work.

Conclusions

1. The Lake Nyos dam.

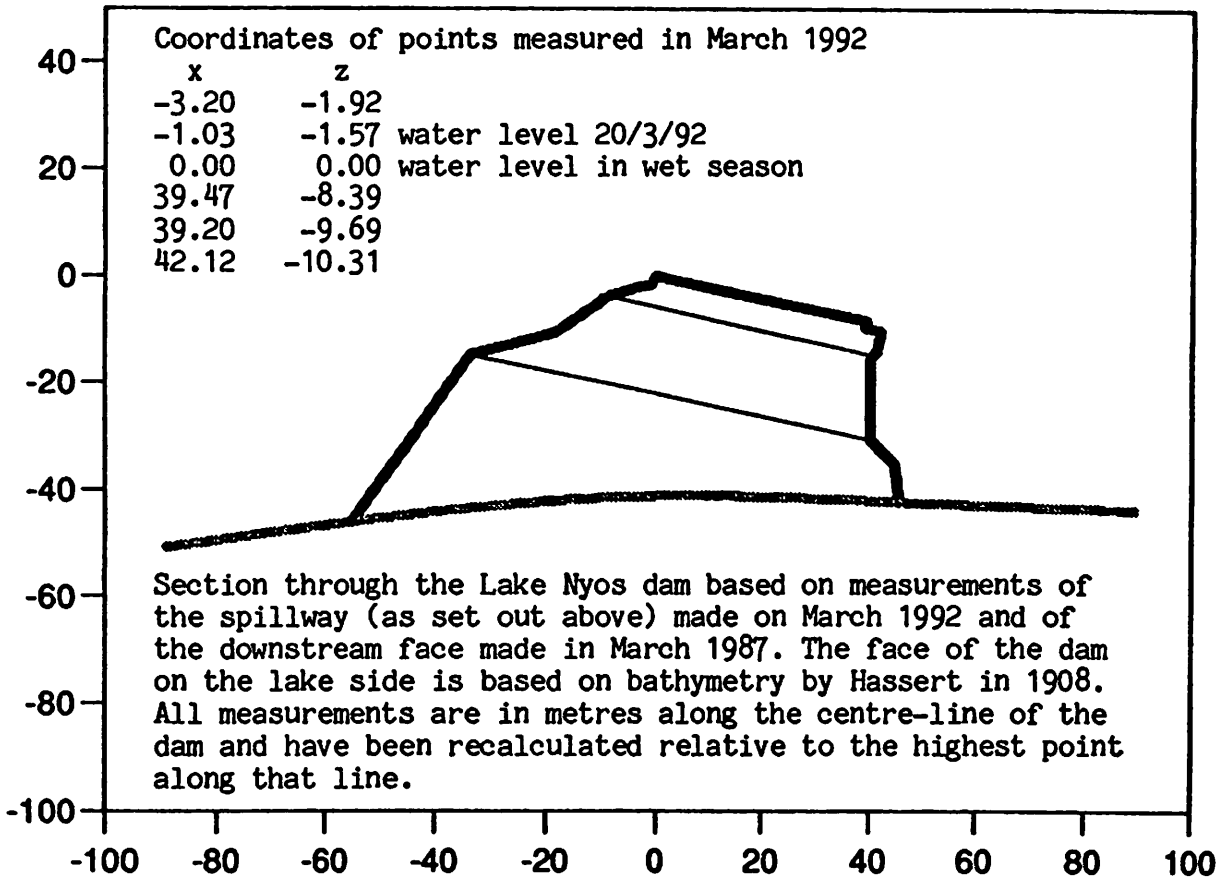
Careful measurements (see figure) suggest that there have been no changes to the Lake Nyos dam since my visit in March 1987 and no detectable change since the first aerial photographs, which were taken in 1958. (Though the accuracy with which the dam can be measured on the aerial photographs does not preclude a small change.) My conclusion is that there is no need for undue concern.

Samples of wood were collected from trees close to the Lake Nyos Dam and the soda spring to the east of the lake to further investigate ^{14}C anomalies in living vegetation in the vicinity of the lake. Samples of sediment were collected from a 2.5 metre section through the delta to the south of Lake Nyos - when processed these samples may give some indication of the rate at which sediments are accumulating in the delta and hence the age of the lake.

Samples of rock for 40-Ar/39-Ar dating were collected from the most recent volcanics in the Lake Nyos area - when processed these should yield information which will help to constrain the age of the lake.

A detailed report on the age and stability of the Lake Nyos dam will be prepared and circulated in due course.

The possibility of setting up gauging stations to measure the rate at which water is flowing through the Lake Nyos dam and through the pyroclastics to the north-east of the lake was investigated. However, access, or rather lack of access, due partly to the deterioration of the Wum-Nyos road and partly to the deterioration of paths in the Lake Nyos area precluded the installation of temporary gauging stations within the time available.



2. The Manengouba lakes.

The Manengouba 'event' of January 1992 was not a warning of problems to come. There is however a serious problem of confidence in this area and I will prepare a full report in which I will suggest that further tests should be undertaken so that we can be quite certain as to exactly what did happen.

2. Lake Bambuluwe

There is no evidence to suggest that Lake Bambuluwe (which is also known as Lake Awing) might contain excess gas - the recent 'event' which was reported to the Ministry by the Divisional Delegate was similar to that at Lake Manengouba and is not cause for alarm. There is, however, a problem of confidence which needs to be addressed. A detailed report on Lake Bambuluwe will be prepared and circulated in due course.

Acknowledgemant

My visit to Cameroon in March 1992 was commissioned and funded by the Overseas Development Administration, Foreign and Commonwealth Office, London. This paper is an edited version of my 'Report' to the O.D.A. which was prepared in May 1992.

ABOUT THE DAM OF LAKE NYOS

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Invited by the Institute for Geological and Mining Research (IRGM), Yaoundé, within the frame of the program 'Campus - remontées magmatiques', I visited Lake Nyos in March 1992 together with M. Ateba of IRGM, O. Leenhardt, and B. Negoum of the Polytechnical Faculty, Yaoundé. The purpose was inspection of the natural dam bounding the lake in the North(-northwest) and exploring possibilities to install a tiltmeter-array inside or close to the dam in order to monitor in-situ microdeformations over a reasonable period of time. The question behind is the controversial debate among colleagues on the dam's present stability and thus on the urgency to take countermeasures against a potential failure (Lockwood et al., 1988; Freeth and Lockwood, 1988; Leenhardt, 1991). A failure could lead to devastating floods and an immense release of carbon dioxide dissolved in the deep waters of the lake.

Monitoring quasi-continuous microdeformation signals as kind of a scientific approach to solve the open questions would constrain and help to clarify

- the mechanical behaviour of the dam in response to the seasonal water level fluctuations of the lake (of order 2m to 3m), i.e. its overall elasticity to the corresponding size of pressure variations;
- the nature of yet unidentified mechanical shocks observed close to the dam by a team from the British Geological Survey using a temporary local seismic network (Walker et al., 1992);
- the existence of a more or less steady weakening or strength corrosion of the dam due to ongoing erosion.

Tiltmeters coupled to the ground in shallow, 3m to 5m deep boreholes appear to be most suitable to monitor such signals. The instruments should have a resolution better than one microradiant and should be self-operating units having automatic data logging, satellite data transmission, and power supply facilities. A two years project could be realized at costs of about 150,000 US$. Roughly one quarter of that amount would be needed for logistics to install the instruments.

All scientists having seen the dam and whom I met during and since that visit agree that the stability of the dam, at present, is uncertain. Consisting of pyroclastic deposits, about 40m high, having a width of 45m in its narrowest, 20m wide part, the 15m wide spillway flooded during the rainy season, exposing well-developed joints and tobel-like holes (marmites), undercaved to at least 10m on its northwestern, 30m deep falling cliff-like side, with water seepage at two or three horizons, and poorly known bathymetry close to the lake side, the dam does certainly not fulfil engineering norms. The strength of the dam is highly dependent on and approximately proportional to the effective pressure (loading pressure minus pore pressure) on any horizon through the dam. Since the material is porous and has non-zero permeability, the pore pressure decays monotonously from the lake side to the cliff side, leaving the effective pressure highest on the latter. Thus, the strongest part of the

dam is where also erosion appears to be strongest. The weakest part is near to the lake where hydrostatic pressure due to the lake water column contributes to high pore pressure, reducing the effective pressure (see Figures 1 and 2 of Appendix).

After discussion with several colleagues it became clear to me that a predominantly scientific approach should not stand alone. The expectations of the people living in the affected area are to forecast or exclude a dam failure from the very beginning of any investigation. This could even not be guaranteed from the results of the proposed tiltmeter campaign, disregarding the pressure to install an effective warning system beforehand. In fact, (geo)engineers should take the leading role in analysing the real threat of the dam.

The problem is known - also to Cameroonian scientists - since the publication of Lockwood et al.'s article in 1988. It is the responsibility of the scientific community not to deny the potential hazard until clarity has been gained. And, it is in the sovereignity and responsibility of the Cameroonian government to seek for a remedy, e.g. by approaching another nation to send a cooperating team of specialists. (The recent sending of a British group of engineers on request from Croatian authorities to inspect and lower the risk of the threatening failure of a bombed reservoir dam in former Jugoslawia may represent a similar case.) The international accord on the ongoing Decade for Natural Disaster Reduction (IDNDR) is a favourable circumstance for any such cooperation.

I would like to thank M.Ateba, G.E.Ekodeck, W.Evans, S.J. Freeth, W. Kessels, G.W.Kling, O.Leenhardt, Father Ten Horn, K.Tietze, H.-G. Wenzel, and W.Zürn for providing written material and/or useful arguments on this matter, the German Ambassador at Yaoundé for his openness and interest in these questions, those responsible for the program 'Campus- remontées magmatiques' for financial support, and in particular my companions M.Ateba and O.Leenhardt for their personal commitment and help during my stay in Cameroon. (Bonn, Febr. 26, 1993)

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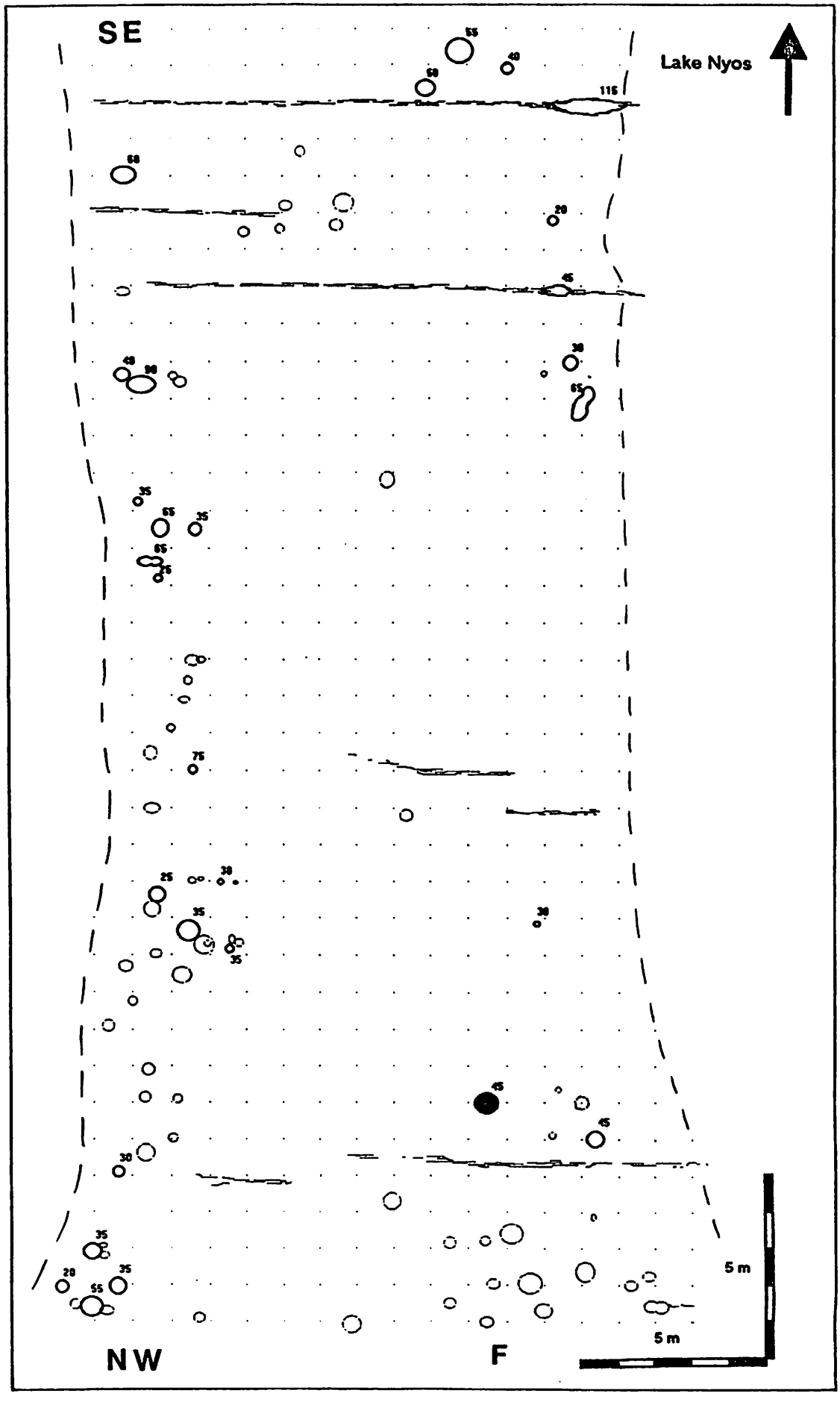
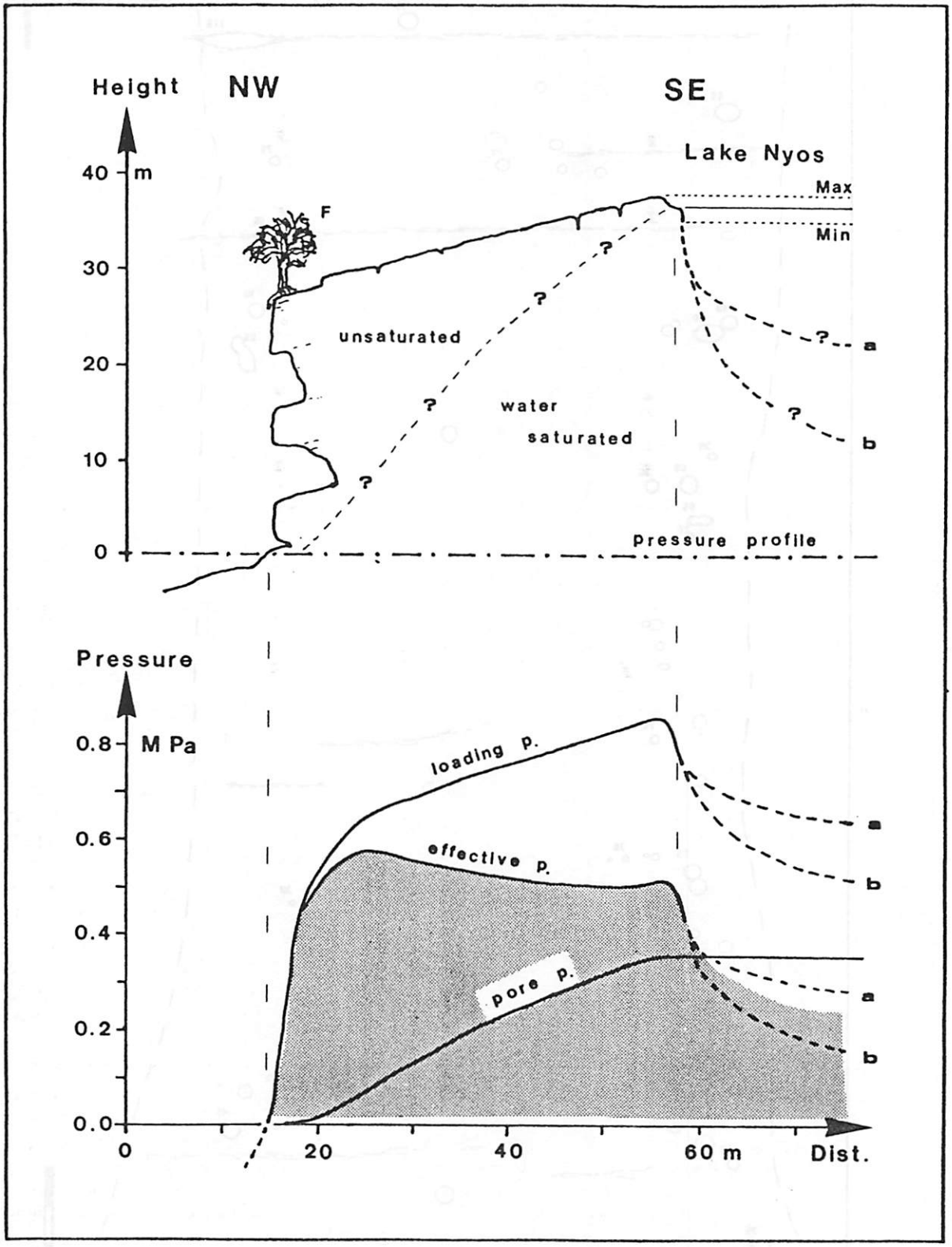


Figure 1.


Height
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Max
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Pressure
0.8
M Pa
0.6
0.4
0.2
0.0
loading p.
effective p.
pore p.
0
20
40
60 m
Dist.

Figure 2.

Fig. 1: Distribution of outstanding tobel-like holes (marmites) and joints on the spillway of the Lake Nyos dam, reconstructed from 55 partly overlapping photographs taken on March 23, 1992, near the end of the dry season. Numbers indicate the measured mean depths of individual holes with regard to the local surface in centimeters. The roughness of the surface of the spillway and the residual sedimentary fillings of the holes (which had partly been removed) did not admit measurements to an accuracy better than 5 cm. Depicted sizes and shapes of the holes are meant to give a rough idea of the true contours. Holes plotted in thin have not been measured and are not always (though mostly) less deep than those outlined in thick. Some holes could have been omitted if hidden from the surface topography of the spillway, attaining values up to about 1m.

A laid out grid of 2m long sticks, clearly visible on the original photographs, served as a reference to locate the holes and joints. Distances should be accurate to better than 10% across the spillway. The 45cm deep hole in black in the lower part was the only one containing water. There was apparently no precipitation during the previous two days. The lake level was at 1.6 m below the upper rim of the spillway, a few meters outside the top of the depicted area. 'F' near the bottom indicates the position of the prominent fig tree on the border of the cliff. During the rainy season, lake water flows from SE to NW over the spillway.

Superimposed on the spillway is a mesh of fine grid points in 1 m spacing. To future visitors, the plot could serve as a reconnaissance tool for continuing erosion of the spillway. Since the photographs have a limited resolution, an additional on-site verification is desirable. I would appreciate if somebody would check its validity in the near future.

Fig. 2: Sketch of the estimated effective pressure (shaded) within the dam along a profile at its base (termed pressure profile in upper part figure). For each point inside the dam, the effective pressure roughly equals the loading pressure (weight) minus pore pressure. For the indicated profile, pore pressure relative to atmospheric pressure decreases from 0.35 MPa (= 3.5 bars, equivalent to the hydrostatic pressure of a 36m water column) on the lake side to zero on the cliff side. The true shape of that decrease is unknown and could be less smooth than drawn in the upper part figure (dashed line separating the unsaturated and water saturated rock).

Assuming an effective porosity of 15% for the pyroclastic material of the dam, a realistic estimate for the bulk density of the water saturated rock is 2.35 g/ccm, and 2.20 g/ccm for the unsaturated rock. These values were taken to construct the loading pressure curve. The uncertainty in the pressure curves on the lake side results from the unknown bathymetry there; two cases, 'a' and 'b' have been considered for comparison. The gross shape of the dam's cross section has been adopted from Fig.3 of Lockwood et al. (1988).

Since rock strength is proportional to effective pressure, the lake side is the weaker part of the dam whereas the cliff side is the more stable part. Erosion and rockfalls at this side could severely destabilize the present situation.

The Main Crater Lake of Taal Volcano (Philippines): Preliminary Chemical Results.

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Taal volcano is an extremely active center in the philippine Archipelago (southwest Luzon) (Neumann van Padang, 1953; Simkin et al., 1981). It is located in a 15 x 20 km wide depression now occupied by a deep fresh water reservoir (Lake Taal formerly called Lake Bombon) (Newhall and Dzurisin, 1988). The bathymetry of this lake shows a maximum depth of 176m and reveals several remnant eruptive centers (Ramos, 1986; in prep.). Taal volcano has five major eruption sites (namely Binintiang Malaki, Binintiang Munti, Balantoc, Main Crater and Mt. Tabaro Eruption Site) where, within historical times, activity shifted from one to another (Newhall and Dzurisin, 1988) (Fig. 1). The principal edifice of the volcano is the Main Crater which has been filled by an acidic lake (1.0 x 1.4 km) at least since the violent eruption of 1911 (Saderra-Maso, 1928). Twelve of Taal Volcano's 33 historic eruptions occured at this crater from 1749 to 1911. Mt. Tabaro Eruption Site was the site of a series of eruptions from 1965 to its last awakening in 1977 (see e.g., Moore et al., 1966; Newhall and Dzurisin, 1988; PHIVOLCS, 1991). Taal volcano is characterized by a phreatomagmatic activity. About one year ago (1992) an increase in the local seismic activity led the authorities to proceed to the evacuation of more than 2600 of the island's 6000 residents. During this event several fissures (up to 400m long) had formed on the volcano's N flank (Smithsonian Institution, 1992a; b).

We visited Taal Main Crater Lake in July and October 91 and again in September 92. Here we describe the preliminary results obtained during these geochemical surveys.

The lake is neither supplied nor drained by any surface stream channel. An active solfatara (crater's N side) delivers low temperature (≈100°C) hydrothermal gases and several hot springs flowing into the lake are also located there. Surface gas bubblings were observed in several parts of the lake (Fig. 1).

In 1992, lake temperature, conductivity and pH recorded along the water column (maximum depth of 80m) indicated almost constant values of about 34°C, 33.3 mS/cm and 2.55 respectively. This suggests the existence within the lake of a powerful convective intermixing. Consequently, the lake displays also chemical homogeneity although slightly more reduced conditions may exist at depth as suggested by Eh, dissolved oxygen, aqueous sulfide and Fe^{2+}/Fe^{3+} values of the waters (Table 1). Compositional data reveal a strong mineralization of lake waters characterized by a very high Na content and, based on the 91 water analysis, by a low SO_4/Cl ratio. The boron content of the lake supports an injection of the lake waters by fumarolic gases.

As shown in Fig. 2, the various chemical species added to the lake are not present in proportion to their concentrations in the wall-rock. The saturation state of the lake was evaluated with SOLVEQ (Reed, 1982) using the 91 water composition. Calculations indicate silica phases as the only saturated minerals. This suggests a cation content of the crateric fluids not simply determinated by an isochemical dissolution of the wall-rock as it is generally the case when lower pH conditions prevail.

Main Crater hot springs (refered as HS1 to HS5 in Table 1) have outlet temperatures ranging from 90°C to 100°C and display near neutral pH values. With the exception of HS5 which could be originated through another process, hot springs chemistry could be explained as a result of a convective recirculation of previously diluted Main Crater lake waters.

Taal Lake was also investigated. It is slightly alkalinized and no significant differences in the chemical composition between a surface and a depth sample were observed. However, compared with the rain water chemistry, the lake is clearly enriched in rock-forming elements and among them sodium shows the major enrichment (Table 1).

The peculiar hydrogeologic situation of Taal volcano makes it quite different from other acidic crater lake such as Kawah Ijen, Kusatsu-Shirane, Poàs or Ruapehu. It is likely that Taal Main Crater Lake is the surface manifestation of a highly complex hydrothermal system in which various physico-chemical processes involving fluids originated from different environments take place. Understanding these processes could help to find out which parameters are suitable to indicate a forthcoming eruption. For instance, during the active periods of 1976 and 1977, the Main Crater Lake showed various changes in its chemistry such as an increase in pH, in dissolved SiO_2, in SO_4 and Cl and a decrease in the ratio of Na/K (Tabirara et al., 1983).

Taal has been recently nominated as a Decade Volcano, prompting the attention to be paid to this hazardous volcano.

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Table 1: Compositional data for Taal Main Crater Lake, Hot Springs, Taal Lake and Rain Water.

Sample	T (°C)	pH	Eh (mV)	SO4 (ppm)	Cl (ppm)	Si (ppm)	Al (ppm)	Fe (ppm)	Fe2+/Fe3+	Mn (ppm)	Mg (ppm)	Ca (ppm)	Na (ppm)	K (ppm)	Ba (ppb)	Sr (ppb)	B (ppm)	O2 (ppm)	H2S (ppm)
7/11/91																			
Om	34.3	2.44	n.a.	2788	10484	149	4.9	43.1	n.a.	38.8	1048	349	5050	740	<100	n.a.	n.a.	n.a.	n.a.
10/7/91																			
Om	33.5	2.36	n.a.	2647	9811	145	5.3	43.3	n.a.	38.2	1037	335	4900	700	<100	n.a.	n.a.	n.a.	n.a.
10m	33.6	2.37	n.a.	3102	10426	146	n.a.	47.0	n.a.	38.5	1040	340	4950	745	<100	n.a.	n.a.	n.a.	n.a.
20m	n.a.	2.37	n.a.	2523	9395	147	4.6	43.9	n.a.	37.3	1035	343	4900	720	<100	n.a.	n.a.	n.a.	n.a.
30m	n.a.	2.37	n.a.	2655	10133	147	4.9	42.2	n.a.	36.8	1031	339	4850	710	<100	n.a.	n.a.	n.a.	n.a.
40m	n.a.	2.37	n.a.	2666	9858	146	4.9	44.7	n.a.	38.3	1036	336	4850	720	<100	n.a.	n.a.	n.a.	n.a.
50m	n.a.	2.38	n.a.	2850	10608	149	5.4	45.6	n.a.	38.5	1035	339	4900	750	<100	n.a.	n.a.	n.a.	n.a.
60m	n.a.	2.34	n.a.	2695	9754	141	5.2	41.4	n.a.	38.3	1020	331	4700	710	<100	n.a.	n.a.	n.a.	n.a.
75m	n.a.	2.38	n.a.	2563	9531	144	6.0	43.7	n.a.	37.7	1019	331	4750	720	<100	n.a.	n.a.	n.a.	n.a.
10/3/92																			
Om	34.9	2.55	512	n.a.	n.a.	136.1	4.50	40.8	0.19	44.6	1018.4	276.5	5115	732	89.2	410.1	38.56	5.20	0.000
40m	34.4	2.58	505	n.a.	n.a.	136.6	4.43	40.3	0.18	45.2	1035.1	280.7	5105	725	n.a.	n.a.	38.18	4.40	0.000
70m	33.9	2.57	495	n.a.	n.a.	136.1	4.47	40.0	0.22	45.1	1042.8	276.8	5325	729	n.a.	n.a.	38.25	4.00	0.005
9/25/92																			
HS1	94.3	5.93	n.a.	n.a.	n.a.	117.0	0.54	19.7	n.a.	20.8	816.7	394.1	4395	621	n.a.	n.a.	35.45	n.a.	n.a.
HS2	100.0	6.16	n.a.	n.a.	n.a.	136.5	0.46	26.3	n.a.	20.8	621.9	280.4	4680	711	n.a.	n.a.	38.98	n.a.	n.a.
HS3	89.8	5.39	n.a.	n.a.	n.a.	120.9	0.42	24.7	n.a.	17.1	546.2	281.7	4435	594	117.8	334.9	31.83	n.a.	n.a.
HS4	90.0	5.72	n.a.	n.a.	n.a.	144.8	0.37	20.6	n.a.	17.2	568.3	237.2	4450	629	n.a.	n.a.	34.98	n.a.	n.a.
HS5	95.0	4.20	n.a.	n.a.	n.a.	128.7	0.27	67.9	n.a.	3.8	61.7	149.5	219.4	75.3	n.a.	n.a.	0.80	n.a.	n.a.
10/5/92																			
Taal Lake	30.1	8.77	n.a.	n.a.	n.a.	3.8	0.15	<0.1	n.a.	<0.1	31.6	31.8	278.4	30.4	n.a.	n.a.	0.83	n.a.	n.a.
7/10/91																			
Rain Water	n.a.	n.a.	n.a.	n.a.	n.a.	1.2	0.02	<0.1	n.a.	<0.1	0.4	4.8	4.5	3.7	n.a.	n.a.	<0.1	n.a.	n.a.

HS1 to 5: Hot Springs in the Main Crater; n.a.: not analyzed; Taal Lake is the fresh lake surrounding Taal Island (water sample from a depth of 85m).

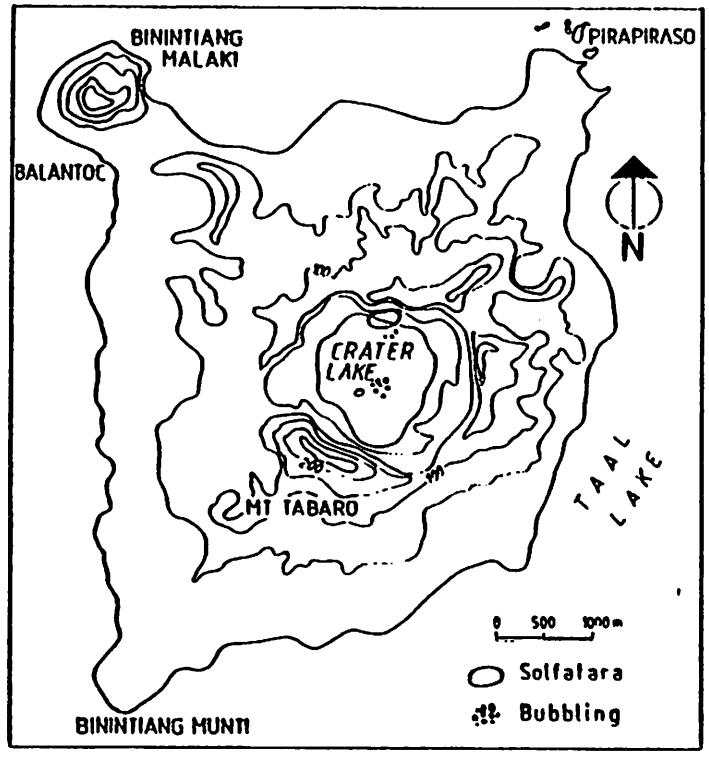

Fig. 1 Map of Taal Volcano Island showing major eruption sites.

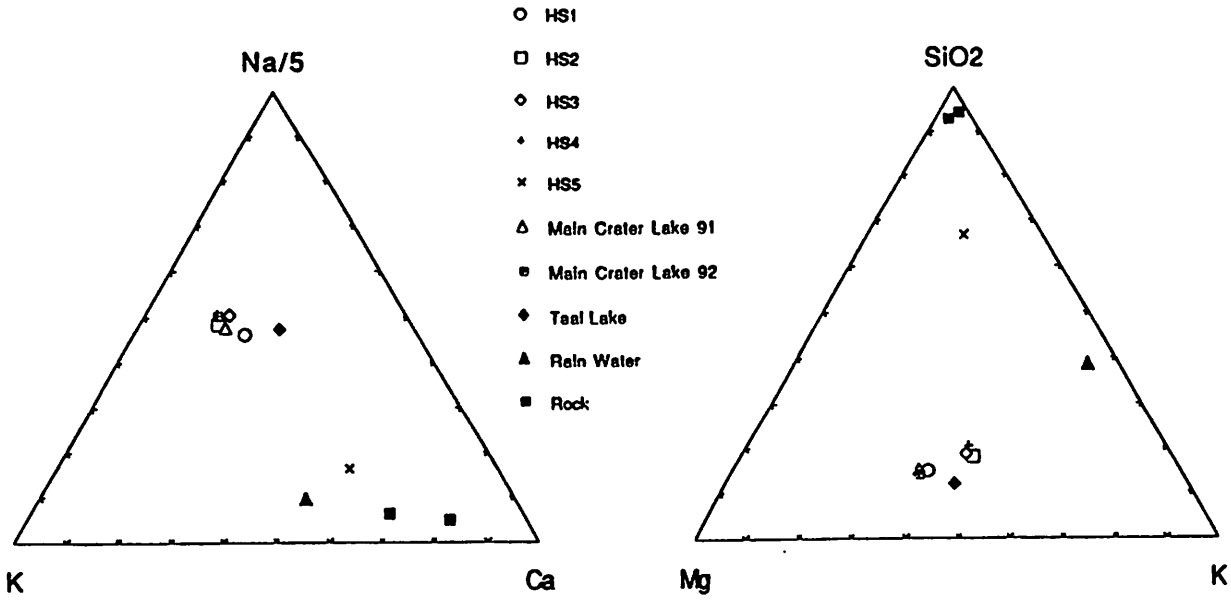

Fig. 2 Relative a) Na, K, Ca- and b) SiO_2, Mg, K-contents in Taal waters and rocks (data from Miklius et al., 1991).

A Call for Contributions to the IWGCL Crater and Caldera Lake Database

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Introduction

At the 2nd Meeting of the IWGCL held in Misasa, Japan last October, one of the stated objectives of the IWGCL was the creation of a multi-faceted database on crater and caldera lakes of the world. As stated in the letter written by by Dr. George Kling and Dr. Minoru Kusakabe to support the the creation of the IAVCEI-IAHS Commission on Crater lakes [June 12, 1992]:

> *"the database would include basic geological and limnological information, and will contain bibliographic references and specific scientific contacts for those interested in collaborative research. Standard geographical information will be included to allow for the future incorporation of the database into a Geographical Information System (GIS). As a repository of scientific information and expertise, the ICCL will also be able to represent its members with a unified voice on various scientific or management issues to governments and international agencies."*

The need for a database was reiterated at the October IWGCL meeting. Through conversations with Dr. Minoru Kusakabe, myself and Joop Varekamp volunteered to begin collecting data for the IWGCL database. Both Joop and I volunteered because we had already begun compiling published and unpublished data concerning crater lakes as part of our research into the crater lake systems of Keli Mutu Islands, and Poas Volcano, Costa Rica, respectively. Our research mainly consisted of compiling a list of known or described crater lakes, and the physical and chemical data associated with each lake.

The main data source utilized in our initial compilation was the Catalog of Active Volcanos of the World (CAVW), Volumes 1-22 published by IAVCEI. These volumes list data for 714 Holocene or younger volcanos. Of these, 619 were considered active at the time of reporting and 68 of these contained one or more crater or caldera lakes. These data have been supplemented by data appearing in the Smithsonian Institution's Bulletin of the Global Volcanism Network (GVN). Preliminary data from these sources have been compiled in Table One (attached at the end of this article). The table currently has information on 89 distinct lakes or groups of crater lakes. Of the 88 distinct crater and caldera lakes included in the table, descriptions in the CAVW or GVN references, or published analyses, indicate that approximately 50% of these lakes contain waters with acidic, sulfur-rich chemistries, and approximately 40% of the lakes have above-ambient temperatures. Approximately 20% of these lakes occupied large basins described as calderas wherease the other 80% occupied small craters. It should be noted here that the CAVW volumes no data on the

volcanic lakes of West Africa (e.g. Lake Nyos); therefore no data on these lakes were incorporated into the preliminary compilation. George Kling and Sam Freeth have published data summaries regarding the West African Lakes and these will be incorporated into the final IWGCL database. As this is a preliminary listing we are sure that some existing crater or caldera lakes have been missed. Also, data for lakes with no recent reports must be regarded as being somewhat suspect.

Elements of the Database

The proposed database will contain:

1) **Location data**: Latitude-longitude, country, state, region, and local identifiers
2) **Climate data**: Temperature, rainfall, humidity, evaporation, long-term averages for these parameters from stations on or near the crater lake.
3) **Lake physical data**: Elevation, surface area, depth, volume, dimensions, bathymetric data, temperature-density profiles, lake level data
4) **Lake chemical data**: pH, Eh, conductivity, dissolved gas concentrations, major, minor, and trace element concentrations, depth profiles of selected properties.
5) **Lake isotopic data**: Stable isotopes of O, H, S, N, C, for dissolved gases and aqueous species. Radiogenic isotopes (e.g. tritium, helium, strontium)
6) **Geologic data**: Geologic data pertaining to the regional or site-specific geologic setting of the crater, caldera, or rift lake. Would also include data pertaining to lake sediments.
7) **Current status**: Data pertaining to the current status of the lake with respect to ongoing passive or active volcanic activity. Data pertaining to current or ongoing monitoring efforts related to physical or chemical characteristics of the lake.
8) **References**: List of all known references containing physical, limnological, chemical, or hydrologic data pertaining to the lake.
9) **Research Contacts**: List of people conducting active research or monitoring of crater and caldera lakes and all persons providing data to the IWGCL database.

Use and Availability of the Database

Joop and I have decided that for now, the bulk of the location, climate, physical and chemical data will be stored in a computer spreadsheet loaded on a personal computer. Such spreadsheets store data in a column and row format and can easily generate ASCII-format files for data transfer purposes. However, some forms of data are not amenable to storage in a spreadsheet (e.g. references) and will be stored in another format. Suggestions and input regarding the final format of the database are welcome (see Solicitations for Comments, Suggestions and Data Contributions below). Access to the database will be provided to all interested parties. However, to encourage contributions of unpublished or just-collected data we will require that users of the database contact the source of any and all unpublished data and obtain written permission from the source before incorporating the data into any official publication. Basic information pertaining to the database and updates on specific lakes will be published in future issues of the IWGCL Newsletter. An IWGCL Database Bibliography will also be created; an updated version of this bibliography will be published in the next IWGCL newsletter. One of the goals of the data collection effort would be publication of a catalog of crater lakes of the world. Following compilation of all submitted data, such a catalog would be created and distributed.

Solicitation for Comments, Suggestions, and Data Contributions to the IWGCL Crater Lake Database from IWGCL Members

This solicitation is being made to all IWGCL members, hence its inclusion in the IWGCL Newsletter. As a means of assessing potential data sources among our membership, we are attaching a short questionnaire and checklist (see next page) which we encourage IWGCL members to fill out and return to either Gary Rowe or Joop Varekamp. You are highly encouraged to submit actual data when you return the checklist.

Table One contains the names, locations, latitude, and some basic data concerning crater lakes that have been entered into the current database. If you have data or information concerning any of these lakes we would appreciate your contributions. We are particularly interested in obtaining data for those lakes that have limited or little information. In addition, although we have collected many of the published references regarding crater lakes, it is unlikely that we have collected them all. Thus if you send information regarding a particular lake or region, we would greatly appreciate it if you could send a complete reference list that contains all the pertinent references regarding the lake's, physical, chemical, or limnologic characteristics. If the references are obscure or of limited access, sending copies of the references would be highly appreciated.

The database is being constructed for use by all IWGCL member and its purpose is to facilitate information and data transfer among all IWGCL members as well as all scientists, government and international agency personnel involved in examining crater lake systems. Joop and I encourage IWGCL members to please make any and all suggestions they feel worthwhile regarding the database format and structure. Concerns regarding database elements should also be addressed. One area that has not been included as a data element, is biological information. Those IWGCL members who have experience in the biologic and biogeochemical aspects of crater lakes are encouraged to submit suggestions regarding what biologic data should be included in the database. Finally, as pointed out by Sam Freeth, there should be some debate on what type of lakes should be included in the IWGCL database. At this point, Joop and I favor inclusion of all lakes that have any relation to past or present volcanic activity. Questions concerning what represents a true crater or caldera lake should be addressed by interested members.

This is your database and we encourage you to help in its creation and maintenence. We envision providing an update to Table One in the next IWGCL newsletter and if feasible, also publish a first edition of the IWGCL Crater Lake Database Bibliography in the next newsletter.

Again, please return the questionnaire and checklist to either Gary Rowe or Joop Varekamp at the addresses listed at the beginning of this contribution.

IWGCL Crater Lake Database Questionnaire and Checklist

Name of Contributor: _____

Address of Contributor (include fax, phone, or E-mail address):

_____

_____

_____

Name of Lake(s): _____

_____

_____

Type of Data You Can or Will Contribute
[Place Check Mark Next to Appropriate Category]

Updated Location Data----------_____

Regional Climate Data: Air Temperature _____ Relative Humidity Rainfall _____

Average Wind Speed on Lake _____ Long Term Climate Data for Lake or Region _____

Lake Physical Data: Surface Area _____ Depth _____ Bathymetric Data _____ Volume ___

Temperature _____ Density _____ Profile data _____ Lake Elevation _____

Lake Chemical Data: General water quality indicators (pH, Eh, Conductivity, Alkalinity) _____

Major cation and anion concentrations _____ Minor and Trace element concentrations _____

Depth Profiles _____ Long-term monitoring data of selected parameters _____

Dissolved gas chemistry _____ Particulate or lake sediment chemistry _____

Lake Isotopic Data: Stable isotopes H _____ O _____ C _____ S _____ N _____ B _____

Water ____Solid phase _____ Radiogenic isotopes _____ Dissolved gas isotopes _____

Geologic Data: General geology of region _____ volcano _____ caldera _____

Geologic maps of region and/or lake site _____Topographic maps of region or lake site _____

Current Status: Descriptions of activity in the lake with respect to degassing status, volcanic or eruptive activity, current geochemical or geophysical monitoring efforts _____

References: A list of available references concerning the lake or lakes you possess data for. This is a minimum and highly critical requirement for all persons submitting data to the IWGCL database. Copies of obscure or local data sources and reference materials would be highly appreciated.

Table One-Preliminary Data Compilation of Crater and Caldera Lakes of the World for the IWGCL Database

[NR = No data reported. Primary Data Source = IAVCEI Catalog of Active Volcanos of the World, Vols. 1-22, 1951-1971. Additional data taken from recent reports supplied by the Bulletin of the Global Volcanism Network. A question mark (?) after a temperature or lake chemistry entry means entry was inferred from descriptive material given in the CAVW or GVN reports. Volume estimates are made using the volume formula for a cone using given depth and surface area data.]

Lake, Crater or Volcano Name	Geographic Location	Lat (both in degrees)	Long	Lake Elev (m)	Surface Area (m^2)	Depth (m)	Volume est. (m^3)	Temp (°C)	Lake Chemistry	Current Status of Lake	Analyses Available?
Sorikmarapi	Sumatra, Indonesia	0.69 N	99.54 E	1996	3.0×10^4	150	1.5×10^6	NR	Acid, Sulfur	Weak solfataric activity	No
Sorikmarapi	"	"	"	2068	1.7×10^3	50	2.8×10^4	NR	NR	reported for the volcano	No
Mt. Tandikat	Sumatra, Indonesia	0.43 S	100.32 E	2265	4.2×10^3	40	7.0×10^4	NR	NR	No recent reports.	No
Kerintji	Sumatra, Indonesia	1.69 S	101.16 E	3360	4.9×10^4	200	3.2×10^6	Warm	Acid, sulfur	Weak solfataric activity. Lake	No
										disappeared and reformed in	No
										1930's. No recent reports.	
Bukit Dahn	Sumatra, Indonesia	3.38 S	102.37 E	2363	6.5×10^4	150	3.3×10^6	NR	Acidic?	No recent reports.	No
Kaba (Lama Crater)	Sumatra, Indonesia	3.52 S	102.62 E	1717	1.8×10^4	NR	NR	NR	NR	No recent reports. One lake	No
Kaba (Baru Crater)	"	"	"	1683	1.0×10^4	NR	NR	NR	NR	was reported to have above	No
Kaba (SW Explosian Pit)	"	"	"	1680	1.5×10^3	NR	NR	NR	NR	ambient temperatures (34-45°)	No
Kaba (Vogelsang Crater)	"	"	"	1627	6.0×10^2	NR	NR	Warm	NR	in the 1970's.	No
Dempo	Sumatra, Indonesia	4.03 S	103.13 E	2804	1.1×10^5	NR	NR	Warm?	Acidic?	No recent reports. Phreatic activity in lake reported in past.	No
Telaga Bodas	Sumatra, Indonesia	7.21 S	108.07	1720	1.6×10^5	NR	NR	54-87	Acid, sulfur	Temperature data from 1913. No recent report.	No
Mt. Kelut (Kelud)	Java, Indonesia	7.93 S	112.31 E	1133	2.4×10^5	15	1.8×10^6	Warm	Acid	Last eruption in February 1990 Geochemial and geophysical monitoring. Recent samples.	Yes
Kawah Ijen	Java, Indonesia	8.06 S	114.24E	2148	4.1×10^5	200	3.6×10^7	27-42	Acid, sulfur	Solfataric activity. Recent lake and gas samples.	Yes
Wai Sano (Caldera)	Flores, Indonesia	8.68 S	102.03 E	643	3.9×10^6	NR	NR	NR	Alkaline?	Receives thermal spring inputs. No recent reports.	No
Keli Mutu (Crater 1)	Flores, Indonesia	8.76 S	121.83 E	1400	7.6×10^4	67	1.7×10^6	20-30	Acid, Sulfur	Recently sampled.	Yes
Keli Mutu (Crater 2)	"	"	"	1420	1.3×10^5	127	5.5×10^6	20-35	Acid, Sulfur	Recently sampled.	Yes
Keli Mutu (Crater 3)	"	"	"	1420	1.1×10^5	64	2.3×10^6	20-30	Acid, Sulfur	Recently sampled.	Yes
Egon	Lesser Sunda Islands Indonesia	8.67 S	122.45 E	~1500	9.0×10^4	NR	NR	NR	Acidic?	No recent report. Yellow-green lake occupies pit crater.	No
Sirung	Lesser Sunda Islands Indonesia	8.51 S	124.15 E	410	2.1×10^5	NR	NR	40	Acid, Sulfur	Lake sampled in 1984. No recent reports. Solfataric activity and boiling springs.	Yes
Sempu	Lesser Sunda Islands Indonesia	1.14 N	124.73 E	1345	2.0×10^4	NR	NR	NR	Acid, Sulfur	Weak solfataric activity. Reported to occupy a maar.	No
Tampusu	Sulawesi, Indonesia	1.25 N	124.82 E	1125	4.0×10^4	25	1.0×10^6	NR	NR	No recent reports.	No
Klabat	Sulawesi, Indonesia	1.47 N	125.03 E	1950	5.3×10^3	20	3.5×10^4	NR	NR	No recent reports.	No
Api Sau (Crater IV)	Sangihe Island Indonesia	2.78 N	125.48 E	1530	2.5×10^3	NR	NR	NR	Acid, Sulfur	Boiling lake in pit crater reported in 1921. Volcano actively erupting since 1983.	No
Awu	Sangihe Island	3.67 N	125.50 E	925	NR	NR	6.0×10^5	31-36	Acid, Sulfur?	Temperature, pH taken in 1991	No
Gamkonora (Crater D)	Halmahera, Indonesia	1.38 N	127.52 E	1363	1.2×10^4	NR	NR	NR	NR	No recent reports. Lake reported to be ephemeral.	No
Todoko (Caldera)	Halmahera, Indonesia	1.30 N	127.43 E	549	1.1×10^6	NR	NR	NR	Acidic?	No recent reports. Fumarolic and solfataric activity reported by the CAVW in 1930's.	No

Table One-Preliminary Data Compilation of Crater and Caldera Lakes of the World for the IWGCL Database-Continued

Lake, Crater or Volcano Name	Geographic Location	Lat (both in degrees)	Long	Lake Elev (m)	Surface Area (m^2)	Depth (m)	Volume est. (m^3)	Temp (°C)	Lake Chemistry	Current Status of Lake	Analyses Available?
Cabalian	Phillipines	10.28 N	125.13 E	NR	NR	NR	NR	NR	NR	No current reports.	No
Taal	Phillipines	14.00 N	121.00 E	~305	NR	NR	NR	Warm	Acid, Sulfur	Occupies pit crater on island in center of Lake Taal. Recent water samples.	Yes
Pinatubo	Phillipines	15.14 N	120.35 E	~800	NR	NR	NR	NR	pH=6	Water samples collected from the lake after 1991 eruption.	Yes
Long Island	New Guinea	5.36 S	147.12 E	150	9.0×10^7	NR	NR	NR	Freshwater?	Caldera lake with parasitic cone. No recent reports.	No
Sakar	New Guinea	5.41 S	148.09 E	660	2.5×10^5	NR	NR	NR	NR	No recent reports.	No
Benda (Caldera)	New Guinea	5.06 S	150.11 E	73	5.1×10^7	NR	NR	NR	NR	No recent reports.	No
Gaua	Vanatu Islands	14.25 S	167.50 E	350	1.6×10^7	100	5.2×10^8	NR	NR	No recent reports. Lake temp above ambient in 1930's	No
Aoba	Vanatu Islands	15.33 S	167.83 E	1260	NR	NR	NR	Hot	NR	Lake reported to be boiling in July 1991.	No
El Chichon	Mexico	17.33 N	93.20 W	840	1.4×10^5	NR	NR	52-56	Acid, Sulfur	Water and gas samples recently collected.	Yes
Colima	Mexico	19.51 N	103.61W	NR	NR	NR	NR	NR	NR	Small ephemeral lake reported at summit area.	Yes
Santa Ana	El Salvador	13.85 N	89.63 W	NR	1.3×10^5	NR	NR	Warm	Acid? Sulfur?	Yellow-green lake occupies base of active crater.	No
Lake Ilopango	El Salvador	13.67 N	89.05 W	438	7.0×10^7	248	5.0×10^9	NR	Freshwater?	Large lake occupying graben. Silicic dome in center of lake. No recent reports.	No
Tecapa	El Salvador	13.50 N	88.51 W	NR	NR	NR	NR	Warm	Acid? Sulfur	Solfataric activity around lake and sulfur-rich muds reported by CAVW. No recent reports.	No
Coseguina	Nicaragua	12.98 N	87.57 W	~350	1.0×10^6	NR	NR	NR	Freshwater?	No recent reports.	No
Rincon de la Vieja	Costa Rica	10.83 N	85.33 W	1520	5.0×10^4	NR	NR	38	Acid, Sulfur	Lake water sampled in 1989. Phreatic eruptions through lake in 1991 have caused small lahars.	No
Poas (Active Crater)	Costa Rica	10.20 N	84.22 W	2250	6.7×10^4	60	1.3×10^6	38-94	Acid, Sulfur	Lake has dried up and reformed each March-April since 1989.	Yes
Poas (Botos Cone)	"	"	"	2550				NR	Freshwater	Water samples collected in 1989	Yes
Irazu	Costa Rica	9.98 N	83.85W	NR	3.1×10^4	15	1.6×10^5	25-30	Acid	Ephemeral lake. Reformed in 1991. Recent samples collected.	Yes
Golovnin Caldera	Kunashir Island Kurile Islands	43.82 N	145.52 E	130	2.6×10^6	62	5.4×10^7	Warm	Freshwater?	Solfataric and fumarolic activity reported on N shore by CAVW	Yes
Golovnin Caldera	"	"	"	~200	4.0×10^4	22	2.9×10^5	36-55	Acid, Sulfur	Hot crater lake located in eastern dome. No recent reports.	Yes
Zavaritzky Caldera	Simushir Island Kurile Islands	46.93 N	151.95 E	NR	2.6×10^6	NR	NR	NR	Acid?	Caldera lake intruded by dome. No recent reports.	No
Zavaritzky Caldera	"	"	"	NR	1.2×10^5	NR	NR	NR	NR	No recent reports	No
Pallas Peak	Ketoi Island Kurile Islands	47.35 N	152.48 E	300	1.1×10^6	NR	NR	Warm	Acid?	No recent reports.	No
Pallas Peak	"	"	"	NR	7.0×10^4	NR	NR	NR	NR	Small lake occupying crater on west dome. No recent reports.	No
Kuntomintar	Shiashktan Island Kurile Islands	48.76 N	154.02 E	NR	NR	NR	NR	NR	Freshwater?	Caldera lake. No recent reports.	No

Table One-Preliminary Data Compilation of Crater and Caldera Lakes of the World for the IWGCL Database-Continued

Lake, Crater or Volcano Name	Geographic Location	Lat (both in degrees)	Long	Lake Elev (m)	Surface Area (m^2)	Depth (m)	Volume est. (m^3)	Temp (°C)	Lake Chemistry	Current Status of Lake	Analyses Available?
Krenitzyn Peak	Onekotan Island Kurile Islands	49.36 N	154.71 E	~900	1.7×10^7	NR	NR	NR	Acid?	Dome intruded into caldera lake in 1952. No recent reports.	No
Ebeko	Paramushir Islands Kurile Islands	50.67 N	155.93 E	~1000	3.0×10^4	20	2.0×10^5	30-62	Acid, Sulfur	Phreatic eruptions from lake in 1930's. No recent report.	Yes
Ksudach (Stubel)	Kamchatka Penisula	51.83 N	157.52 E	415	2.5×10^6	84	7.0×10^7	NR	Freshwater	Recently sampled. Receives hydrothermal inputs.	Yes
Ksudach (Klyuchoe)	"	"	"	417	5.4×10^6	96	1.7×10^8	NR	Freshwater	Recently sampled.	Yes
Mutnovsky	Kamchatka Penisula	52.35 N	158.27 E	NR	7.5×10^3	NR	NR	Warm	Acid? Sulfur?	CAVW reports indicate warm sulfur-rich lake in pit crater. No recent reports.	No
Mutnovsky	"	"	"	NR	7.0×10^4	NR	NR	Warm	Acid? Sulfur?	CAVW reports indicate warm sulfur-rich lake in pit crater. No recent reports.	No
Maly Semiachik	Kamchatka Penisula	54.12 N	159.88 E	~1400	7.5×10^5	NR	NR	Warm	Acid, Sulfur	Recently sampled.	Yes
Uzon Caldera	Kamchatka Penisula	54.53 N	160.08 E	700	NR	NR	NR	Warm	Acid, Sulfur to Alkaline	Many lakes of various sizes and chemistries present due to caldera hydrothermal activity. Recent samples of lake water and sediments collected.	Yes
Yugama Lake	Kusatsu-Shirane Volcano, Honshu Island, Japan	36.32 N	138.50 E	~2100	5.0×10^4	27	4.5×10^5	0-34	Acid, Sulfur	Extensively monitored. Water samples collected regularly.	Yes
Karagamal Lake	"	"	"	~2100	1.5×10^4	NR	NR	NR	Freshwater?	Occupies small pit crater. No recent reports.	No
Mizugama Lake	"	"	"	~2100	1.9×10^4	NR	NR	NR	Freshwater?	No recent reports	No
Zao (Okama or Gosikinuma Lake)	Honshu Island Japan	38.15 N	140.45 E	~1670	1.0×10^5	63	2.1×10^6	Warm	Acid? Sulfur?	CAVW reports phreatic activity through lake. No recent reports.	No
Narugo	Honshu Island Japan	38.73 N	140.73 E	~300	1.2×10^5	NR	NR	Warm	Acid?	CAVW reports lake with associated solfataric activity. No recent reports.	No
Tyokai (Torino-umi)	Honshu Island Japan	39.08 N	140.03 E	~1600	7.0×10^4	NR	NR	NR	Freshwater?	Lake occupies small pit crater. No recent reports.	No
Iwate (Onasiroko Lake)	Honshu Island Japan	39.85 N	141.00 E	2040	3.5×10^4	6	7.0×10^4	NR	NR	CAVW reports solfataric activity in and around lake.	No
Iwate (Okama Lake)	"	"	"	"	2.0×10^3	14	9.0×10^3	NR	NR	No recent reports.	No
Osore-Yama	Honshu Island Japan	41.32 N	141.08 E	~250	2.3×10^6	15	1.2×10^7	Warm	Acid?	CAVW reports thermal inputs into the lake. No recent reports.	No
Aso (Crater 1 of Nakadake Cone)	Kyushu, Japan	32.88 N	131.10 E	NR	NR	NR	NR	20-78	Acid?	Recent eruptions through lake starting December 1990.	No
Anatahan	Mariana Islands	16.35 N	145.67 E	NR	NR	NR	NR	NR	NR	Recent survey of Island	No
Raoul Island (Blue)	Kermadec Islands	29.27 N	177.92 W	122	4.8×10^5	NR	NR	NR	Freshwater?	No recent reports	No
Raoul Island (Green)	"	"	"	122	1.6×10^5	NR	NR	NR	Acid?	Eruption through this lake in 1872. No recent reports.	No
Niuafo'ou (Big lake)	Tonga Islands	15.60 S	175.63 W	~25	1.4×10^7	84	3.8×10^8	NR	Brackish	Caldera lake. No recent reports.	No
Niuafo'ou (Small Lake)	"	"	"	NR	7.5×10^5	NR	NR	NR	NR	No recent reports.	No
Fernandina	Galapagos Island	0.37 S	91.55 W	~500	1.9×10^6	NR	NR	NR	Alkaline	Sampled after 1968 caldera-forming eruptions. Eruptions and avalanches destroyed lake in 1988-90.	Yes

Table One-Preliminary Data Compilation of Crater and Caldera Lakes of the World for the IWGCL Database-Continued

Lake, Crater or Volcano Name	Geographic Location	Lat Long (both in degrees)	Lake Elev (m)	Surface Area (m^2)	Depth (m)	Volume est. (m^3)	Temp (°C)	Lake Chemistry	Current Status of Lake	Analyses Available?
Los Copahues	Chile	37.85 S 71.17 W	~2800	7.1×10^4	>40	$>9.4 \times 10^5$	Warm	Acid, Sulfur	Eruptions through lake in July 1992 ejected sulfur-rich lapilli.	Yes
Nilahue	Chile	40.35 S 72.07 W	NR	NR	NR	NR	NR	NR	Lake filling eruption crater of 1955 eruption. No recent reports.	No
Nemrut Dagi	Turkey	38.65 N 42.02 E	~2400	1.0×10^7	NR	NR	NR	Freshwater	Caldera lake. No recent reports.	No
Nevado del Ruiz	Columbia	4.88 N 75.37 W	~5300	NR	NR	NR	Hot	Acid, Sulfur	Ephemeral lake formed from meltwater prior to 1985 eruption. Lake gone since eruption.	No
Galeras	Columbia	1.22 N 77.30 W	~4100	NR	NR	NR	Hot	Acid, Sulfur	Ephemeral lake most recently observed in 1988. Has dried up in wake of increased activity.	Yes
Azufal de Tuquerres	Columbia	1.08 N 77.73 W	3795	NR	NR	NR	Hot	Acid? Sulfur?	CAVW reports hot lake emitting CO_2 and H_2S. No recent reports.	No
Cotacachi (Lake Cuicachi)	Ecuador	0.31 N 78.36 W	3064	3.1×10^6	180	1.9×10^8	16-18	Alkaline	Caldera lake receiving minor hydrothermal inputs. Recent sample collected at depth.	Yes
Quilotoa	Ecuador	0.86 N 77.92 W	3250	3.1×10^6	>360	$>3.8 \times 10^8$	13-23	Alkaline	Highly mineralized caldera lake receiving low-T CO_2 gas inputs. Recent samples.	Yes
Sourfriere St. Vincent	West Indies	13.33 N 61.18 W	~750	1.5×10^6	180	7.5×10^7	25-99	Alkaline	Intruded by dome in 1971-72. Ejected by 1979 eruption. No recent reports.	Yes
Sete Cidades (Blue Lake)	San Miguel Island Azores	37.87 N 25.78 W	~270	3.0×10^6	NR	NR	NR	Freshwater?	Caldera lake. No recent reports.	No
Sete Cidades (Green Lake)	San Miguel Island Azores	" "	~270	6.1×10^5	NR	NR	NR	Freshwater?	Caldera lake. No recent reports.	No
Agua de Pau	San Miguel Island Azores	" "	~750	1.5×10^6	NR	NR	NR	Freshwater?	Caldera lake with several reported historic eruptions. No recent reports.	No
Furnas	San Miguel Island Azores	" "	~250	1.8×10^6	NR	NR	NR	Freshwater?	Lake in western caldera. Low T fumarolic activity on eastern shore. No recent reports.	No
Mt. Ruapehu	New Zealand	39.28 S 175.57 E	2566	2.1×10^5	~140	9.0×10^6	0-60	Acid, Sulfur	Extensively monitored. Recent water and gas samples collected.	Yes
Grimsvotn	Iceland	64.42 N 17.33 W	1340	2.5×10^7	>350	$>3.0 \times 10^9$	0-4	Alkaline	Large subglacial caldera lake covered by 200 m thick ice sheet. Lake temperature and water chemistry profiles done in 1990.	Yes

Note: Data regarding West African rift lakes is reported in: Kling et al., 1991, A comparative view of Lakes Nyos and Mounoun, Cameroon, West Africa, Verh. Internat., Verein. Limnol., v. 24, 1102-1105; and Freeth, S.J., 1992, Potentially hazardous lakes in West Africa, in: Freeth et al., Natural Hazards in West and Central Africa, Vieweg, Germany.

CALENDAR OF FUTURE EVENTS

August 29 - September 3, 1993. 5th. International Conference on Natural and Man-made Hazards, Quindgao, China.
For further information write to: Mohammed I. El-Sabh, Centre Oceanographique de Rimouski, Allee des Ursulines 310, Rimouski, Quebec G5L 3A1, Canada.

September 25 - October 1, 1993. IAVCEI General Assembly: Ancient Volcanism and Modern Analogues, Canberra, Australia.
For further information write to: Secretariat: IAVCEI ACTS, GPO Box 2200, Canberra ACT 2601, Australia.

November 15-17, 1993. 1st. International Workshop on Environmental Geology, Morelia, Michaocan, Mexico.
Abstract deadline 31 July 1993.
For further information write to: Departamento de Geologia y Mineralogia, Instituto de Investigaciones Metalurgicas, Universidad Michoacana de S. Nicolas de Hidalgo, Edificio Q, Cuidad Universitaria, Morelia, Michaocan, Mexico (Fax 52-451-67436)

September 12-16, 1984. International Volcanological Congress - IAVCEI, Ankara, Turkey.
For further information write to: Dr. Ayala Tankut, Organizing Secretary, International Volcanological Congress, Department of Geological Engineering, Middle East Technical University, 06531-Ankara, Turkey. (Fax 90-4-286-86-28)

[October] 1994. 3rd. Meeting of the International Working Group on Crater Lakes, [Crater Lake, Oregon] U.S.A.
Further information [including confirmation of the date and venue] will be circulated in due course by the organiser: Dr.J.C.Varekamp, Department of Earth and Environmental Sciences, Wesleyan University, Middletown, Connecticut 06459-0139, U.S.A.

This is a selection of future events some of which will, I hope, be of interest to I.W.G.C.L. members. For future Newsletters I would encourage members to send me information on meetings which they think might be of interest to other members. - ed.

List of 'Members'

Prof.B.N.Akpati, Nigerian Institute of Oceanography, Lagos, Nigeria.
Dr.P.Allard, Centre des Faibles Radioactivites, Gif-sur-Yvette, France.
Prof.S.Aramaki, Hokkaido University, Sapporo, Japan.
Dr.M.Badrudin, Merapi Volcano Observatory, Yogyakata, Indonesia.
Dr.P.J.Baxter, University of Cambridge, United Kingdom.
Dr.A.Bernard, Universite Libre de Bruxelles, Belgium.
Dr.S.L.Brantley, Pennsylvania State University, U.S.A.
Dr.T.Casadevall, United States Geological Survey, Denver, U.S.A.
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Dr.B.W.Christenson, Wairakei Research Centre, Taupo, New Zealand.
Mr.P.Delmelle, Universite Libre de Bruxelles, Belgium.
Dr.V.J.Dietrich, Eidgenossische Technische Hochschule, Zurich, Switzerland
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Dr.S.M.Fazlullin, Institute of Volcanology, Petropavlovsk, Russia.
Mr.J.N.Fonji, Ministry of Mines, Water and Power, Yaounde, Cameroon.
Dr.S.J.Freeth, University College of Swansea, United Kingdom.
Dr.W.F.Giggenbach, Inst. of Geological Sciences, Lower Hutt, New Zealand.
Dr.R.B.Glover, Institute of Geological Sciences, Taupo, New Zealand.
Dr.M.Halbwachs, Universite de Savoie, Chambery, France.
Dr.M.L.Hall, Instituto Geofisico, Escuela Politecn. Nacl., Quito, Ecuador.
Dr.J.Hirabayashi, Kusatsu-Shirane Volcano Observatory, Tokyo, Japan.
Dr.A.W.Hurst, D.S.I.R., Geology and Geophysics, Wellington, New Zealand.
Dr.S.Kanari, Hokkaido University, Sapporo, Japan.
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Dr.G.W.Kling, University of Michigan, Ann Arbor, U.S.A.
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Prof.O.Leenhardt, Maurecort, France.
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Dr.J.C.Varekamp, Wesleyan University, Middletown, U.S.A.
Dr.S.N.Williams, Arizona State University, Tempe, U.S.A.

M. K.

International Working Group on Crater Lakes

NEWSLETTER no.7

March 1994

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(The IWGCL is a Commission of the International Association of Volcanology and Chemistry of the Earth's Interior)

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Editorial

I am very pleased to be able to draw attention to the report by Minoru Kusakabe (on page 2) concerning the successful conclusion of negotiations for our Group to become a Commission of the International Association of Volcanology and Chemistry of the Earth's Interior. We all owe a debt of gratitude to our Secretary for representing our Group at the meeting in Canberra and for preparing the successful submission for Commission status.

In his report Minoru draws attention to the suggestion, by the IAVCEI Secretary General, that it might be appropriate if we were to add the word 'volcanic' to the name of our Commission. Could I agree with the general principle and also ask members that they consider the name not only in abstract but also in practice, for example as a name on future issues of this Newsletter. A quick check through previous issues of this Newsletter will reveal that the vast majority of articles are concerned with 'Volcanic Crater Lakes' some of which may also be Calderas and some of which may be Gas-rich, though not necessarily so.

At the meeting of our Group in Misasa (October 1992) we were pleased to accept an offer from Joop Varekamp to organise our next meeting in America. There was general discussion around a provisional date of October 1994 with Crater Lake, Oregon as a possible venue. At the meeting in Misasa we also accepted an offer from Sergei Fazlullin to organise our 4th meeting in Kamchatka alongside the "8th International Symposium on Water-Rock Interaction" in August 1995. Unfortunately we did not know, when we discussed provisional dates for these meetings, that access to Crater Lake was closed (due to snow) from September through to the following May. To bring the date of our next meeting forward would have presented problems for the organisers in obtaining funding, to push it back to early Spring would have clashed with a period of 'study leave' scheduled by the organiser and to push it back to September 1995 would have brought it into juxtaposition with the meeting in Kamchatka. Following discussions between the organisers it has therefore been decided that our 3rd meeting will be in Russia in August 1995 and that our meeting in the United States will be rescheduled for August 1996. I am pleased to be able to report that preparations for the IWGCL meeting in Kamchatka are progressing well, and would draw your attention to the 'announcement' on page 43.

I would like to thank all those members who have sent me their e-mail numbers. My list, which now has 26 names on it, will help to reduce the cost of distributing information to members. I was particularly impressed by the response which I received from our members in North America and whilst I fully appreciate that e-mail is not a facility which is available to many of our members I would ask anyone who has easy access to e-mail but has not sent me their number if they could please do so.

The submission date for this Newsletter was set at 31 December 1993 and I would like to thank all those members whose contributions arrived before, or shortly after, that date. However, this is an informal Newsletter for which strict deadlines would be inappropriate and I therefore continued to accept contributions which arrived in the earlier part of this year. A careful reading of certain contributions would indeed reveal that they are based on field work undertaken in early 1994. It is my intention to continue with the same policy and set a deadline for the next Newsletter of 31 December 1994 and continue to accept contributions after the deadline, but only if they do not take the size of the Newsletter over 50 pages.

S.J.F.

IWGCL becomes a Commission of IAVCEI

Minoru Kusakabe
Secretary of IWGCL
Institute for Study of the Earth's Interior, Okayama University
Misasa, Tottori-ken 682-01, Japan

As Secretary of the International Working Group on Crater Lakes (IWGCL), I am very pleased to be able to report that our group has at last been recognized as a full Commission of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI). The decision was made by IAVCEI's Executive Committee during the Association's General Assembly Meeting held in Canberra, Australia from September 25 to October 1, 1993. Dr. Wally Johnson, Secretary General of IAVCEI, sent me the following fax in this regard;

".... the IAVCEI Executive Committee has approved unanimously recognition of the Task Group on Crater Lakes* as a full commission of the Association. The Executive Committee was impressed with the achievements of the IWGCL and the Task Group, and particularly the efforts that have been made to establish links with hydrologists and the IAHS. We all look forward to the Commission contributing to the life of IAVCEI and to enhancing further the vigour and relevance of the Association. ...."

During the Canberra meeting, a session termed "**Scientific Horizons**" was held on the 26th of September. It was organized and chaired by Dr. Paulo Gasparini, President of IAVCEI, as a special night session for IAVCEI's Commissions and Task groups to report their current and future scientific activities. The Commissions and Task Groups occupy an important place within the framework of IAVCEI; for they represent a forum where experts in the various sub-fields of volcanology can exchange data and ideas for the progress of the discipline. Kusakabe, representing the IWGCL, gave a summary talk on its history, structure, rationale, objectives, and current and future activities, based on the **Proposal for Commission on Crater Lakes** which is found in the IWGCL Newsletter No. 6 (Kusakabe and Kling, 1993).

I am also happy to report that Dr. Michel Meybeck (Universite Pierre et Marie Curie, Paris), President of International Commission on Water Quality, IAHS, also did agree to become a member of our steering committee just before I went to Canberra. The structure of our group which now represents a wide range of disciplines from volcanology to hydrological sciences, certainly contributed to the approval of our Commission status by IAVCEI's Executive Committee.

We need a name for our new Commission. It is tentatively called the **Commission on Crater Lakes** in IAVCEI; but because our group consists of people representing a wide spectrum of disciplines, the name should reflect and be compatible with studies of not only crater lakes but also caldera lakes. I circulated a questionnaire to the IWGCL's steering committee members with respect to the new naming, and have so far received the following proposals.

1. Commission on Volcanic Crater Lakes
2. Commission on Volcanic Lakes
3. Commission on Volcanic and Gassy Lakes
4. Commission on Caldera and Crater Lakes
5. ...

I am yet to hear from all committee members, but I would like to suggest that a final decision to this effect be delayed pending our next general meeting. If you feel otherwise or have other ideas then do endeavor to contact me before the next meeting.

---

* IWGCL became the Task Group after the 1992 Misasa IWGCL meeting.

Preliminary Investigation of Maly Semiachik Volcano, Kamchatka

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1. Department of Chemistry, College of Arts and Sciences, The University of Tokyo, Komaba, Meguro-ku, Tokyo 153, Japan
2. Institute of Volcanology, Far East Division, Russian Academy of Science, Petropavlovsk-Kamchatky, Russia

Introduction

Japan-Russia Joint Research on Maly Semiachik Volcano, Kamchatka has been conducted from July to August in both 1992 and 1993. This volcano occupies the central part of the Eastern Volcanic Belt of Kamchatka (54°07'N, 159°53'E, Fig.1), being predominantly basaltic stratovolcano containing a strongly acidic crater lake at the southernmost summit of the cones (Troitsky crater, Photo plate 1). The lake is 550 m in diameter and the elevation of the lake surface is 1170 m (Fig. 2). The volcanic activity record of this volcano is scant (only one unreliable eruption in 1805), mostly solfataric activity along the crater wall. Its scientific observation starting in 1946 has been conducted rather sporadically. The chemical investigation of the lake water in 1965 showed that the water was quite acidic and highly mineralized (pH 0.7, total minerization 32 g/L) and the water temperature was 30-34 °C. The maximum depth of the lake was 140 m in 1960s. Increasing volcanic activity from 1965 till 1973 reduced the pH value to 0.5 and raised the water temperature and mineralization up to 38-41°C and 42 g/L, respectively. Recent report of this volcano by Gavrilenko et al. (1993) indicates that the volcanic activity at the crater lake has been decreasing.

Bathymetry

The bathymetry by echo sounding in 1993 showed a maximum depth of 117 m, considerably shallower than in 1960s (140 m, Fig.3). Only one effervescent area was observed at the deepest point where we sampled floating sulfur coming up to the lake surface from the subaqueous fumarolic vent(s). We measured the temperature of subaqueous molten sulfur pool(s). The observed highest temperature of the pool was 166°C in 1992 and 157°C in 1993.

Water chemistry

The analytical results of the lake water are listed in Table 1 which includes dissolved SO_2 and H_2S gas data. Compared with the results in 1973 (Table 16 in *Active Volcanoes of Kamchatka*, Fedotov and Masurenkov ed., 1991), the lake water in 1992-93 was considerably diluted (about a third of the former in mineralization) with snow melt water which is channeled by a single inflow stream from the north-east. The water temperature in the summer in 1992-93 was less than 10°C, much cooler than before. No fumarolic activity on the crater wall was observed. These facts suggest that the volcanic activity at the lake during a recent few years has been decreasing. This is also supported by the polythionate data from 1986 to 1993 (Fig.4). The years of low polythionates (1986 and 1991) may be either in a high activity or in a low subaqueous gas discharge (Takano et al., 1993). We can see which state is the case for both years, based on the dissolved SO_2/H_2S ratio (Takano et al., 1993). However, the ratios are not

available for these years. Instead chloride and sulfate concentrations can be used as an auxiliary indicator to estimate the volcanic activity at the crater lake. Both anions in 1986 are much concentrated than those in 1991. This suggests that the volcanic activity in 1986 was much more intensive than in 1991. In 1986 polythionate concentrations were low because of a high heat flow (Gavrilenko et al., 1993) and probably high SO_2/H_2S gas discharge from the subaqueous fumarole vents. On the other hand, in 1991 injection rate of SO_2 and H_2S into the lake seems to be too weak to produce much polythionates in the lake water. Figs. 5 and 6 illustrate the vertical distribution of major cations and anions in the lake water, respectively. The figures show a slightly less mineralization of the water at the lake surface and sometimes at the bottom. This may be due to a transient mixing of the lake water with the snow-melted water.

Microbiology

We found only a weak activity of sulfur-oxidizing bacteria sampled at the point closer to the subaqueous fumarolic vents in 1992. In the next year, however, the microbe concentrations in the order of 10^3-10^4/mL were obtained for the water sampled throughout the lake. Cultivation experiments using a various medium suggest that the microbe found in the lake water is *Thiobacillus thiooxidans*.

References

Gavrienko, G.M., Dvigalo,V.N., Fazlullin, S.M. and Ivanov, V.V. (1993). The present-day state of Maly Semiachik Volcano (Kamchatka). *Volcanology and Seismology,*, No.2, 3-7.

Takano, B., Ohsawa, S. and Glover, R.B. (1993). Surveillance of volcanic activity at Ruapehu, New Zealand, by aqueous polythionates. *J. Volc. Geotherm. Res.*, (in print).

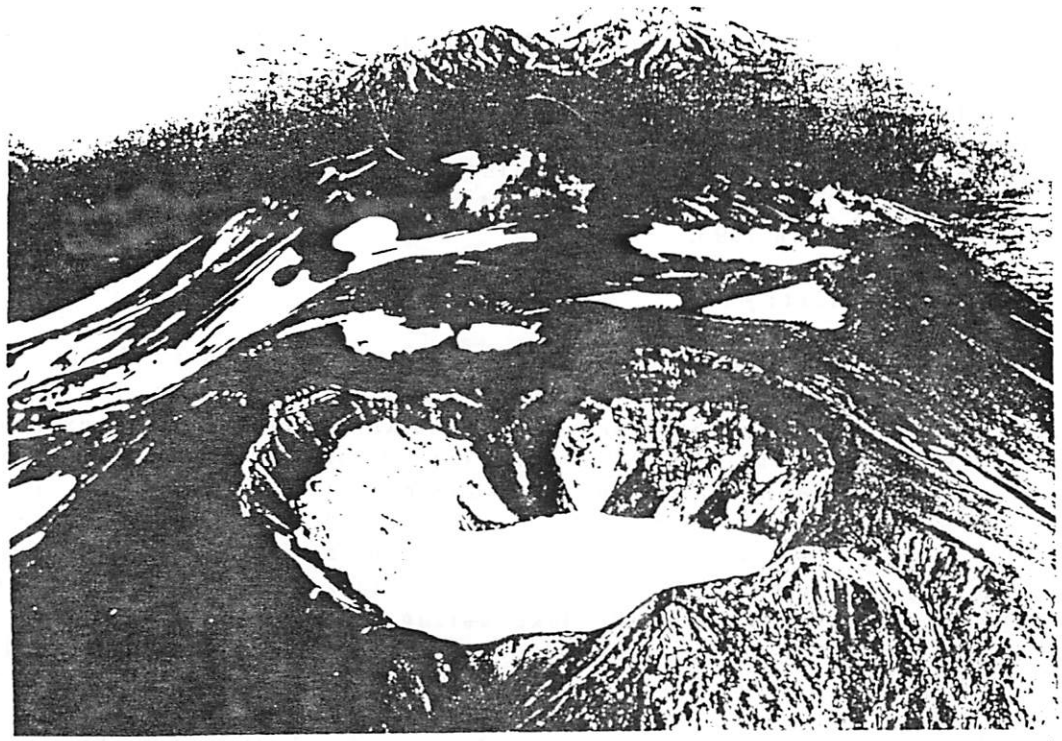
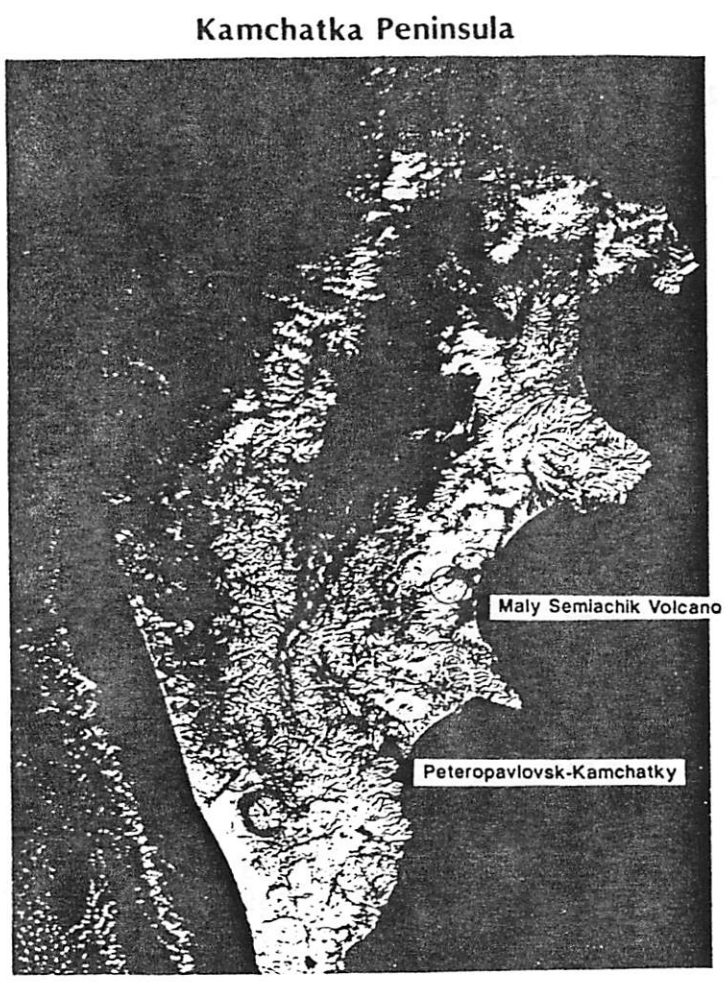


Photo plate 1. Troitsky Crater viewed from south. From the northern rim, a stream of snow-melt water flows down to the lake. Basaltic ash covers the hydrothermally- altered crater wall.



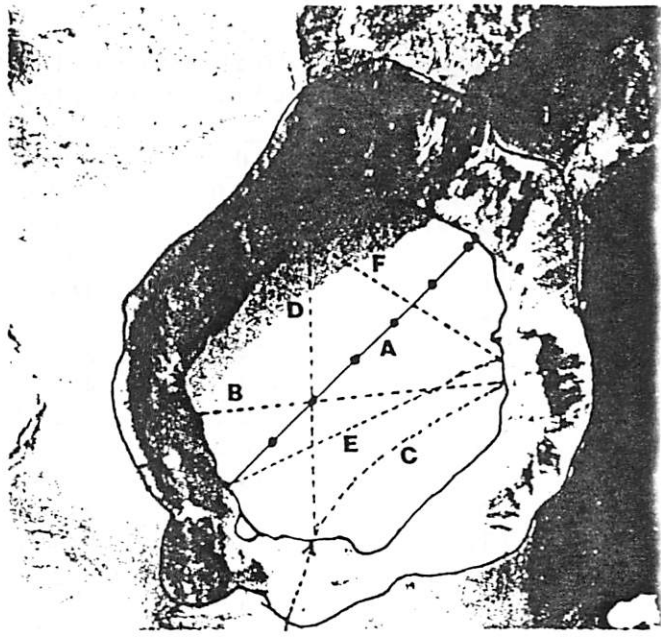


Fig.1 (left). Location of Maly Semiachik Volcano viewed from a satellite.

Fig.2 (upper). Echo-sounding lines, **A, B, C, D, E, F.** The crssing point of the lines, **A, B,** and **D** is the effervescent zone.

Fig.3 (bottom). Bathymetry of the Troitsky crater. The shaded area shows a column of rising volcanic gas bubbles.

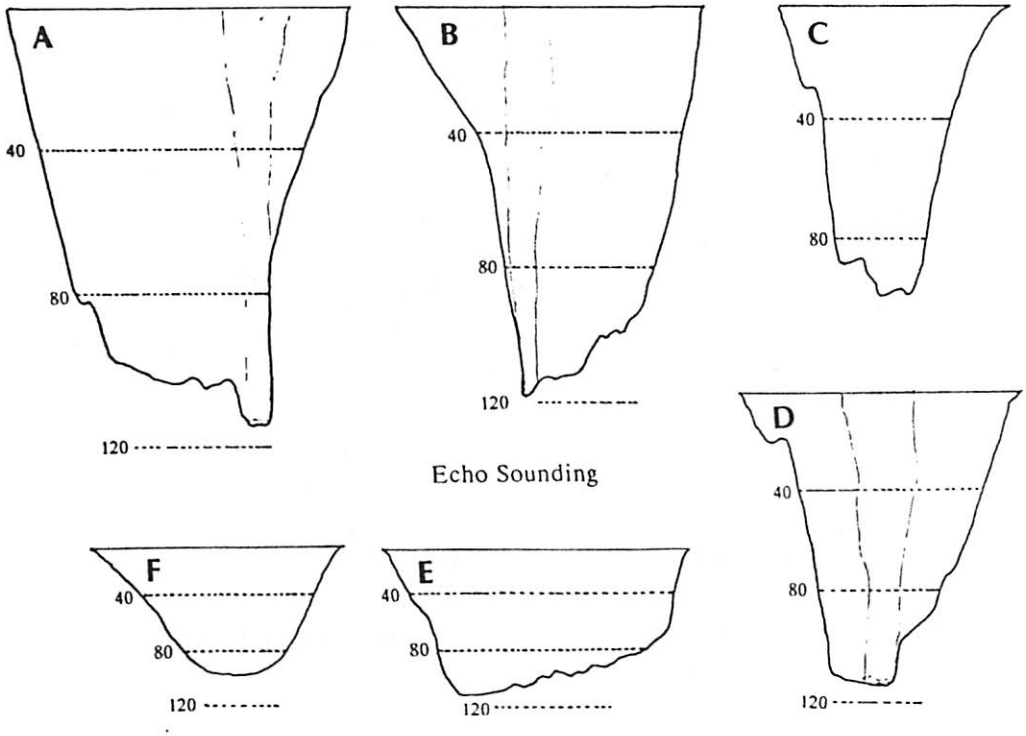


Table 1. Analytical results of the Maly Semiachik Crater Lake water sampled on August 13, 1992 (mg/L).

Depth	0 m	20 m	50 m	80 m	110 m
pH	1.0	0.95	0.99	0.99	0.99
Temp. °C	-	9.0	8.9	9.2	9.5
Li	76.7	87.5	92.9	93.6	78.1
Na	201	164	195	199	199
K	44.1	48.6	47.7	51.4	50.0
Mg	174	205	218	213	185
Ca	407	456	461	458	405
Sr	2.13	2.48	2.52	2.49	2.16
Ba	0.062	0.061	0.070	0.051	0.081
B	13.0	14.6	15.4	15.2	13.0
Al	572	739	753	715	595
Ti	3.33	3.86	3.84	3.77	3.44
V	1.99	2.29	2.39	2.33	1.97
Cr	0.22	0.24	0.25	0.26	0.22
Fe	427	624	538	578	408
Ni	0.12	0.53	0.23	0.51	0.62
Cu	0.054	0.068	0.067	0.073	0.113
Zn	0.84	0.85	0.88	0.94	0.83
Pb	0.052	0.068	0.040	0.067	0.094
SO_4	9470	10600	10990	10990	9240
Cl	3510	3990	4160	4200	3500
S_4O_6	93.7	260	288	286	265
S_5O_6	148	365	389	401	253
S_6O_6	77.7	162	180	182	132
$SO_2(aq)$	0	3.0	3.2	3.2	0
$H_2S(aq)$	0	1.3	1.1	1.0	0

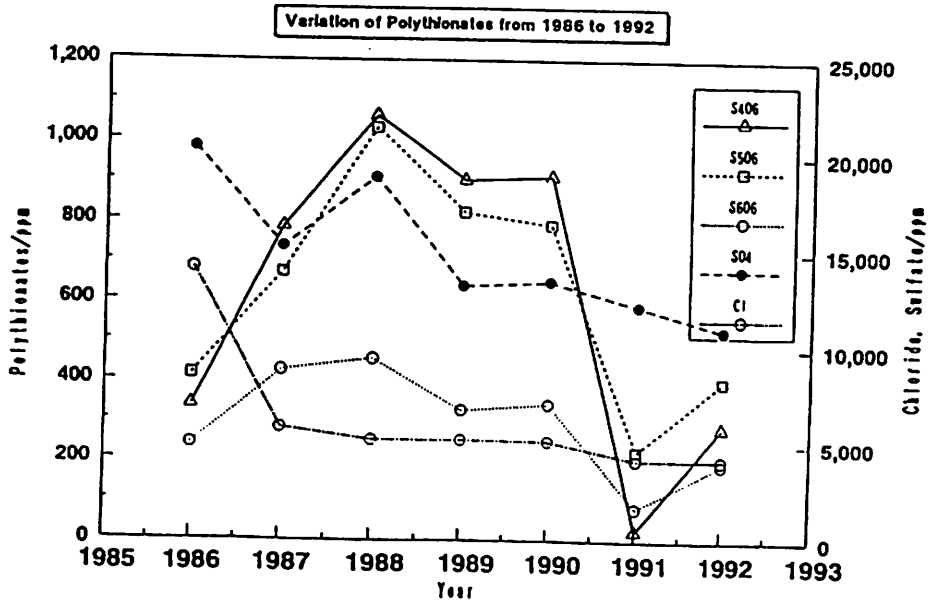


Fig.4. Variations of polythionates, chloride and sulfate in the water sampled from 1986 to 1992.

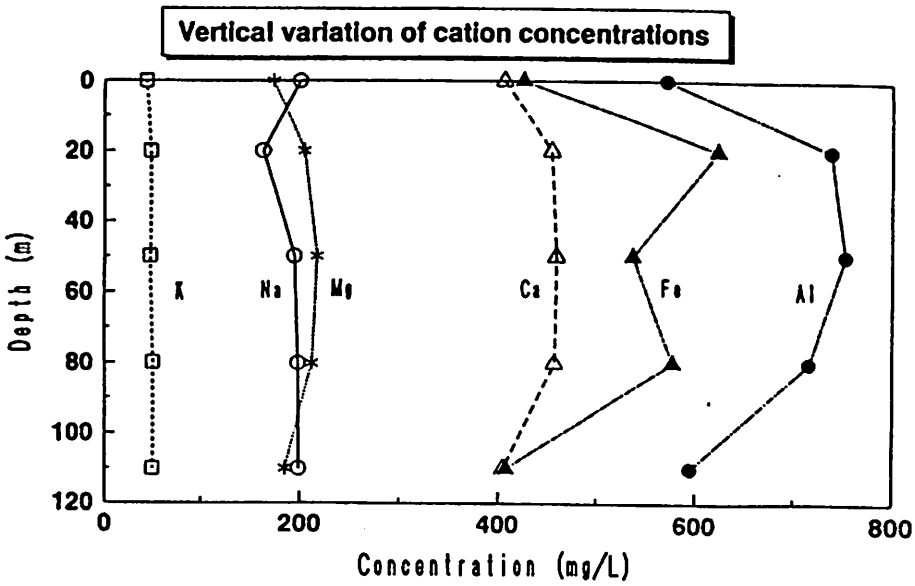


Fig.5. Variations of major cation concentrations with depth.

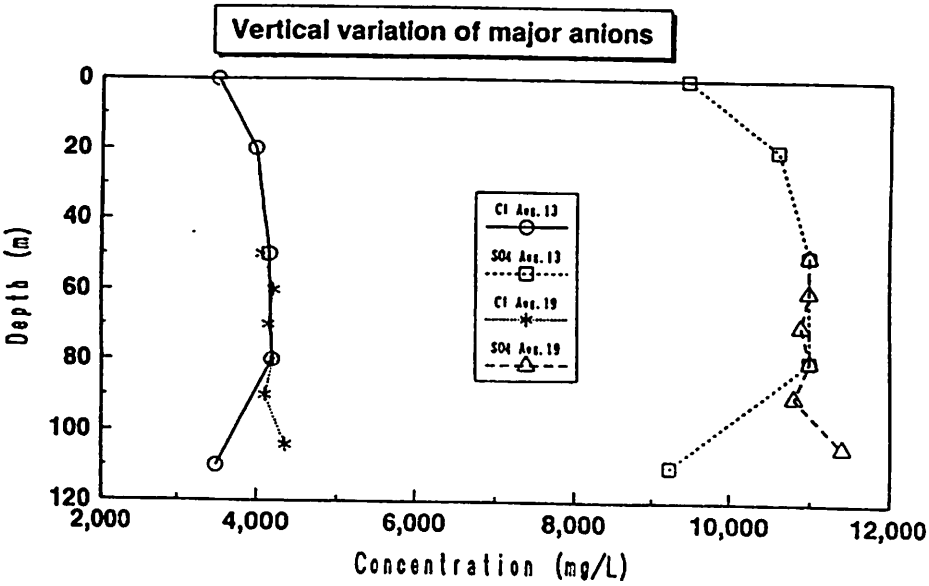


Fig. 6. Depth profiles of chloride and sulfate ions in the water sampled on a different date.

WATER LEVEL MEASUREMENTS AT LAKE NYOS, CAMEROON.

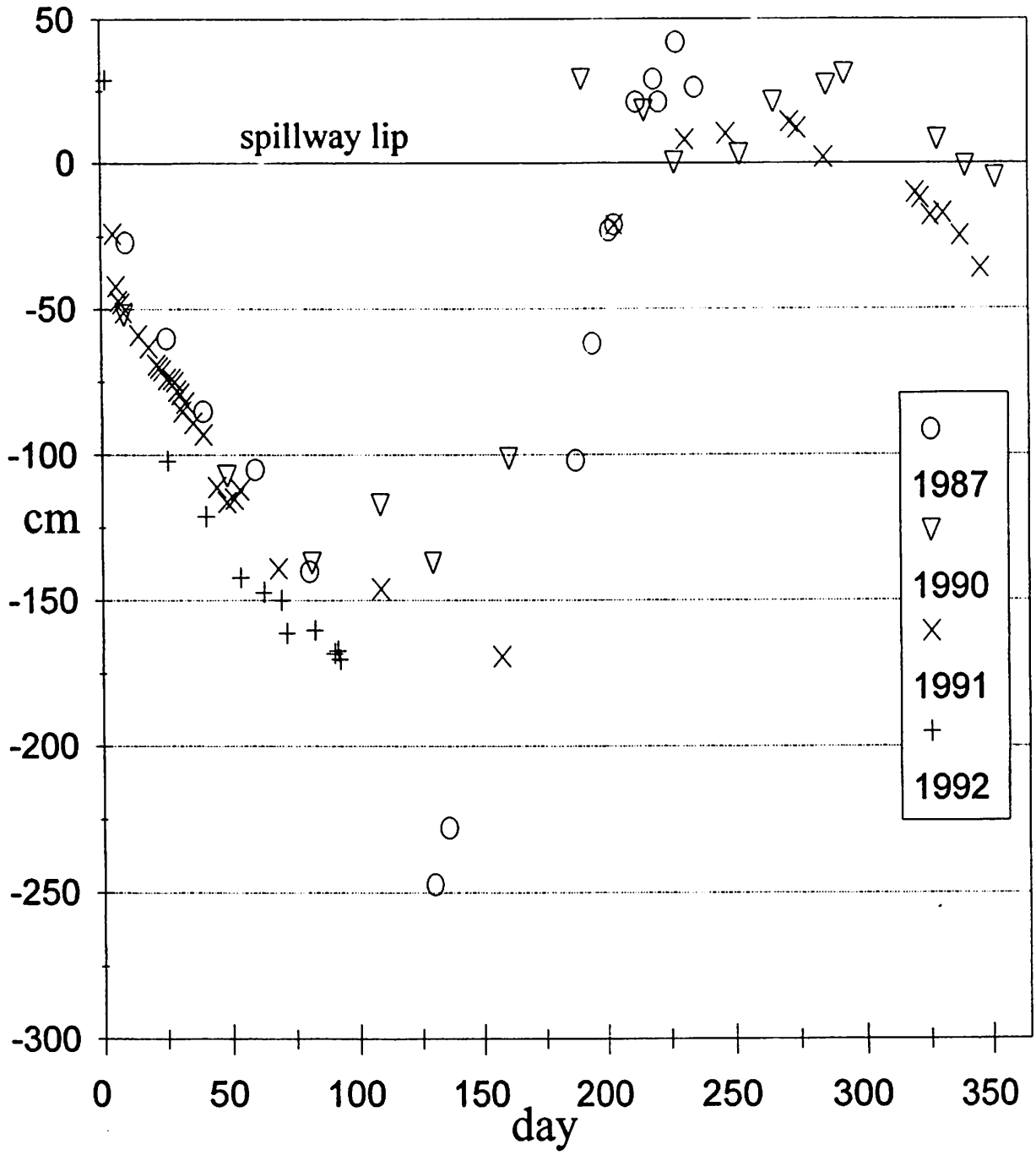
Evans, W. C., U.S. Geological Survey, Menlo Park, CA 94025.
Kling, G. W., University of Michigan, Ann Arbor, MI 48109.
Tuttle, M. L., U.S. Geological Survey, Denver, CO 80225.
Lockwood, J. P., U.S. Geological Survey, Volcano, HI 96718

In the wake of the 1986 gas release from Lake Nyos, arrangements were made for a local inhabitant, Ephrain Cha, to make occasional measurements of lake surface level. A nail driven into a rock ledge some meters east of the spillway has served as the benchmark from which a measuring device (tape, stick, or rope) could be lowered to lake surface. Cha had no experience in making these kinds of measurements but passed by the lake frequently on hunting expeditions and appeared willing to take the readings when in the area. Peace Corps worker Steve Tebor assisted Cha in making the first few measurements (through May 1987). In late 1987, Cha's measuring equipment was confiscated by the Cameroonian military in an attempt to keep all local inhabitants out of the Nyos area. In December 1989, we resupplied him and made arrangements with the authorities to allow the work to continue.

According to Cha, water begins to flow over the spillway when lake level is 55 cm below the nailhead. The spillway lip is formed by a layer of pyroclastic ejecta. The resistance of this layer to erosion has resulted in the spillway lip being reasonably level for a length of about 10 m. Careful surveying in 1990 revealed 8 places spread along this 10-m length that were 58±1 cm lower than the nailhead, in fair agreement with Cha's observation. One very narrow (~5 cm) channel may allow a small amount of overflow at slightly lower water level, but overflow stream width should rapidly increase from several cm to several m as lake level rises to within 58 cm of the nailhead. The following table was prepared by subtracting 58 cm from the measured values. Thus outflow becomes significant at listed values >0 cm. Values labeled "our readings" were made on various sampling expeditions and show reasonable agreement with Cha's values.

The data are plotted in the accompanying figure. The seasonal pattern is fairly well defined and allows some judgements to be made about individual data points. It seems that on average, the lake level drops ~1.5 cm/day after surface outflow ceases during the dry months of December, January, and February. The first point in 1992 is thus probably in error. Subtracting 1.0 m yields a reasonable value and suggests that a recording error was made. The large drop of 18 cm/day between the first 2 dates in 1991 is also a problem but may be a recording error in the 05 Jan point. Apart from these 2 points, no obvious problems exist in the data, but other errors certainly might have been made. Also, even though the measurement area is somewhat sheltered, wind speed and direction as well as wave action no doubt affect these single-point lake level measurements to some extent.

We intend to relate these measurements to rainfall data from the anchored climate station. This will be particularly useful in looking at the fluctuations in outflow during the rainy season and in removing any possible sampling bias. (For example, is Cha less likely to travel to the lake during days of excessive rainfall?) Eventually, we hope to have some improved constraints on the lake's water budget.


50
0
-50
-100
-150
-200
-250
-300
cm
spillway lip
1987
1990
1991
1992
0
50
100
150
200
250
300
350
day

Lake Nyos surface level (in cm). Datum is spillway lip. Benchmark (nailhead) = +58.

10-Jan-87	-27	09-Jan-90	-52	05-Jan-91	-24	02-Jan-92	29
26-Jan	-60	18-Feb	-107	06-Jan	-42	26-Jan	-102
09-Feb	-85	23-Mar	-137	07-Jan	-47	10-Feb	-121
01-Mar	-105	19-Apr	-117	08-Jan	-48	23-Feb	-142
22-Mar	-140	10-May	-137	09-Jan	-51	03-Mar	-147
10-May	-247	10-Jun	-101	15-Jan	-59	10-Mar	-150
16-May	-228	10-Jul	29	19-Jan	-63	12-Mar	-161
07-Jul	-102	04-Aug	18	22-Jan	-69	23-Mar	-160
14-Jul	-62	16-Aug	0	23-Jan	-70	31-Mar	-168
21-Jul	-23	10-Sep	3	24-Jan	-71	01-Apr	-167
23-Jul	-21	23-Sep	21	26-Jan	-74	02-Apr	-170
01-Aug	21	13-Oct	27	28-Jan	-74		
08-Aug	29	20-Oct	31	29-Jan	-75		
10-Aug	21	25-Nov	8	30-Jan	-78		
17-Aug	42	06-Dec	-1	31-Jan	-79		
24-Aug	26	18-Dec	-5	01-Feb	-85		
				02-Feb	-82		
**********our readings**********				05-Feb	-89	******our readings******	
				09-Feb	-93		
16-May-87	-228	08:30 21-Sep-90	20	14-Feb	-111	02-Apr-92	-170
		15:00 21-Sep-90	19	18-Feb	-116		
12-Dec-89	-5	06:45 22-Sep-90	22	21-Feb	-115		
		15:45 22-Sep-90	20	23-Feb	-112		
		06:46 23-Sep-90	18	10-Mar	-139		
		~16:00 23-Sep-90	21	19-Apr	-146		
		06:37 24-Sep-90	15	07-Jun	-169		
				23-Jul	-21		
				20-Aug	8		
				05-Sep	10		
				29-Sep	14		
				02-Oct	12		
				12-Oct	2		
				16-Nov	-10		
				18-Nov	-12		
				22-Nov	-18		
				27-Nov	-17		
				04-Dec	-25		
				12-Dec	-36		

An inverted radiocarbon sequence from the Lake Nyos delta!

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Introduction

Lake Nyos is confined by a narrow natural dam which, if it were to fail, could devastate the valleys to the north. Not only could the lake level be lowered by as much as 40 metres, thus releasing about 60 million cubic metres of water, but the disturbance and the reduction in pressure on the underlying water would almost certainly trigger a gas release, similar to that which caused the 1986 disaster.

The dam itself is the eroded remnant of a once extensive cone of pyroclastic rocks. If the dam is only a few hundred years old, as some have suggested, then it is being eroded away quickly and must surely fail in the near future. But if the dam is many thousands of years old, as I believe to be the case, then there is less immediate cause for concern. The age of the Lake Nyos dam is therefore of considerable practical importance as far as the people living in the area are concerned.

Three ways of constraining the age of the dam have been suggested but as yet none of these has yielded an age which is generally accepted. Shortly after the disaster Jack Lockwood collected two samples of carbon from near the base of the downstream face of the dam, these he had dated and one yielded a radiocarbon age of 400 years (Lockwood and Rubin, 1989). However, for reasons which are explained below, there are various problems associated with radiocarbon dating of samples from the Lake Nyos area so this age should not necessarily be taken at face value. At much the same time I myself collected two samples of rock, one from the dam itself and one from a lava flow which post-dates the pyroclastics, both of which yielded K-Ar ages in excess of 100,000 years (Freeth, 1988). There is however the possibility that these samples may contain inherited argon so whilst I would regard this age as 'realistic' it must be treated with a degree of circumspection. The age of the dam can also be constrained by considering the rate at which it is eroding away. When measurements taken in March 1992 (Freeth, 1993) are compared with those from aerial photographs taken in 1958 there are no detectable changes and this would appear to preclude an age of less than about 3000 years (full details of this study are currently being prepared for publication).

Given the problems inherent in obtaining a 'reliable' age for Lake Nyos, and the desirability of determining whether it is a few hundred or many thousands of years old, it was suggested to me by Olivier Leenhardt that we might be able to collect a sequence of samples from the delta at the southern end of Lake Nyos, have them carbon dated, determine the rate at which the delta sediments had accumulated and thus constrain the age of the lake. This was an interesting idea though I was somewhat sceptical since we had previously determined the C-14 content of a sample of lake water taken from a depth of 120 metres (Freeth et al., 1987) and found that it contained only 7% 'modern' carbon. At that time I therefore believed (erroneously) that much of the vegetation in the Lake Nyos area would be 'contaminated', to a greater or lesser extent, with ancient carbon and would therefore yield anomalous ages. To check on the extent of 'contamination' I suggested to Olivier Leenhardt that if he were to collect some samples from trees that are living near Lake Nyos we could see whether they gave consistent results. This he did and when they were analysed we found, somewhat to my surprise, that the trees living around Lake Nyos gave

perfectly normal modern ages.

Three samples collected from trees that were living on the Lake Nyos delta were found to have an average C-14 content of 116.6% 'modern' and a sample from the fig tree living on the spillway had a C-14 content of 116.5% 'modern'. All normal vegetation contains more than 100% 'modern' C-14 because of the effect on the C-14 reservoir of atomic bomb tests and 116.5% is just about on the global average for 1990, which is when these samples were collected.

However, a sample which Olivier Leenhardt collected for a tree growing close to the spring to the north of Lake Nyos, which is fed by water seeping from the lake, and a further sample which I myself collected in 1992 from the spring to the north-east both showed significant C-14 deficits - equivalent to an apparent age of around a thousand years. It could therefore be argued that if the sample collected by Jack Lockwood came from a recent tree which had been fed by water seeping through the dam this could account for its apparent age! (Full details of these results will be published in due course.)

Having established that vegetation growing around Lake Nyos did not contain anomalous concentrations of C-14 I therefore arranged a visit in March 1992 so that I could collect a sequence of samples from the delta sediments.

The delta

Lake Nyos consists of two parts, a fairly steep sided 'crater', with a depth of around 200 metres, to the south-east of which is a shallow basin. Sediment eroded from the hills to the south of Lake Nyos has been washed into this basin to form a delta which now extends over about one third of the original surface area of the basin. The delta was formed at a time when the level of Lake Nyos was rather higher than it is at the present day. Even at the height of the Wet Season, when water is flowing out of the lake over the spillway, most of the surface of the delta is at least a metre above lake level. When Lake Nyos was formed the natural dam which forms the spillway was at least 1.5 metres higher than it is now and subsequent erosion has lowered it to its present level. Presumably, soon after the 'maar forming' event which created Lake Nyos, unconsolidated pyroclastics were washed off the surrounding hills to form a delta which was subsequently abandoned when erosion reduced the height of the dam and hence the level of the lake. The two main streams which drain the hills to the south have cut 'canyons', through the delta sediments, which are up to 2.7 m deep and about 10 m wide. It is difficult to estimate the total thickness of the delta sediments but from the bathymetry of the basin and the extent of the delta I would suggest that they are probably around 15 metres thick at the delta front.

Sample collection

When I visited Lake Nyos in March 1992 one of my primary objectives was to dig (or more accurately to pay someone to dig) a pit in the delta sediments so that I could collect a sequence of samples which could then be radiocarbon dated. However, the journey to Lake Nyos proved to be far more difficult and time consuming than it had been during my previous visit in 1987 (Freeth, 1993) and it was also fairly obvious that to dig a pit, which would expose a thicker section than those which had been cut by the streams, would require considerable time and effort. Therefore to make the best use of the limited time which I had available and to maximise the depth from which sediment samples were collected I decided to collect from

one of the stream sections. With the benefit of hindsight this may not have been the best decision which I have ever taken! However, having taken the decision I selected a well exposed section of stream bank on the western of the two main streams and about 100 metres back from the delta front.

The section selected was fairly clean and had an indistinct horizontal layering. Overall the delta sediments appeared to coarsen upwards with an indistinct transition from very fine to fine silt at a depth of about 2 metres and a clear transition at a depth of about 50 cm above which the sediment was very sandy.

Before collecting the samples I was careful to cut back and clean up the section surface, and remove some loose material which had accumulated at the base of the section. At the time I was confident that I was sampling in situ delta sediments and that I had cut the section back far enough to avoid any possibility of surface contamination. Had I not been confident that I had exposed an uncontaminated in situ section then I would not have collected the samples. Four samples were collected from depths of 0.3, 1.0, 1.75 and 2.5 metres, each of which weighed about 500 gm. These samples were carefully sealed and taken back to the laboratory for analysis.

Sample analysis

The samples were analysed at the Natural Environmental Research Council Radiocarbon Laboratory in East Kilbride. Prior to analysis the sediment samples were digested in 0.5M hyodochloric acid, washed to neutral pH and dried.

The results of the analyses are set out in the table below:

Lab no.	Field No.	Depth	^{14}C	$\delta^{13}C$
SSR-4851	LD1	0.3m	100.6 ± 0.5% modern	-16.8‰
SSR-4852	LD2	1.0m	106.5 ± 0.5% modern	-16.3‰
SSR-4853	LD3	1.75m	108.7 ± 0.5% modern	-16.0‰
SSR-4854	LD4	2.5m	118.4 ± 0.6% modern	-17.8‰

Interpretation

At first sight the results of the analyses would appear to be quite bizarre since, if taken at face value, they would imply that the sediments are entirely post-1950 (i.e. that they are post-bomb), that the sediment at the base of the sequence is no more than a a few years old and that slightly older sediments have been reworked and deposited on top of them. And whatever else may have happened we know that the delta surface is now above lake level and that there have been no major changes to the delta since Lake Nyos was visited by Hassert in 1908 (Hassert, 1912).

I would interpret the section from which the samples were collected as resedimented volcanic ash from the last of the Lake Nyos 'maar' forming events - the fine ash being washed off the surrounding hills first, followed by progressively coarser material and with a final, sandy, layer eroded from coarse pyroclastic deposits. If this interpretation is correct then I would expect the fine ash to contain very little organic carbon but that any which it does contain should give an age appropriate to the maar forming event. From the results which were obtained it would appear that there is little or no original organic carbon in the fine sediment and that the carbon which they do contain has been introduced within the last couple of decades or so. But how can organic carbon have been introduced in such a way as to give the appearance of a perfectly inverted sequence?

Whilst pondering the apparent paradox of an inverted sequence of 'recent' ages in an otherwise normal sequence of 'old' sediments it struck me that there seems to be a relationship between the apparent age of the samples and the water level in the lake (as shown in figure 1)

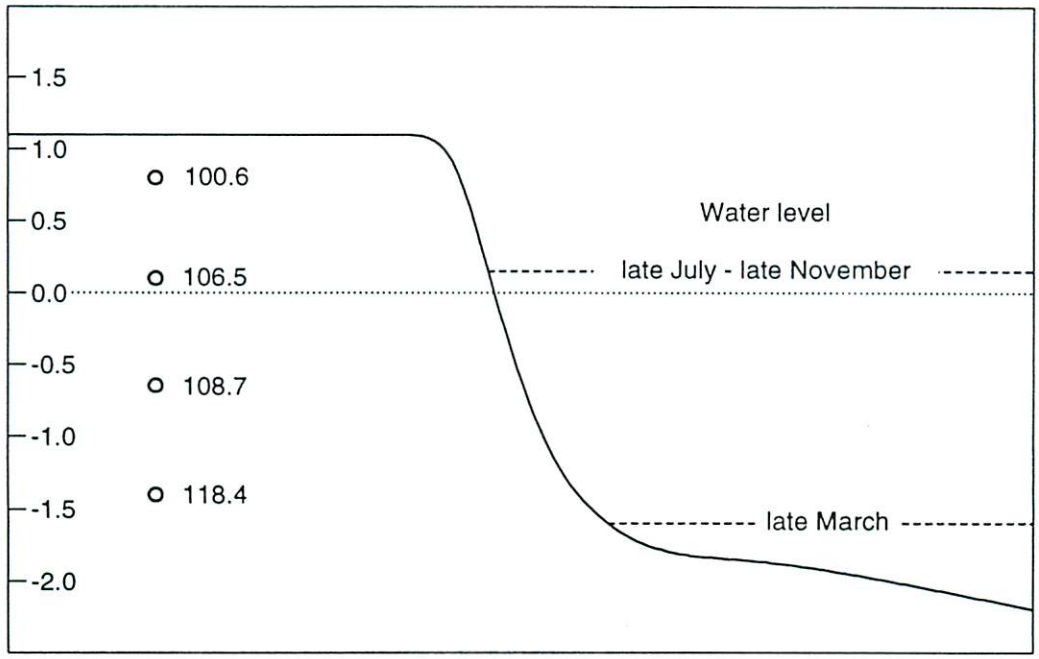

Figure 1. Sketch section through the Lake Nyos delta, drawn to show the relationship between the soil samples, which were radiocarbon dated, and the fluctuating water level. The vertical scale is in metres and is calculated relative to the lowest point on the lip of the spillway. The C-14 content is given as '% modern'. The water level rises to about 15 cm above the lip of the spillway during the Wet Season then falls to its minimum level at the end of the Dry Season, in late March, before rising again during the next Wet Season.

When the water level in the lake is at its maximum, from late July through to late November (mid Wet Season to early Dry Season), it should be a little less than a metre below the level of the delta. But during the Dry Season the water level falls steadily to about 2.7 metres below the delta surface (in late March) and then rises again during the early Wet Season. [For further information on the fluctuating water level in Lake Nyos see the contribution by Evans, Kling, Tuttle and Lockwood in this issue.] So the soil sample from 0.3 metres is from a level which would always have been well above lake level. The soil sample from 2.5 metres is from a level which would have been below lake level for all but about 2 months of the year, but even when above lake level it would have been only a little above stream level, so it would have been permanently saturated. And the samples from 1.0 and 1.75 metres are from levels which would have been below lake level for about four and about five months of the year respectively. There is therefore a relationship between the amount of time which a sample site spends below water level each year and its C-14 content. This suggests to me that in the samples which I collected there is a direct relationship between biological activity and water level even in samples which were collected well back from the surface of the section. The sample from the base of the section, where the soil is permanently saturated, containded slightly more C-14 than the trees which are living on the delta surface. This would suggest that the carbon comes from the last few years, some very recent and some a few years old when C-14 levels were slightly higher, due

to bomb contamination. The samples from the middle of the section, where the soil is wet for only part of the year, contained rather less C-14. This would suggest a more mixed origin for the carbon, some very recent but rather more from biological activity over the last few decades. And the sample from close to the delta surface, where the soil is generally dry, contained a mixture of carbon from 'recent' biological activity but with very little from the last decade or so.

Conclusions

It would seem that the samples which I collected from the Lake Nyos delta were thoroughly 'contaminated' by recent biological activity!

To 'publish' a sequence of ages which fail to add anything to our knowledge concerning the age of Lake Nyos may not seem to be the most productive of exercises but I hope that in making these results public knowledge I will draw attention to a more general problem - that of contamination in areas of possible biological activity. If my samples from the Lake Nyos delta were so thoroughly contaminated is it not possible (perhaps even probable) that the samples which Jack Lockwood collected from a similarly wet environment at the base of the Lake Nyos dam were also contaminated, to some extent, with recent carbon?

Clearly further work is needed, and uncontaminated samples from the delta may yet resolve some of the questions concerning the age of lake Nyos.

Acknowledgements

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I would particularly like to thank Dr. Doug Harkness, Head of the Radiocarbon Laboratory, for his helpful comments on the possible significance of the results. And I would also like to thank Mr. Thadeus Mah for his assistance in the field.

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ON THE CLASSIFICATION OF VOLCANIC LAKES

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INTRODUCTION

In the previous issue of this NEWSLETTER a communication by G.Rowe and J.Varekamp presented their database of crater lakes with a list of the world crater lakes. Obviously, the next step in this field will be specifying and broadening the data on the volcanic lakes. All this will require generalization of the data on some basis, i.e. working out the criteria for classification. It is possible that some different classifications will be offered based on different criteria.

In the present communication I report my approach to the classification of volcanic lakes. It is not finished and complete, all possible suggestions, amendments and thoughts are therefore welcome.

TERMINOLOGY

In publications there are some variations of naming the objects which are in the center of interest of IWGCL: crater lake, caldera lake, thermal or hydrothermal lake. I suggest that we give a general name for all these types of lakes - volcanic lake.

A volcanic lake is a reservoir occupying a part of the negative form of volcanic relief (volcanic crater, maar, explosive funnel, caldera) into which the flows of endogenetic energy and material take place to a greater or lesser degree. Though the inflow may be quite low at the moment (e.g. lakes in maars). However in such lakes the interaction of water with erupted material takes place which undoubtedly affects the composition of the water. Besides, the possibility of activation of volcanic processes always remains.

METHODOLOGICAL ASPECTS AND STUDIES OF VOLCANIC LAKES

Volcanic lakes are natural historic formations that can be affected by two groups of factors:

1. Geological structure of the volcano, caldera, or hydrothermal system; structural confinement due to certain types of volcanism; morphological features of the volcanic edifice; fluid flow and its chemical composition; endogenetic energy flow.

2. Geographic. Most significant are meteorological, spatial, and biotic factors.

As a result of interaction of exogenic and endogenetic factors the lakes form (azonally, as a rule). The supply of deep energy and material to the surface takes place at specific conditions. The estimate of proportion of endogenetic and exogenic flows of material and energy, in my opinion, will allow us to forecast the geochemical processes taking place in the lake and the influence of biotic factors as well as to make prognosis of hydrological and hydrochemical structure of the lake, to estimate the major processes controlling sedimentation.

A volcanic lake, its hydrological structure and chemical composition can be regarded as indicators of the deep processes taking place in the entire volcano. It is assumed that by knowing the processes governing the formation of a volcanic lake we then can have an access to learning and identifying the physical-chemical conditions in the depths of the volcano or hydrothermal system.

APPROACHES TO THE CLASSIFICATION OF VOLCANIC LAKES

This classification is based on the proportion of endogenetic and exogenic flows of energy and material supplied to a volcanic lake. This principle can, probably, also be used as a basis to consider the influence of volcanism upon other types of lakes.

In terms of the relation to volcanism, the lakes located in areas of active volcanism can be divided into two groups:

1. Lakes genetically not related to volcanism but periodically or accidentally influenced by volcanic activity.
2. Volcanic lakes.

In the first group we can enumerate the following possible factors affecting the life of the lake:

(a) volcanic ashfalls
(b) lahars
(c) nuees ardentes (glowing avalanches)
(d) lava flows (episodically)
(e) discharge of fumaroles or hydrothermal springs at the bottom or on the shore
(f) effluent waters of streams going through volcanic strata (constant)

The lakes genetically related to volcanism may be located in craters, calderas or in the areas of hydrothermal systems. Such lakes can be represented as a cell to which material and energy from endogenetic and exogenic sources are supplied. If we try to estimate these sources, during a year, for example, the proportions of the yield of one or the other will show the dominance of this or that source. Out of the possible combinations of material vs energy flow ratios we can draw several combinations:

Q1 - the sum of endogenetic heat supplied at a time unit
Q2 - the sum of the exogenic heat supplied at a time unit
Q3 - the sum of the endogenetic material supplied at a time unit
Q4 - the sum of the exogenic material supplied at a time unit

Based on this I propose the first feature of the volcanic lake - material vs energy flow ratio.

	I	II	III	IV	V
total Q1/Q2	>1	>1	<1	<1	<<1
total Q3/Q4	>1	<1	>1	<1	<<1

One of the very important features of a lake are its redox conditions at the depth. There are the following variations that determine the form of the material state:

A - Waters of the lake at every depth are saturated with oxygen, which controls the redox potential of the system.
B - Waters of the lake are saturated with reducing gases (H2, H2S, CH4, etc.). The conditions of the medium are therefore reducing. And a thermal wedge is either absent or very weakly expressed.

C - Waters in the upper part of the lake have oxidising conditions whilst the lower part has reducing conditions. As a rule, the boundary between two types of conditions runs along the thermocline.

The pH value significantly influences the state of the material in lake water. I suggest the following gradations of this characteristic:

H1 pH<1 - region where almost all metals are mobile. Pretty aggressive solutions.
H2 1<pH<4.5 - region of existence of one of the principle petrogenic elements, iron (with a valence of +2 or +3).
H3 4.5<pH<6.5 - region where other petrogenic elements exist in solution, aluminum. Hydrocarbonate-ions appear in the solution.
H4 6.5<pH<8.0 - neutral conditions typical of the majority of surface waters.
H5 pH>8.0 - carbonate-ions start to appear in the solution which significantly influences photosynthesis. The contents of Al and Si increase.

Cations in solutions are complexed, depending on the dominant anions, the principle cations are Cl(-), HCO3(-), SO4(2-). I suggest that we to assign an appropriate symbol to lake water when one of the anions rises above 80% and that if concentration of any anion is less than 20% that we neglect it.

The dominant anion when the name is complex should be put at the end. Concentration is measured in mg-equivalents.

S - sulphate-ion
Cl - chloride-ion
C - hydrocarbonate-ion

Another very important characteristics of the lake is its volume and the area of its surface. I suggest that we use base 10 logarithms of these values expressed in square and cubic meters:

logS/logV

This way, using the offered approach we can write the formula of the lake which will give an idea to its principal features. For example, the formula for the Maly Semiachik crater lake in 1972 would be:

H1; B; (Cl-S);I; 5.36/7.17

It is assumed that lakes belonging to one group have much in common. Therefore, if we have one well studied lake, then we will be able to forecast the condition of other lakes.

Crater lakes in Eastern Indonesia

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Indonesia is well endowed with large calc-alkaline volcanoes and the wet tropical climate has led to the establishment of a number of crater lakes. Well known lakes include Kawah Idjen and Lake Kelut on Java and the Rindjani crater lake on Lombok. We discuss here Lake Batur (Bali), Wai Sano (West-Flores), Keli Mutu (Central Flores), Egon Lake (East Flores) and Sirung lake (Pantar) and chemical analyses of the waters are listed.

Lake Batur is a large lake within the Batur caldera in N-central Bali. The Batur caldera is actually two nested calderas, with the active Gunung Batur in the middle, which has had regularly eruptions during this century. The lake occurs on the east side of the caldera, with long and short diameters of about 7.5 and 2.5 km. The maximum depth of the lake is about 80 meters and its surface area is about 15 km^2 (Fig.1). The lake has no surface outlets, but it has a substantial drainage basin (surface area of the outer Batur caldera is >100 km^2). A small hot spring with a composition close to that of lake water feeds the lake near Air Bunga (Table 1). The lake waters are dilute (Table 1) with low levels of Cl and SO_4, indicative of a geothermal input. The pH is relatively high, possibly a result of evaporation. Stable isotope and other chemical data indicate that the geothermal or volcanic input component is small. The lake shows no evidence for chemical stratification in its major cations or anions, although the pH in the lowest 10 meters is lower (7) compared to the top 65 meters of the lake (pH=8.5-8.9). This pH shift may be caused by absorbed CO_2 but the overall concentrations of H_2CO_3 still have to be very low.

Lake Wai Sano is a caldera lake in eastern Flores, south west of Ruteng, measuring 2.75 by 1.75 km. The depth is in excess of 30 meter. Fumarolic vents and hot springs surround the lake, and the lake water temperature is above ambient. Lake water and spring water samples were collected by VSI colleagues and the analytical data are shown in Table 1. This is a large acid lake with a pH near 3. One of the springs feeding the lake has very high Cl (1.7 %) and B (594 ppm) contents, but very low S contents, and a near-neutral pH. Some H_2S may be discharged into the lake that is subsequently oxidized to H_2SO_4. The spring fluids must have undergone extensive water/rock interaction and these presumably originally acidic fluids have been largely neutralized.

The three Keli Mutu lakes just east of Ende (Flores) are famous in Indonesia: their picture is printed on 5000 Rupiah notes.They have a mysterious beauty with colors changing through the seasons from green to deep red. The color changes are presumably related to changes in the saturation with ferric hydro-oxides in repsonse to changes in pH and Eh during the rainy season. The lakes have existed for more than 150 years and have highly acidic concentrated solutions. Hydrothermal eruptions have repeatedly deposited lake sediments on the crater walls. Two of the lakes are in continuous motion through convection, the central lake is partially covered by a sulphur slick. The third lake is very quiet and may be stratified. Representative water analyses are shown in Table 1. Their lake water compositions have varied dramatically during this century. A detailed account of the Keli Mutu lakes is in press by Pasternack and Varekamp.

Egon volcano is located just east of Maumere, the capital of Flores. It is more than a day climb into the Egon crater, which consists of heavily altered rocks with abundant fumaroles. A small, very shallow lake occupied about 1/3 of the crater floor during our visit. The crater floor is covered by lakebeds, suggesting that the lake may have been larger in the past. There was no direct evidence for a gaseous input into the lake, and most of the chemical constituents probably were brought into the lake water through leaching of the altered crater walls and fumarolic deposits by runoff (Table 1).

Sirung lake, in the crater of Sirung volcano on Pantar, is a shallow acid lake with grey clayey sediments. The lake is surrounded by fumaroles including a boiling spring with a very concentrated acid brine that feeds the lake. The lake was last visited in 1989 and had not changed dramatically since 1984. Although the boiling spring provides a substantial influx of dissolved components, sulfur emissions must also occur below the lake surface. Sirung lake was described by Poorter et al., 1984.

Crater lake fluids are usually mixtures of volcanic/geothermal fluids and rainwater. The question arises how much of the dissolved element load came with the volcanic gas input and how much is derived from acid leaching of rocks, either in the lakes or within the volcanic structure below the lakes. The Cl/B ratio may be a potential monitor for the extent of fluid/rock interaction versus volcanic gas input. Both elements show conservative behaviour and should be largely retained in acid fluids, except during high temperature boiling. The Cl/B ratios in these lakes and springs varies from 17 to 1261, with many of the measured values around 100. Arc lava flows have Cl/B ratios of 50-150, whereas sea water has Cl/B of about 4430. Virtually no data exist (as far as we know) on Cl/B ratios in high temperature "pristine" volcanic gases. If these are found to be dramatically different from "rock Cl/B" , this may provide a method to determine mixing proportions of volcanic gas versus rock-derived elements as well as sea water contributions.

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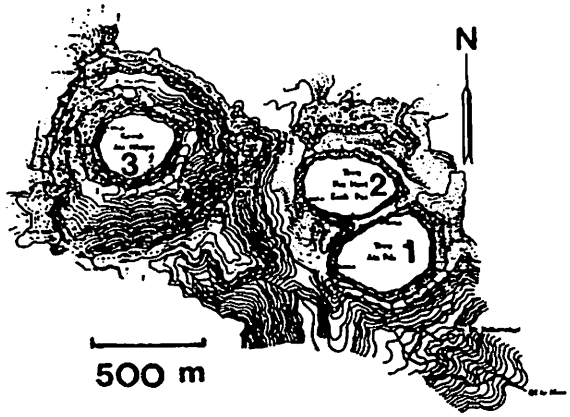
Figure 1.
Bottom. Map of the Batur caldera with Batur lake. The central black dot is the active crater of Gunung Batur, the two circular traces are the nested calderas. **Top.** The three Keli Mutu lakes on central Flores: **lake 1**: dark green, alternating with deep red, **lake 2:** turquoise, with floating sulfur, **lake 3:** dark red or black, was green in the past; set within a larger crater.



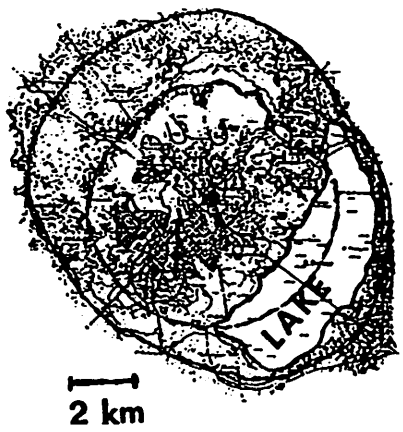


Table 1. Chemical analyses of crater lake and spring fluids. Data after Pasternack, 1993 and for Sirung after Poorter et al., 1989a;1989b.

	Batur lake 0 m 1992	Batur spring 1992	Wai Sano lake 1992	Wai Sano spring 1992	Keli Mutu lake 1 1992	Keli Mutu lake 2 1992	Keli Mutu lake 3 1992	Egon lake 1989	Sirung lake 1984	Sirung spring 1984
T °C	23	57	28	90	20	28	20	22	40	100
pH	8.9	8.1	3.0	6.1	1.8	0.4	3.2	2.2	0.8	1.4
Si	14	59	48	50	91	66	50	53	66	154
Ca	33	53	96	2100	599	869	437	52	1510	17400
Mg	67	80	10	30	242	1280	34	18	920	12200
Na	362	317	272	7740	229	939	53	32	660	11200
K	31	27	26	1176	53	542	5	6	240	2400
Fe	<1	<1	14	<2	1190	2620	21	41	1760	17700
Zn	<0.1	<0.1	0.2	<0.2	1.8	8.8	0.2	0.1	9	85
Li	0.4	0.3	0.6	21.4	0.3	1.4	<0.1	<0.1	0.2	2.4
B	1.4	1.6	30.4	594	21.1	230	0.9	1.9	ND	92
SO_4	486	404	418	31	9780	48900	1585	1328	18700	1740
Cl	231	203	504	17100	2670	25100	88	116	14950	116000
F	<1	<2.5	<2.5	ND	238	2840	16	<2.5	23	13
Cl/B	165	127	17	28	126	109	98	61	ND	1261

ND-not determined

Geochemical survey of Galunggung and Kelut crater lakes in Java, Indonesia.

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This note reports the chemistry of waters collected during a two weeks field work in December 1993 from the crater lakes of Galunggung and Kelut volcanoes and some associated springs.

The water samples were filtered in the field (with 0.45 or 0.1µm filters) and acidified to pH < 2 with HNO_3. Alkalinity (acid titration), TDS and pH were measured in the field. Na and K were analyzed by Atomic Absorption and Ca, Mg, Si, Ba, Sr, B and Mn by DCP-AES. Anions (Cl^-, SO_4^{--} and F^-) were analyzed with a DIONEX DX100 ion chromatograph.

Galunggung volcano (7°15' S, 108°04' E) is an active volcano in West Java. Past eruptions occurred during historical times in 1822, 1894 and 1918. Its last eruption occurred in 1982-1983 after 63 years of repose and constrained 80.000 persons to evacuate their homes. About 370 million m3 of tephra mostly of basaltic andesite composition (53-49%SiO_2) have been produced (Katili, 1984 and 1986). Following this eruption, the crater has been filled with a lake. I have no information regarding the depth of this lake but the volume is estimated at 7.5 million m^3 (Casadevall, 1991). A pumping station was recently build in the crater apparently to control the lake level and reduce potential hazards due to lahars in this densely populated area of Java.

Last december, only a very weak steaming activity was noticeable on the South East walls of the crater.

The sulfates content (404 $mg.L^{-1}$) of the surface waters (see GC1, Table 1) is likely to be of volcanic origin and show that the emission of volatiles from the magmatic/hydrothermal system at depth is still reaching the surface.

Kelut volcano (7.93°S, 112.31°E) is beside Merapi volcano (Central Java), the most dangerous volcano of Java with a record of 29 eruptions since 1311 (Sudradjat, 1992). The repose intervals between eruptions range between 1 and 75 years. The crater lake is at an elevation of 1133m and is well known to be a potential lahar hazard for people living in the vicinity of this volcano (Verstappen, 1992). After the 1919 eruption which killed 5110

people, several tunnels were built through the crater walls to drain the water lake and mitigate the lahar hazard. This work reduced the lake volume from 40 million m^3 to about 3 million m^3.

The last eruption occurred in February 1990 (GVN bulletin 15/1, 1990) and destroyed all the geophysical instruments monitoring the crater lake. Thanks to the work of the VSI (Volcanological Survey of Indonesia), the drainage tunnel has been repaired and is now efficiently keeping the volume of the lake at about 2.4 million m^3. Last December (at the end of the dry season), the overflow of the lake into the drainage tunnel was estimated at 2.4 m^3/min.

The lake surface was warm and steaming and its color was pale green. Surface temperatures measured over a 6 days period from the lake shore ranged from 40.4 - 41.5°C. In the center of the lake above its greatest depth, the surface temperature was slightly higher (42.8°C). This is still higher than the pre-eruptive lake temperatures recorded just before the February 10, 1990 eruption (GVN bulletin 15/1, 1990, Badrudin, 1992, Vandemeulebrouck and Halbwachs, 1992). No upwelling was easily visible at the surface of the lake. The maximum depth found in the lake is 32m. Water samples collected at different depths show that the lake is well mixed. The lake chemistry is a near-neutral Na-chloride water (KC1-5, table 1).

A significant fumarolic activity is still present in the eastern part of the crater not covered by the lake. Numerous fumaroles with temperatures in excess of 100°C were found. The maximum temperature recorded was 647°C, a blue sublimate (Mo-blue oxide?) is present at the mouth of this 647 °C fumarole. Gas chemistry is probably a very diluted volcanic gas.

Small streamlets (KS) flowing from the crater walls into the lake and springs (KOS, table 1) found on the South East flank of the volcanic edifice were also collected.

Currently, the seismic activity of Kelut volcano is recorded at the Margomulyo Volcano Observatory (about 7km from the crater) but there is no more geophysical monitoring of the crater lake. A minimum monitoring of the lake waters (temperature, pH) should be resumed shortly. Because of the small volume of Kelut crater lake in comparison with much larger crater lakes like Ijen volcano, and because its volume is kept constant by the drainage tunnel, this lake present an ideal situation for monitoring

volcanic activity. Due to its small size, the crater lake could be very sensitive to changes related to magma degassing at depth as was observed just before the last eruptive activity (Badrudin, 1992, Vandemeulebrouck and Halbwachs, 1992).

Many thanks to the Volcanological Survey of Indonesia, especially to M. Badrudin and Deden who provided the logistical help during the course of this field work. Thanks also to P. Delmelle and S Debrouwer for their help when trying to measure the water flow at the outlet of the Kelut tunnel.

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Table 1: Water chemistry of Galunggung and Kelut crater lakes and associated springs of Java, Indonesia .

SAMPLE	Date	Temp. °C	Depth	pH	TDS mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	Si mg/l	Ba mg/l	Sr mg/l	B mg/l	Mn mg/l	F- mg/l	Cl- mg/l	SO4-- mg/l	HCO3- mg/l
GC 1	Dec.12,1993	23	0m	7.0	n.a.	18	4	108	34	14	l.d	0.2	<0.1	<1	0.5	6	404	n.a.
KC1	Dec.16,1993	41.0	0m	5.9	n.a.	720	92	104	55	114	0.08	0.5	11	1.7	7	1291	659	258
kC2	Dec.18,1993	42.8	0m	n.a.	2750	678	91	103	56	112	0.08	0.5	11	1.7	8	1317	669	242
kC3	Dec.18,1993	-	15m	n.a.	2740	700	92	105	55	109	0.08	0.5	11	1.7	6	1297	631	238
kC4	Dec.18,1993	-	32m	n.a	2770	692	90	104	56	107	0.08	0.5	11	1.7	6.5	1292	663	253
kC5	Dec.20,1993	41.6	0m	6.0	2740	674	92	106	56	114	0.08	0.5	11	1.6	7	1358	657	n.a
KS1	Dec.16,1993	20.3		6.3	16	2	0.4	3	0.3	12	l.d	0.01	<0.1	<1	0.5	1.3	5	n.a
KS2	Dec.17,1993	20.9		6.5	23	2	1	4	0.3	15	l.d	0.02	<0.1	<1	0.5	0.9	6	n.a
KS3	Dec.17,1993	22.7		n.a.	66	6	1	12	2	29	l.d	0.05	<0.1	<1	0.3	2.6	26	n.a
KOS1	Dec.19,1993	22.3		6.0	527	15	4	169	26	27	0.06	0.6	<0.1	2.6	0	15	498	n.a
KOS2	Dec.19,1993	32		5.7	1080	71	11	367	53	40	0.05	1.5	0.14	5.0	0	25	1309	n.a
KOS3	Dec.19,1993	22.3		5.9	700	23	4	281	15	41	0.04	1.2	<0.1	0.9	0	7	773	n.a
KOS4	Dec.19,1993	22.3		4.9	810	23	5	321	23	41	0.05	1.2	<0.1	1.9	0	9	955	n.a

n.a. = not analyzed, l.d. = below detection limit
Al, Fe and Ti are < 0.1 ppm.
polythionates are < 1ppm

RECENT GEOCHEMICAL SURVEY OF THE ACID CRATER LAKE OF KAWAH IJEN VOLCANO (EAST JAVA).

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Introduction:

This report presents the preliminary results obtained during a field trip done at Kawah Ijen in December 1993.

The 1000 m wide crater of Ijen volcano (8°.03'S, 114°.14'E) has been filled with a lake for at least one century. The lake waters are hot (T>35°C), strongly mineralized (TDS≈105g/l) and extremely acidic (pH<0.4) (Delmelle and Bernard, 1994). By its volume, the Ijen lake is probably the largest accumulation in the world of such acidic waters.

Since 1796, the activity of the volcano has been restricted to phreatic eruptions. Kawah Ijen has erupted 5 times during the 20th century, the most violently in 1952 (Newhall and Dzurisin, 1988). Recently, the activity of the volcano intensified in July-August 1993 with hydrothermal explosions occuring in the center of the lake (Smithsonian Institution, 1993; Wahyudin et al., 1993). According to the Volcanological Survey of Indonesia (VSI) the lake turned white after the activity ended. This was likely due to a remobilization of the sediment, which is mainly fine-grained α-cristobalite. At the time of our visit, the lake had recovered its usual turquoise-green color.

Sampling:

Pyroclastic sulphur material was found along the shoreline. A similar observation was also reported 10 days after the volcano activity had returned to normal (comm. pers., Clive Oppenheimer, September 93). Pyroclastic sulphur eruption has been previously reported at Poàs crater lake (Bennett and Raccichini, 1978; Francis et al., 1980). Together with the occurence of sulphur spherules which are seen floatting on the lake surface, this supports the suggestion that liquid sulphur is present beneath Ijen lake. The sulphur deposit was produced during the recent subaqueous hydrothermal activity. It is green sulphur, highly vesicular and which has morphological and grain size similarities with basaltic scoria. Disseminated pyrite has been identified in it.

The lake surface waters had a maximum temperature of 42.7 °C. Their pH and TDS values were around 0.1 and 111g/l respectively. At present, temperature of the fumarolic gases of the solfatara do not exceed 198°C.

On the *west* flank of the volcano, there are several small streamlets which flow into the Banyupahit creek. About 1.5 km from the crater, the so-formed Banyupahit River has a discharge of 45 l/s. In the vicinity of the volcano, it is the single visible outlet of the lake. Ten kilometers further on, the Banyupahit River enters the village of Blawan where it is swollen by rivers and cold and hot springs. From this point the river bears the new name of Banyuputih ("putih" is the indonesian name for white).

Water from the crater lake (I93-1, I92-1 and I93-3), the Banyupahit (BPA-1, BPA-2, BPA-3, BPA-4, BPA-5, BPA-6 and BPA-7) and Banyuputih (BPU-1 and BPU-2) rivers (KL-1 and KL-2) and Blawan hot springs (BLW-1 and BLW-2) were sampled. The VSI provided us 6 lake water samples (VSI-1 to VSI-6) which cover the period from May 93 to October 93. These lake samples were neither filtered nor diluted in the field. Consequently, gypsum and silica precipitated during storage. Cations and anions concentrations of all the samples were determined using DCP-AES, AA and HPLC.

Results:

The chemical composition of the waters are presented in Table 1. Previous lake water analyses (I90-1, I92-1 and I93-1) are also shown. Based on the available data, the lake waters have exhibited a relatively constant chemical composition since 1990. The most sensitive elements are Na, Si, and Ca. While Si and Ca are controlled by precipitation of α-cristobalite and gypsum, Na concentration is not correlated with the formation of a solid phase in the lake waters. There were no significant change in the lake water composition associated with the 1993 hydrothermal activity. Lake water polythionates ($S_xO_6^=$, x=4-6) concentrations have remained relatively constant at least since May 93 (Fig. 1). Mg/Cl and SO4/Cl ratios did not exhibited significant change before and after the explosion of July 3 (Fig. 2).

We believe that the hydrothermal activity of 1993 has been restricted to the cleaning of subaqueous fumarolic vents which were partially blocked by more or less solidified liquid sulphur. The present high temperature (Fig. 3) and low pH values of the lake (compare with those measured previously, Delmelle and Bernard, 1994) could then result from an increase in the subaqueous fumarolic discharge rate.

Figure 4 shows the evolution of some rock-forming elements concentration of the Banyupahit River as it flows. Except for Ti which exhibits higher concentration, the small streamlets that feed the river are chemically similar to the lake waters. This strongly suggests

Table 1: Compositional data for Kawah Ijen volcano waters (in ppm except pH)

Sample	Date	pH	SO4	Cl	HCO3	Si	Al	Fe	Mn	Mg	Ca	Na	K	Ti	Ba	Sr	Cu	Pb	B
Crater Lake																			
I90-1	*9/18/90*	0.18	59305	22146	-	67.6	5490	1862	40.9	688	1106	585	1702	4.9	0.4	6.9	0.4	-	46.2
I92-1	*10/26/90*	0.19	63580	24460	-	173	6078	1923	47.1	714	1027	982	1284	5.3	0.5	12.0	-	-	53.8
VS-1	*5/15/93*	-	69551	21528	-	-	4300	1953	31.2	666	-	790	1364	4.7	0.10	8.7	-	3.9	39.6
VS-2	*6/15/93*	-	62588	20300	-	-	4394	2056	33.2	666	-	828	1426	4.4	0.11	9.3	-	-	38.8
VS-3	*7/07/93*	-	72397	22933	-	-	4269	2040	33.0	677	-	768	1326	4.5	0.12	9.3	-	4.2	38.5
VS-4	*8/31/93*	-	76173	23811	-	-	4437	2079	33.3	679	-	782	1364	5.2	0.15	9.2	-	-	39.5
VS-5	*9/10/93*	-	76943	23670	-	-	4367	2096	33.1	690	-	768	1368	5.0	0.16	9.5	-	4.3	38.6
I93-1	*9/18/93*	0.28	74133	21832	-	81.9	5530	1888	38.4	569	911	940	1180	5.8	0.35	7.9	-	7.9	54.4
VS-6	*10/11/93*	-	67944	21520	-	-	4346	2052	34.1	682	-	774	1382	5.0	0.14	9.4	-	-	39.5
I93-2	*12/10/93*	0.12	70154	21218	-	84.3	4781	2076	33.1	729	1197	734	1306	4.5	0.11	10.9	0.48	3.6	35.9
I93-3	*12/23/93*	0.09	77044	23485	-	89.6	4865	2170	35.2	751	1262	812	1400	4.0	0.57	11.7	-	-	42.8
Banyupahit River																			
BPA-1	*12/12/93*	0.03	70657	24138	-	44.6	5000	2362	-	779	1026	802	1372	18.8	0.05	10.5	0.30	3.6	38.9
BPA-2	*12/12/93*	0.09	71560	21899	-	47.1	4970	2373	36.7	767	1067	782	1372	23.7	0.05	10.7	0.32	3.7	39.9
BPA-3	*12/12/93*	0.21	74279	23924	-	49.6	5010	2515	37.9	821	815	825	1419	23.2	0.13	10.0	0.53	6.6	46.5
BPA-4	*12/14/93*	0..55	35856	11749	-	52.1	3082	2067	23.4	511	691	520	933	24.1	0.05	7.9	0.77	2.9	23.6
BPA-5	*12/14/93*	0.63	44760	14012	-	54.0	2972	2099	23.5	527	725	517	947	24.9	0.05	8.0	0.73	3.0	23.4
BPA-6	*12/24/93*	1.02	15590	5564	-	48.9	1184	780	10.2	188	384	190	358	9.7	0.07	3.5	0.34	1.4	10.3
BPA-7	*12/24/93*	2.84	2565	1368	-	57.5	241	9.8	5.8	136	343	94.8	36.5	<0.2	0.04	1.9	0.06	0.38	1.4
Cold Rivers																			
KL-1	*12/24/93*	7.73	73.1	33.3	-	32.9	0.13	0.08	<1	19.8	41.6	16.4	8.15	-	-	0.18	-	-	-
KL-2	*12/24/93*	7.86	166	70.6	-	34.3	0.29	0.12	<1	51.5	101	31.5	15.4	-	-	0.43	-	-	-
Hot Springs																			
BLW-1	*12/24/93*	6.2	242	80.0	841	77.2	0.45	1.14	<1	98.5	150	126	45.0	<0.2	0.04	0.66	-	-	1.6
BLW-2	*12/24/93*	6.32	291	88.6	939	78.9	0.30	1.01	<1	115	128	130	48.0	<0.2	0.05	0.52	-	-	1.4
Banyuputih River																			
BPU-1	*12/24/93*	4.55	346	135	-	47.5	15.2	0.88	<1	38.6	92.5	32.0	14.5	<0.2	0.02	0.48	<0.02	<0.2	-
BPU-2	*12/24/93*	5.12	293	125	-	35.7	6.67	0.88	<1	44.3	103	32.0	15.9	<0.2	0.02	0.64	<0.02	<0.2	-
Rain Water	*12/22/93*	-	1.81	5.9	-	<1	<0.1	0.11	<1	<0.5	<1	0.51	-	-		-	-	-	-

(-: not analyzed)

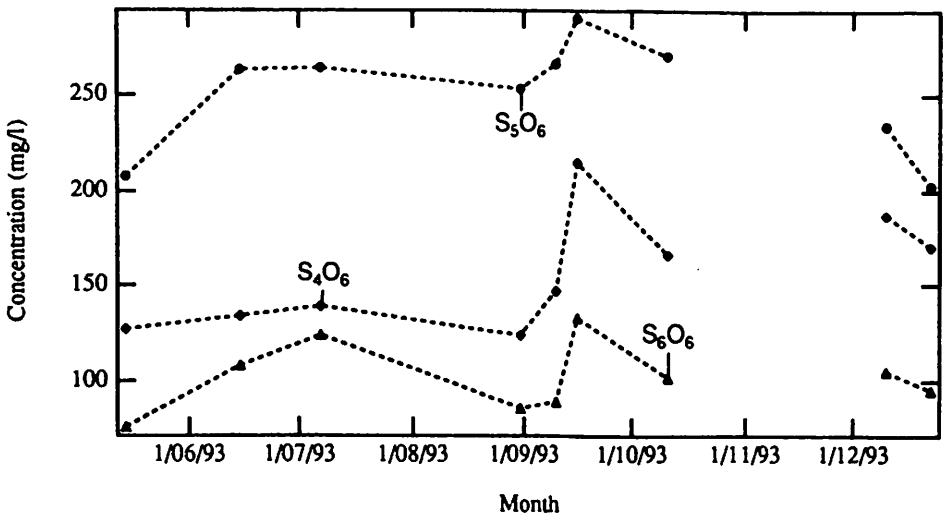

Fig. 1 Temporal variation in lake water polythionates concentration.

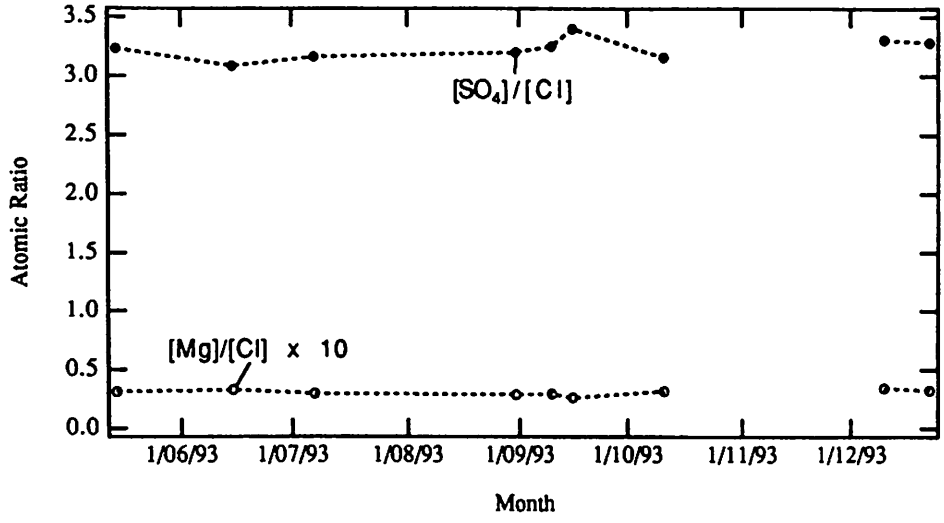

Fig. 2 Temporal variation in lake water SO_4/Cl and Mg/Cl ratios.

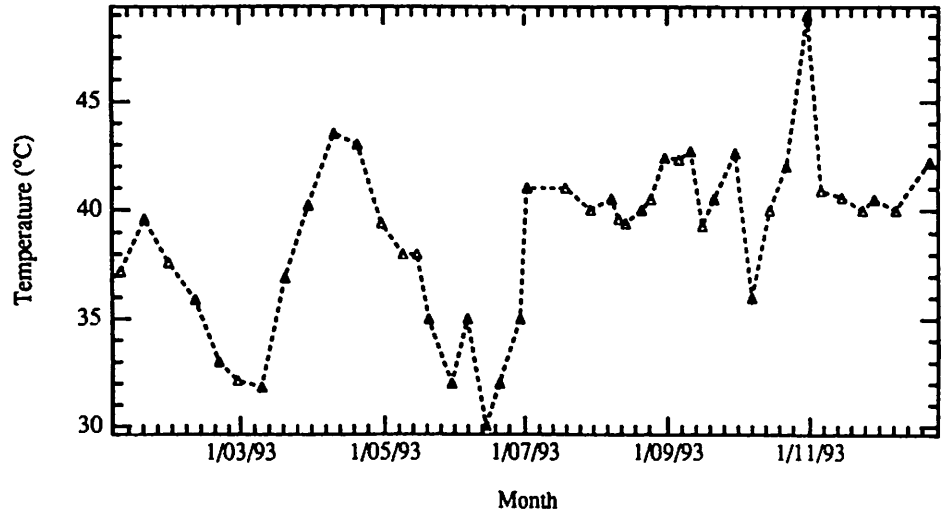

Fig. 3 Temporal variation in lake temperature (Data from the VSI).

that they are undiluted lake brines. There is a dilutional trend in the elements concentration with distance from the crater. A similar pattern was already noticed 30 years ago (Zelenov, 1969). pH of the river rises to 2.84 when it enters the village of Blawan.

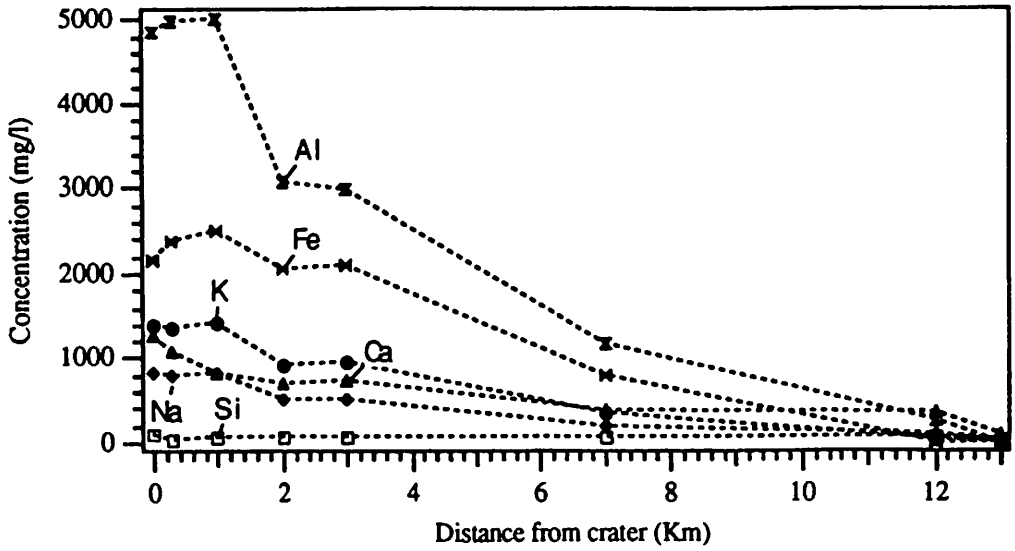

Fig.4 Evolution of the cations concentration of the Banyupahit River with distance from the crater.

The springs sampled at Blawan have temperatures ranging from 48.2 to 50.2°C. They are near-neutral waters with a high content in HCO_3^- and significant SO_4, Cl, Na and Mg concentrations (Table 1). When the hot springs and the cold rivers waters mix with the Banyupahit River, a white precipitate is immediately formed. After the mixing, the river (now called Banyuputih) has a pH around 5.5 and flows with a discharge of about $1 m^3/s$.

Acknowledgments

Many thanks to Prof. B. Takano who performed the polythionates analyses on the lake water samples. D. Badrudin and D. Wahyudin from the VSI provided us great facilities during the field work. Our thanks to S. de Brouwer for assistance in the field.

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Reconnaissance Field Work at Ol Doinyo Lengai Volcano, Tanzania: A Brief Description of Current Activity and Preliminary Results

By Gary Rowe[1*], Kevin Koepenick[1], Susan Brantley[1],and Andrew Nyblade[1]

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Introduction

This article gives a brief description of field work at Ol Doinyo Lengai Volcano and surrounding areas of the East African Rift in northern Tanzania from January 14th through January 29th, 1994. The purpose of this work was a preliminary assessment of the CO_2 flux associated with summit degassing at Ol Doinyo Lengai Volcano. In this article we discuss the current status of the volcano, objectives of the research and the methods used to reach these objectives. We also describe the measurements made and the types of samples collected. Although there is no crater lake at Ol Doinyo Lengai, we believe that research regarding CO_2 degassing in a volcanic rift setting will be of interest to most members of the IWGCL.

Geologic Setting

Ol Doinyo Lengai Volcano is in northern Tanzania (2.75°S, 35.90°E) and is part of the East African Rift system. The rift system extends southward from Ethiopia to northern Tanzania and is a region of extensive alkaline volcanism. Because of the generally arid climate and a drainage system that is directed westward away from the rift valley, several highly alkaline, brackish lakes have formed on the rift floor. In addition, the rift walls are the source of CO_2-rich springs that drain into the lakes.

Among the volcanic centers of the rift, Ol Doinyo Lengai is notable in that it is the only volcano in the rift system (indeed, in the world) that is actively producing carbonatite lavas. Such lavas, are composed almost entirely of sodium carbonatite; such lavas are erupted at low temperatures (550-600°C) and display highly variable viscosities. Historic volcanic activity has been primarily effusive although several periods of explosive activity have occurred in this century (1917, 1940-41, 1954, 1966-67). The last period of explosive activity in 1966-67 resulted in the formation of a deep pit crater. This crater has been gradually infilled by nearly continuous effusive activity involving sodium-rich carbonatite lavas that began in 1983 (Nyameru, 1988, Keller and Kraft, 1990). In June 1993, particularly vigorous effusive activity was observed at Ol Doinyo Lengai. This activity resulted in the extrusion of several large blocky flows that covered most of the southern half of the active crater and the formation of several new spatter cones (Fig. 1 and 2). Several minor flows with pahoehoe textures were also observed in the active crater and a small flow was erupted on the western flank of the volcano. The activity also included some explosive eruptions which deposited small amounts of ash on the outer slopes of the volcano. No eruptive activity was reported when the crater was visited in October 1993 (B. Dawson, written communication, 1993).

Volcanic Activity at Ol Doinyo Lengai in January 1994

Field work in the active crater occurred over the period January 19-21, 1994. During the visit no effusive activity was observed in the crater. The distribution of lava flows appeared unchanged from descriptions of the active crater given by Barry Dawson during his October 1993 visit to Ol Doinyo Lengai (B. Dawson, University of Edinburgh, U.K., written communication, 1993).

Sporadic rumbling, cracking and groaning noises were heard throughout our visit. The noises seemed to be coming from the center of the crater but were particularly evident at large fractures that marked the southern edge of an oval-shaped depression between cones T5/T9, T8, T15, and T20 (Fig. 1). Significant rumbling also occurred near cone T23, which was the site of the most vigorous discharge of high temperature gases. Significant amounts of gas were also being discharged from vents associated with cones T5/T9, T8, and T20, as well as at large fractures (width 0.25-0.50 m) on the southern edge of the central subsidence feature (site T, Fig. 1).

We surveyed fumarole temperatures in the active crater on January 19th. Temperature and observational data taken during the survey are summarized in table 1. Temperatures of fumaroles issuing from radial, tangential, and ring fractures that penetrate the walls of the crater rim generally were between 50 and 80°C. Many of these fractures emitted gases with a distinct sulfur smell and were lined with native sulfur crystals. Temperatures of fumaroles on the crater floor ranged from 65 to 273°C. The highest temperatures were recorded in the large vent at the top of cone T8 (248°C) and in fractures located along the southern boundary of the subsidence feature (273°C, site T). On the basis of visual inspection, we believe that gases being discharged from vent T23 must have had similar, elevated temperatures.

Objectives of Current Research

The main objective of the project was to measure the flux of CO_2 and other volatiles being released by Ol Doinyo Lengai Volcano. However, additional goals were to: (1) sample fumaroles of the active crater, (2) do soil-gas surveys to identify zones of degassing on the flanks of the volcano, (3) make soil-gas-flux measurements to assess the importance of flank CO_2 degassing at Lengai, and (4) obtain chemical, isotopic, and discharge data for alkaline springs of the rift valley of northern Tanzania.

Field Methods and Sample Collection

We sampled four low-temperature ($t < 100°C$) and two high temperature ($t = 250\text{-}275°C$) fumaroles for gases using evacuated glass flasks filled with 50 mls of 4 molar NaOH solution (Table 1, Fig. 1). We also collected samples at five fumarole sites, for analysis of $^3He/^4He$ isotopes using copper tubes. At two sites, we collected fumarole condensate samples; however, the gases were largely anhydrous and only a few milliliters of condensate were obtained for chemical and isotopic analysis. This observation is consistent with data reported for gas samples collected in 1988. At that time, gases sampled consisted mainly of CO_2 (96.6%) with trace amounts of CO, H_2, H_2S, and N_2 (Javoy et al., 1989). The gas samples will be analyzed under the supervision of Dr. Terry Gerlach at U.S. Geological Survey Cascades Volcano Observatory. $^3He/^4He$ analyses will be done under the supervision of Dr. Peter Schlosser at the Lamont-Doherty Earth Observatory of Columbia University.

Our soil-gas-CO_2 surveys and flux measurements were along north-south and east-west transects at the eastern and northern flanks of the volcano respectively. Both transects were approximately 1.5 km long and were perpendicular to major north-south and east-west trending linear features identified from aerial photographs. We collected radon and soil gas samples at 70 to 100 cm depth at intervals of 50 to 100 m. Radon was used as a screening tool because it has been shown at other volcanos (e.g., Vulcano, Italy, Baubron et al., 1991) that high radon concentrations are positively correlated with CO_2 and He of volcanic origin. We made the soil-gas flux measurements with a plastic flux chamber and an infra-red CO_2 detector using the static gas accumulation method. Data from these measurements are still being analyzed.

We also made soil-gas CO_2 surveys and flux measurements in and around the active crater along the east-west trending transect shown on figure 1. Fluxes in the active crater were highly variable and ranged from barely detectable 0.05 L $CO_2/m^2/hr$, to maximum fluxes approaching 25 L $CO_2/m^2/hr$. Elevated fluxes were associated with fractures and areas of fumarolic activity.

We also attempted to measure the flux of gases discharging from two of the high-temperature sites (top of cone T8, fractures at southern edge of depression at site V). We made the flux measurements by first measuring the cross-sectional area of the vent or fracture and then obtaining a gas velocity profile across the vent by use of a Pitot tube attached to an electronic manometer. Gas velocity estimates ranged from 6 to 9 m/s across the vent, and the average was about 7 m/s. Multiplying by the total cross-sectional area of the two vents (approximately 4.5 m^2) gives a volume flux of approximately 28 m^3/s. If we assume that the density of the gas is similar to that of hot air at 250° C (0.7 kg/m^3) the mass flux would exceed 1200 metric tons per day. If the gas samples collected at these vents prove to be CO_2-rich, then significant quantities of CO_2 (i.e., several hundred metric tons/day) are being discharged at Ol Doinyo Lengai.

In addition to our work at Ol Doinyo Lengai we sampled approximately 20 springs along the western rift wall bordering Ol Doinyo Lengai, Lake Natron, and Lake Manuara. We collected filtered water samples for determination of major and trace elements. We collected samples for ^{13}C and $^3He/^4He$ determinations at selected springs. We measured temperature, pH, and alkalinity in the field. We also made discharge measurements where possible.

On January 29th we flew over Ol Doinyo Lengai and attempted to make an airborne measurement of the CO_2 flux of the active crater. Although we noted an apparent CO_2 anomaly (100 ppm above atmospheric CO_2) when flying directly over the active crater, the CO_2 meter we used was not sensitive enough ($\pm$ 50 ppm CO_2) to allow us to see any anomaly outside of the active crater nor was an accurate flux measurement possible. We hope to fly over Ol Doinyo Lengai with a high-resolution instrument (e.g., Miran) to measure the CO_2-flux of the volcano more accurately in future visits to the volcano.

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Table 1-Fumarole Temperature and Sample Type Data

[All temperatures in degrees Celsius, NM = Not measured, RA = Radial fracture perpendicular to crater rim, RI = Ring fracture parallel to crater rim; TA = Fracture tangential to crater rim, NA = Fumarole not associated with fracture. S = sulfur, xls = crystals or crystal linings, T = temperature, Soda = gas sample collected in evacuated bottle filled with 4N NaOH, He refers to samples collected in copper tubes for helium isotope analysis, FC = fumarole condensate samples, (#) is number of samples collected at each site]

Fumarole Designation	Temper-ature	Fracture Type	Visual Notes	Sample Type
A	77	RI	Weak steam, no S smell or xls	Soda (1)
B	78	RA	Weak steam, S smell and xls	He (1)
C	65-70	RA	Weak steam, S smell and xls	None
D	77	RA	Weak steam, S smell and xls,	None
E	63-75	RA	Weak steam, S smell and xls	None
F	50-70	RA	Weak steam, S smell and xls	None
G	50-75	RI	Weak steam, S smell and xls	None
H	NM	NA	No visible steam, near C1, low T	None
I	72	TA	Weak steam, S smell and xls	None
J	NM	NA	Weak steam, low T	None
K	78	RI	Weak steam, S xls	None
L	72	TA	Weak steam, S smell and xls	None
M	70	TA	Weak steam, S smell and xls	Soda (1)
N	45-60	RI	Weak steam, S smell and xls	None
O	62-78	TA	Weak steam, S smell and xls	Soda (1), He (1)
P	77	NA	Weak steam	None
Q	83	NA	Weak steam	None
R	84	NA	Weak steam	None
S	82-107	NA	Weak steam	Soda (1), He (1), FC (1)
T	208-273	NA	Associated with fractures at south edge depression, S smell	Soda (3), He (1)

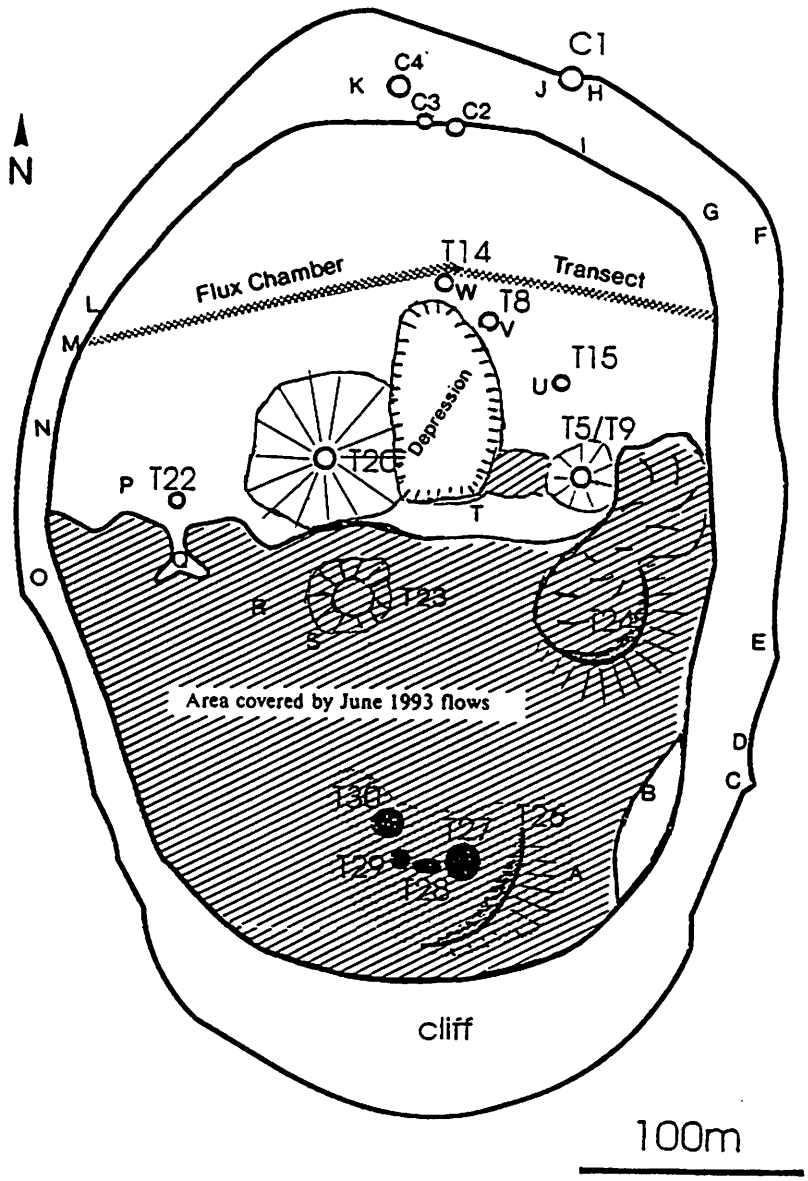

Figure 1.--Plan view of active north crater of Ol Doinyo Volcano, showing major features of the crater as of January 21, 1994. Letters refer to fumarole locations and sampling sites referenced in Table 1. Diagonal hatched area includes flows formed during the June 1993 period of activity. Numbered features preceded by a T or C refer to splatter cones previously labelled by Barry Dawson and coworkers (see recent Global Volcanism Bulletin reports for numbering system description). Modified from sketch maps provided by Barry Dawson and Cindy Ebinger.

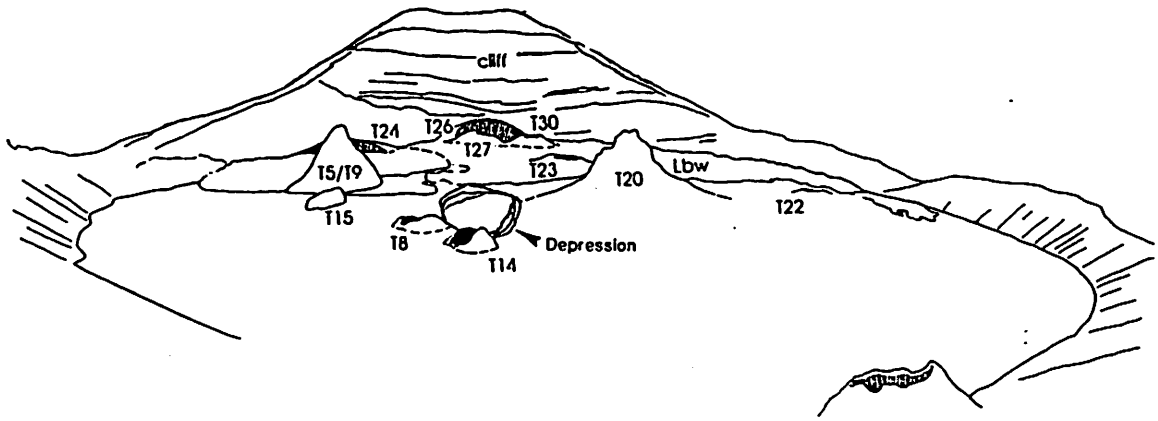

Figure 2.--Schematic sketch of active crater of Ol Doinyo Lengai Volcano as it existed on January 21st, 1994. View is from crater rim looking southwest. Depression formed between T5/T9, T8, T14, and T20 is labeled. Modified from sketch map provided by Cindy Ebinger of Leeds University.

Special Issue of the Geochemical Journal
Magmatic Volatiles and Volcanic Discharges

A special issue of the Geochemical Journal (journal of the Geochemical Society of Japan) will be issued in October, 1993, as volume 27, number 4/5, in memory of the late Professor Sadao Matsuo who died of a sudden heart attack on 8 May 1992 (obituary in *Geochem. J.* **26**, 179-180, 1992). Professor Matsuo was one of the pioneers of modern geochemistry of volcanic gases, geothermal waters, and mantle minerals in terms of stable isotope and rare gas composition. The 16 papers in this volume, edited by M. Kusakabe and H. Shinohara, have been contributed by Professor Matsuo's friends, colleagues and former students all over the world, and cover the full range of his interests.

Six of the papers deal with mantle degassing based on noble gas and stable isotope geochemistry, including a model for the origin of terrestrial noble gases, discussions on the behavior of noble gases during magmatic processes, noble gas characteristics of the mantle wedge, and degassing of mantle CO_2. Five papers discuss the chemical variation in volcanic and hydrothermal gases to reveal mixing of magmatic gases with crustal gases, meteoric ground water and seawater, based on He-Ne isotopic systematics and H, O, and C elemental and isotopic variations. The other five papers enphasize evaluation of analytical gas data, including sampling and analytical techniques of volcanic gases, and the importance of trace metals carried by high temperature volcanic gases and their use in monitoring the activity of volcanoes. For titles and authors of the papers, please see the attached talble of contents.

Ordering information

Extra copies of this special issue can be purchased from The Geochemical Journal, Business Center for Academic Societies in Japan, 16-9-5, Honkomagome, Bunkyo-ku, Tokyo, 113, Japan. Facsimile number 81(3)5814-5822. Each copy costs ¥4000 plus postage and handling charge depending on how it is paid. For orders placed from outside of Japan, postage is ¥400 for surface mail, ¥1300 for air mail. An extra charge of ¥2500 is required for bank drafts, or ¥300 for credit card payment. Credit cards accepted are Diners Club, Master Card, Eurocard, American Express, VISA or Access. Specify card, card number and expiration date. You may also order it through your local book store.

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Special Issue of the Geochemical Journal

Crater Lakes

The special issue will be issued in 1994 as volume 28 of the Geochemical Journal (journal of the Geochemical Society of Japan). It is a collection of papers presented at an international symposium on "Hazardous Crater Lakes" held in Misasa, Japan from 19-24 October 1992, as part of the second meeting of the International Working Group on Crater Lakes (IWGCL).

The special issue contains 10 papers on latest information on fluid-volcano interactions using crater lakes as a trap or condenser of magmatic volatiles; (1) chemical and thermochemical evaluation of hot crater lake systems like Keli Mutu and Kelut (Indonesia), Kusatsu-Shirane (Japan), Poas (Costa Rica), Ruapehu (New Zealand), and some Italian crater lakes, (2) gas build-up in Lake Nyos, the mechanism of gas outburst, and mitigation of a future similar gas disaster, and (3) records of past volcanic activities from lake sediments (Lake Mashu). From this wide range of subjects, a better understanding of the processes occurring beneath volcanoes and associated lakes was attempted.

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ANNOUNCEMENT
FOR
THE THIRD MEETING OF INTERNATIONAL WORKING GROUP ON CRATER LAKES

This is to notify that the 1995 IWGCL meeting will be held in Russia. The meeting to be held in USA which was agreed at Misasa was postponed to 1996, as a result of negotiation between the US and Russian members (Dr. J.C. Varekamp, Dr. G.L. Rowe and Dr. S.M. Fazlullin). The 1995 meeting will be held in Vladivostok during 17-22 August, 1995, within the 8th International Symposium on Water-Rock Interaction (WRI-8) as one of its scientific sessions. The temporary topic of the session is "Physico-chemical Processes in Volcanic Lakes". The First Circular of WRI-8 will be sent to the IWGCL members soon. The participants in WRI-8 should pay the registration fee which is indicated in the First Circular. Also they should send their registration forms to the WRI-8 Organizing Committee in Vladivostok as soon as possible, preferably by e-mail or fax of which numbers are in the First Circular.

After the final sessions in Vladivostok, we plan to have a field workshop in Kamchatka (23-28 August, 1995) which will be held separately from the excursion of WRI-8. Therefore the cost of our workshop is different from that of the WRI-8 excursion, but it has not been decided yet. It will be announced later in the WRI-8 Second Circular. We plan to visit Uzon Caldera and its vicinity by helicopter and take samples which may be used for international analytical intercalibration of volcanic gases and waters. No financial support for the participants is so far expected.

All correspondence to the Organizing Committee of the Third Workshop should be sent to:

Sergei M. Fazlullin, Institute of Volcanology, 683006, Piip St. 9,
Petropavlovsk-Kamchatky, Russia
E-mail: fazlulin@volcan.kamchatka.su

or

Bokuichiro Takano, The University of Tokyo, College of Arts and Sciences,
Department of Chemistry, Komaba 3-8-1, Meguro-ku Tokyo 153, Japan
E-mail: bokusan@tansei.cc.u-tokyo.ac.jp
Fax: +81 3 3485 2904

Those who wish to participate in this Workshop should send their and their accompanying member's names, mailing address, telephone, fax and e-mail number to S.M. Fazlullin or B. Takano before JUNE 30, 1994 for pre-registration.

CALENDAR OF FUTURE EVENTS

May 23-27, 1994. World Conference on Natural Disaster Reduction, Yokohama, Japan.
Sponsor: United Nations Department of Humanitarian Affairs.
For further information write to: International Decade for Disaster Reduction Secretariat, Palais des Nations, CH-1221 Geneva 10, Switzerland. (Fax: 41-22-755-8695).

July 15-16, 1994. Scientific Meeting on Monitoring and Assessment of Natural Hazards Using Space Technology, Hamburg, Germany.
For further information write to: Ramesh P. Singh, Institut fur Weltraumwissenschaften, Frei Universitat Berlin, Fabeckstrasse 69, W-1000 Berlin 33, Germany. (Fax: 49-30-832-86-48).

July 18-29, 1994. Fifth Field Workshop on Volcanic Gases, Bandung, Indionesia.
Organised on behalf of the IAVCEI Commission on the Chemistry of Volcanic Gases by VSI.
For further information contact: either Dr.A.D.Wirakusumah, Volcanological Survey of Indonesia, Jl Diponegoro 57, Bandung 40122, Indonesia (Fax. 62-22-702-761) or Dr.J.-C.Sabroux, IPSN/DPEI/SERAC-CEA, Batiment 389, F-91190 Gif-sur-Yvette, France (Fax. 33-1-69-085-650).

September 12-16, 1994. International Volcanological Congress - IAVCEI, Ankara, Turkey.
For further information write to: Dr. Ayala Tankut, Organizing Secretary, International Volcanological Congress, Department of Geological Engineering, Middle East Technical University, 06531-Ankara, Turkey. (Fax 90-4-286-86-28)

July 2-14, 1995. 21st General Assembly of the International Union of Geodesy and Geophysics, Boulder, Colorado, U.S.A.
For further information write to: IUGG XXI General Assembly, c/o American Geophysical Union, 2000 Florida Avenue,NW, Washington, DC 20009, U.S.A.

August 17-28, 1995. 3rd. Meeting of the International Working Group on Crater Lakes, Kamchatka, Russia.
For further informatiuon turn to page 43.

August 1996. 4th. Meeting of the International Working Group on Crater Lakes, Crater Lake, Oregon, U.S.A.
Further information [including confirmation of the date and venue] will be circulated in due course by the organiser: Dr.J.C.Varekamp, Department of Earth and Environmental Sciences, Wesleyan University, Middletown, Connecticut 06459-0139, U.S.A.

This is a selection of future events some of which will, I hope, be of interest to I.W.G.C.L. members. For future Newsletters I would encourage members to send me information on meetings which they think might be of interest to other members. - ed.

Guidelines for Authors

1. Format - the Newsletter is printed on A4 paper, camera-ready copy should therefore be prepared so that the text occupies an area which measures 160mm x 250mm. Please remember that this also applies to figures and tables.

2. Layout - the title of the contribution should be followed by the name of the author and the author's full address.

3. Text - text should be single spaced. Where possible contributions should be printed using a 10 point type face, either with uniform spaceing (as in these guidelines) or better still with proportional spaceing. Smaller font sizes tend to illegibility and larger sizes use too much paper.

4. Tables - where appropriate small tables should be incorporated within the text. For preference large tables should use the same type face as the text and, if possible, be prepared so that they can be read in the same orientation as the text.

5. Figures - line drawings should be in black on white and the lettering should be either 10 point or slightly larger. Please note that half tone illustrations cannot be printed.

6. Pagination - pages should not be numbered, contributors who wish to suggest a page order, where figures or tables are used, should do so in pencil and on the reverse side of the paper.

S.J.Freeth
October 1993

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The end of IWGCL Newsletter, No. 7.

Current Research on Volcanic Lakes

Newsletter of the IAVCEI Commission on Volcanic Lakes

No.8 March 1995

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Current Research on Volcanic Lakes is the Newsletter of the Commission on Volcanic Lakes of the International Association of Volcanology and Chemistry of the Earth's Interior. Previous issues of this Newsletter, from no.1 (February 1989) to no.7 (March 1994), were published as the *Newsletter of the International Working Group on Crater Lakes.*

Editorial

I am pleased to be able to draw attention to the report by our Secretary (set out below) concerning the recognition of our Group as an IAVCEI Commission and the consequent change in name from 'International Working Group on Crater Lakes' to 'Commission on Volcanic Lakes of the International Association for Volcanology and Chemistry of the Earth's Interior'.

With the change in name of our Group has come the necessity to change the name of this Newsletter. In the two previous Newsletters I have drawn attention to a problem which would arise with a change in name, in that whilst the previous title 'Newsletter of the International Working Group on Crater Lakes' could be easily abbreviated to 'IWGCL Newsletter' the obvious equivalent 'Newsletter of the IAVCEI Commission on Volcanic Lakes' allows of no such simple abbreviation. Partly to avoid an unmanageable (and unquotable) title and partly to better reflect the contents of this Newsletter, which has tended more and more to be reports on work in progress or recently completed rather than news of work planned for the future (which was part of the original intention of this Newsletter), I have decided, in consultation with members of the Committee, to adopt the title **Current Research on Volcanic Lakes**.

It was recently suggested to me, by Bill Evans, that it might useful to print abstracts of papers to be presented at forthcoming meetings, in this Newsletter. Since abstracts frequently contain information on work in progress which might not otherwise be available and since abstracts in general are seldom seen by people who do not attend the meeting in question this seemed to me to be an excellent idea and one which should be strongly encouraged. It also seemed to me that this could be extended to include not only abstracts for forthcoming meetings but also abstracts of papers which have been presented during the previous year. The reason for this being that few of us prepare abstracts significantly in advance of a meeting deadline and are very unlikely to prepare an abstract specifically to meet the deadline of this Newsletter if the meeting deadline is still some way off. I would therefore like to ask all members to send me abstracts of recent papers especially those of papers on volcanic lakes which were presented at local or specialist meetings which might not have been attended by many of our members.

Improvements in the technology available to me have made it possible for me to print a significant part of this Newsletter on a laser printer using a proportional typeface. The advantages of this, apart from greater clarity, are an increase in the number of words per page with a consequent reduction in the number of pages used and therefore a reduction in printing and distribution costs. However, to take full advantage of this technology I will need to have contributions sent in electronic form. From my point of view the easiest way for me to achieve this would be for members to send the text for their contributions to me by e-mail. That way I can then edit contributions into a uniform format and produce a more polished product. I would therefore like to ask members to bear this in mind when preparing contribution for next year's Newsletter.

It was with very mixed feelings that I recently heard the announcement that one of our more distinguished founder members, Jack Lockwood, would soon be retiring from U.S.G.S. though I understand that he intends to continue working, on those things which interest him, in his new role as an "Emeritus Scientist". Over the years Jack has made a major contribution to our understanding of Lake Nyos and it is my sincere hope that he will continue to take an active interest in the work of members of our group.

S.J.F.

Commission on Volcanic Lakes
International Association of Volcanology and Chemistry of the Earth's Interior

This is the official name of our group from now on.

After a struggle of over 4 years, we were finally recognised as a full commission of IAVCEI in 1993 (see IWGCL Newsletters Nos. 6 and 7). This meant that we needed to decide the official name of our commission and accordingly the name to be used on our newsletter. Considering the importance and necessity of having our new name as soon as possible, I proposed to the 7 steering committee members (excluding myself) of our group that we choose our preference on a new name by ballot through the mail during September and October 1994. "Commission on Volcanic Lakes" was chosen as the name of our commission taking the result of the ballot into account. The name has been circulated through all members of our group for approval during November-December 1994 by mail. since there were no negative comments returned by the deadline set at the end of last December, the above name has been automatically finalised.

The above name had been informed to the President and Secretary General of IAVCEI

Minoru Kusakabe
Secretary

pH profile at Lake Nyos

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It is well established that the CO_2 content of Lake Nyos is unusually high and that it is increasing in a measurable rate. Knowledge on the CO_2 profile as well as the pH profile of the lake is essential to better understand the lake's carbonate chemistry. The in-situ pH profile was first reported by Tietze (1987), but his values (pH=3.7-3.8) are too low for natural lake environments as pointed out by Bernard and Symonds (1989). In this note we will report the preliminary results on in-situ pH and CO_2 measurements made during the November 1993 expedition to Lake Nyos.

In the expedition we used a new CTD (SEACAT SBE 19-01) for conductivity, temperature and pH measurements. The CTD has been adjusted for fresh water and equipped with a pH sensor. Deep waters were collected using a gas bag-attached Niskin water sampler and a syringe sampler (Kusakabe et al., 1989, 1990). Since the total carbonate content ($HCO_3^- + H_2CO_3$) is given in the syringe method, we must subtract HCO_3^- from the total carbonate to obtain H_2CO_3. Fortunately for us, anion composition of the lake water is overwhelmingly dominated by HCO_3^- (>99.8 % on the molal basis below the chemocline), and it can safely be assumed that the HCO_3^- ion bears half of the electric conductivity of the water. Also, it has been known that there is a good linearity between the molality of HCO_3^- and electric conductivity of the water over their entire range of variation (Nojiri et al., 1993), so subtraction of HCO_3^- from the total carbonate determinations is readily achieved on the basis of the CTD data.

Figure 1 compares the pH profile measured with the CTD and that calculated from carbonate equilibria. The calculated pH values have been computed assuming equilibrium dissociation of H_2CO_3 at temperatures in the lake. In the calculation we used the Debye-Hückel activity coefficient for HCO_3^- and the temperature dependent first dissociation constant for H_2CO_3 (Read, 1975). Both profiles co-vary with depth below the chemocline at 44 m, but there is obviously consistent difference between them which amounts to 0.28±0.04 in pH unit. The reproducibility of our pH measurement is better than 0.01 judging from high reproducibility of pH values at a single depth. The pattern of the measured pH profile,

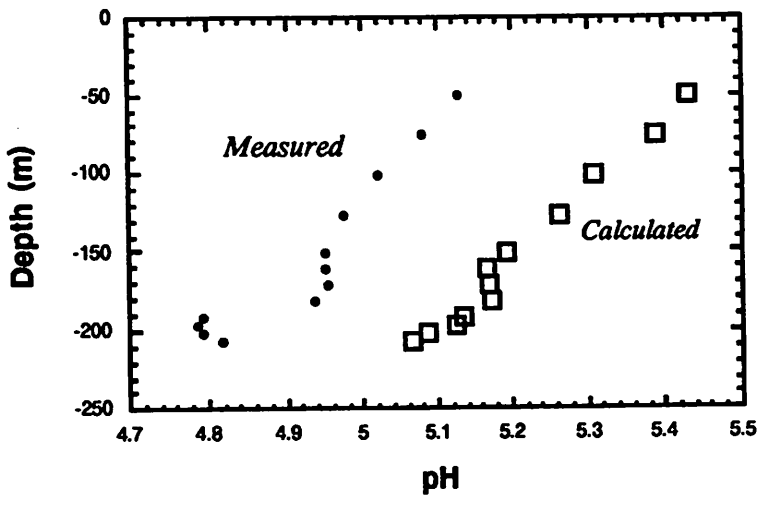

Fig. 1. Comparison of measured (raw) and calculated pH values as a function of depth.

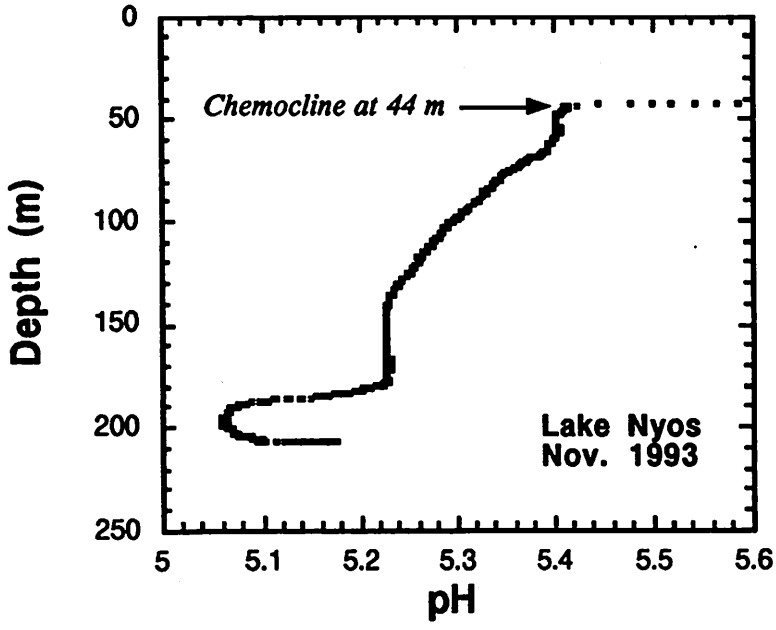

Fig. 2 Profile of corrected pH at lake Nyos in November 1993.

therefore, is considered to represent that of the in-situ values. Thus, addition of 0.28 to the measured pH values to obtain the corrected pH profile may be acceptable. The correction of the pH values by 0.28 may be minimized if the pH sensor is carefully calibrated just before use.

Variation with depth in the corrected pH is shown in Fig. 2. It sharply decreases to pH 5.40 at a depth of 44 m where a chemocline is well developed. Below the chemocline it further decreases rather gradually to pH 5.22 at a depth of 140 m and remains almost constant at this value down to 180 m depth. Below this depth the pH shows a peculiar pattern; sharp decrease to 195 m depth where a minimum is recognized at pH 5.06 and sharp rise toward the bottom where pH=5.18. The sharp decrease below 180 m probably indicates that siderite saturation is reached at >180 m and removal of CO_3^{2-} ion as siderite from the solution has shifted dissociation reaction of carbonic acid rightward, making the solution pH lower. This is consistent with the results of SOLVEQ calculations. At the lake water-sediment interface where abundant siderite is present, a small fraction of the mineral may dissolve by reaction with proton to produce an equivalent amount of Fe^{2+} and HCO_3^-. Production of these ionic species should increase the ionic concentration of the solution, but the difference in pH between the minimum value of 5.06 at 195 m and 5.18 at the bottom corresponds to ionic increase of only 0.002 milli-equivalent/kg, which is very difficult to detect with our current technique.

The corrected pH profile can then be coupled with the HCO_3^- profile to calculate the H_2CO_3 profile of the lake. In the following discussion, dissolved carbon dioxide ($CO_{2\,aq}$ + H_2CO_3) is expressed as H_2CO_3. Concentration of H_2CO_3 was calculated from the following equation;

$$pH = log(a_{HCO3^-}/a_{H2CO3}) - pK_1$$

where a_{H2CO3} and a_{HCO3^-} are activities of carbonic acid and bicarbonate ion, respectively, and pK_1 stands for the first dissociation constant of H_2CO_3. Figure 3 compares thus calculated H_2CO_3 profiles and the measured H_2CO_3 concentrations from the syringe method (this study) and the cylinder method (Evans et al., 1994). It is rather surprising that the H_2CO_3

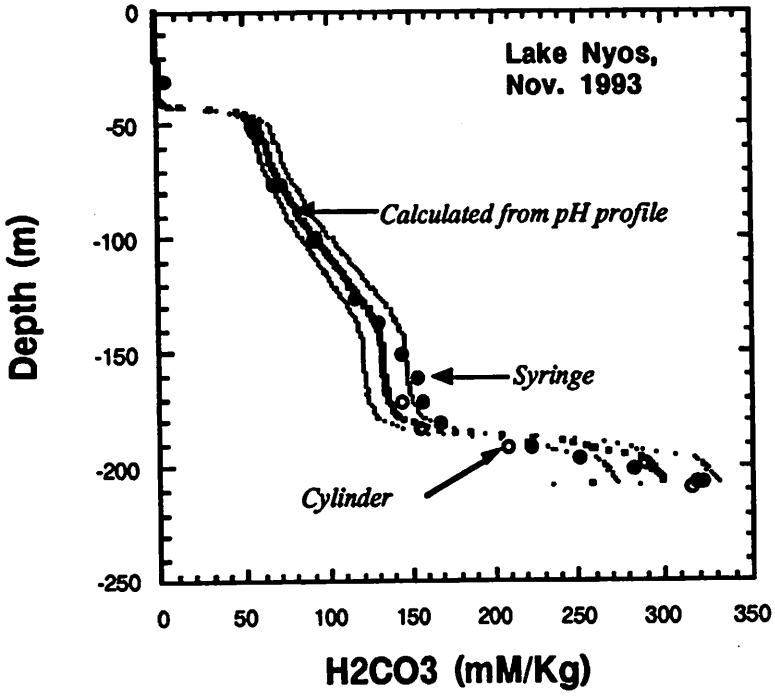

Fig. 3. Comparison of the CO_2 profile calculated from the corrected pH profile (Fig.2) with the measured CO_2 concentrations by the syringe method (solid circles, this study) and the cylinder method (open circles, Evans et al., 1994).

concentrations calculated on the basis of a logarithmic quantity such as pH show satisfactory agreement with the measured values. More importantly the calculated CO_2 profile agrees quite well with the cylinder data which were obtained absolutely independent of the chemical data used to construct the pH-based CO_2 profile. This implies that the above pH correction may be justified. Agreement of the measured CO_2 values by the syringe (November 1993) and cylinder methods (April 1992) is also satisfactory, implying that the rate of CO_2 increase in bottom water is declining, although the syringe data between 150 m and 170 m appear slightly higher than the cylinder data. H_2CO_3 concentrations can also be estimated with high accuracy from the measured conductivity, since there is a good linearity between them.

It has repeatedly been recommended that the gassy lakes in Cameroon should be degassed to avoid future gas disasters (e.g., Freeth et al., 1990, Kling et al., 1994, Villevieille, 1994, Kusakabe, 1995). Recently, artificial degassing of CO_2 from bottom water was successfully attempted at Lake Monoun (Halbwachs et al., 1993) and a similar degassing experiment is being made at Lake Nyos in March 1995. When large scale degassing is performed at these lakes, it is quite essential to monitor the chemistry of the lake water during the degassing in order to assess its effect on possible changes in the thermal and chemical structures, especially that of CO_2, of the lake. As degassing proceeds, rise in pH is expected due to reduction of H_2CO_3 concentration relative to HCO_3^-. Our calculations show that the monitoring can be achieved almost *in real time* and *on site* through the use of carefully calibrated CTD.

Acknowledgements

We thank the Ministry of Mines, water and Power, Cameroon, especially Mr. J. Fonji, for their help in logistics for our November 1993 field trip to Lake Nyos.

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On the speciation of fish in West African crater lakes

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There are at least 34 volcanic lakes in western Cameroon; a few of which were formed by lava flows cutting off shallow basins but the vast majority, including all the deepest lakes, are in volcanic craters. And of these, six are known to contain endemic species of fish, that is species which are not found elsewhere.

My attention was first drawn to the lakes which contain endemic fish in the aftermath of the Lake Nyos disaster, since by its very nature a disaster of the Lake Nyos type would temporarily de-oxygenate the surface water and kill any fish which happened to be in the lake. This was indeed the case with Lake Nyos, which contained a few fish that had survived from an artificial introduction that had taken place a decade or so before the 1986 disaster. It therefore follows that, any isolated lake which contains endemic fish could not have suffered from a Lake Nyos type disaster, at least on the timescale on which it would take fish to evolve into separate species. And consequently such lakes are very unlikely to contain a hazardous quantity of gas at the present time (Freeth, 1992).

More recently my attention was drawn to the rate at which fish might evolve by a study (Schliewen, Tautz & Paabo, 1994) of the mitochondrial DNA of the 11 endemic species of cichlid fish in Lake Barombi Mbo (4°39'N 9°24'E) and the 9 endemic species in Lake Bemin (5°10'N 9°38'E) which concluded that the population in each lake was derived from a single introduction which had then evolved, by sympatric speciation, into the variety of endemic species which are observed at the present day.

It seems to me that if the crater lakes in western Cameroon were all of a similar age and if they all had a similar degree of restricted access (as far as fish are concerned) then the hypothesis that of the thirty or so lakes the two which had been studied by Schliewen and colleagues (1994) both contained flocks of endemic species derived by sympatric speciation from a single introduction would seem thoroughly reasonable. However, the lakes are not of a similar age and the degree of access is very variable.

None of the lakes have been studied in sufficient detail for their ages to be reliably established, but there is every reason to suspect that crater forming events have occurred from time to time over the last 30 million years or so and therefore that most of the crater lakes are probably between a few hundred and a few million years old.

Access to some of the crater lakes would present few problems. For example, Lake Monoun is a 96 metre deep crater lake, a medium sized stream flows in one end, out the other, then for about two kilometres across a flat marshy area and into a major river, the Noun. Monoun was the site of a gas disaster in 1984 (Sigurdsson et al., 1987) which would have killed any fish that were there at the time, yet within less than three years of the disaster there was a thriving population of fish back in the lake. At the other extreme there are lakes to which access would be virtually impossible. For example, the Manengouba lakes are set in a three kilometre

diameter caldera from which there is no external surface drainage. The lakes themselves are in craters on the caldera floor and are at least 60 metres below the lowest points on their crater rims. The water levels in these lakes is maintained by sub-surface drainage within the caldera and the nearest stream of a size sufficient to support fish is well outside the caldera rim!

The six crater lakes which are known to contain endemic species of fish although they vary greatly in area and depth are otherwise similar in character. Lake Barombi Mbo is at least 25,000 years old and may be as much as one million years old, it is 111 metres deep and is drained by a "steep sided outlet stream" (Cornen et al., 1992) which has an average slope of about 12° where it leaves the lake. The outlet stream has cut down by about 100 metres through the crater rim so access will have slowly improved over the years. Lake Bemin (or Beme) is only 15 metres deep and has an overflow at its northern end (Thys van den Audenaerde, 1972) which is connected by a short tributary to the Mbu river. Lake Dissoni (or Soden) is 81 metres deep and has an overflow on its western side (Hassert, 1912) which runs down a gentle slope to the Uve river. Lake Ejagham is 17 metres deep and is surrounded by a low crater wall through which its overflow has cut a 3 metre deep trench (Thys van den Audenaerde, 1967). Lake Barombi Koto is only 6 metres deep and has an overflow to the north-east (Hassert, 1912) which drains down a gentle slope to the Meme river. Lake Bwando (or Mboandong) is a small shallow lake in fairly flat area about 1 km to the south-east of Lake Barombi Koto.

Thus all the lakes which are known to contain endemic fish (with the possible exception of Lake Bwando), despite their variation in other respects, have outlets which flow down more or less gentle slopes to the nearest river.

As far as I am aware all the other lakes in western Cameroon have either no external surface drainage or have outlets which flow down steep slopes or over high waterfalls. It would therefore appear that all the lakes with restricted, but possible, access contain endemic species of fish.

I would not wish to appear to question the genetics on which the conclusions reached by Schliewen, Tautz & Paabo (1994) are based - that the fish are closely related seems beyond doubt. But their hypothesis that the two lakes which they investigated had each recieved only a single introduction of fish would seem to me to be highly questionable. If all the lakes which might contain endemic fish do contain endemic fish then surely it is more likely that fish finding their way from a local river into one or other of these lakes would be a rare event, but not a singular event as far as each lake is concerned. Unless there is some mechanism by which the first successful introduction of fish is able to exclude any subsequent successful introduction.

Rather than a single introduction, followed by sympatric speciation, could I therefore suggest that fish might have found their way into these crater lakes from time to time. There would presumably be one species in the local river which stood a greater chance than the others of finding its way into the lake and if two, or more, introductions took place within a short (in evolutionary terms) interval then the two populations would hybridise with each other. But if there was a large interval between

introductions either due to random chance, or to climatic fluctuation (Giresse et al., 1991), this might allow sufficient time for the two populations to diverge so that the second introduction was unable to hybridise with the first and thus give rise to two separate but closely related species. It would surely be possible to construct a model whereby each endemic species was due to a separate introduction with the relationships between the species being partly due to genetic changes in the river population between introductions and partly to post-introduction genetic changes in the endemic species. However, even though it might be possible to construct such a model, it seems to me that previous models (such as the one proposed by Trewavas, Green and Corbet, 1972) which involve both multiple introduction and sympatric speciation would be easier to reconcile with all the available information, including that concerning the age and geomorphology of the west Cameroonian crater lakes.

The problem of speciation within the West African crater lakes has interesting ramifications, irrespective of whether or not speciation took place entirely within a particular lake. The endemic species in a lake have presumably evolved since that lake was formed and therefore if the age of a lake were known it would place an upper limit on the time available and consequently a lower limit on the rate of genetic change.

For the evolutionary geneticists to take full advantage of the powerfull techniques available to them they need to have a propper appreciation of the context within which the species they are studying have evolved. In the case of the West African crater lakes very little is known, for certain, about their age and, as far as I am aware, there have been no detailed studies of thr geomorphological evolution of any of them. If only we had more information on the ages of the lakes and on the geomorphology, not only of those lakes which contain fish but also on those into which fish have failed to find a way, we might have the context for a far moreinteresting evolutionary study than would be possible at the present time. When the International Working Group on Crater Lakes was set up one of our stated aims was to foster collaboration between scientists working in different disciplines and it seems to me that here we have an excellent example of an interesting problem which would benefit from just such a multi-disciplinary approach.

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Monticchio crater lakes (Italy): hazardous CO_2 reservoir?

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Introduction

Crater lakes pertaining to Quaternary Italian volcanoes have been recently investigated, and their chemical compositions have been considered with reference to possible residual anomalies associated to past volcanic activities (Martini et al., 1994).

Monticchio lakes, hosted in the crater of Vulture, the southernmost peninsular volcano of Italy, are here taken into account, and the chemical characters of the 38m deep Piccolo lake appear as profitably compared with those from other Italian lakes of similar depths; accordingly, Lakes Vico, Nemi, Martignano, and Averno, already considered by previous investigation, are taken as terms of reference.

Monticchio lakes belong to the Vulture Polygenic Volcanic Complex, located at the intersection of two fault systems (Cristofolini et al., 1985). A mainly explosive activity started at about 1My, with pyroclastic flows and effusive events; a second phase characterised by large plinian activity, flows and lahars, and a final stage consisting of thick lava flows and domes, then followed (La Volpe et al., 1984; Guest et al., 1988; Brocchini et al., 1994). Large hydromagmatic episodes, producing two maar-like craters, are dated at about 0.04 My (Watts, 1985) although more recently Laurenzi et al. (1993) suggested 0.13 My for the Monticchio lakes pyroclastic units.

The volcanic products are strongly undersaturated, and typically contain haüyne with subordinate leucite; their bulk chemical characters change from initial phonolitic-trachytic to final tephritic-foiditic compositions (Hieke Merlin, 1967; La Volpe et. al., 1984; De Fino et al., 1986). A carbonatitic-melilitic event has been suggested as possibly related to the diatreme-forming explosive activity (Principe and Stoppa, 1994).

Experimental data.

The sampling and the analytical procedures followed during this investigation are substantially the same as reported in Martini et al. (1994). In particular, the collection of the samples has been carried out along a vertical profile above the deepest point of lake bottom.

Water samples in closed containers have been collected at different depths; samples for the determination of dissolved CO_2 have been stored in glass bottles containing a Na_2CO_3 solution.

Temperature, pH and dissolved O_2 have been measured at the surface. The analytical methods include automatic titration, ion-chromatography, potentiometry, and atomic absorption spectrophotometry.

Table 1 gives the analytical results from Monticchio lake, as well as from springs pertaining to the same volcanic system (Fig. 1).

Discussion

Besides the chemical data obtained for the samples collected at different depths, expecially interesting information appears to arise from the comparison of the observed values for temperatures, pH, CO_2 and NH_4, with those previously obtained for other lakes here considered.

The constant pattern of temperature with depth (Fig. 2) allows to neglect any thermal input at the lake bottoms. The decrease of pH with depth, as the result of CO_2 increase, appears similar for Monticchio and Averno (Fig. 3), but the concentration of CO_2 in the deeper samples (Fig. 4) represents a much more striking evidence for Monticchio. This effect can derive from decay of organic material, to which also the increase of NH_4 can be ascribed (Fig. 5). On the basis of the data in Table 2, however, this explanation appears as not fully convincing; in fact, the values of CO_2 and of the $CO_2/(HCO_3+CO_3)$ ratios indicate for Monticchio a quantitative contribution of CO_2 at depth which cannot be easily justified by this mechanism. A gaseous input through the lake bottom could be considered as a better

explanation, by also taking into account that several springs uprising in the area have significant CO_2 concentrations as well (Tables 1 and 3).

Lakes Vico, Martignano, Nemi and Averno are characterised by flat bottoms (Figg. 6 and 7) ascribed to undisturbed sedimentary refilling (Martini et al., 1994); the funnel-like shape, and the relatively high average depth/diameter ratio for Piccolo lake (Table 4; Fig. 6), can fit a substantial "cleaning" by fluids emitted at depth.

If we consider the recent disasters produced by degassing from crater lakes (Sigurdsson et al., 1987; Sigvaldason, 1989), the higher CO_2-potential possibly associated to Monticchio with respect to the other lakes, while not representing an actual impeding risk, yet reconfirms that lacustrine basins at Quaternary volcanoes deserve some degree of attention when planning measures of civil protection against natural hazards.

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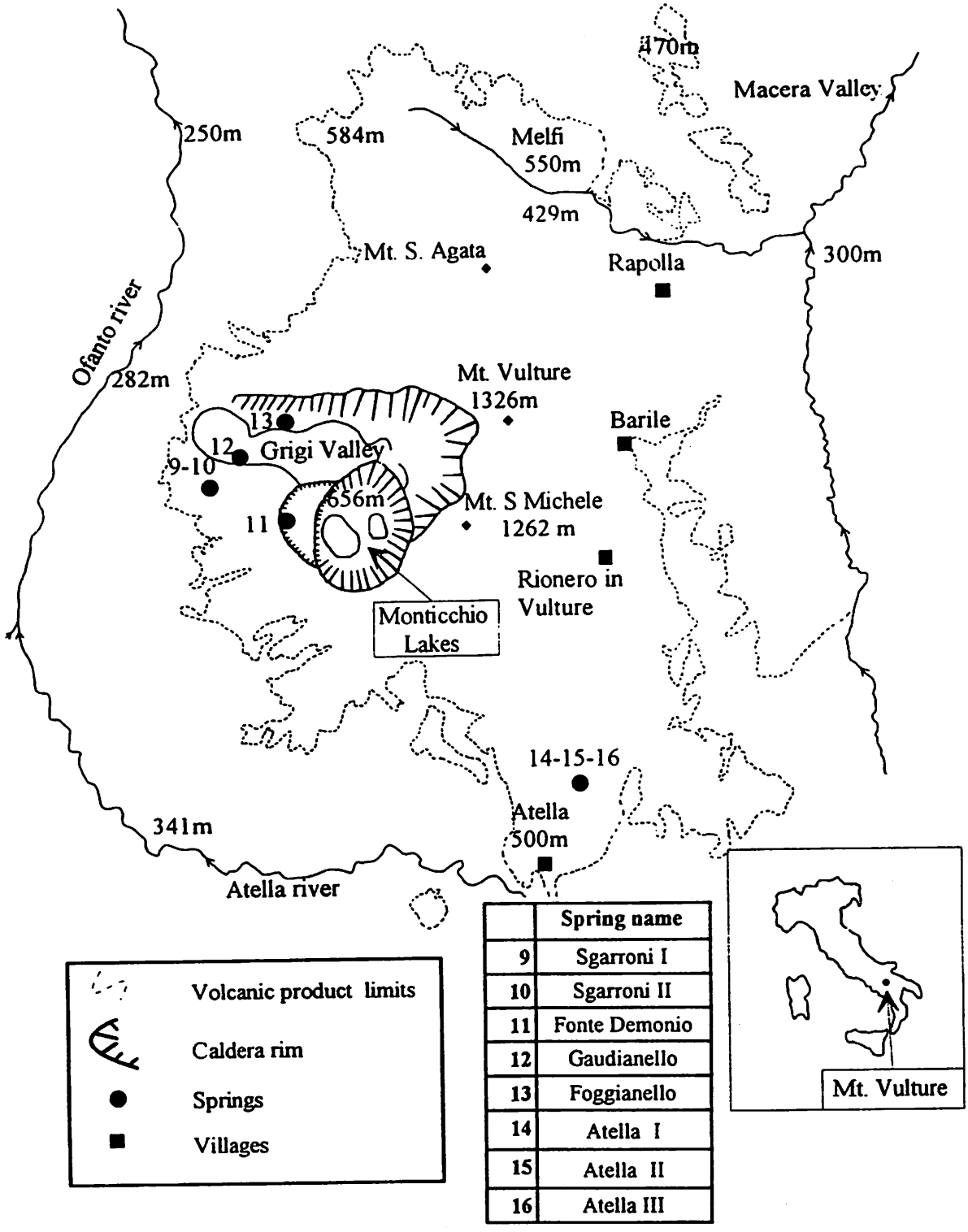

	Spring name
9	Sgarroni I
10	Sgarroni II
11	Fonte Demonio
12	Gaudianello
13	Foggianello
14	Atella I
15	Atella II
16	Atella III

Fig.1.Geological sketch map of Mt. Vulture area (simplified after Guest et al, 1988).

	Depth	T	pH	Cond.	O_2	O_2 %	Na	K	Ca	Mg	Alk.	Cl	SO_4
L. Piccolo	0m	13.6	7.49	0.34	6.13	54.7	33	23	33	6	177	22	17
L. Piccolo	-10m	13.6	7.22	0.34	5.89	52.5	34	22	34	7	177	24	12
L. Piccolo	-20m	12.3	6.35	0.43	2.5	21.8	40	25	34	13	528	22	9
L. Piccolo	-30m	13.8	6.4	0.52	1.42	12.7	39	27	44	13	647	23	8
L. Piccolo	-35m	13.6	6.35	0.98	1.72	15.2	40	28	50	14	860	22	6
L. Piccolo	-39m	13.5	6.61	1.03	2.03	18	54	29	48	12	982	21	4
Sgarroni I		20.1	5.9	1.42	1.1	14.6	133	40	153	55	952	350	20
Sgarroni II		19.5	5.91	1.32	2	20	97	37	200	63	1,135	473	26
Demonio F.		17.3	6.18	2.89	1.1	10.5	390	192	370	75	2,025	102	437
Gaudianello		16.1	5.97	1.33	5.13	48.5	95	38	168	43	775	42	138
Foggianello		17.6	6.98	0.49	7	68.7	66	23	88	21	293	203	4
Atella I		18.1	8.1	0.49	9.52	94.1	20	12	50	11	206	27	5
Atella II		18.9	5.88	0.94	3.15	31.5	104	23	110	37	497	37	150
Atella III		17.6	6.84	16.6	3.55	34.7	5,137	775	270	130	8,784	1,064	4,536
		°C		mS/cm^2	ppm		ppm						

	Depth	CO_2	NH_4	Li	Fe	NO_3	PO_4	Br	F	B
L. Piccolo	0	73	0.08	<0.01	0.04	0.7	<0.01	0.04	0.22	8
L. Piccolo	-10	84	0.08	<0.01	0.05	0.45	<0.01	0.06	0.19	7
L. Piccolo	-20	661	10.71	<0.01	45	0.11	<0.01	0.1	0.12	19
L. Piccolo	-30	851	17.91	0.02	15	<0.01	0.02	0.15	0.11	20
L. Piccolo	-35	896	34.74	<0.01	21	<0.01	0.02	0.26	0.06	23
L. Piccolo	-39	1,117	47.7	0.02	45	<0.01	0.03	0.33	0.06	37
Sgarroni		1,347	0.15	0.13	0.11	0.33	<0.01	0.09	0.05	40
Sgarroni II		1,893	0.09	0.09	0.02	0.44	<0.01	0.1	0.05	39
Demonio F.		1,490	0.29	0.46	0.01	0.4	0.1	0.38	0.03	100
Gaudianello		941	0.05	0.08	<0.01	0.06	0.03	0.1	0.09	24
Foggianello		41	0.06	0.05	<0.01	0.92	<0.01	0.02	0.15	26
Atella I		50	0.08	0.03	0.01	0.41	<0.01	0.02	0.07	8
Atella II		1,380	0.07	0.11	<0.01	0.04	0.03	0.15	0.08	35
Atella III		1,958	10.89	2.1	0.61	1.04	<0.01	0.47	0.49	2,195
		ppm								

Table 1. Physical characters and chemical compositions of Monticchio Lake and of representative springs around the studied area (see Fig. 1).

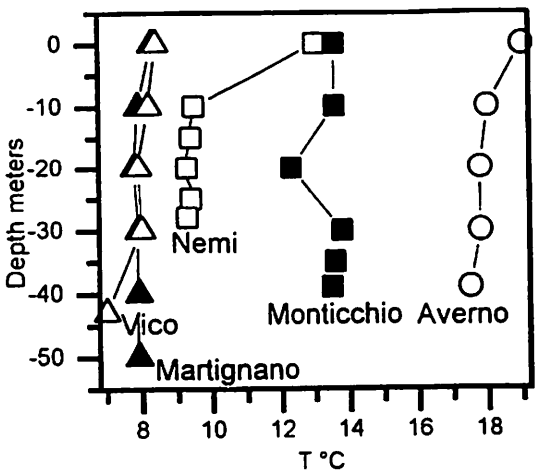

Fig. 2. Temperature profiles for Monticchio Lake (this study) and for other Italian crater lakes (Martini et al., 1994).

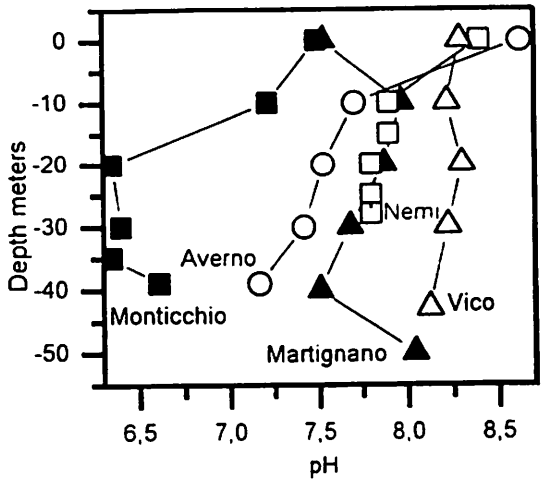

Fig. 3. pH profiles for Monticchio Lake (this study) and for other Italian crater lakes (Martini et al., 1994).

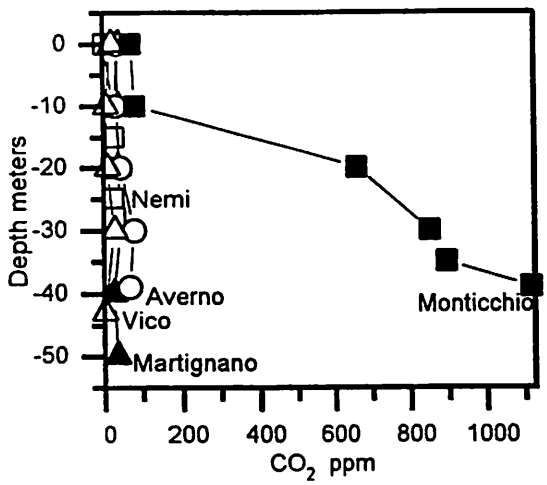

Fig. 4. CO_2 profiles for Monticchio Lake (this study) and for other Italian crater lakes (Martini et al., 1994).

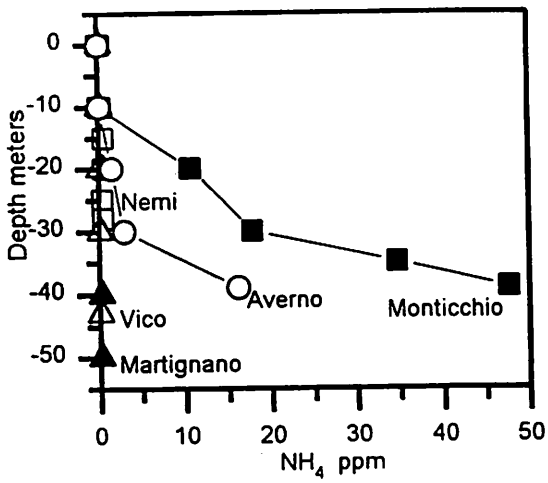

Fig. 5. NH_4 profiles for Monticchio Lake (this study) and for other Italian crater lakes (Martini et al., 1994).

	Depth	NH_4	CO_2	R*
Nemi	0	0.27	9	0.05
	-27m	0.56	30	0.16
Vico	0	0.18	21	0.14
	-40m	0.31	13	0.08
Martignano	0	0.14	41	0.27
	-50m	0.16	35	0.23
Averno	0	0.09	36	0.11
	-38m	16.2	68	0.10
Monticchio	0	0.08	145	0.41
	-38m	47.7	1238	1.13
		ppm	ppm	

Tab. 2 - Distribution of NH_4 and CO_2 in the different lakes (values in ppm). as well as of the CO_2 / HCO_3+CO_3 ratios (R*).

Spring	R*
Sgarroni I	1.41
F. Demonio	0.73
Gaudianello	1.21

Tab. 3 - CO_2 / HCO_3+CO_3 ratios (R*) in cold springs uprising around Vulture volcano.

	Surface Area	Volume	Max Depth	Avg Depth	D*
Nemi	3.8	0.065	31	18	0.013
Vico	12.1	0.261	48	22	0.011
Martignano	5.3	0.151	52	28	0.011
Averno	1.3	0.038	38	29	0.023
Monticchio	0.5	0.016	38	33	0.111
	km^2	km^3	m	m	

Tab. 4 - Physical characters of the different lakes. D*: Average depth / Diameter.

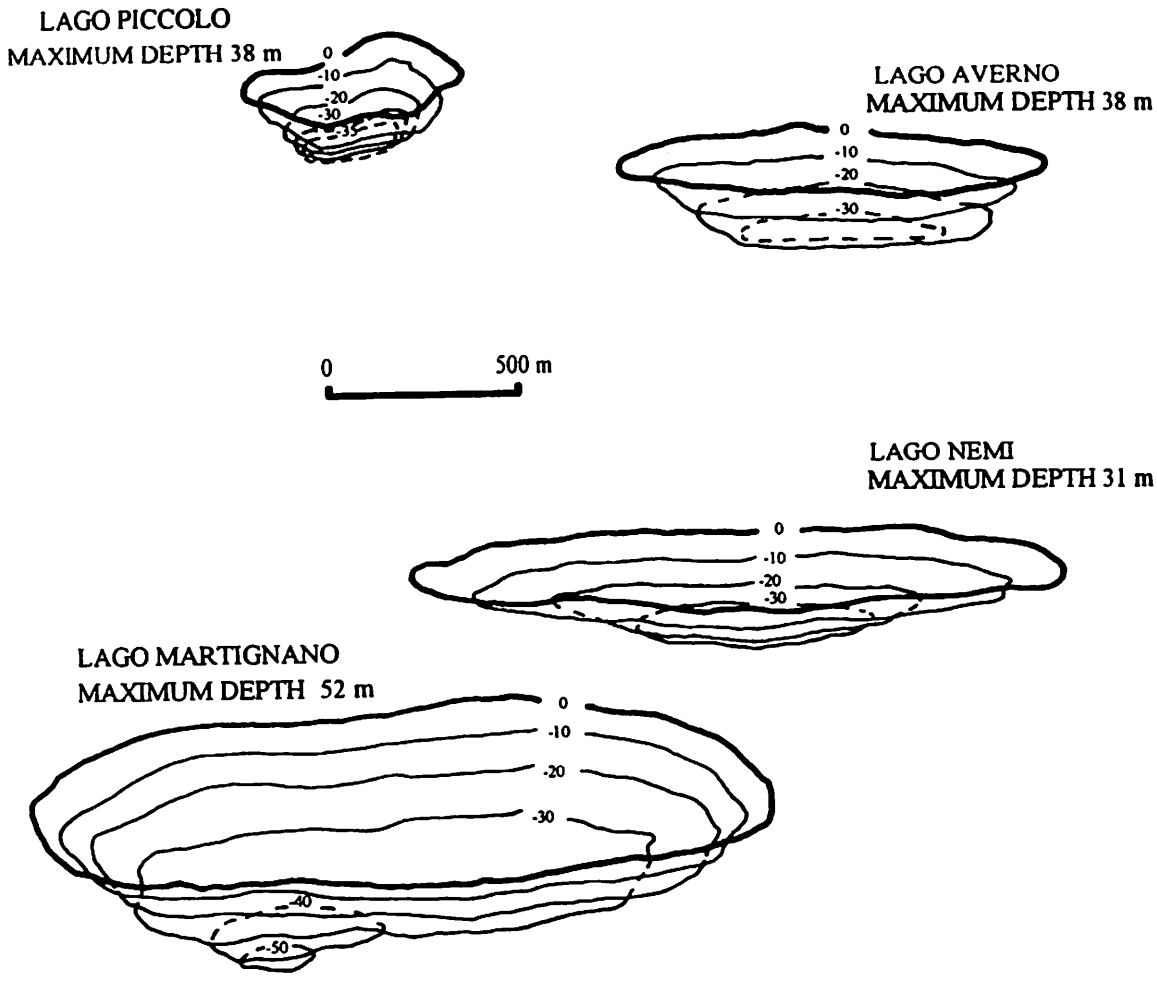

Fig.6. Reconstruction of the shapes of Monticchio (present study) and Averno, Nemi, Martignano lakes (Martini et al, 1994). Exaggerated vertical scales.

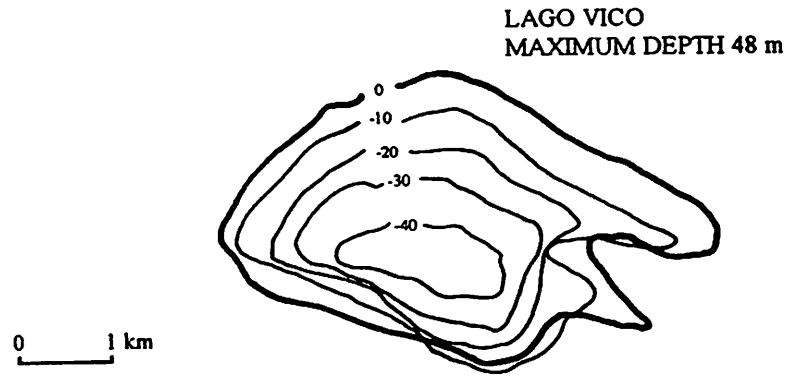

Fig.7. Reconstruction of the shape of Vico lake (Martini et al, 1994). Exaggerated vertical scale

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WORKSHOP ON THE INVESTIGATION OF CRATER LAKES IN INDONESIA
17-18 July 1994, Bandung

On August 21, 1986 a huge volume of carbon dioxide burst out from Lake Nyos, Cameroon. More than 1700 people and a large number of livestock were killed by asphyxiation. The event drew wide attention of scientists as well as Government authorities in Cameroon as a catastrophe which has never been recorded with any scientific knowledge on such scale. It was recognized that a similar event with 37 casualties had taken place 2 years prior to this event at Lake Monoun located 100 km south of Lake Nyos. The International Conference on Lake Nyos Disaster was thus convened by UNESCO in Yaoundé, Cameroon, 16-20 March 1987 to identify the cause and mechanism of the disaster and to discuss the preventive measure of such disaster. The Conference concluded that the gas came from a deep-seated volcanic reservoir along the Cameroon Volcanic Line which has been active for several million years. The identification of mechanism of the burst, however, needed further study. Through studies carried out by international teams and through discussions at several international workshops, the scientific view was consolidated that the source of the gas burst was a large volume of carbon dioxide dissolved in the deep part of the crater lake. As a consequence, a preventive measure for such gas burst has been explored by installing a simple controlled degassing system. Furthermore, it has been proposed that the carbon dioxide gas pumped out from the bottom of the lake could be utilized as a precious agent for environmental experiments for the Global Climate Change. Considering the gravity of the disaster and the effectiveness of the preventive measure, the prevention of Nyos type disaster has been adopted as a pilot project of the International Decade for Natural Disaster Reduction (IDNDR).

Since the Nyos type phenomenon has not been known in Indonesia, crater lakes in Indonesia have not been investigated systematically in view of Nyos type disaster. However, a disaster caused by explosion of carbon dioxide occurred in Simila crater in Dieng, Indonesia, which killed 149 people in 1979. Although the mechanism has not been elucidated yet, the event was considered to be caused by a trapped carbon dioxide gas resulting from volcanic activities.

With the concern of the potential of such a disaster in Indonesia, the Volcanological Survey of Indonesia and the Research and Development Center for Limnology of the Indonesian Institute of Sciences in cooperation with UNESCO and international scientific community convened the Workshop on Investigation of Crater Lakes in Indonesia in Bandung, 17-18 July 1994. The purpose was to introduce the state-of-the-art in the development of studies on Nyos type disaster, and to discuss a workplan for investigation of such a possibility in Indonesia. The Workshop was attended by Indonesian scientists from the volcanological, limnological and environmental field, and international experts from France, Italy, Japan, New Zealand, Russia and the USA. Dr. W. Tjetjep, Director of the Volcanological Survey of Indonesia, in his introductory remarks identified 63 crater lakes existing in Indonesia. Mr. P. Hehanussa from the Research and Development Center for Limnology further pointed out that 14 lakes, not necessarily crater lakes, are deeper than 100 meters which fits the primary condition for the Lake Nyos type gas accumulation. The Workshop was followed by presentations of the results of studies on the Lake Nyos disaster by two international experts. It was overwhelmed by an enthusiasm to learn a new scientific finding and to apply the scientific results to Indonesian crater lakes.

The conclusions of the Workshop are summarized in the following recommendation.

RECOMMENDATION

The Workshop on the Investigation of Crater Lakes in Indonesia, 17-18 July 1994, Bandung:

Recalling the catastrophic event which took place at Lake Nyos, Cameroon, 1986, killing more than 1700 people,

Learning the results of scientific research that the catastrophe was caused by sudden exhalation of carbon dioxide gas dissolved in the deeper part of the crater lake,

Learning also the fact that this singular phenomena is particular to deep crater lakes in tropical and volcanic area,

Learning further the fact that an effective measure to prevent such a disaster has been already explored without significant cost,

Recognizing that Indonesia is situated in tropical and tectonic active area, and therefore numbers of crater lakes exit in its territory which might have a potential risk of the Nyos type disaster,

Being aware and concerned of unprecedented consequences of such disaster which might occur in densely populated areas,

Acknowledging the fact that these lakes in Indonesia have never been systematically investigated in this specific point of view,

Recalling the spirit of the International Decade for Natural Disaster Reduction (IDNDR) which calls for international cooperation for disaster reduction by best utilizing available technology,

Urges the Volcanological Survey of Indonesia, the Research and Development Center for Limnology and other relevant institutes in Indonesia to cooperate in the inventorization of deep crater lakes with appropriate field survey, and, if necessary, identify appropriate disaster prevention measure,

Invites relevant international scientific bodies such as the International Working Group on Crater Lakes, the United Nations and its specialized agencies, such as UNESCO, and international funding agencies to support the Indonesian initiative.

Scientific Background

Seven years of geophysical, geochemical and limnological survey of Lake Nyos and Lake Monoun since 1986 have revealed that these lakes have a permanent recharge system which provides dissolved CO_2 as well as various chemical species in the form of spring issuing at the bottom. On the other hand, meteoric water from the tropical precipitation constitutes the inflow and outflow at the surface.

Deep volcanic lakes in tropical region, in general, are thermally stratified separating warmer, therefore lighter water near surface and cooler, therefore denser water near bottom. Solution of carbon dioxide is denser than pure water. If sufficiently cool CO_2-charged mineralized water is supplied at the bottom of such lakes, stratification becomes even more intensified, thereby CO_2 accumulation takes place. When a gas-rich deep layer becomes close to the saturation, any kind of disturbance may trigger effervescence that eventually results in a violent degassing of the whole layer. Consequently, the released CO_2 gas will flow down valleys and asphyxiate human being and animals on its path before being dissipated in the atmosphere.

In order to detect such risk, thermal and chemical stratification of deep lakes should be surveyed. Use of a CTD (conductivity-temperature-depth profiler) or combination of temperature measurement by thermister and chemical analysis of water samples collected from various depths will be relevant. Lowering down a simple garden hose to the bottom of the lake may suffice to prove the lake water is gas-free or not. When necessary, bathymetric survey should be carried out. The criteria for rating priority in the survey shall be 1) lakes in high population areas; 2) lakes with a high depth to surface area ratio and; more generally, lakes deeper than 80m; 3) lakes in tectonic settings that allow generation and rise of CO_2, i.e. , zones of crustal extension (basaltic volcanism) and comparatively low heat flow.

A method for controlled extraction of CO_2 gas through self-siphoning has been explored and tested at Lake Monoun. When water reaches a level where the hydrostatic pressure is equal to the partial pressure of CO_2, bubbles appear. The bubbles dynamically push up water in the tube, which is eventually called as self-siphoning. In principle, no significant cost is incurred for this work except sufficient length of pipe and initial cost for the operation.

The global change of CO_2 in the atmosphere was one of the important subjects of discussion at the Agenda 21 of the United Nations Conference on Environment and Development (UNCED), Rio de Janeiro, June 1992. Scientifically, how the global change of atmospheric CO_2 will affect the biosphere is not fully understood, particularly regarding the effect on tropical vegetation and forest. It has been proposed that the extracted CO_2 gas through self-siphoning could be used for an experimental CO_2 controlled greenhouse. Since the CO_2 content needs not reach the critical point of causing gas burst, higher possibility exits to find lakes storing a sufficient volume of CO_2 for such experiment.

Another type of gas related disaster occurred in highly populated Dieng Volcanic Plateau. A CO_2 gas trapped near surface burst out at Sinila killing 149 villagers in 1979. A thorough program for investigation of the accumulation of CO_2 and other poisonous volcanic gases near surface of hydrothermally active areas should also be carried out.

Workplan for Inventorization of Deep Volcanic Lakes in Indonesia

1. Criteria for selection of lakes

   - genetic relation to volcanoes
   - depth greater than 80 meters
   - low heat flow area (excluding volcanic lakes)
   - soda springs or any other evidence of CO_2 release in the area
   - high population density around the lake

2. Institutes to be involved

- Volcanological Survey of Indonesia
- Research and Development Center for Limnology, the Indonesian Institute of Sciences

3. International Cooperation

- UNESCO (secretary)
- Japanese scientific team
- French scientific team

4. Action Plan:

immediate start:

Compilation of literature
creation of a comprehensive list of lakes;
selection of crater lakes and lakes filling volcano-tectonic depressions (Kivu Type);
Establishment of priority list (about 20 lakes)

by the end of 1995:

Completion of a few pilot studies

within a few years:

Completion of inventorization of deep volcanic lakes in Indonesia and establishment of a new workplan for disaster reduction and/or proposal of activities which might be reduced from the inventory

Epilogue to the Workshop

According to the conclusion of the Workshop, relevant bodies are searching a way to materialize the Recommendation within their capacity. Since the investigation extends both volcanological and limnological aspects, the project will be implemented in close cooperation between the Research and Development Center for Limnology (Center), and the Volcanological Survey of Indonesia (VSI). It is anticipated, however, that the survey will be lead by the Center because of the logistic reason. So far, much attention has not been paid on this project at the side of the Center due to the presently undergoing movement and expansion of the Center. According to Mr. P. Hehanussa, the Center will soon start field investigation at the Lake Toba. He said the Crater Lake project will be incorporated in the workplan. Dr. Kusakabe, Okayama University, proposed that the university could send his students to collaborate with Indonesian counterpart. UNESCO Office, Jakarta may provide modest fund for this initiative. The fund to carry out the project is still insufficient. It is the hope of all those concerned that the investigation could be a forum for exchange of information and expertise particularly among two institutions in Indonesia and international teams from France and Japan. Practically, since full fledged field activities may not take place during the rain season (November to May), we have some more time to find a good solution for the initiation of the Project.

December 27, 1994

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Abstracts of papers to be presented to a Joint IAVCEI/IAHS Symposium on Volcanic Crater Lakes at the 21st General Assembly of the International Union of Geodesy and Geophysics, Boulder, Colorado, July 1995.

Eruptions of pyroclastic sulphur at crater lake of Copahue volcano, Argentina.

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Copahue volcano (2930 m) is located in the southern volcanic zone of the Andes (37° 45' S 71° 18' W). The active cinder cone is situated in its summit and contains a circular crater lake 250 m in diameter and of unknown depth. The crater lake is filled by continuous input of meteoric water and glacial melt. Pure water interacting with exsolved magmatic gases (HCl, SO_2, H_2S) produces acid sulpha-chloride hot (25°-100°) crater lake of extremely low pH (0.1-0.2). Water also contains dissolved silica and cations like Mg^{++}, Ca^{++}, Fe^{+++}, Na^{+} as a result of interactions with the wall rocks. In 1992 began an eruptive cycle characterized by sporadic phreatic explosions which generated tephra fall deposits and lahars as a consequence of the ejection of hot water from the crater lake onto the snowpack mantling the volcano. About 30 percent of the erupted material is pyroclastic sulphur making Copahue the second terrestrial volcano - the first was Poás (Costa Rica) - that erupted sulphur in this form. Sulphur particles are greenish coloured and most of them resemble basaltic scoriaceous lapilli and ash in shape, but tiny spheres and other forms are also present. Some fragments include pyrite crystals. Fragments show x-ray diffraction peaks of orthorhombic elemental sulphur and SEM show well developed bi pyramidal crystals some of them fused together. In the laboratory they melted at 116°C. Chemical composition is 98% S, 2% Fe, with some trace element content Se 270 ppm, As 160 ppm and Au 48 ppb.

The utility of heat and mass fluxes at Lake Nyos, Cameroon

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Many studies of volcanic crater lakes have used mass and heat fluxes to examine conditions beneath the lake that are inaccessible to measurement, such as degree of access of lake water to magma and even likelihood of an eruption. In several detailed studies, cycling of lake water down into the volcano and back up into the lake has been considered important. In these cases, sufficient heat to drive such a convective system is provided by magma or hot rock, heat sources seemingly not present at Lake Nyos, Cameroon. Nevertheless, the chemical, isotopic, and temperature data collected in six years of monitoring this lake after the massive release of CO_2 in 1986 strongly suggest that sub-lacustrine circulation is important. A large

increase in bottom water salt load (3 x 10^6 kg) after the gas release demonstrated an inflow of mineralised water (1.9-2.4 ppt TDS). However, rapid horizontal mixing in this strongly stratified lake made it unclear whether the inflow was spread diffusely over the lake bottom or concentrated at discreet vents. Inferences about the incoming fluid are based entirely on its effect on bottom water.The evolution of bottom water is consistent with inflow of fluid that is qualitatively similar to existing lake water; specifically, very high in ferrous iron (≥150 ppm) and isotopically shifted slightly along an evaporation trend from local meteoric water. Because a likely cause of the high iron and the isotopic enrichment is prior residence within the lake, the major part of the inflow fluid is apparently recycled lake water. The net heat flow into the lake seems too low to drive convection but does correspond closely with the heat of solution of CO_2 gas at its measured recharge rate (2.5±0.5 x 10^8 mol/a). This correlation suggests that inflow is controlled mainly by gas-driven convection below lake bottom rather than by alternative possible mechanisms, such as local hydraulic gradient, seasonal changes in lake level, or simple diffusion.

A numerical simulation of the temperature and CO_2 structure in Lake Nyos

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A one-dimensional model of the vertical structure of Lake Nyos is formulated and applied to simulate the temporal evolution of CO_2, temperature and dissolved solids. The model incorporates an advanced second-moment turbulence closure model of mixing in the lake. It is initialized by conditions observed immediately after the disastrous outgassing event in 1986 and integrated forward for 10 years, forced by seasonally modulated heating and nocturnal cooling, and heavy summer-time precipitation at the surface. The effect of inflowing stream on the density structure is included. Carbon dioxide, heat and dissolved matter input from bottom sediments are prescribed.

Several scenarios are investigated. The base run consists of the normal heating/cooling/rain cycle at the lake surface and steady diffusion of heat, CO_2 and dissolved matter at the bottom. It shows that the CO_2 builds up quite rapidly in the bottom layers (3-4 years). These layers are highly stable however. There is a seasonal modulation of properties in the upper 30-40 m but the middle layers do not change much. These results are consistent with observations of the lake since the disaster.

Anomalous scenarios investigated with the model included a secular cooling trend, anomalously large cooling and precipitation during summer for two years in a row, and a temporary disruption of the CO_2 input at the bottom. The results suggest that it is difficult to overturn the lake from the top under reasonable anomalous scenarios of events at the lake surface. However even a temporary cessation of CO_2 input at the bottom rapidly destabilizes the bottom layers and could lead to intense mixing there and possible outgassing of CO_2 from the lake. Careful analysis of the measurements in the lake since the disaster support this hypothesis. However, the exact cause of disruption of the normal course of events at the bottom is not quite clear.

Chemical characters of crater lakes at quiescent volcanoes

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Lakes hosted in craters can act as condensers of fluids emitted from deep volcanic systems and the chemical analysis of lake waters can provide information about the gaseous flows towards the surface.

The available data from previous experiences at active volcanoes (e.g. Ruapehu, Poas, Galunggung, Kusatsu-Shirane) indicate rater close correlations between the degassing extent from the underlying magmas and the chemical composition of lake waters. Something similar, however, should apply even to quiescent volcanoes and to water bodies of limited extent, and useful information should also be derived from water pools pertaining to recently active volcanic systems. Generally speaking, wherever gaseous species emitted by volcanic systems bubble through surface water bodies, the physico-chemical characters of the solutions are expected to provide hints about the processes in progress at depth.

Eruptive events can be considered as the main impending risk for people living in volcanic areas, but the recent disasters produced by degassing lakes suggest a careful consideration of hazards even without true volcanic activity. The data obtained by systematic investigation of crater lakes and of minor water bodies at volcanic systems, while reconfirming the information available so far, allow the inference of different degrees of natural hazards.

The Lonar crater lake

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The Lonar lake, in one of the largest natural craters of the world, is situated at Lonar (19° 59' N 76° 31' E) in Buldhana district of Maharashtra. The first European to have sen it was Cornet J. E. Alexander in 1823 during the course of a journey through Berar. He communicated a vivid description of it to the Edinburgh Philosophical Journal. The theory and origin of the depression, put forward by Professor Orlebar in 1838 did not receive the attention it deserved. Blanford, Oldham and La Touche were amongst the earliest geologists to have discussed this lake. The circular feature is 2,000 m across and about 135 m in depth, with a shallow lake at its bottom. The lake is spread over 107 hectares and measures 1,200 m across. The crater is located in Deccan basalts which are fine grained, massive, vesicular non-porphyritic types. Venkatesh made a geochemical study of samples of rocks, soils, silts, waters, and plants from the area, particularly for nickel and other metals and concluded that the below average values did not support the meteorite impact theory. Crawford studied the mantle convection pattern under India as calculated by H.-S. Liu that showed two points of upwelling, corresponding to the Lonar lake and the Girnar Circular Complex in Gujarat. He felt that the crater was more endogenic than of impact origin. Gravity and magnetic measurements favoured a crypto-volcanic origin for the crater, associated with a volcanic pipe or a carbonatite plug. Maskelynite found in 1973 from the crater has led to interesting studies of the shock metamorphosed breccias and melt rocks of this crater.

Mineralogy and geochemistry of bottom sedimentogenesis in active underwater hydrothermal systems confined to volcanic calderas

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Recent underwater sedimentogenesis in active hydrothermal systems is noted for a specific combination of intense terrigenous removal, hydrothermal and hydrodynamic factors. This results in the origin of a dynamic multi-component physicochemical system. Its typical feature is variability even within one manifestation. Examples of various system types include Uzon Caldera lakes (Kamchatka) and sea-flooded Ushishir Caldera (Central Kuriles) associated with active post-magmatic hydrothermal systems.

Peculiarities of sedimentogenesis in the volcanic lakes of Uzon Caldera are linked with distinctive hydrochemical zoning which results from mixing of deep high-temperature sodium chloride solutions with superficial waters. Variations in physicochemical conditions of sedimentation and tectonic setting of lakes caused specific mineralogy and geochemistry of bottom sediments. Several different types of sedimentogenesis are identified.

The influence of hydrothermal solutions on the bulk composition of bottom sediments in isolated Ushishir Caldera is significantly reduced and shaded by hydrodynamic factors and by terrigenous removal. The mineral composition of bottom sediments is homogeneous, whereas their hydrothermal component is defined based on behaviour of some elements (first of all Fe, P, Hg and As) that have maximum concentrations at sites of underwater thermal spring discharge.

The subglacial Grímsvötn caldera lake, S-Iceland: chemical thermometry and energy release

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An ice covered crater lake in the caldera of the subglacial Grímsvötn volcanic center, SE-Iceland, is periodically drained by glacial bursts and recharged by hydrothermal fluid, meltwater and precipitation. The draining of the lake occurs when the water level of the lake has reaches the elevation of a subglacial outlet from the caldera. At this stage the crater lake is emptied into the glacial river Skeióará during the subsidence of the ice cover into the caldera. Discharge monitoring of the drained water gives information on the volume of water that accumulated during the recharge period and chemical analysis of the water gives information on the relative amounts of hydrothermal fluid, glacial meltwater and precipitation.

Analysis of the crater lake water thus offers the possibility of estimating the thermal energy released by the volcano during a single recharge period which, on average, lasts about 4 years. The method of resolving the discharged water body into hydrothermal fluid, meltwater and precipitation is based on the application of chemical thermometers. The reconstruction of the thermal fluid is based on the Na/K temperature estimate which is only slightly affected by dilution with glacial meltwater and precipitation. Since the silica content of precipitation and glacial meltwater is close to zero, the silica content of the discharge is assumed to be derived exclusively from the thermal fluid. By calculating a silica content for the thermal fluid based on the corresponding alkali temperature, the absolute volume and heat content of the geothermal component in the discharge can be estimated.

Variation in the chemical temperature for the geothermal fluid and heat content of the discharge has been observed since 1972. A volcanic eruption in the Grímsvötn caldera in 1983 was preceded by an increase in the fluid temperature from about 90°C in 1972 to about 240°C in 1983. In 1991 the temperature had decreased by about 100°C. Variations in the total energy release (amount of meltwater) are not directly related to the temperature of the geothermal fluid. It is suggested that variation in energy release from the subaquatic geothermal system is controlled by crustal inflation/deflation of the caldera floor which controls permeability above the heat source.

Rollover in volcanic crater lakes?

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It is a common experience in natural (e.g. lakes) and engineering environments for seemingly stable stratified fluids (a dense layer overlain by a light layer) to suddenly overturn. What is required to destabilise the configuration is a heat flux from bottom to top of the fluid. the engineering community has attached the name "rollover" to the process. An example is a liquid natural gas (LNG) tank which becomes stratified when a new cargo is pumped into the tank to pond below leftover "weathered" LNG. The configuration is on first glance, seemingly stably stratified. The heavier, new LNG underlies lighter old LNG (which has changed composition hence density through fractional distillation). Heat entering the bottom of the storage tank from the foundations will warm the bottom layer and will eventually destabilise the stratification. Warm LNG, kept liquid under the head of the overlying fluid is suddenly transported to the top where it flashes due to the removal of hydrostatic pressure, leading to violent off-gassing of LNG. This phenomena is quantifiable and is examined here in the context of volatile charged bottom layers of volcanic crater lakes to delineate the conditions in which it could occur in these lakes and the time evolution of the process when it does occur.

Energy-flux balance models for crater lakes

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Some crater lakes survive for decades at relatively constant water level, indicating a balance between their fluid input rates and losses. We investigated the limiting conditions under which crater lakes can exist, constraining some of the mass fluxes by assuming an energy steady state condition. An energy flux balance statement of a crater lake contains the volcanic or geothermal inflow (mass flux and temperature), the conductive heat input from below, radiative heat gains and losses (short wave-length solar radiative input, the radiative heat loss if $T_{lake}>T_{atmosphere}$), the conductive heat loss at the lake surface, evaporative heat losses, and the heat used to raise the temperature of entering meteoric waters. We equate all these fluxes and then solve iteratively for a steady state lake temperature. The dominant parameter that controls the heat dissipation and therefore the lake temperature is lake surface area. The rain fall and catchment area determine the survival potential in terms of hydrological balance. The calculations used an expression that relates the gas temperature to the mass flux of a gas (H_2O with 2 mol % SO_2, 5 mol % CO_2) flowing through a porus medium that is cooled by conduction. Lakes with a radius <50 m can handel only a small gas input (e.g., SO_2 flux<50 tons/day) or they will rapidly evaporate, even in areas with heavy rainfall. Lakes with a radius >250 m are thermally very stable and need major gas input changes to create even small temperature variations. The algorithm provided for a lake with a given diameter at a given set of atmospheric conditions a characteristic steady state temperature for each gas input. Coupling of these results with time series of chemical changes may provide a good test for the validity of the approach. The results may be used as a baseline to assess the potential of eruptions. Once calibrated, lake water temperature measurements may replace SO_2 flux determinations, as carried out at open-crater volcanoes.

Abstract submitted to the IWGCL session of the 8th International Symposium on Water-Rock Interaction, Vladivostock, August 1995

Lake Nyos, Cameroon: explaining the gas release from the system standpoint

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The catastrophic gas releases from the Cameroonian Lakes Nyos and Monoun are certainly two of the most unusual geologic disasters in recent history. In the years following the catastrophic gas release from Lake Nyos, water-column monitoring by several scientific teams has identified CO_2
recharge to bottom waters at a rate well constrained at $2.5 \pm 0.5 \times 10^8$ mol/a. Until recently however, the actual mechanism of gas release (which reportedly killed 1700 people) was poorly constrained, with proposed mechanisms ranging from a sub-lacustrine volcanic eruption to simple lake overturn. Now, the water-column results along with data from climate stations and regional spring and lake sampling have been integrated into a model that better constrains many lake processes, including the mechanism of gas release. Some important features of this evolving model are:

1) The water-column stratification pattern remained after the release strongly suggests that degassing began at a ~50m chemochline, not at lake bottom (210 m).

2) The release became very high-energy (explosive?) only in the final phase, when extremely gas-rich water near lake bottom became involved in the process.

3) During the present recharge period, the annual increase in heat content (1×10^{12} cal) near lake bottom (>175 m) can be accounted for entirely by the heat of solution of CO_2 gas at its measured recharge rate.

4) Isotopic and chemical evidence suggests that there is a net transport of CO_2 only, not water into the lake bottom.

5) Due to evaporation rates of up to 1 cm/day, deepest seasonal mixing of dilute water above 50 m most likely occurs in the dry season months of October to February, not in August when the gas release occurred.

Points 1-3 almost preclude a volcanic eruption or even sufficient sub-lacustrine heat to drive hydrothermal convection. Points 3 and 4 suggest that sub-lacustrine convection is gas driven; bottom water sinks through the sediments, dissolves cold CO_2 from the diatreme, and then returns to the lake. Point 5 limits the possibility that an overturn in surface waters acted as a trigger for the gas release and favours instead random mechanical input such as a landslide or seiche. The value of considering volcanic crater lakes as condensers and calorimeters is exemplified by Lakes Nyos and Monoun even though the flux of heat is very low in these systems.

CALENDAR OF FUTURE EVENTS

July 2-14, 1995. 21st General Assembly of the International Union of Geodesy and Geophysics, Boulder, Colorado, U.S.A.
For further information write to: IUGG XXI General Assembly, c/o American Geophysical Union, 2000 Florida Avenue,NW, Washington, DC 20009, U.S.A.

August 4-14, 1995. 30th. International Geological Congress, Beijing, China.
For further infromation write to : Secretariat Bureau, 30th. International Congress, P.O.Box 823, Beijing 100037, China.

August 17-28, 1995. 3rd. Meeting of the International Working Group on Crater Lakes, Kamchatka, Russia.
For further informatiuon turn to page 40.

August 1996. 4th. Meeting of the International Working Group on Crater Lakes, Crater Lake, Oregon, U.S.A.
Further information [including confirmation of the date and venue] will be circulated in due course by the organiser: Dr.J.C.Varekamp, Department of Earth and Environmental Sciences, Wesleyan University, Middletown, Connecticut 06459-0139, U.S.A.

This is a selection of future events some of which will, I hope, be of interest to I.W.G.C.L. members. For future Newsletters I would encourage members to send me information on meetings which they think might be of interest to other members. - ed.

The 8th International Symposium on Water-Rock Interaction. International field-related workshop devoted to crater lakes, Kamchatka, 23-28 August 1995.

The Workshop is a continuation of scientific session WRI-8 "Physico-chemical processes in volcanic lakes", that will be held in Vladivostok (17-22 August). It is possible to participate only in this workshop.

Scientific program.

It will include 2 main topics:

1. Geochemistry and isotope geology of sulphur in volcanic lakes.

2. Hydrobiology and biogeochemistry of volcanic lakes.

Additionally a discussion about new methods of chemical analyses of complex solutions is planning. During field trips a water sampling with subsequent determinations will be held:

1. Water separated from muddy rest:
pH, HCO_3, Cl, F, SO_4 and other sulphur anions,
H, K, Na, Ca, Mg, Fe, Al - obligatory,
Mn, Pb, Cu, Zn, As, Sb - desirable,
Si, B, C organic, Br, PO_4, Li, Rb, Cs, Sr - recommended.

2. Muddy rest (diameters of particles > 0.4-0.45 micro m):
Cl, F, S(with determinations of sulphur forms),
P, K, Na, Ca, Mg, Fe, Al, Mn, Ti, Si, C org.

3*. Dissolving gases:
O_2, N_2, CO_2, Ar, CH_4, H_2, He, H_2S, SO_2, CH gases

4. Quantitative and qualitative composition of plankton.
Sampling will be conducted by plankton net and bathometer.

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* Water samples for determinations of dissolving gases will be placed into glass bottles with volume 0.5 l.

Results of chemical analyses of water and determinations of plankton composition will be calculated and published in the NEWSLETTER where used methods of sampling is desirable to describe.

Field trips to caldera of Uzon, Chyornoye lake of Central Semyachik volcano, crater lake of Maly Semyachik volcano and Karymskoye lake are planned.

Publications.

Both oral and poster forms of presentations are possible. Organising Committee intends to publish abstracts of these presentations. It will be a limit of two presentations for one participant. Maximal size of abstract is two pages of A4 format. Official language is

English. Title of abstract, name of author, and place of work have to be placed at the top of abstract. They should be sent to Organising Committee before 15 August 1995.

Registration.

Registration form and fee should be sent to Prof. Takano. Registration fee is 100 $ (50 $ for students). This money cover the costs of Abstract Volume, stationery and others during 3 days of Workshop. Total pricing for one person is expected to be 800-900 $. Travel by bus and helicopter, accommodation and meals are included in this cost.

Scientific session.

It will be held from 23 to 26 August 1995 at the field base of Institute of Volcanology in the caldera of Karymsky volcano. Reception of participants will be from 10 a.m. 22 August to 12 a.m. 23 August at Petropavlovsk-Kamchatsky airport. Participants of WRI-8 in Vladivostok will be registered there. Slides 35 mm, OHP and videotapes VHS are possible to use at the presentations.

Weather conditions.

The weather at Kamchatka is very changeable. In August average temperature during daytime doesn't exceed 10-15°C, at night - 3-5°C. There are frequent rains and fogs. So your clothes should be water-proof, wind-proof and warm. During field trip you will sleep at your sleeping bag. So it is necessary to take with you sleeping bag and light rug under it.

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Guidelines for Authors

Contributions may be submitted either in electronic form or as camera-ready copy, the former is preferable since it allows copy to be edited into a common format.

Electronic copy:

1. Format - copy may either be sent on a disk (most commonm formats are acceptible, but if in doubt please check with the editor) or preferably by e-mail.

2. Layout - the title of the contribution should be followed by the name of the author and the author's full address.

3. Text - if sent by e-mail should be left justified only.

Camera-ready copy:

1. Format - the Newsletter is printed on A4 paper, copy should therefore be prepared so that the text occupies an area which measures 160mm x 250mm. Please remember that this also applies to figures and tables.

2. Layout - the title of the contribution should be followed by the name of the author and the author's full address.

3. Text - text should be single spaced. Where possible contributions should be printed using a 10 point type face, either with uniform spaceing (as in these guidelines) or better still with proportional spaceing. Smaller font sizes tend to illegibility and larger sizes use too much paper.

4. Tables - where appropriate small tables should be incorporated within the text. For preference large tables should use the same type face as the text and, if possible, be prepared so that they can be read in the same orientation as the text.

5. Figures - line drawings should be in black on white and the lettering should be either 10 point or slightly larger. Please note that half tone illustrations cannot be printed.

6. Pagination - pages should not be numbered, contributors who wish to suggest a page order, where figures or tables are used, should do so in pencil and on the reverse side of the paper.

S.J.Freeth
March 1995

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The end of Newsletter No. 8

M. Kusakabe

Current Research on Volcanic Lakes

Newsletter of the IAVCEI Commission on Volcanic Lakes

No.9 March 1996

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Current Research on Volcanic Lakes is the Newsletter of the Commission on Volcanic Lakes of the International Association of Volcanology and Chemistry of the Earth's Interior. Issues of this Newsletter, from no.1 (February 1989) to no.7 (March 1994), were published as the *Newsletter of the International Working Group on Crater Lakes.*

Editorial

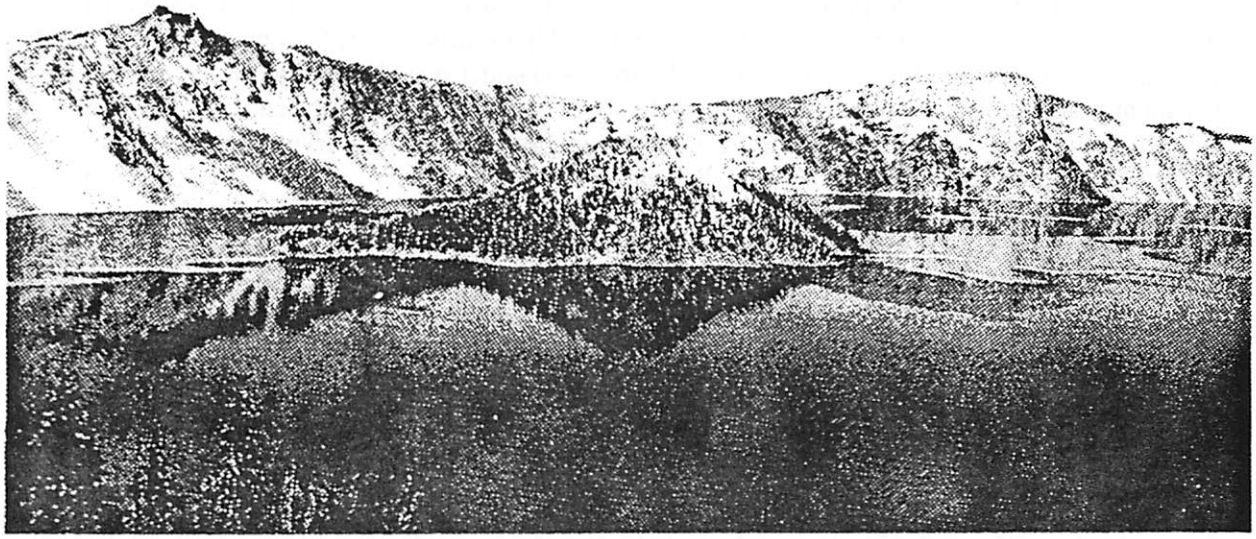
This year with nine papers on 'current' research and two reports on meetings which took place within the last year this Newsletter is bigger, and hopefully better, than ever. I would like to think that the increase in the number of contributions is in some way due to my own efforts as editor but more realistically I realise that it is more likely to be due to the coincidence of two eruptions beneath crater lakes within the last year, Ruapehu in June 1995 and Karymsky in January 1996, preliminary reports on both of which are included in this Newsletter.

The main item of news, as far as the Commission on Volcanic Lakes is concerned, is that our next meeting is scheduled for the 5th to the 9th of September at Crater Lake, Oregon. I would like to draw particular attention to the announcement of this meeting, which is printed on the reverse of this page, and express the hope that a significant number of our members will be able to attend.

As many members will already be aware a change to IAVCEI's Statutes and By Laws was approved, at the IUGG General Assembly in Boulder, Colorado, which will allow individuals to become personal members of IAVCEI. I have been asked by Wally Johnson, the Secretary General of IAVCEI, to draw this change to the attention of our members. This I am pleased to do and I enclose a copy of the 'Application Form for Membership' in the hope that a significant number of our members will wish to apply. Should any of your colleagues wish to join, and I hope that you will encourage them to do so, please feel free to distribute photocopies of the enclosed form.

Progress continues in the development of this Newsletter. Last year I drew attention to the fact that I now had access to equipment which would enable me to prepare the master copy using a laser printer and to the advantages which this could bring in terms of greater clarity and an increase in the number of words per page, with a consequent reduction in the cost of production. To take full advantage of this 'new technology' I asked that members should, if possible, submit their contributions in electronic format and somewhat to my surprise all the contributions to this year's Newsletter arrived either by e-mail or on disk. I hope that my request did not discourage any members who might not have easy access to the relevant technology. It must be remembered that this is an informal Newsletter for *all* our member, some of whom work under difficult circumstances and that it is contributions from these members which can sometimes be the most valuable. When requesting contributions I did not specify any specific electronic format since I did not have any idea what systems members of our Group might be using and since I had been advised, by my colleagues in the Swansea Computer Centre, that we had the facilities here to convert almost any format into the system which I am using it seemed easier to request contributions and then cope with any problems which might arise. During the last couple of months I have discovered that anything sent in an IBM compatible format presents no problems but that contributions in Macintosh, although they can in theory be converted, present in practice what at times has seemed like an unending series of problems. I would therefore request that in future anyone working in Macintosh should convert their contributions into an IBM compatible format prior to sending them. Similarly, figures sent as PostScript files can be printed with no problems whilst other formats have proved less amenable. Receiving contributions in an electronic format has not only allowed me to adopt a uniform printed format but has also made it possible to edit the contributions - since this is an informal there has been no editing as far as content is concerned but I have done what I can to edit the English into a form which I hope will be readily understood by our many members for whom English can at times be a bit of a struggle. I hope that my efforts in this direction have the general approval of our members. A revised set of *Guidelines for Authors* are printed towards the end of this Newsletter.

S.J.F.



CRATER LAKES, TERRESTRIAL DEGASSING AND HYPER-ACID FLUIDS IN THE ENVIRONMENT

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A Chapman Conference and the 4th official meeting of the IAVCEI Commission on Volcanic Lakes, to be held 5-9 September, 1996, at the Lodge, Crater Lake, OR, USA.

We invite volcanologists and geochemists with an interest in crater lakes, volcanic degassing, geothermal/ore forming environments and the chemistry of acid fluids to consider submitting abstracts and participating in this meeting. **Please contact the conveners if you would like to receive future information.**

Chemical Characters of Lakes in Volcanic Areas

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Lakes hosted in craters and calderas, often representing beautiful natural phenomena, can behave as condensers of the fluids emitted from the deep volcanic systems, and the chemical analysis of lake waters can provide information about the gaseous flows towards the surface.

Mudflows and lahars of significant extent are reported as the main hazards associated with crater lakes (Kelut, Indonesia, 1919 and 1990; Ruapehu, New Zealand, 1953). The base surge which swept the shore of Lake Taal, Philippines, in 1965 can also be ascribed to volcanic activitie of the same type. More recent disasters at Monoun and Nyos, Cameroon, in 1984 and 1986 respectively, have been produced by simple degassing from crater lakes.

Surveys on the chemical composition of volcanic lakes have been carried out in recent times (Brantley et al., 1987; Bernard et al., 1993; Delmelle and Bernard, 1993, 1994; Badrudin, 1994; Bernard, 1994; Christenson, 1994; Evans et al., 1994; Fazlullin, 1994; Freeth, 1994; Kusakabe at al., 1995; Martini et al., 1994; 1995; Ohba et al., 1994; Pasternack and Varekamp, 1994; Takano and Fazlullin, 1994; Tanaka et al., 1994; Tjetjep, 1994; Varekamp and Pasternack, 1994).

The results of the investigations on crater lakes of significant extent have made it possible to derive correlations between their chemical compositions and volcanic activity; accordingly, programs of volcano surveillance are in progress at different active systems. However, even when dealing with minor water bodies, through which bubbling gases can be observed, the physical-chemical characters of the solutions are expected to provide some hint about the processes occurring at depth. A rather widespread investigation has been carried out on so-called "boiling pools" pertaining to active and quiescent volcanoes, and the analytical data are given in Table 1.

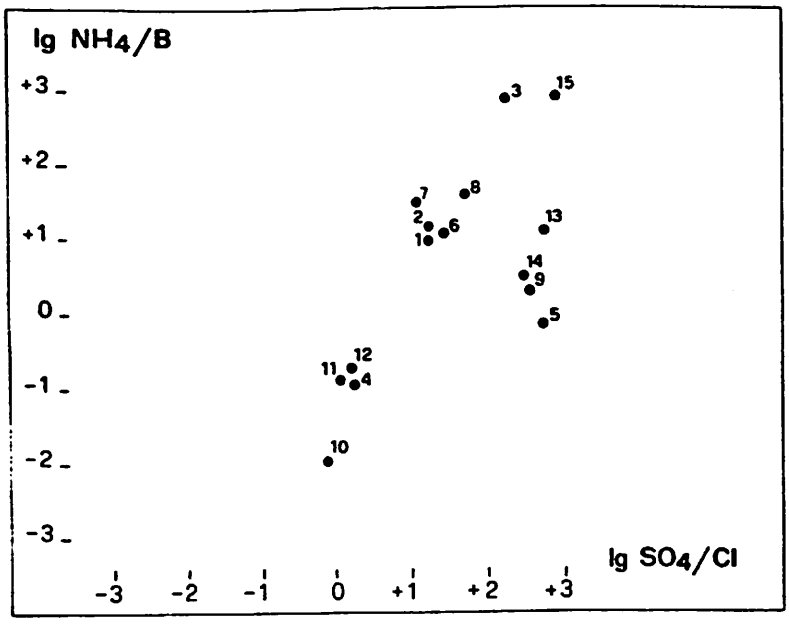

Figure 1. Variation of the ratio NH_4/B and SO_4/Cl for boiling pools from different locations. 1 = Krafla (Iceland); 2 = Seltun (Iceland); 3 = Hakone (Japan); 4 = Kirishima (japan); 5 = Noboribetsu (Japan); 6 = Ribeira Grande (Azores); 7 = Caldeira Velha (Azores); 8 = Furnas (Azores); 9 = Los Azufres (Mexico); 10 = Chichol (Mexico); 11 = Poas (Costa Rica); 12 = Ruapehu (New Zealand) 13 = Ketetahi (New Zealand); 14 = Lassen (U.S.A.); 15 = Pisciarelli (Italy). From Martini et al., 1991.

Table 1

Chemical composition of waters from lakes and "boiling pools" in volcanic areas (values in ppm).

No.	pH	Ca	Mg	Na	K	C	Cl	SO_4	NH_4	B	Li
1	2.0	35	11	41	18	-	15	6240	15	3.0	0.01
2	7.0	296	79	124	58	481	188	547	1.0	3.3	2.1
3	4.3	0.10	0.16	168	34	-	478	53	5.2	3.7	0.65
4	6.7	0.16	0.05	76	14	102	89	37	0.40	1.1	1.5
5	0.6	240	37	51	14	-	853	792	0.41	26	0.06
6	0.7	150	37	46	16	-	1848	725	0.43	73	0.05
7	2.0	122	31	71	2.8	-	5.3	2587	665	216	0.05
8	2.6	112	22	15	15	-	3.5	605	3.1	0.40	0.01
9	6.5	2.8	2.7	14	10	26	4.6	134	18	0.05	0.01
10	0.1	280	1251	2600	1287	-	54300	183025	10	52	0.06
11	0.1	1300	620	851	468	-	69250	39840	3.1	45	0.07
12	0.3	910	980	1049	526	-	50245	44640	3.4	31	0.07
13	2.5	38	22	9.9	5.1	-	9.2	1742	13	0.76	0.07
14	3.5	202	646	559	173	-	899	2875	0.59	8.7	0.04
15	5.5	17	0.37	24	3.5	32	32	365	49	7.6	0.02
16	1.0	19	30	36	32	-	1420	4225	6.3	32	0.01
17	1.9	7.0	3.5	8.7	7.8	-	11	4320	198	77	0.01
18	4.5	282	4.0	2140	385	-	3340	455	11	46	1.0
19	2.4	43	26	54	3.5	-	220	720	11	53	0.01
20	2.4	50	19	16	2.3	-	0.70	1682	17	0.05	0.01
21	1.5	400	70	44	51	-	1848	2400	0.11	4.5	0.04
22	6.5	118	0.56	2530	187	46	3550	82	2.3	34	7.0
23	5.3	3.2	1.9	4.6	0.78	7	4.3	53	12	0.05	0.01
24	2.1	134	51	83	3.0	-	99	2545	10	3.2	0.07
25	2.0	88	51	60	6.2	-	0.70	3315	29	172	0.03
26	2.4	154	70	87	20	-	5.3	1718	95	17	0.03
27	9.2	1.6	0.16	460	21	171	569	106	1.4	6.0	3.3
28	6.3	20	0.11	1035	136	85	1848	38	36	28	7.7
29	7.5	7.4	0.68	874	31	732	1030	144	4.5	30	9.8
30	4.0	1.6	6.9	18	3.5	-	0.70	4560	1605	81	0.01
31	0.1	4420	498	497	230	-	7995	22270	9.0	25	0.65
32	2.8	19	116	31	2.5	-	28	672	1.3	0.05	0.01
33	2.3	37	47	14	0.35	-	43	1008	0.86	0.05	0.01
34	7.9	0.4	0.12	460	14	607	47	310	0.32	12	1.8
35	2.6	42	14	6.4	0.80	-	15	805	11	0.05	0.03
36	2.5	6.8	3.3	37	23	-	15	350	0.63	0.29	0.01
37	1.9	8.6	5.0	37	32	-	2.8	1450	1.2	0.05	0.02
38	2.0	542	3.4	39	31	-	107	4130	2.0	0.06	0.01
39	2.1	80	14	17	67	-	5.7	3840	540	0.39	0.03

Table 1 Locations of the investigated manifestations

Sample	Volcanic area	
1	Lassen	USA
2 - 4	Yellowstone	USA
5 - 6	Chichón	Mexico
7	Los Azufres	Mexico
8	San Vicente	El Salvador
9	Momotombo	Nicaragua
10 - 12	Poás	Costa Rica
13	Rincón de la Vieja	Costa Rica
14	Irazú	Costa Rica
15	Uzon	Kamchatka
16	Kirishima	Japan
17 - 18	Noboribetsu	Japan
19	Usu	Japan
20	Hakone	Japan
21	Kusatsu-shirane	Japan
22	Tongonan	Philippines
23	Inan-Maharang	Philippines
24	Ambang	Indonesia
25	Lahendong	Indonesia
26	Sikidang	Indonesia
27	Whakarewarewa	New Zealand
28	Waiotapu	New Zealand
29	Ohaki	New Zealand
30	Ketetahi	New Zealand
31	Ruapehu	New Zealand
32	Seltun	Iceland
33	Krafla	Iceland
34 - 35	Furnas	Azores
36 - 37	Fogo	Azores
38	Nysiros	Greece
39	Phlegrean Fields	Italy

We know from the wisdom of our ancestors that natural phenomena are a "continuum" (Nature does not take jumps, according to the greek philosopher Aristotle), and sharp differences arise only for extreme situations, while following the changing characters of evolving systems is much more difficult.

From the standpoint of evaluating geological hazards through the chemical composition of water bodies associated with volcanic systems, there is no problem in distinguishing the important influence of magma degassing in strongly acidic waters, or its lack of influence in fresh neutral waters. Problems arise when investigating intermediate situations, possibly indicating changing degrees of geological hazard. Besides the overall chemical composition, however, different characters can be derived by taking into account species sensitive to changes in the stages of activity. Chloride, sulphate, and sodium among major components, ammonium, boron, and lithium among minor components can be selected. Chloride and sulphate originate from reaction of gaseous species H_2S, SO_2, HCl, with aquifers; sodium and lithium from weak leaching of country

rocks. Ammonium is associated to a gas phase, and boron pertains to vapour phases.

Different distributions of these chemical species can be observed as the result of interaction of magma degassing with shallow aquifers. By using NH_4/B and SO_4/Cl ratios, different extents of enthalpic flows from the deep systems had been estimated (Figure 1); a more detailed consideration has been subsequently carried out by means of a statistical factor analysis, whose results are given in table 2.

Table 2

Results of factor analysis

Factor	Associated variables	Variance explained
1	Sulphate, chloride, magnesium, potassium, calcium	0.441
2	Ammonium, boron	0.165
3	Sodium, lithium	0.144

Factor 1 should correspond to alteration of rocks by acidic solutions, factor 2 to the influence of gas and vapour phases, factor 3 to leaching of rocks by neutral solutions; a decreasing importance of deep originated convective flows with respect to shallow aquifers can be accordingly derived from factor 1 to factor 3.

The values of the statistical scores allow to evaluate the manifestations here studied as mainly associated to different processes (Table 3).

Table 3

Factor	Associated manifestations
1	Lassen, San Vicente, Momotombo, Poás, Rincón de la Vieja, Irazú, Uzon, Hakone, Kusatsu-shirane, Inan-Maharang, Ambang, Ruapehu, Seltun, Krafla, Furnas (35), Fogo, Nysiros
2	Chichón, Los Azufres, Kirishima, Noboribetsu (17) Usu, Lahendong, Sikidang, Ketetahi, Phlegrean Fields
3	Yellowstone , Noboribetsu (18), Tongonan, Whakarewarewa, Waiotapu, Ohaki, Furnas (34)

The evidence obtained through these simple considerations sometimes only reconfirm the information available so far; the shift from one group to another, however, which implies dramatic changes in the feeding system, can be easily recognized by means of simple analytical operations.

Sophisticated procedures to obtain more detailed evaluations could also be used profitably; this possibility, however, is not always at hand, and the usefulness of simple tools must not be underevaluated.

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State of the Bannoe Lake (Uzon Caldera, Kamchatka) in August 1994

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The Bannoe lake is located in the frameworks of the recent hydrothermal system in the Uzon caldera (Kamchatka). It has an oval form and size of 30 x 40 m. The lake profile has a funnel-shaped form with a narrow fissure of sublatitudinal trend in its south-eastern sector. The depth of the lake was 20 m at maximum to 1989. In 1989, after a phreatic explosion, the lake deepened to 32.5 m. Discharge of numerous gas streams were observed from the lake bottom. The most powerful gas discharge was located at the maximum depth at the activity upsurge zone in 1989. A "pot" with melted sulfur was also located here. At the depth of 26.5 m, at the "pot" zone, there was a sulfur core with a thickness of 15-40 cm (Karpov and Fazlullin, 1995) which divided lake water from the sulfur melt. A medium temperature in the sulfur "pot" determined by direct instrumental measurements, ranged from 132 to 142 °C. Water temperature in the lake differed from 65-96 °C (at the core) to 38-45 °C at the surface.

A zone of rising of gas streams is characterized by extremal values of all gas-hydrochemical parameters. It is especially shown by a distribution of mineralization, pH, Eh values and H_2S concentration. Maximum inflow of slightly mineralized waters is at the northern part of the lake.

Values of pH differ from 5.1 (at the bottom) to 5.7 (at the surface). Three zones are distinguished of distribution of solute H_2S: values from 0 to 5 range from 28 to 50 mg/l; an inversion is observed deeper than at 5 m and H_2S concentration decreases to 2-10 mg/l; increase of H_2S concentration is gradual from 18 m, sharp from 20 m, and then the concentration reaches 300-310 mg/l at the depth of 25 m. Eh values range from -20 to -127 mV.

The following elements were defined in the spontaneous gas (vol.%): H_2S (0.35-0.46), CO_2 (34.65-80.1), N_2 (16.72-60.3), O_2 (2.2-5.0), H_2 (0.31-0.74), CH_4 (0.03-0.12), CO (~2*10-4), Ar (0.14-0.51), and He (~3.4*10-3).

The following concentration ranges (ppm) were determined for dissolved metals: Fe (15-225), Zn (3.5-41.5), Mn (3.5-42.1), Cu (1.6-8.5).

As we imagine, the Bannoe lake is a natural chemical reactor with high gradients of distribution of physical-chemical parameters owing to the redox processes with participation of H_2S, O_2, Fe and bacterial activity in the peripheral meso-temperature zones of the lake.

Lake-phantom in the crater of the Gorely volcano, south Kamchatka

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The Gorely volcano belongs to the East Kamchatka Volcanic Belt and is located 75 km to the south of Petropavlovsk-Kamchatsky. Its summit is 1829 m above sea level. The volcano presents a large massif, which is formed by the superimposition of several stratovolcanic cones and numerous flank cinder cones. The volcano has a shape extremely dissimilar to other Kamchatka volcanoes and looks like a ridge with gentle slopes, covered by lava flows. There are four large craters at the volcano summit with small nest-shaped craters located inside them (Fig.1).

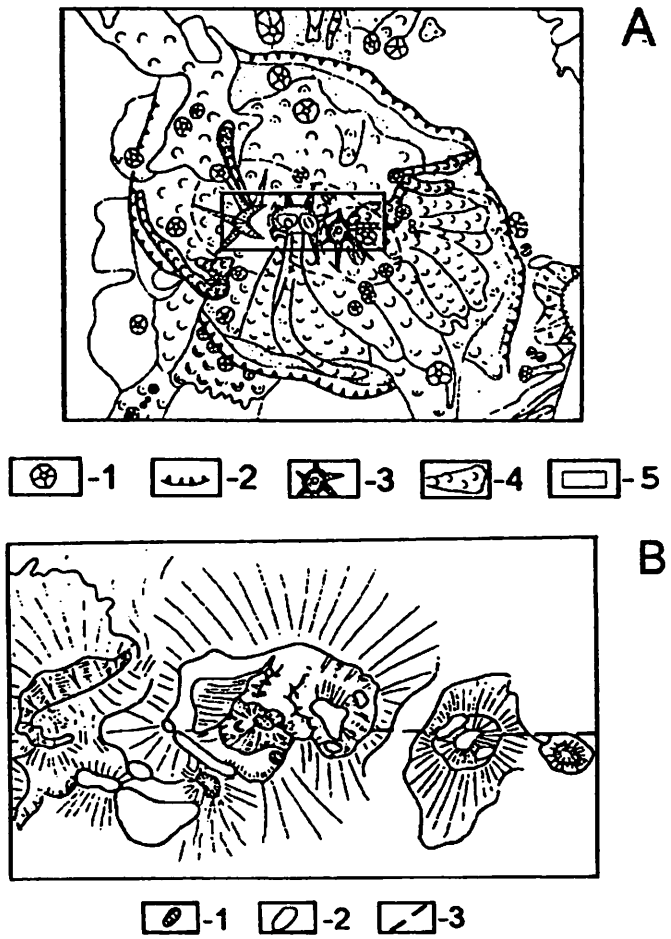

Figure 1. A. The Gorely volcano caldera structure, 1 - cinder cones; 2- caldera walls; 3 - stratocones; 4 - lava flows; 5 - detailed area. B. Schematic map of crater part of the Gorely volcano, 1 - crater lake; 2 - thermal grounds; 3 - fault.

About ten of the Gorely eruptions have occurred during historic times. The last of which ne occurred in the mid-1980's and was characterized by weak phreato-magmatic activity accompanied by volcanic ash and pyroclastics ejected up to 5 km high. Based on intensity of ejections and geological effect, this eruption is classified as belonging to a middle type (Kirsanov and Ozerov, 1983). At the present time Gorely is in the active

state. The most intense fumarolic activity is concentrated in the Central crater of the volcano and in a few sites nearby.

Previous research on Gorely was initially focused on the study of its structure, evolution, the dynamics of eruption and fumarolic activity, and the composition of erupted products. Reports concerning the presence of crater lakes in the Gorely volcanic massif, including the Central crater, were lacking in detail.

A lake in the Central crater was first reported in August 1960 (Kirsanov and Ozerov, 1983), and subsequently in 1978-1979, when the surface of lake was boiling as a result of intense volcanic gas release. Further observations were made in the December 1982, and a newly boiling lake was mentioned in 1984, when increasing fumarolic activity in the Central crater began (Kirsanov and Ozerov, 1983; Fedotov et al., 1985). The lake disappeared before the 1985 eruption and in its stead a well-shaped funnel, up to 100 m deep was formed. Bright red-coloured fluorescence was observed in July-November 1986, at the bottom of the funnel. Based on a colour scale it is suggested that the temperature there was about 900 °C. On 9 September 1985 a bright yellow patch at the bottom of funnel (T ~ 1000 °C) was seen by observers as well as blue flame torches up to 40-45 m high. These phenomena are caused by exothermic reactions in volcanic channels under shallow-deep condition (Ivanov et al., 1988).

It is not known when the lake in the Central crater of the Gorely volcano was formed, after the last eruption in 1986 (Budnikov, 1986), but from 1992 to the present the active crater has been filled by a lake. This is confirmed by our observations during the summer and autumn of 1995 and by observation from a helicopter on 15 December 1995. Since it is hard to reach the lake at present the characteristics of its current condition are based on visual observations, remote sensing, and other indirect evidence.

The lake is located in the central part of active crater of the Gorely Volcano, which seems like a well. The diameter of the well is about 60-70 m and the height of its sheer walls are up to 40 m. It is suggested that the depth of the lake also reaches some tens of meters. The surface of the lake is a bright emerald coloured, which is typical for all crater lakes with acid and ultra-acid water composition, high mineralization, relatively high temperature, and large amounts of colloidal elemental sulphur (e.g. Delmelle and Bernard, 1994). There are well-defined gas releases on the lake surface and, as a result, intense water motion occurs. The latter is confirmed by the continuously changed pictures of bright yellow floating sulphur on the lake surface. Also, intense fumarolic activity takes place at the vertical walls of the well filled by the lake (particularly, on the SW side).

The current state of our knowledge of the Gorely volcano allows us to suggest that the formation of a lake in the active crater, during the quiet stage of volcanic activity, as well as the phreato-magmatic character of recent eruptions are caused by large water breaks into the volcanic channel at shallow depths. It seems likely that an underground water reservoir exists within the caldera.

Further detailed hydrochemical and hydrogeological research is required, including work in the immediate vicinity of the crater lake. It is suggested that analysis of the water composition in the crater lake (when it exists) will be part of the Gorely studies related to the prediction of future eruptions.

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Recent changes in the physico-chemical characteristics of the crater lake of Maly Semyachik volcano, Kamchatka

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Maly Semyachik volcano is located on the Eastern Ridge of Kamchatka, 20 km west from the Pacific Coast. The volcanic massif is a combination of three stratocones of different ages (Paleo-, Mezo-, and Kaino-Semyachik). A strongly acid lake occupies the active crater of the youngest cone (Troitsky crater). This lake is about 500 m in diameter, more than 100 m deep, and has a volume of about 1.5-1.8 x 10^7 cubic meters (Fig.1). The elevation of the lake surface is 1172 m a.s.l.. The acid brines which fill the lake are characterized by mineralization of about 30 g/l, pH from 0.4 to 1.0, and a temperature range from 0 °C to >40 °C. Volume, heat content and the chemical balance of the lake depend on the relationship between input (fumarolic gases and meteoric waters) and discharge (evaporation and latent outflow).

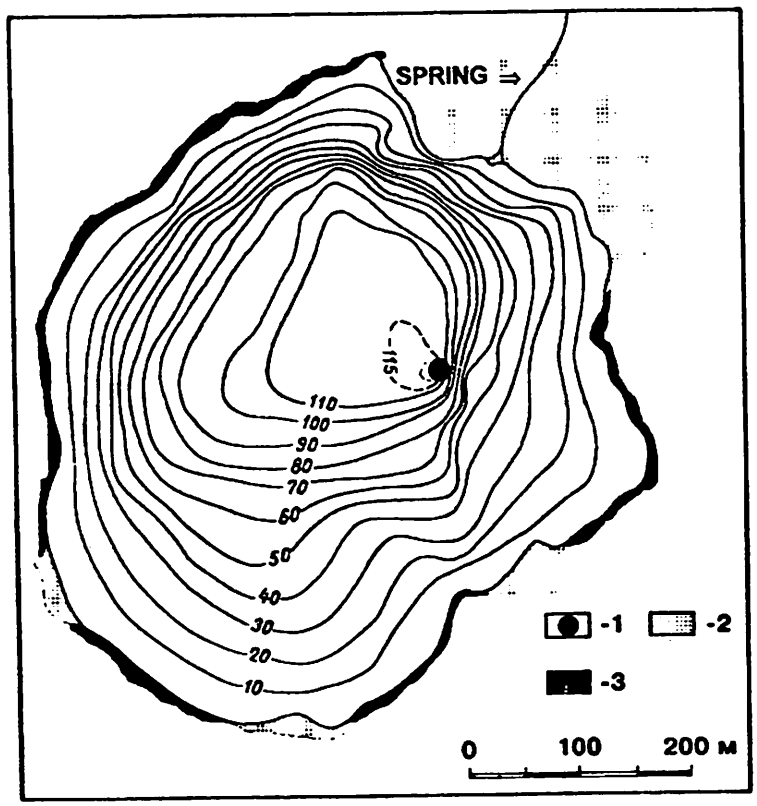

Figure 1. Bathometric map of the Maly Semiachik crater lake (depth in metres). 1 - hydrothermal vent; 2 - stone-falls; 3 - rock outcrops.

It is suggested that the physico-chemical state of a crater lake reflects the level of seismic activity in its vicinity. In particular, regular observations conducted between 1965 and 1991 in the crater lake of Maly Semyachik volcano display a close relationship between local seismic events and changes of water level, temperature, and chemical composition. All significant swarms of volcanic earthquakes, recorded during this time interval, changed the drainage regime within the volcanic edifice and were accompanied by temporal variations in the measured parameters (Fig.2).

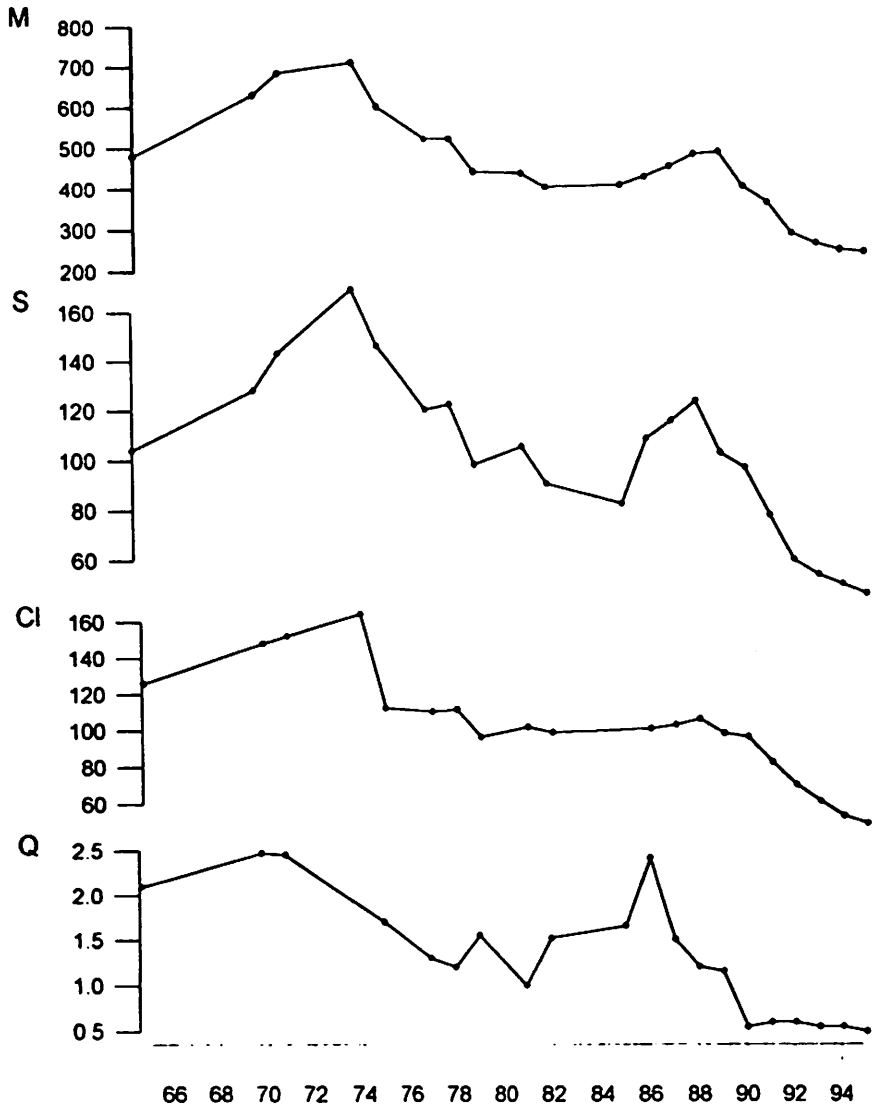

Figure 2. Temporal variations in the lake water of the Maly Semyachik volcano crater lake. M, S and Cl are respectively dissolved mineral components, dissolved forms of sulphur and chloride ions (in thousands of tonnes in the total lake volume). Q is the heat content of the crater lake water mass (in 10^{15} J)

During the period from 1986 to 1991 the level of the lake surface was at a maximum high. An echo sounding bathometric survey, undertaken by G. Gavrilenko in 1986, reported a maximum depth of 132 m (Dvigalo *et al.*, 1988; Gavrilenko *et al.*, 1993). After a swarm of volcano-tectonic earthquakes in 1992 the level of lake began to decrease. A bathometric survey in 1993, by Yu. Egorov detected a maximum depth of 117 m (Fig.1). This suggests that a 15 m reduction in of water level occurred and that the current level correlates with 1965-1978 values.

Following volcanic activity in 1986 there has been a pronounced decrease in the observed characteristics of the lake water. This tendency is seen in temperature (after 1986), total content of chloride ions and dissolved sulphur compounds (after 1988), and total mineralization (after 1989) (Gavrilenko *et al.*,1992), and continued through to 1995. Temperatures recorded at the lake surface in summer time have not exceeded 5°C. The lake is covered by ice in winter (this fact was firstly detected in 1992). The chloride ion content, dissolved sulphur compounds, and total dissolved solids in 1995 were the lowest values ever observed. Undoubtedly this is related to the period of steady-state of the Maly Semyachik volcano which started after the 1986 volcanic activity.

There was an evident correlation between changes in the crater lake's hydrological regime and a lack of volcano-tectonic activity in the region in 1992-1995 (Gavrilenko *et al.*, 1992, 1993). There were no significant volcanic or seismic events during this time interval, similarly in 1970, 1975-1976, 1978, 1986 and 1992.

Regular observations of the Maly Semyachik crater lake are scheduled for 1996.

After the text of this report was written, important and unusual geological events occurred in the vicinity of Maly Semyachik volcano in early 1996. These events may have been about to happen but indubitably were provoked by a strong earthquake on 31 December 1995, the hypocentre of which was located within the focal zone beneath the Kronotksky Gulf (East Kamchatka).

The next strong seismic event, of magnitude Mo = 6.9, occurred on the 01 January 1996 (09:57 GMT) beneath Karymsky volcano. Subsequently, Karymsky volcano, which had been dormant since 1982, began to erupt. Concurrently, a submarine eruption began at the bottom of Karymsky Lake 5 km south of Karymsky volcano. This eruption was related to the activity of the Akademii Nauk (Academy of Sciences) volcano which had been considered to be extinct.

At approximately the same time a swarm of volcanic earthquakes ensued in the Karymsky - Maly Semyachik region, including the nearby Maly Semyachik volcano (01 January 1996). The most important earthquakes were as follows (V. V. Ivanov, pers. com., 1996):

1. 12:16 GMT 10 km S W of Maly Semyachik. Depth (D) = 50 km; Magnitude (Mo) = 5.1; energy class of earthquake (Ks) = 12.6.

2. 12:58 GMT 6 km SW of Maly Semyachik. D = 50 km; Mo = 4.7; Ks = 12.3.

3. 13:36 GMT immediately beneath the volcano. D = 48.5 km; Mo = 5.4; Ks = 12.8.

We assume that all these events must be reflected in the state of volcanic activity and, correspondingly, in the state of lake in the crater of the active volcano. As indicated above, during past few years the surface of the lake was frozen in the winter, and December 1995 was no exception. However, during a helicopter flight on 23 January 1996 a thawed area reaching 50 m in diameter was observed in the centre of crater lake. This suggests that the water temperature had increased and therefore that activity in the lake had restarted. Further development of this process can be expected in future.

The regional seismic and volcanic activity in the Karymsky - Maly Semyachik region is unlikely to make an immediate impact on the state of the crater lake. The volume of water in the Maly Semyachik crater lake exceeds 15 millions cubic meters and a huge amount of energy and endogenic matter would be required (especially, in the winter) for there to be any external appearance of activity. Our research will be continued when more favourable weather conditions return.

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A subaqueous eruption from the caldera of Akademii Nauk volcano on January 2-3, 1996

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On January 2nd 1996, at about 08:00 local time, an eruption began from the Karymsky volcano in Kamchatka. The eruption was preceded by an upsurge in seismic activity, which began in April 1995. Volcanologists had made a forecast that an eruption would probably occur. On December 31st 1995, at 19:26 local time, an earthquake of M=5.8 occurred in the Kronotsky gulf, 50-60 km north-east of the volcano. On January 1st, at 20:57 local time, an earthquake of M=5.2 was recorded immediately in the Karymsky volcano region and then, at 21:57 local time, an earthquake of M=6.9 occurred at a distance of about 25 km to the south of the volcano. During the next day, more than 10 events of M ≥5.0 took place in the epicentral zone of the earthquake of M=6.9. On January 2nd, at 15:40 local time, a group of volcanologists from the Institute of Volcanology arrived in the eruption area by helicopter. Flying in the vicinity of the volcano, two eruptive centres were noted: one, near the summit of Karymsky and another, 5-6 km south of the volcano, in the Karymsky Lake (d~4 km, maximum depth 115 m), which fills the caldera of the Akademii Nauk volcano. The eruption from Karymsky volcano began with the formation of a vent with a diameter of 20-30 m, located 50 m below the summit of the volcano. Very violent pulsed emissions of gas jets, highly loaded with ash, rose to one kilometre above the eruption vent on the south-west slope. Steam - gas jets, occasionally with noticeable black-coloured matter, were ejected by pushes to several hundred meters from beneath the water of the Karymsky Lake. The presumed eruptive centre was located 100-200 m from the shore in the north-west sector of the lake. Turbulent steam - gas uprushes rose to 5-6 km above the water surface, which can be outlined as a circle 200 m in diameter. Ice covering the lake had entirely melted. On January 3 and 4 the eruption of the Karymsky volcano increased. On January 3, the near-summit crater increased in size, reaching 50 m in diameter. Two eruptive vents were active: one in the summit crater and another on the south-west slope. One could see pure gas and steam ejections (gas blasts) to be alternated and enhanced by explosions with ash ejections, both vents being active simultaneously. Most frequently, ash was ejected from the upper eruptive vent, whereas white-coloured gas was commonly ejected from the lower vent. Ash ejection lasted for 2-3 minutes, then gas blasts occurred lasting 1.5-2 minutes. An ash and gas eruptive column rose to some 1-1.2 km above the eruptive vents and then drifted oceanward in the wind to the east and south-east. The surface of the Karymsky Lake steamed intensely. Clouds of steam rose to 800-1000 m above the lake. Areas of green coloured water were visible through rents in the clouds. A newly-formed beach zone of black colour was distinctly seen. In the northern and north-eastern sector of the lake a narrow spit, beginning from the source of the Karymsky river and extending for 250-300 m to the centre of the lake, had formed. The water level in the lake went down by a few meters. The upper reaches of the river had dried up, but as volcanologists reported, on January 2, waves from the underwater eruption (up to 10 m high or maybe higher) had overflowed the north shore of the lake, and the huge water mass flooded a wide valley, 1.5 km below the source of the river. During a surveillance flight over the eruption area on January 4, large areas of the valley at this place were seen to be covered by black mud. Within the newly-formed beach zone of the lake 70-100 m wide, three fumarole vents were clearly seen. They seemed to follow a fault zone of north-eastern strike. In the immediate area of the Karymsky river source, within a radius 500-800 m, the surrounding hills were covered with snow, in which thousands of craters with diameters ranging from 10 cm to 1.5-2 m were seen. These craters were the imprints of lithic fragments which had been violently ejected from the lakeside vents. The area buried by ash from the Karymsky volcano was preliminarily estimated to be 150-200 km^2. The of light grey coloured ash is dacite in composition. At a distance of 8 km from the volcano particles ranging from 0.16 to 0.06 mm were dominant. According to estimates, made by Prof. S. A. Fedotov, on January 2 and 3 the ash ejection rate from the summit crater reached 3-4 t/s. High gas abundance in the air was felt in the vicinity of the volcano.

Results of inspections from the air show great changes in the configuration of the shore zone of the lake. The level of water continues to fall because of its intense evaporation. The temperature of water in the lake probably increased very abruptly and all fish in the lake seem to have died. We suppose that a volcanic cone formed on the lake bottom (or probably an extrusive dome formed or an exposure of a sill occurred). It is not excluded that its summit will emerge above the water surface. In the underwater part of the eruption the formation of pillow lava flows is possible and after the active phase of the eruption ceases, fumaroles will be very active and we have every reason to expect the appearance of "smokers" (underwater smokers), i.e. the zones of ore material deposition.

Table 1. Chemical composition of water from Karymsky Lake and Karymsky Hot Springs.

Component mg/l	No of sample 04.01/5	22.01/1	22.01/2	11.02/3	22.01/5	11.02/1
H^+	0.00	0.60	0.08	0.69	0.00	0.00
NH_4^+	0.1	0.1	0.1	0.2	0.1	0.1
Na^+	61.1	56.6	85.1	75.0	341.7	255.0
K^+	4.8	8.5	9.8	7.3	43.2	13.9
Ca^{2+}	40.1	66.1	126.3	66.0	50.1	5.6
Mg^{2+}	46.2	19.5	53.5	14.4	30.4	<0.2
Fe^{2+}	-	<0.3	<0.3	<0.3	<0.3	0.0
Fe^{3+}	0.1	24.0	5.25	<0.3	<0.3	0.0
Mn	1.40	2.00	3.30	-	0.5	-
Zn *	0.02	0.04	-	-	0.04	-
Cu *	0.008	0.05	-	-	0.0003	-
Cd *	0.02	0.001	-	-	0.003	-
Ni *	0.002	0.019	-	-	0.003	-
Cl^-	49.7	49.0	67.5	35.5	224.4	303.0
F^-	1.36	2.06	2.51	1.8	0.43	1.7
SO_4^{2-}	172.9	405.8	730.1	379.0	691.6	86.5
HCO_3^-	200.1	0.0	0.0	0.0	70.8	42.7
CO_3^{2-}	0.0	0.0	0.0	0.0	0.0	23.4
H_3BO_3	-	<0.7	<0.7	<0.7	14.8	32.6
H_4SiO_4 dissolv.	108	210	279	-	193	-
H_4SiO_4 coll.	0	0	0	-	209	-
pH	8.10	3.22	4.10	3.16	6.75	9.35
T °C	10	22	26-28	19	56	98
Date of sampling	04.01.96	22.01.96	22.01.96	11.02.96	22.01.96	11.02.96

04.01/5 - Karymsky river; 22.01/1, 22.01.2 - Karymsky lake at shore; 11.02/3 - Karymsky lake, central part; 22.01/5 - explosive funnel N3, 11.02/1 - Akademii Nauk springs.
Analyses were made at the Institute of Volcanology.
* - Data by S. M. Fazlullin, "-" - not determined

Routine observations carried out from January 2 through to February 11, 1996, have shown that the climactic phase of the subaqueous eruption continued for no more than 12-15 hours. Actually, it was a series of frequent explosions probably of phreato-magmatic genesis, during which vapour-gaseous mixture with cinder-bomb material was ejected to the surface. In the northern sector at the shore of the lake west of the Karymsky river-head, barked trees were noticed which were evidence of two eruptive sources located at 500-600 m distance from each other. In this zone, the main concentration of bomb material ejected from the lake was observed. Besides, a portion of the shoreline (150-200 m long and 5-15 m wide) east of the river-head sank several metres into the lake.

The main eruption centre appeared to be 500 m from the lake shore and smaller peripheral eruptive centres were also observed. As a result of the eruption, in the NNW sector of the lake near the shore, a beach zone formed in the form of a wide cape 0.4 km^2 in area, the narrow spit of which is followed to the SE to 620 m from the old shore. The length of the new shoreline is 2.4 km. A large shoal was observed around the new peninsula and, according to the preliminary estimations, the ejected material deposits in the lake were at least 1 km^2 in area and 5-10 x 10^6 m^3 in volume.

Table 2. Chemical composition of water extracts from ash

Component mg/100g of ash*	No of sample 3.01/Ovs.	3.01/Budn.	4.01/Fazl.
H^+	0.00275	0.4208	0.5616
Na^+	27.85	133.4	115.9
K^+	3.72	23.52	<14.2
Ca^{2+}	38.82	872	304.3
Mg^{2+}	7.57	54.4	25.4
Fe^{2+}	20.14	14.4	<10.9
Fe^{3+}	0.61	9.6	<10.9
Cl^-	42.74	163.5	257
F^-	4.86	12.64	8.3
SO_4^{2-}	181.4	2643	1112
HCO_3^-	0.0	0.0	0.0
CO_3^{2-}	0.0	0.0	0.0
H_4SiO_4 dissolv.	4.5	78	-
H_4SiO_4 coll.	0.0	0.0	-
pH	5.26	3.07	2.95

3.01/Ovs. - sample collected at 800 m distance from Karymsky lake.
3.01/Budn. - sample collected at a hut at Dvor volcano.
4.01/Fazl. - sample collected at 8 km distance from Karymsky volcano and at the same distance from Karymsky lake.
* samples of ash with snow were collected, the volume of water and the dry weight of ash were measured and the chemical composition of the water was then recalculated relative to the weight of ash.

Thermal springs of the Akademii Nauk volcano, that discharge at the southern shore of the lake, 3 km from the eruption centre, ejected the material which filled their gryphons as a result of this eruption. The gryphon edifices were destroyed and several new mud pots were formed. The chemical composition of the solution (sample 11.02/1), Table 1)) was not changed.

Near the central part of the newly-formed beach, composed of sand-gravel and bomb material, a chain of five explosive vents with diameters from 1.5 to 30 m was observed in the submeridional direction. In the north, the chain was bounded by a round thermal site, with a diameter of about 50 m. This site was emitting large quantities of vapour, it was covered by sublimates and one could smell the odour of hydrogen sulphide. There was a dry funnel, with a diameter of about 3 m, high gas emission and a temperature of 97 °C in the central part of this site.

The other explosion funnels had water at a depth of 1.2-1.5 m with a temperature from 33 to 70 °C, the level of which depended on the water level in the lake. In the three funnels which were closest to the lake shore and in the opposite shore zone, gas emissions with a temperature of 97-98 °C were observed.

The chemical analyses (Table 1, sample 22.01/5) show that hot water seeps at this beach, have a chiefly bicarbonate-chloride-sulphate-sodium composition which is similar to that of the Karymsky springs, with the total mineralization reaching 1.5 g/l. But the water composition in the lake is different. These are mainly sulphate-sodium-calcium solutions with rather high concentrations of F, Fe and Mn. Ni and Cu are also abundant (Table 1, samples 22.01/1, 22.01/2, 11.02/3). Note low pH of the lake water and high alkalinity of the Karymsky river water (sample 04.01/5, Table 1).

Sample 04.01/5 was taken from the river 6 km below the river-stream on January 4, 1996 when run-off from the lake ceased owing to the damming of an effluent channel by the ejected material. Melt water (leaching ashes) from the neighbouring creeks and solutions from the discharge zone of the Karymsky thermal springs are assumed to be in the river. It is really similar to the Karymsky springs in saline composition, but has a much higher pH and higher Ca and Mg concentrations. Obviously, that the composition of the Karymsky river waters, the pH of which is similar to the solutions of the Akademii Nauk springs, cannot be explained only by a simple mixture of waters from the Karymsky springs and melt waters.

Taking into account the chemical composition and pH of water extracted from the Karymsky volcano ash (Table 2), we can suppose that the water composition of the lake is affected by gaseous components of fluids which discharge into the eruptive zones and by water-soluble components of magmatic material lying at the lake bottom. The possibility cannot be excluded of both the breakthrough of a vapour-gaseous reservoir which feeds the Akademii Nauk springs and the participation of thermal waters from the Karymsky springs in the discharge.

If somebody would like to join for study of this phenomenon, please contact us by e-mail: faz@volcan.kamchatka.su

See reverse.

(January 4, 1996,
Mt. Karymsky and Lake Karymsky)

Some notes on the last years of Ruapehu Crater Lake (1994-1995)

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Ruapehu is a very awkward volcano; as soon as one has got used to it exhibiting a particular behaviour pattern, it changes. After about 10 years of fairly low-level activity, in which the regular heating up of the lake did not lead to any significant eruption, in 1995 it finally produced a substantial eruption, which resulted in the complete disappearance of its Crater Lake, which had been present since soon after the 1945 eruption. At the time of writing, in December 1995, a lower level of activity has resulted in small lakes reforming in the two eruptive vents, but the eruption is not over yet, and these lakes may be very temporary.

This is an entirely informal report, not giving the views of anyone but the authors. It looks at some aspects of the monitoring of Ruapehu Crater Lake, and what signals were given that might have warned us of a major eruption.

Monitoring Technique

A Datalogger based on a programmable calculator was installed on the south side of Crater Lake, by the promontory informally known as Logger Point, at the end of February 1993. Crater Lake temperatures were recorded by a platinum resistance sensor, and acoustic signals were detected by a hydrophone, both sensors being suspended at a depth of about 20 metres about 100 metres out from the shore. The acoustic energy in a number of frequency bands was measured using a combination of filtering and direct calculation of spectral energy. A number of measurements were normally made every two hours, although longer intervals were used when the battery voltage was low.

All of the readings from the last set of measurements, and some readings from the previous set, were encoded into a 256 byte message which was transmitted by a 2 W, 401.650 Mhz (UHF) transmitter every 100 seconds. The power system was a combination of solar cells and lead-acid secondary batteries.

The ARGOS satellite telemetry system uses two satellites, which provide about 10 passes overhead each day at the latitude of Ruapehu, with each pass lasting up to 10 minutes. If at least two identical messages were received from a transmitter during a satellite pass than the message was taken as valid, and it was processed and added to the data recorded by a computer in France, usually within a few hours of the transmission. The data could then be obtained by Internet FTP as required.

An intermittent fault in the UHF transmitter resulted in only limited data being obtained before December 1993, after which the system then operated until the data logger was destroyed by an eruption on 29 June 1995, except for a period during July and August 1994 when the solar cell was covered by snow and the battery voltage dropped too low for the datalogger to operate. Figs 1a and 1b show all the data received from December 1993 until June 1995. Crater Lake temperature measurements made at the outlet are shown by asterisks (*), and the plus signs (+) linked by dotted lines show values of the Mg/Cl ion ratio (*1000) in samples taken from the outlet area of Crater Lake.

Lake Temperature

The temperature record during 1994 followed the regular cycling pattern which has been normal for Crater Lake since about 1988, with rapid temperature increases followed by rather less rapid decreases. Typically, the Argos temperature was 6 °C above the outlet temperature, with the difference increasing with lake temperature. A maximum temperature of 47.5 °C was reached in February 1994, followed by a decline to 22 °C. There was then a minor rise to 33 °C in June, followed by another decrease, with the temperature then stabilising in the 14-16 °C range. In December 1994 another rapid temperature increase began, which led to very high temperatures in January 1995. Due to a technical problem, the maximum of the temperature sensor scale was only 47.5 °C, and the sensor temperature in January 1995 went past this limit, staying above this temperature until the middle of March.

On 26 April 1995 there was a very rapid increase in temperature, indicating a large power input into the lake, coinciding with strong acoustic signals. This was practically certainly the time at which an eruption-produced wave considerably disturbed the equipment, shifting the main electronics box by a metre, and a heavy battery 2 metres. The cables to the hydrophone and sensor were also shifted by this eruption, suggesting that these sensors may have been affected also. The temperature sensor did not come on scale in June, even though the outlet temperature was decreasing, and it may be that the temperature sensor had been damaged by this eruption.

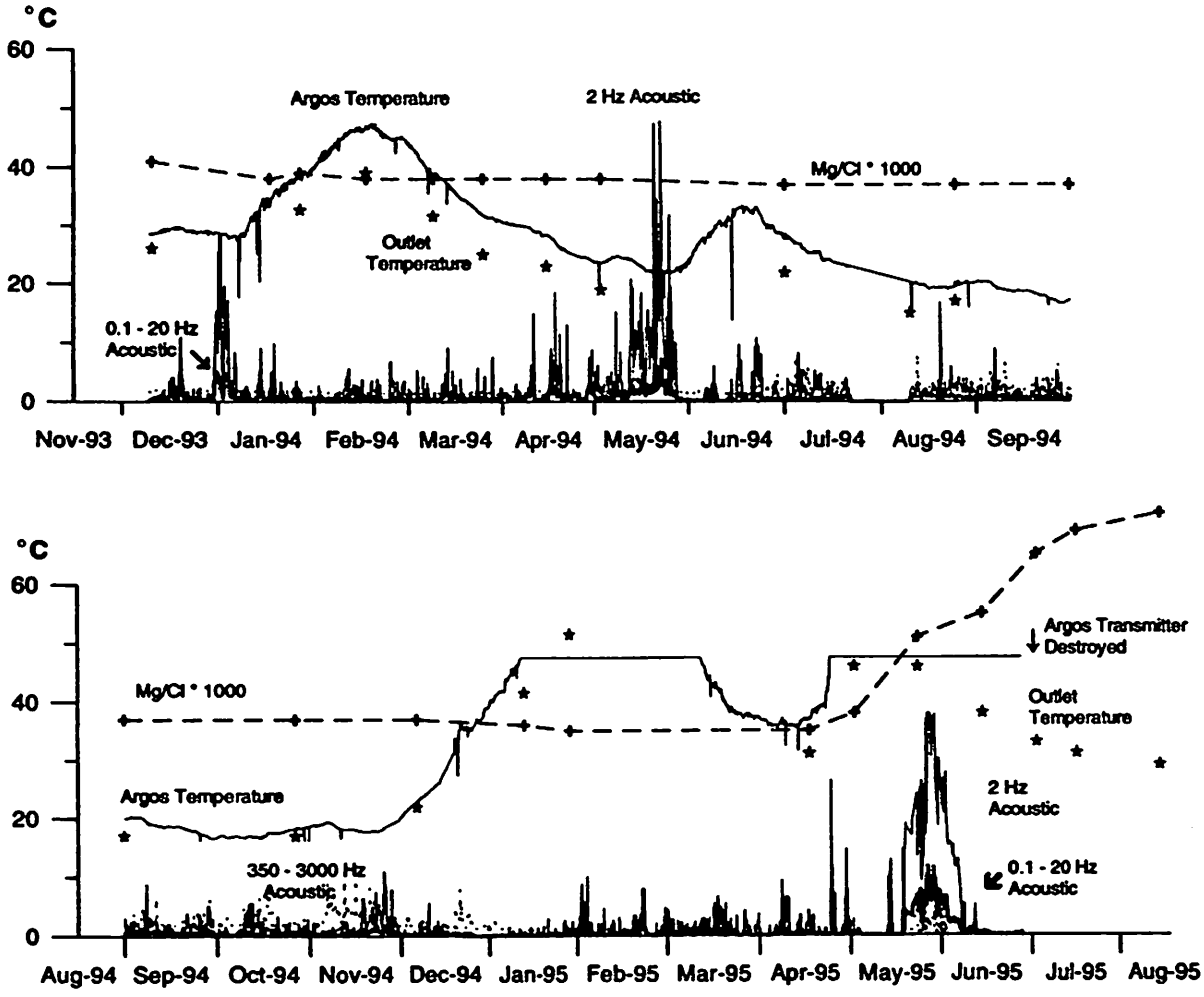

Figure 1. Plots of temperature recorded by Argos telemetry system at Crater Lake (top thin line), manual temperature readings (*), 1000*Mg/Cl ionic ratio (- - + - -), and acoustic energy on arbitrary sound pressure scale, in the 1.5-2.5 Hz band (thin line) and 0.1 - 20 Hz band (thick line).

Another eruption on 29 June 1995 completely demolished the equipment beside the lake, whilst the hydrophone and temperature sensor were found in a damaged condition by the outlet on 4 July, together with much of the polypropylene rope used to install it. On this day, the lake temperature measured at the outlet was 33 °C, and it continued to decrease, reaching 29 °C on 15 August. This decreasing temperature was the main reason why the eruption sequence that commenced on 18 September was so unexpected.

Acoustic Signals

Acoustic signals were filtered to measure the power in a number of frequency bands. The 2 Hz band has a sharp filter, to pass signals in the 1.5-2.5 Hz band, so as to see whether the acoustic energy in this band

correlates with seismic signals of the same frequency. The 20 Hz band has a broader filter, passing all frequencies from 0.1 Hz to 20 Hz. The third band used during 1993/94 was the audio band, covering the audio range of 350-3000 Hz.

The first two heating phases in 1994 were both preceded by strong acoustic signals, with most energy being recorded in the 2 Hz frequency band. Hurst & Vandemeulebrouck (In Press) described the January - March 1994 heating and its acoustic and seismic precursors in detail. One conclusion of that paper was that the acoustic signal was produced independently from the seismic signals, which also occurred before the lake temperature began to increase. Even stronger acoustic signals in May 1994 preceded the second heating phase.

Only a moderate level of acoustic signals was recorded in November 1994, just before the third heating phase started. Most of the energy was in the 350 - 3000 Hz audio band. Because the battery voltage was very low, at this time, it is possible that the actual acoustic level may have been higher than the recorded values. Very strong acoustic signals were recorded during May 1995. The low-frequency channels were both overloaded, but the level of sustained acoustic power was the highest for the whole period. There was also a high level of acoustic noise in an ultrasonic band (15-60 kHz) at this time, but since the filters for this band had only been installed in January 1995, there were no previous events to compare the values in this band with.

Possible Precursors

An increase in the Mg/Cl ratio in Crater Lake water is an indication of the interaction of water with fresh magma. After a long period without significant increases, this parameter started to increase after the 26 April 1995 eruption. Together with the high level of acoustic noise in May 1995, this was a factor suggesting a build up of Ruapehu activity.

There was significant volcanic tremor at Ruapehu during several intervals in the period April - June 1995, a magnitude 3.2 earthquake accompanied the 29 June eruption. This earthquake was of very long duration (> 20 minutes) and very low frequency, with energy down to 1 Hz. There were very few if any volcanic earthquakes at Ruapehu with energy below 2 Hz in the last few years until this event. After a second smaller eruption on 3 July, the level of seismic activity dropped away, and was at low levels until 18 September, when the first eruption of the main sequence occurred, accompanied by more low frequency energy.

The low level of seismicity, and decreasing temperatures, in July and August suggested that the 29 June eruption was the climax of a heating event, rather than a precursor of further activity. Without the telemetered temperature and acoustic power values after 29 June, monitoring of Ruapehu was reliant on sampling trips and seismicity. These did not prove adequate for predicting a major eruption sequence, which is not very surprising when we still do not understand how there could be such strong interaction between the lake water and fresh magma (from the Mg/Cl ratio), yet the power input to the lake seemed very small (from the decreasing lake temperatures). One possibility is that small eruptions were bringing so much snow and ice into the lake that the measured lake temperatures were strongly affected. Continuous temperature measurements might have given a better indication if this was happening.

The overall conclusion is that it is difficult to get an appreciation of a volcano's behaviour without all possible monitoring systems operating. To do this requires us to have the resources, and take the risks, of installing new monitoring systems soon after eruptions have destroyed the previous systems, even though there is a considerable likelihood that the new systems will be destroyed within a fairly short time.

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Preliminary studies of some peridotite xenoliths from Nyos volcanoes (Cameroon): implications for the evaluation of volcanic hazards.

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Abstract

Peridotites occur abundantly in scoria cones and maar deposits in the region of Nyos, (Central part of the Cameroon Line). The host lavas are basanites and alkali basalts. Xenoliths comprise spinel lherzolites and spinel harzburgites with four main mineral phases: olivine, orthopyroxene, clinopyroxene and spinel, in order of decreasing amount. The only additional phase is a pargasitic amphibole, present in some samples. The nodules display protogranular or porphyroclastic textures. Mineralogical, geochemical and isotopic data show that the lithosphere beneath the Nyos regions has been affected by at least two events: partial melting and extraction of magma, and patchy metasomatism. The lowest conditions of equilibration are 930-1045 °C and 7.5 kb. Thus, spinel lherzolites and spinel harzburgites xenoliths in Nyos volcanoes have been sampled by magmas in a mantle column at depths ranging from 24 to more than 80 km.

The helium isotope ratio from fluid inclusions in pyroxenes is similar to that of gases dissolved in Lake Nyos water, strengthening the mantle origin of the latter. The existence of fault complex and crustal pockets of mantle fluids gives to the Nyos region a high potential of volcanic hazards.

Introduction

The Nyos volcanic area belongs to a group of strombolian and phreatomagmatic volcanoes of the Cameroon Line characterized by the occurrence of peridotite xenoliths in their deposits. The present investigation on alkali basalt-hosted mantle xenoliths from Nyos volcanoes aims to calculate the depths at which mineralogical assemblages were in equilibrium and to gain knowledge on the relations between fluid inclusions and the gases contained in Lake Nyos water.

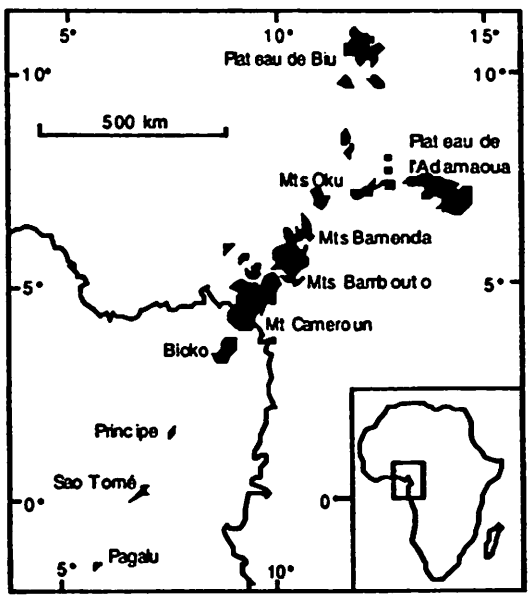

Figure 1 : Location of Nyos region (Mt Oku) on the Cameroon Line

The Nyos volcanic area which is part of Oku massif is located at the intersection of the Cameroon Line and the Adamawa volcanic province (fig. 1) whose bounding faults correspond to the continuation into the African continent of the South Atlantic Ocean fracture zones (Benkhélil, 1988). Oku massif is one of the important continental massifs of the Cameroon Line and is composed of four major adjacent stratovolcanoes (Oku, Babanki, Nkambe and Nyos).

Geophysical investigations in the Nyos region have revealed that the level of seismicity is low compared with that associated with the mount Cameroon area. Composite fault plane solutions determined from P-wave onsets of local events are generally consistent with normal faulting. The analysis of telesismic P-wave residuals showed that the heterogeneity is greater within the crust and least in the upper mantle, low velocity area exists in the Bamenda (Oku massif) and Mount Cameroon regions which represents a velocity perturbation of up to 5 % which may extend into the upper mantle. This probably represents the area of magma chambers associated with the active Mount Cameroon volcano (Tabod, 1991). The low P-wave velocity perturbation in Oku area is likely induced by pockets of gaseous and or liquid fluids (Nana et al., 1994). Volcanic eruption locations were controlled by N30°E, N70°E and N170°E orientated faults. These faults are observed on landsat images, topographic and geologic documents. Basanites, alkali basalts, trachybasalts, trachyandesites and trachytes cut and rest upon Pan-African granitic and metamorphic basement. Peridotite xenoliths are scattered in scoria cones and maar deposits of Elum, Enep, Nyi and Nyos. These ultramafic xenoliths provide an opportunity for direct examination of upper mantle characteristics.

Spinel harzburgites and spinel lherzolites exhibit protogranular or porphyroclastic textures. Olivine and orthopyroxene porphyroclasts (2-6 mm) display undulose extinction and may be rimmed by neoblasts. Amphibole is rare and restricted to one lherzolite described by Schenker and Dietrich (1987).

The olivines are chemically homogeneous within each samples. Within the nodule population, the composition range in Fo content is rather narrow : from 89.2 to 91.5. CaO and MnO invariably display low values and are typical of high pressure olivines. Endiopside composition in harzburgites is similar to the composition of endiopside that coexists with diopside in some lherzolites. As with pyroxenes in mantle xenoliths from Adamawa (Dautria and Girod, 1986), endiopside compositions indicate a depleted mantle. Similar to olivine, orthopyroxene has no detected zoning. Forsteritic olivine (Fo 91.5-89.2) and enstatite (En 91-92) are characteristic of residual peridotites (Nixon et al., 1981). There are often small, but significant composition variations within individual spinels and between separate grains within the same rock. In figure 2a, Cr-spinels plot between depleted and undepleted mantle domains (Reid & Geoffrey, 1978). Pargasite has similar compositions to amphibole developed at the expense of garnet in lherzolites (Dautria et al., 1992).

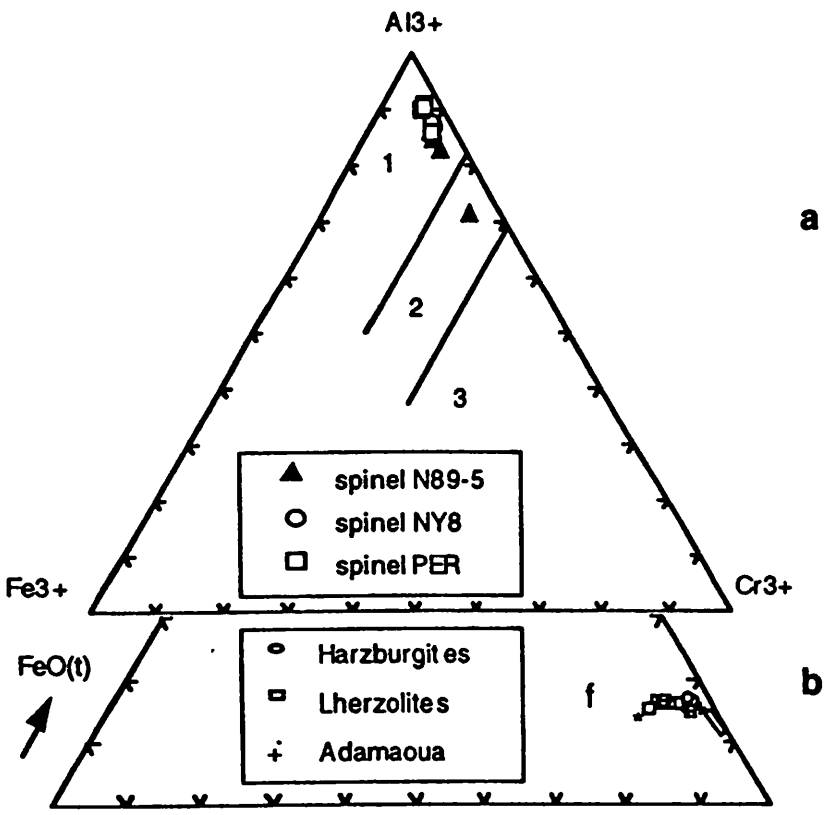

Figure 2: **a** - Trivalent ion distribution (Al^{3+}, Fe^{3+} and Cr^{3+}) in the spinels of peridotites (fields are from Reid and Geoffrey, 1978). **b** - Distribution of whole-rock compositions in the FeO(t)-Al_2O_3-MgO diagram.

Discussion

Both mineral compositions and bulk rock data (reported in table 1) indicate a consistent group of xenoliths. Systematic variations in bulk major and compatible trace element concentrations are observed (Nana, 1991). These trends are interpreted as resulting from variable degrees of partial melting of the upper mantle. Chemically, peridotite xenoliths from Nyos and Adamawa have variable compositions ranging from that of primitive mantle to that of depleted oceanic peridotites (fig. 2b).

Samples	NY8	N89-5	PER
olivine	Fo 89.2-91.2	Fo 8.4-91.2	Fo 89.2-90.6
OPX Al2O3	3.00 - 4.00	3.40 - 4.60	4.30 - 4.60
OPX CaO	0.57 - 0.90	0.60 - 1.20	0.50 - 0.75
OPX Cr2O3	0.29 - 0.50	0.25 - 0.70	0.25 - 0.30
CPX Al2O3	6.7 - 7.0	7.0 - 7.50	6.5 - 7.25
CPX Na2O	2.3 - 2.4	0.9 - 1.0	1.00 - 2.30
CPX TiO2	0.25 - 0.40	0.35	0.25 - 0.70
CPX MgO	14 - 15	18	14.5 - 18.20
CPX Cr2O3	0.75 - 0.80	0.70 - 0.95	0.50 - 0.85
Sp. Al2O3	57 - 58	44 - 56	55 - 61
Sp. Cr2O3	9 - 10	9 - 12	6 - 10
Equilibrium Conditions	1045°C-920°C. > 7.2 Kb	1330°C-1200°C 25-30 Kb	1200°C-930°C 25-32 Kb
Helium Isotopes	^3He (*10^{-13})	^4He (*10^{-8})	R/Ra
CPX	3.30 ± 0.05	3.91 ± 0.05	6.04 ± 0.007
OPX	1.20±0.03	1.40±0.004	6.12 ±0.014

	Whole rocks		
	NY8	N8-95	PER
SiO2	44.77	42.05	44.84
TiO2	0.17	0.05	0.06
Al2O3	4.66	1.64	1.94
Fe2O3	1.5	0.54	0.61
FeO	6.12	8.93	7.27
MnO	0.13	0.12	0.11
MgO	38.03	44.86	42.87
CaO	3.95	1.18	1.63
Na2O	0.17	0.0	0.0
K2O	0.0	0.03	0.0
P2O5	0.02	0.03	0.02
PF	0.47	0.56	0.64
V	78	77	61
Cr	2 377	2 391	2 563
Ni	1 850	1 861	2 042
Co	62	62	72
Cu	19	19	0.02
Zn	42	41	44
Sc	15	15	13

Table 1: Chemical characteristics of Nyos peridotite minerals, whole rock and He isotope analyses from fluid inclusions in pyroxenes.

Mineralogical, geochemical and isotopic data show that these xenoliths have had a complex history involving partial melting and mantle metasomatism. Thus, the lithosphere beneath the Nyos regions has been affected by at least two events :

1) partial melting and extraction of MORB leaving a depleted mantle characterized by Mg-rich olivine (Fo > 91%) and orthopyroxene, high temperature and pressure of equilibration (1200-1330°C and more than 25 kb), and ^3He / ^4He ratio values of fluid inclusions in pyroxenes. Also, whole-rock compositions are similar to that of depleted oceanic peridotites;

2) patchy metasomatism which yielded pargasitic amphibole and aluminous pyroxenes and spinel.

Following the equations of Brey & Köhler (1990), complete assemblage equilibration occurred at 920-930 °C and 1200-1300 °C. High temperature is assigned to melting conditions which led to the depletion of the residual. The mineral characteristics of the harzburgites and lherzolites are those of refractory peridotites. Low temperature suggests re-equilibration during decompressive upwelling of mantle material to shallow levels. Equilibrium pressures are high in harzburgites (>20 kb) and low in some lherzolites (≤7.5 kb). Thus, spinel lherzolite and spinel harzburgite xenoliths in Nyos volcanoes have been sampled by magmas in a mantle column at depths ranging from 24 to more than 80 km. The absence of plagioclase in shallow level spinel lherzolites is assigned to low activity of Al_2O_3 and CaO in depleted peridotite compositions. This depletion also explains the absence of garnet in xenoliths from the deep mantle.

With reference to Lupton (1983), the depleted character of these xenoliths is fossilized by the He isotope ratio of fluid inclusions in pyroxenes. Nyos region's tectonic setting is favorable for the circulation of hot fluids in the crust since it has a fissured rigid basement. This is strengthened by the recent volcanic eruptions and the presence of many thermal and thermomineral CO_2-bearing springs (Le Maréchal, 1976). As CO_2 is the main constituent of fluid inclusions, the ratio ^3He / ^4He which is similar to that of gases in lake Nyos water

(Giggenbach, 1990) confirms the mantle origin of the latter. Gases released during mantle partial melting related to volcanic events at Nyos and its vicinity may be now confined in intracrustal pockets as revealed by seismic wave perturbations (Tabod, 1991; Nana et al., 1994). Since the area is located at the intersection of Cameroon Line and the Adamawa volcanic province, the permanent activity of deep-seated faults of the Atlantic ocean fracture zones may provoke the release of gases from these pockets. This makes the Nyos region one with a high potential of volcanic hazards.

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Heat and mass balance calculations on Kawah Ijen crater lake reveal its excess degassing and low probability as an ore forming environment.

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Introduction

The Kawah Ijen volcano, east Java, has contained a hot crater lake (T ≈ 36-45°C) for at least 200 years (Neumann van Padang, 1951). This crater lake is probably the world's largest accumulation (≈ 32 x 10^6 m^3) of strongly acid (pH ≈ 0.2) and highly mineralized (TDS ≈ 105 g l^{-1}) waters. The geochemistry of the lake is dominated by the continuous absorption of heat and volatiles (SO_2, H_2S, HCl and HF) from a cooling and degassing magma. Acid leaching of volcaniclastic material is the main source of rock-forming elements in the lake. Bottom sediments are composed of α-cristobalite (> 95 wt.%) precipitated from the lake solution (Delmelle & Bernard, 1994). According to previous water analyses (van Bemmelen, 1949; Tazieff et al., 1966; Delmelle & Bernard, 1994; unp. data), the chemical composition of the lake is relatively stable with time, despite the persistent loss of dissolved species through the Bunyupahit stream, whose source is the crater lake (Delmelle & Bernard, 1994b). This implies that there is a net influx of magmatic volatiles and rock-forming elements to the lake in order to balance the outflow due to the water seepage. The volcano is passively degassing and SO_2, H_2S, HCl-rich fumaroles (T ≈ 200°C) are discharging near the lake shore. By applying a box model (Hurst et al., 1991; Rowe et al., 1992; Ohba et al., 1994) to Kawah Ijen which describes mass and heat flow into and out of the crater lake, it is possible to estimate the power output and the magmatic volatiles release from the volcano. The model was run using a set of time-series data on lake level and lake temperature over the period 1980-1993. This contribution reports the calculation results and, based on a comparison with field measurements, has important implications for the degassing process, and the formation of a high-sulfidation ore forming environment at Kawah Ijen. Details of the calculations are not presented here, but will be described elsewhere.

Power output and magmatic heat flux

Heat and mass balance calculations were carried out by assuming that hydrothermal fluids which are injected into the lake are mixtures, with an average composition of approximately 30 wt.% steam and 65 wt.% water at temperatures of 200°C. This estimate was made by setting in the model a constraint on the seepage mass rate, which corresponds to the observed flow rate of the Banyupahit stream. Calculations indicate that the yearly average flows into and out of the lake were fairly constant, suggesting that inputs and outputs were adequately balanced. The energy which is dissipated mostly at the summit of the volcano from subaerial fumarolic degassing and from evaporation at the lake surface ranges between 180 and 600 MW, and averages to ≈ 400 MW over the period 1980-1993 (Fig. 1). The energy dissipated at any time from the lake surface represents the minimum magmatic heat flux into the subsurface hydrothermal system. The average power input to the lake is ≈ 300 MW, corresponding to a magmatic heat flux of ≈ 800 W m^{-2}. These values compare with those estimated at similar crater lake systems such as Poas (≈ 100-1000 W m^{-2} for the period 1978-89, Rowe et al., 1992; Stevenson, 1992) and Ruapehu (≈ 100-10 000 W m^{-2} for the period 1966-89, Hurst et al., 1991; Stevenson, 1992).

Flux of volatiles and magma degassing

In order to sustain a long-term average power input of ≈ 300 MW to the lake, a magma must crystallize, cool and degas. Thus, a magma solidification rate of ≈ 7.3 x 10^6 tons $year^{-1}$ (0.003 km^3 $year^{-1}$) is required in order to sustain such a high heat flow. Assuming a typical water content in the magma of 3 wt.%, this result implies a degassing water flux of 2.3 x 10^5 tons $year^{-1}$, which contributes no more than 10% of the total magmatic heat flux. Rates at which volatiles (S, Cl, and F) are extracted from the magma can be obtained by using this flux of water loss. The initial volatile content of the magma is approximated by making the assumption that the volatile ratios in magmatic fluids released at depth compare with those measured in typical high-temperature gases from subduction-related volcanoes (e.g. Symonds et al., 1994). The following fluxes are deduced: 29 tons day^{-1} S (or 1.1 x 10^4 tons $year^{-1}$), 7.8 tons day^{-1} Cl (or 2.9 x 10^3 tons $year^{-1}$), and 0.3 ton day^{-1}

F (or 1 x 10^2 tons $year^{-1}$). These degassing fluxes are in the same range as those deduced for Poas (Rowe et al., 1992; Rowe, pers. commun., 1995), but are about 100 times lower than the volatile fluxes estimated for Satsuma Iwojima volcano (Hedenquist et al., 1994).

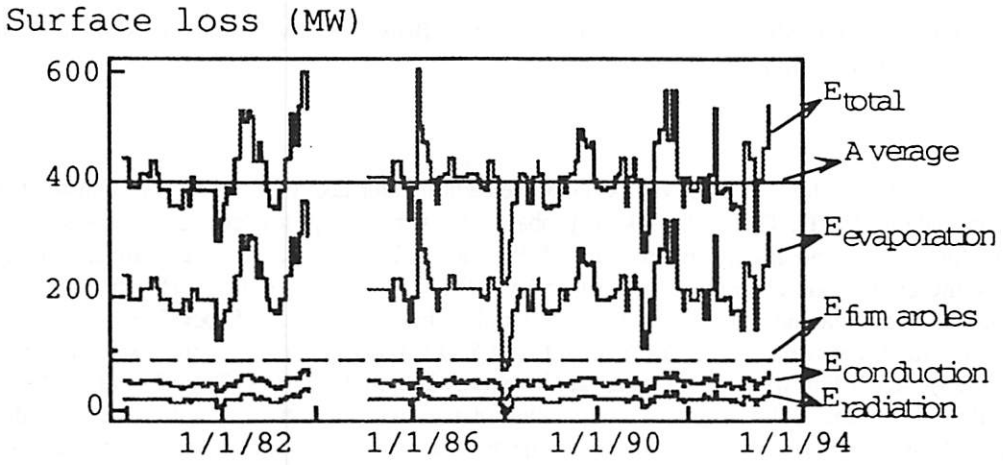

Figure 1: The power output delivered at the summit area of Kawah Ijen is expressed as the sum of energy losses (E) through aerial degassing (fumaroles) and evaporation, conduction and radiation processes at the lake surface. Each of these terms is calculated by means of equations described in Rowe et al. (1992) and Stevenson (1992). Note that the evaporation term accounts for about 72% of the total sink of the crater lake.

Maintainance of a constant lake chemistry within the period 1980-1993, despite the net seepage through the Banyupahit stream, requires that S, Cl, and F are replenished in the lake through the adsorption of magmatic gases. Estimates of long-term releases from the magma of S, Cl, and F are then calculated on the basis of the measured flow rate (≈ 50 kg s^{-1}) and compositional data of the Banyupahit stream (Delmelle & Bernard, 1994b; unp. data). Loss of volatiles out of the system by fumarole degassing is also calculated (Symonds et al., 1994), using a SO_2 flux of 50 tons day^{-1} and the gas composition (unp. data). The results are compared with the previous values predicted on the basis of the magma solidification rate (Fig. 2).

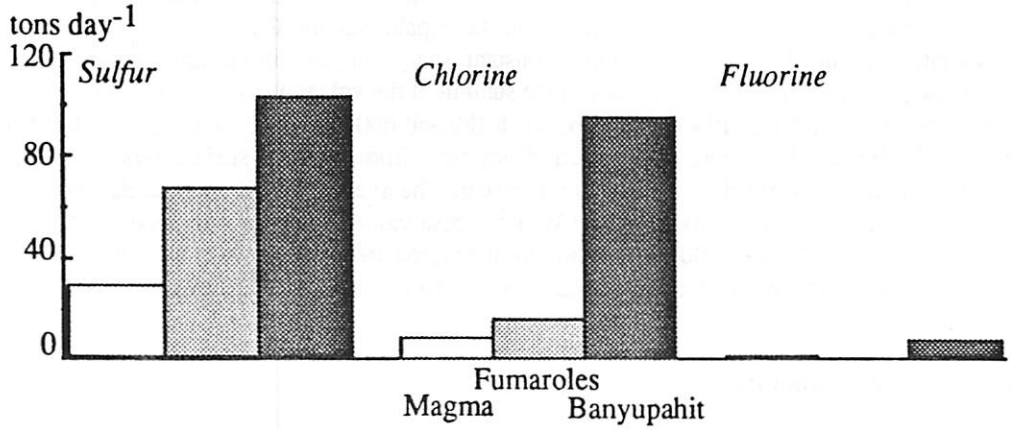

Figure 2: Volatile fluxes as calculated from i) the solidification mass rate of the magma, ii) the SO_2 flux and composition of the fumaroles, and iii) the flow rate and composition of the Banyupahit river.

The fluxes exiting the summit area through the Banyuaphit stream and fumarolic degassing are a factor of six (for S) to an order of magnitude (for Cl and F) higher than those deduced from the power output calculations. Since there is no evidence for involvement of a magma with unusually high S, Cl, and F concentrations, an alternative hypothesis which could explain the volatile fluxes measured at Kawah Ijen is to consider that the volume of magma degassing is much higher than that solidifying. Such an apparent paradox

could be explained if convective transport of magma through a conduit causes degassing from a magma reservoir at several kilometers depth. This mechanism was proposed to occur at several volcanoes which show excessive degassing (Kazahaya et al., 1994; Stevenson & Blake, in press). It should be noted that the apparent low S flux with respect to that of Cl in the Banyupahit stream is likely to be the result of the deposition of S in the sublake system, probably in the form of native S. Thus, the measured S flux certainly represents a minimum value.

Implications for a high-sulfidation ore-forming environment

The acidic hydrothermal solutions discharged as hot springs or contained by a crater lake are thought to be responsible for the shallow (< 1 km) oxidized alteration assemblage associated with high-sulfidation Cu-Au deposits that occur along convergent plate margins (Giggenbach, 1992; Hedenquist, 1995; Hedenquist et al., 1994). Whether or not these solutions can lead to significant deposition of metals is still unclear. Kawah Ijen has been passively degassing for at least 200 years, but an acidic lake could have existed atop of this edifice for a much longer period. Several lines of evidence suggest that this acidic crater lake system represents a geochemical environment in the process of forming a hydrothermal ore deposit. To balance the net loss of rock-forming elements in the Banyupahit stream (and to keep the lake composition constant), $\approx 3.5 \times 10^4$ tons year^{-1} of rock has to be leached by the acidic waters (Delmelle & Bernard, 1994a). Thus, to produce a vuggy silica core similar in size ($\approx 10^8$ tons) to those associated with high-sulfidation ore deposits, it will take $\approx 3 \times 10^3$ years (Fig. 3). This result is consistent with the time ($\approx 10^4$ years) required for a single intrusion to crystallize. Previous modelling calculations showed that upon neutralization through water-rock interactions, the lake brine will develop an oxidized alteration assemblage similar to that described in the shallow part of the hydrothermal Au-Cu deposits. Finally, metal sulfides (pyrite-enargite-bismuthinite) are associated with floating native sulfur (Delmelle & Bernard, 1994a).

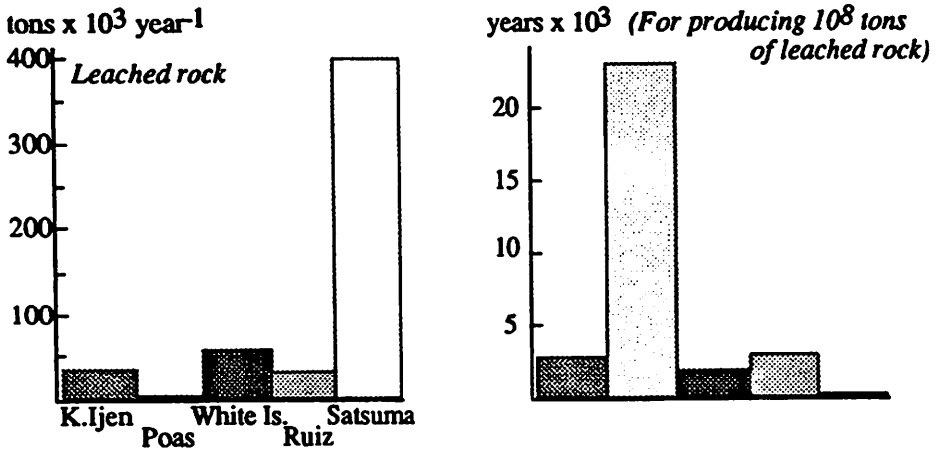

Figure 3: Estimated rates of rock leaching by acidic solutions associated with magmatic hydrothermal systems, including Kawah Ijen, Poas, White Island, Nevado del Ruiz, and Satsuma-Iwojima (Left); and time required to produce in these edifices a body of residual silica similar in size to those typically found in high-sulfidation Au-Cu ore deposits (Right). Data from Rowe et al. (1992), Giggenbach (1987), Lopez and Williams (1993), and Hedenquist et al. (1994).

An estimate of the flux of base metals (Cu, Zn, and Pb) at the surface of the edifice can be obtained by considering the seepage rate through the Banyupahit stream. Although significantly higher than that estimated for other magmatic hydrothermal systems, this flux value is unlikely to be representative of an ore-forming environment (Fig. 4). Indeed, highsulfidation Cu-Au deposits typically contain > 10^5 tons Cu and 10^2 tons Au, and these amounts wouldn't be formed even if the flux continues over $\approx 10^4$ years. Moreover, the fact that highly acid and oxidizing conditions prevail in the upper part of the hydrothermal system above the magma conduit, will probably prevent any deposition of metals.

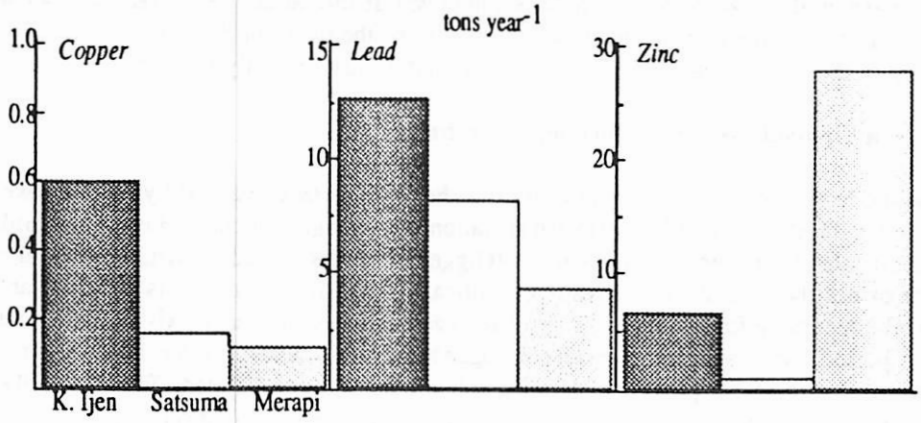

Figure 4: Estimated base metal fluxes at the surface of volcanoes presenting different expressions of a magmatic hydrothermal activity. An acidic lake fills the crater of Kawah Ijen, both hot springs and high temperature volcanic gases are present at Satsuma Iwojima, and only high temperature volcanic gases discharge at Merapi. Data from Hedenquist (1995).

Conclusions

Heat and mass balance calculations at Kawah Ijen crater lake suggest that the system is close to steady state. An average power of 400 MW is delivered at the summit area of the volcano. Most of the heat is dissipated through evaporation at the lake surface. The solidification of 0.003 km^3 $year^{-1}$ of magma ensures a power input of 300 MW to the lake. Degassing accounts for only 10% of the total magmatic heat flux. On the basis of a comparison between calculated and measured volatile releases, it is suggested that the volume of magma degassing is higher than that deduced from the power output value. Kawah Ijen may behave like other volcanoes which show excessive degassing. Although, there are lines of evidence which tend to suggest that the acidic lake brine could be adequate as a potential ore-forming fluid, both the flux of base metals, as sampled at the surface, and highly oxidized conditions which occur in the hydrothermal system feeding the lake, indicate a low probability for Kawah Ijen lake system to be currently an ore-forming environment.

Acknowledgments: This study was supported by the Belgian National Foundation for Agricultural and Industrial Research (FRIA). D. Wahyudin and M. Badrudin (Volcanological Survey of Indonesia) made available a precious set of data on Kawah Ijen. G. Rowe, D. Stevenson, and J. Hedenquist gave helpful criticisms regarding this work. We thank C. Mandeville who smoothed the english.

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Towards a Catalogue of Volcanic Lakes

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Introduction

When the International Working Group on Crater Lakes (later to become the IAVCEI Commission on Volcanic Lakes) was set up, in the wake of the 1986 Lake Nyos disaster, one of the first tasks which it set itself was to compile a Catalogue of Crater Lakes. Initially the intention, as proposed by Minoru Kusakabe during an 'informal' meeting of members of the Group (Kogashima, July 1988), was "to prepare a catalogue of crater lakes which possess limnological and volcanological similarities to Lake Nyos and Lake Monoun". This objective was extended when the IWGCL applied to become a Commission of IAVCEI (in 1991) to include all crater lakes and subsequently to include all volcanic lakes. Following the 1992 IWGCL meeting in Misasa a report on that meeting was published in Eos (Kusakabe, 1993) which set out the objectives of the Group and mentioned the *intention* to compile a Catalogue of Crater and Caldera Lakes - this created considerable interest and a number of people wrote to this Newsletter asking how they might obtain copies of the Catalogue! Since then other people have written in, from time to time, requesting the type of information which would be immediately accessible if a comprehensive catalogue were available. However, it is now nearly 10 years since the Lake Nyos disaster and, despite the obvious interest, progress towards a definitive catalogue of volcanic lakes has been less than spectacular.

As far as I am aware there have been very few attempts to compile comprehensive lists of volcanic lakes for specific countries or regions. Most studies have concentrated on selected groups of lakes which, for one reason or another, were of particular interest to their authors. One major exception to this is the list of Cameroonian volcanic lakes which was initially compiled by George Kling when he was investigating the Lake Monoun disaster (Kling, 1988). This list was subsequently extended (Freeth, 1992) to include volcanic lakes in Nigeria and Equatorial Guinea, which are part of the same West African volcanic province, and it has now been further revised and amended (see attached table), particularly as far as lake locations and areas are concerned, using data derived from large scale (1 : 50 000 and 1 : 200 000) topographic maps.

During the 1992 IWGCL meeting in Misasa, Gary Rowe and Joop Varekamp offered to create a "multi-faceted database" for crater and caldera lakes, based partly on a compilation which they had already begun as part of their research on crater lakes in Costa Rica and Indonesia. This offer was accepted and a 'call for contributions' to the database was published in the following year's Newsletter (Rowe and Varekamp, 1993) accompanied by a questionnaire and a table of "preliminary data", much of which had been derived from the *IAVCEI Catalog of Active Volcanoes of the World.*

Thus by 1993 two partial catalogues existed, one for a small but important part of the World and the other for lakes associated with (and mostly in the caldera of) recently active volcanoes. I have no wish to preempt or in any way intrude on the initiative by Gary Rowe and Joop Varekamp to produce a comprehensive database. However, a *comprehensive* database is clearly a major undertaking and in the meantime I thought that it might be helpful to the membership in general to try to put together and initial *list* of volcanic lakes. I have therefore condensed together the two lists mentioned above and added in a limited amount of data which I have collected together from other sources. My initial list is in no sense comprehensive but I hope that it represents a useful step on the way towards the development of a comprehensive list of volcanic lakes.

I have restricted the attached list to volcanic lakes of known depth (or in a few cases to lakes of known minimum depth) and I have presented the lakes by country and in depth order. This may or may not be an appropriate way to present a list since it implies that depth is the most important characteristic of a volcanic lake and other people may feel that there are other characteristics which should be given priority. Giving priority to depth is a reflection of my own work in West Africa in that the deeper a lake the greater its capacity to contain dissolved gas and consequently the greater the potential hazard in the event of a Lake Nyos type 'overturn'. I hope that by presenting a partial list in this way I will prompt other members to write to me with corrections, with data to fill in the empty spaces in my table and with information on other lakes of known depth which can be added to the list.

One great advantage in establishing even a partial list of volcanic lakes is that with current 'on-line' methods of bibliographic data retrieval it is but a short step from the name of a lake to a full listing of recent papers which mention that lake in their abstract. And from recent papers it is usually possible to trace back previous work. However, the names of volcanic lakes can cause problems since many have (or have had) alternative names or alternative spellings (or mis-spellings) and computer based databases are notoriously stupid when it comes to recognising even minor variants on the same name. A good example of the problems which can arise can be seen by tracing back the various names by which Lake Nyos is or has been known. The first scientific study of this lake was undertaken by a German team in 1908, at a time when it was in the German colony of Kamerun. In their published report (Hassert, 1912) Lake Nyos is referred to as Große Ndü See which literally means Great or Large Ndü lake - it is incidentally interesting to note that große is the descriptive not the comparative form of the adjective so it does not imply the exitance of a Small Ndü Lake. Their report opens with the comment that "in the district of Bafam there are many young, rock strewn and cratered volcanic cones some of which contain lakes, of which the largest, Ndü in the territory of Njos, was discovered by Glauning in 1905" and goes on to state that Glauning initially called it Ilüi See but subsequently decided to call it Ndü (or Ndi) See, which apparently translates as Gott See [God Lake]. Presumably when Glauning visited the area he was told that gods lived in the lake and selected a name for his 'discovery' accordingly. After the First World War the by then ex-German colony of Kamerun was divided between Great Britain and France with the district in which Lake Nyos is located becoming part of the British territory of Southern Cameroons. Access to Lake Nyos is difficult, at the present time, and would have been exceedingly so in the earlier part of this century, it is therefore hardly surprising that the next published record is of a visit in 1950 (Duckworth, 1951), by which time the current name had been adopted. And Lake Nyos is also the name which was used on the first detailed (1:50 000) topographic map of the area, published by the British Directorate of Overseas Surveys, in 1961, at the very end of the colonial era. However, after independence and the reunification of Cameroon a further set of topographic maps (1:200 000) were prepared by the Institut Géographique National, Centre de Yaoundé and on these Lake Nyos appears as Lake Lwi. Fairly obviously Ilüi and Lwi are transliterations of the same name, presumably the name by which Lake Nyos is known in one of the local languages, but since there are a multiplicity of languages spoken in the area (Freeth, 1993) it is difficult to know which. If there had been any doubt as to which name would eventually prevail it was resolved by the 1986 gas disaster - firmly labelled the Lake Nyos disaster by the international press, though some spelled it Nios, and this is the name which has been adopted by government and international organisations. So Lake Nyos appears in the published literature under three different names each of which has at least two alternative spellings. At the other extreme there are some names which have been used for a number of different lakes. As far as I can make out the most popular name is Green Lake, there are at least 5 Green Lakes in North America and two in Africa, both of which are volcanic. And there are many other lakes which are green in some other language. There is also the problem of names which are difficult to handel, at least as far as a computer based database is concerned, either because they are to long or because they are split into separate sections in a way that those unfamiliar with the language in which they originate would find confusing. A classic example of both problems arises with the local names by which the three crater lakes near the summit of Keli Mutu volcano, on the Indonesian island of Flores, are known - Tiwu Ata Polo, Tiwu Ata Mbupu and Tiwu Nua Muri Koohi Fah (Pasternack and Varekamp, 1994). These names apparently translate as: Enchanted Lake, Lake of Elders and Lake of Young Men and Maidens, respectively. So it is hardly surprising that they tend to be known as the Keli Mutu Lakes and this brings up another problem in that for many caldera lakes the name of the volcano in which they are situated and the actual name of the lake itself tend to be used interchangeably. The attached list uses what I believe to be the most commonly used current name for each lake. Clearly in any future, more comprehensive, list it would be appropriate to append a list of synonyms and alternative spellings. At the present time I have what I believe to be a fairly complete list of alternative names for West African lakes but I have very little information as far as the rest of the World is concerned and I would therefore be pleased if members could send me relevant information so that a comprehensive list of synonyms can be published in a future Newsletter. I would also be pleased if members could send me any information which would help to improve the accuracy with which the location of each lake is quoted. Accurate locations are not only important in themselves but they also help to avoid any lake creeping into the list twice under two alternative names. It might also be appropriate to include in any future list a comment concerning the meanings of names, particularly since some lakes may have alternative names which are in reality the same name in different languages, but this too would depend on members sending in relevant information.

In the attached list an attempt has been made to distinguish between various different types of volcanic lake. To what extent a real distinction can be drawn between crater lakes and caldera lakes is not entirely clear particularly since if a caldera is defined as a depression at the summit of a volcano and a volcanic crater as any

depression formed as a consequence of a volcanic explosion then clearly the two definitions overlap - many caldera are craters though most craters are not caldera. 'Definitions' of these terms in the literature tend to be based on descriptions as to how these two types of structure are formed and are therefore more genetic explanation that strict definition and as such are not very helpful. For the purposes of this list I have attempted to draw a distinction between those lakes which lie in a depression surrounded by an elevated rim of volcanic rocks (caldera lakes) and those which lie in depressions in otherwise flat volcanic terrain (crater lakes). Clearly caldera and craters belong to a continuous range of structures with no obvious discontinuity in it, so any distinction must, by its very nature, be artificial - and there may therefore be no point in attempting to draw a distinction. Even if a real distinction could be drawn between caldera and craters this would still leave the question as to how to classify a crater on the floor of a caldera! There is also the problem of how to classify volcanic lakes of composite origin. This problem is well illustrated by Lake Monoun, the first of the two lakes in Western Cameroon to release a cloud of toxic gas in the mid-1980's. Lake Monoun lies in a valley between two volcanic cones, a lava flow from one of which blocks the down slope part of the valley. The general impression is of a shallow lake ponded back by a lava flow. However, when a detailed bathometric survey was undertaken (Sigurdsson et al., 1987), following the 1984 disaster, it revealed not one but two deep craters in the central part of the lake. For the purposes of this list I have attempted to classify each lake according to its dominant structure but I will have to leave others to judge whether or not this is a useful classification.

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Africa

Cameroon

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Nyos	6° 26' N	10° 18' E	208	1501	153	crater
Manengouba-N	5° 02' N	9° 50' E	168	293	18.6	caldera
Benakuma	6° 26' N	9° 57' E	138	1606		crater
Wum	6° 24' N	10° 03' E	124	295		caldera
Barombi Mbo	4° 39' N	9° 24' E	111	3972	272	caldera
Gagouba	7° 07' N	13° 41' E	104	103		crater
Monoun	5° 35' N	10° 35' E	96	565	14.0	crater
Manengouba-S	5° 02' N	9° 50' E	93	60	3.4	caldera
Dissoni	4° 44' N	9° 17' E	81	1330	70.5	caldera
Enep	6° 18' N	10° 02' E	78	320		caldera
Nefo	5° 35' N	10° 27' E	64	40		crater
Ngaoundaba	7° 08' N	13° 42' E	62	29		crater
Bambuluwe	5° 52' N	10° 12' E	58	184	7.2	crater
Mfou	5° 33' N	10° 42' E	58	76		crater
Oku	6° 12' N	10° 28' E	52	2271	71.6	caldera
Mbalang	7° 19' N	13° 44' E	52	399		crater
Baleng	5° 33' N	10° 25' E	52	35		caldera
Ngouondam	5° 37' N	10° 33' E	49	135		crater
Tizong	7° 15' N	13° 35' E	48	44		crater
Kuk	6° 24' N	10° 13' E	47	407		caldera
Elum	6° 20' N	10° 02' E	35	285		caldera
Negop Gbang	5° 33' N	10° 34' E	23	66		crater
Ejagham	5° 45' N	8° 59' E	17	481		crater
Njupi	6° 27' N	10° 19' E	17	271		lava dam
Beme	5° 10' N	9° 38' E	15	280		crater
Debundsha	4° 06' N	8° 59' E	14	96		crater
Mfouet	5° 32' N	10° 35' E	14	85		caldera
Baledjam	7° 08' N	13° 52' E	13	204		crater
Edib	4° 58' N	9° 39' E	13	95		caldera
Pètponoun	5° 38' N	10° 39' E	12	408		
Barombi Koto	4° 28' N	9° 16' E	6	1260	4.8	caldera
Bambili-S	5° 55' N	10° 15' E	4	417		caldera

Africa (cont.)

Ethiopia

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Bishoftu			87	900		crater
Pawlo			63	600		crater
Aranguadi			28	500		crater

Kenya

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Simbi	0° 22' S	34° 38' E	25	49		crater
Green	0° 47' S	36° 16' E	5	141	0.5	crater

Nigeria

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Oku	7° 56' N	8° 48' E	3	4000		crater
Tilla	10° 33' N	12° 08' E	2	524		caldera

Uganda

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Mutanda			50	23 000		lava dam
Bunyoni	1° 18'S	29° 54 E	39	51 500		lava dam

Asia

Indonesia

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Kawa Ijen	8° 04' S	114° 14' E	200	410		crater
Kerintji	1° 41' S	101° 10' E	200	49		crater
Burkit Dahn	3° 23' S	102° 22' E	150	65		crater
Sorikmarapi-1	0° 41' N	99° 32' E	150	30		crater
Keli Mutu-TiN	8° 46' S	121° 49' E	127	917	6.4	crater
Batur			80	15 000		caldera
Satonda	8° 07' S	117° 45' E	69	772	34	
Keli Mutu-TAM	8° 46' S	121° 49' E	67	604	4.2	crater
Keli Mutu-TAP	8° 46' S	121° 49' E	64	817	5.3	crater
Sorikmarapi-2	0° 41' N	99° 32' E	50	2		crater
Tandikat	0° 26' S	100° 19' E	40	4		crater
Kelut	7° 56' S	112° 19' E	32	240	2.4	crater
Wai Sano	8° 41' S	102° 02' E	<30	3900		caldera
Tampusu	1° 15' N	124° 49' E	25	40		crater
Klabat	1° 28' N	125° 02' E	20	5		crater

Japan

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Mashu	43° 35' N	144° 32' E	211	18 370		caldera
Gosikinuma	38° 09' N	140° 27' E	63	100		caldera
Yugama	36° 19' N	138° 30' E	27	50		caldera
Osore-Yama	41° 19' N	141° 05' E	15	2300		caldera
Okama	39° 51' N	141° 00' E	14	2		caldera
Onasiroko	39° 51' N	141° 00' E	6	35		caldera

Russia

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Klyuchoe	51° 50' N	157° 31' E	96	5400		caldera
Stubel	51° 50' N	157° 31' E	84	2500		caldera
Golovnin-1	43° 49' N	145° 31' E	62	2600		caldera
Bannoe	54° 32' N	160° 05' E	32	1		caldera
Golovnin-2	43° 49' N	145° 31' E	22	40		caldera
Ebeko	50° 40' N	155° 56' E	20	30		caldera

Asia (cont.)

Turkey

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Nemrut	38° 39' N	42° 01' E	167	11 000	980	caldera

Europe

France

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Pavin	45° 55' N	2° 54' E	92	440		crater

Germany

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Laacher See	50° 24' N	7° 18' E	52	2210		crater

Iceland

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Grimsvötn	64° 25' N	17° 20' E	<350	2500		caldera

Italy

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Albano	41° 45' N	12° 40' E	177	4500		crater
Bracciano	42° 07' N	12° 14' E	165	50 700		crater
Bolsena	42° 36' N	11° 56' E	156	105 000		crater
Martignano	42° 07' N	12° 19' E	54	5300	151	crater
Vico	42° 19' N	12° 11' E	48	12 100	261	caldera
Averno			39	1300	38	crater
Piccolo			38	500	16	caldera
Nemi	41° 43' N	12° 42' E	32	3800	65	crater

North America

Guatamala

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Atitlan	14° 42' N	81° 11' W	341	137 000		caldera

United States of America

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Crater Lake	42° 57' N	122° 06' W	590	53 200	17 300	caldera

South America

Argentina

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Copahue	37° 45' N	71° 18' W	<40	71		caldera

Ecuador

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	type
Quilotoa	0° 52' N	77° 55' W	<360	3100		caldera
Cuicachi	0° 19' N	78° 22' W	180	3100		caldera

The third meeting of the IAVCEI Commission on Volcanic Lakes, Russia, 15-26 August 1995

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The third meeting of the IAVCEI commission on volcanic lakes took place during the period from 15th to 26th of August 1995, at first in Vladivostok, then in Kamchatka, Russia. Reports were presented within the frameworks of the section "Physical-chemical processes in crater lakes" of the "8th International Symposium on Water-Rock Interaction". The following papers were published in the proceedings of the WRI-8 symposium (eds. Y. K. Kharaka and O. V. Chudaev, Balkema, Rotterdam):

1. B. Takano, M. Matsuo, K. Sugimori & S. M. Fazlullin. Bathymetry and chemical investigation of crater lake at the Maly Semyachik volcano, Kamchatka.

2. A. Bernard & D. Tedesco. Geochemistry of the crater lake of the Kelut volcano, Indonesia.

3. P. Delmelle & A. Bernard. Power output and volatile fluxes at the Kawah Ijen volcano, Indonesia.

4. W. C. Evans, G. W. Kling & M. N. Tuttle. Lake Nyos, Cameroon: Examining the 1986 gas release from the system standpoint.

5. G. A. Karpov & S. M. Fazlullin. The creation and prolonged existence of the zone of molten native sulfur at the bottom of thermal lake within the volcanogenic-hydrothermal system (Uzon caldera, Kamchatka).

6. M. Kusakabe, G. Z. Tanyileke, Y. Nojiri & I. Kita. Decreasing thermal and chemical fluxes at Lake Nyos, Cameroon.

7. A. A. Migdisov, A. Yu. Bychkov & Yu. V. Alekhin. Experimental study of sulfur solubility in gaseous and water: H_2S-bearing solutions and sulfur equilibrium in volcano crater lakes.

8. T. Ohba, K. Nogami & J. Hirabayashi. Isotope ratios of lake water in the active crater at the Kusatsu-Shirane volcano, Japan.

9. D. S. Sheppard & J. M. Deely. The effect of drainage of an active volcanic crater lake into a river system.

10. K. Sugimori, B. Takano, M. Matsuo, K. Suzuki & S. M. Fazlullin. Activity of sulfur-oxidizing bacteria in the acidic crater lake.

11. E. Viollier, D. Jezequel, G. Michard, M. Pepe, G. Sarazin & P. Alberic. Trace element geochemistry of the Pavin crater lake (France): chemical reactions and recycling in the monimolimnion.

The field excursions in Kamchatka started on the 20th of August. A special program was prepared for the members of CVL group: M. Kusakabe, B. Takano, T. Ohba, A. Bernard, P. Delmelle, W. Evans, G. Karpov and S. Fazlullin. This program was organised by S. Ushakov and E. Kalacheva, from the Laboratory of Geochemistry of Volcanic Gases and Volcanic Chemistry, and S. Bondisenko and L. Fazlullina helped with the organisation of the field excursions.

The daily journal of the group was as follows:

August 20. Sunday. Flight from Vladivostok to Petropavlovsk-Kamchatsky. Accommodation at the "Sputnik" boarding-house. A party in the evening included video-films about Kamchatka.

August 21. Monday. The weather was unacceptable for helicopter flights with all of the passes covered by clouds. The participants were therefore able to enjoy a rest for the first time in a long period.

August 22. Tuesday. The weather became worse, it was raining all day. An excursion was therefore arranged in Petropavlovsk; the participants visited the Museum of local lore, the Museum of the Institute of Volcanology and the Kamchatkan Center for Monitoring Seismic and Volcanic Activity. In the evening a party was organized at which everybody could appraise at the true worth kamchatkan fish and beer and the participants were presented with pictures of kamchatkan volcanoes.

August 23. Wednesday. The weather improved and at 14:00 (local time) helicopter flights were able to begin. The first landing was in the area of the Institute of Volcanology's camp at the Karymsky volcano. After unloading supplies for the camp the helicopter then flew on to Maly Semyachik volcano. Unfortunately it had to land 250 m below the summit, owing to the cloud cover, and members of the group had to then carry their equipment themselves. However, all the problems of the ascent were forgotten with a spectacular view of the crater lake. A water sample, with volume of about 10 litres, was collected and then divided into several parts. And some of the participants also made *in situ* measurements. Further information concerning the crater lake of the Maly Semyachik volcano can be found in IWGCL Newsletters Nos. 4 and 7.

August 24, Thursday. The group was taken by helicopter to the Uzon caldera where a lecture was given, by Dr. G. A. Karpov, about the geology of the caldera, its water geochemistry and recent mineral and ore formation. Field excursions were then made to several volcanic lakes: Khloridnoe, Bannoe, Vosmerka and Dalnee. This was followed by a flight to the Valley of Geysers, where the group admired the sights, then by a flight to the Karymsky volcano. Following a discussion of the results of measurements made during the two previous days it was suggested that the programme of inter-laboratory calibration should be continued. For the next stage of this programme it was suggested that 10 litres of water, which were collected in 1993 from the crater lake of the Maly Semyachik volcano, could be made available.

August 25. Friday. In the morning the group flew to the area of the Academy of Sciences springs (98 °C), drainage from which takes place on the shore of the Karymsky lake. Several participants took samples of water and gas. The group returned to Petropavlovsk-Kamchatsky at 15:00. A farewell party was organized, in the evening, at which the participants in the CVL field workshop were able to exchange impressions with the participants in the WRI-8 field excursions.

August 26. Saturday. Departure of the field workshop participants.

Each participant in the CVL field workshop paid 960 US$ for the services in Kamchatka the principal part of which was used to cover helicopter expenses.

Russian organizers have obtained a great experience in carrying out international meetings. We are grateful to all the participants for their faith.

Symposium on Volcanic Crater Lakes, 21st. IUGG General Assembly, Boulder Colorado, 10 July 1995

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A Symposium on Volcanic Crater Lakes, sponsored by IAVCEI and IAHS, was co-convened by Joop Varekamp and myself during the 21st. IUGG General Assembly in Boulder, Colorado. When the proposal for this Symposium was first put forward, in June 1993, the intention was to invite a limited number of members of our group, people who would either expect to be at the Assemble for other reasons or who lived in the western part of the States, and who could give an overview of their recent work. Thus it was hoped that the Symposium would provide a 'shop-window' for recent work on crater lakes to a very wide audience, but without detracting from the Commission meeting scheduled to take place in Russia a month later. Sadly the intention and its realisation proved to be rather different matters - but more of that later.

Boulder is an fine place for a meeting, major or otherwise, it is very easy to get to, the setting is spectacular and the facilities are excellent. For anyone from outside North America the trip to Boulder is long and arduous. In my own case I was able to leave home at a reasonable civilized hour, catch an early afternoon flight and arrive in Denver in the early evening. However, when the time difference is added on it was the early hours of the following morning and by the time I found my hotel, in the quaintly named Boulder suburb of Gunbarrel, I had been travelling for the best part of 24 hours. It is never easy to find one's way around in a strange city and somehow the apparent simplicity of an American grid system frequently seems to hide traps for the unwary - roads which appear to intersect on the map so often seem to turn into overpasses or no entries of one type or another. But any irritation I might have felt at the inconsiderate nature of the road engineers was dispersed the following morning when I woke and saw the setting in which they had built their roads. Boulder is at the very western edge of the Great Plains and the view from my hotel, across the city to the towering ramparts of the Front Range of the Rocky Mountains, was quite magnificent. There are many places in the World where mountain ranges rise from flat plains but I know of nowhere where the change is quite so abrupt or the line quite so straight - almost as though some celestial engineer had used a ruler when drawing out the plans.

The City of Boulder is a very pleasant place to spend a few days. At its heart is the "Historic District" the centre of which has been 'pedestrianised' and which is, in many respects, far more like the tourist brochure version of San Francisco that San Francisco is itself - street entertainers, pavement cafes, outdoor markets and, best of all, a generally relaxed air about everything.

The campus of the University of Colorado, Boulder is to the south, on the opposite side of a small creek from the 'downtown' area of the City. In a strange sort of way the University is within, yet separate from, the City. Although it seems to have a distinct perimeter some of the city roads extend into the campus and there is at least one which extends in from both sides but somehow gets lost in the middle - very confusing for the casual visitor. The general appearance of the University campus is very pleasant but to my European eyes somewhat eccentric. I had it on very good authority that the 'style' in which the vast majority of the buildings had been constructed was Tuscan. But to me they looked like concrete framed buildings hung on the outside with panels of masonry and topped of with pitched pantile roofs - pleasant but stylistically more reminiscent of Seattle than Sienna.

The Assembly itself was very well organised, but given that it was attended by many thousands of 'delegates' there would have been total chaos if this had not been the case. As with any large meeting there were many parallel sessions - on the day of the Symposium on Volcanic Crater Lakes there were a total of 31 symposia scheduled, including one on Magma Degassing and Explosive Eruptions and another on the Effects of Pinatubo. Competition for the prime meeting venues had obviously been fierce and small meetings, such as ours, were very reasonably tucked away in less favoured venues. Although the room which we were allocated was more than adequate finding it involved quite a feat of navigation - round the back of a major building, into a sports complex, past a swimming pool, up a flight of stairs, and second on the left. Sadly this meant that far from providing a 'shop-window' for recent work to a wide audience we ended up presenting our contributions to a small dedicated audience - not that there is anything wrong with that, but rater that it defeated the initial intention. Unfortunately not all of those who were scheduled to present papers were able to attend, presumably due to lack of financial support - of the 8 abstracts received by the convenors (and published in last year's

Newsletter) 6 were presented, a rather better proportion than for the Assembly as a whole. Although the total number of papers presented was disappointingly low I personally thought that they were all of an unusually high standard. Of the 6 papers presented 2 were on general matters, 3 on Lake Nyos and one on Grímsvötn. The papers on Lake Nyos were all, to a greater or lesser extent, concerned with the evolution of stratification within the lake and the contrasting approaches from different perspectives was especially interesting. I myself was particularly struck by the similarities between certain aspects of the model developed, and subsequently published in *J. Geophys. Res.* (**101,** 8187-8203), by my colleague Laksmi Kantha, an aeronautical engineer from the University of Colorado, and a model for the destabilisation of Lake Nyos presented by Prof. A. Rice, from Rhodes University, Grahamstown, which had been developed from the standpoint of the chemical engineer. Once models from such differing perspectives start to converge I think we can be confident that we are heading in the right direction. The multiplicity of symposia and the complexity of the organisation made it difficult to dip in and out of sessions as one might in other large meetings - I personally found that by the time I had figured out where to go and found the venue I had usually already missed the paper I wanted to hear. Far more successful, from my point of view, were the 'poster' presentations. These were all collected together in an immense indoor stadium the large 'playing' area was set up for poster presentations, as was a wide gallery which ran around the upper level behind the seating. Unfortunately neither of the Volcanic Crater Lake posters materialised and in general the proportion of posters presented was very low. But then that made access easier and I for one gained a great deal from wandering around looking at the displays. Even though the area set aside for crater laker posters was empty, Lake Nyos still managed to get into the act in a poster prepared by Youxue Zhang, from the University of Michigan, for the Symposium on Magma Degassing. This poster presentation covered degassing from fluids in general and that aspect of it which set out to model the dynamics of carbon dioxide driven limnic eruptions, such as those at Lakes Nyos and Monoun, was subsequently published in *Nature* (**379,** 57-59).

Guidelines for Authors

1. Submission - contributions should if possible be submitted in electronic form, either by e-mail or on a 3.5 inch disk in an IBM compatible format (MS-DOS or in a commonly used word processing format such as WordPerfect or Word) but ***not*** in Macintosh. Where electronic submission is not practicable contributions should be sent as camera-ready copy.

2. Format - the Newsletter is printed on A4 paper, copy should be prepared with this in mind and contributions should preferably be designed to occupy one or more full pages.

3. Layout - the title of the contribution should be followed by the name of the author and the author's full address.

4. Text - copy should be designed to be printed using a 10 point type face (these guidelines are printed in 10 point Times Roman). Camera-ready copy should be double spaced using any type face which clearly separates individual letters.

5. Tables - where appropriate small tables should be incorporated within the text. For preference, large tables should use the same type face as the text and, if possible, be prepared so that they can be read in the same orientation as the text.

6. Figures - line drawings should be in black on white and the lettering should be either 10 point or slightly larger. The text occupies an area which measures 160mm x 250mm - this also applies to figures so please design them accordingly. Please note that half tone illustrations cannot be printed. For preference figures should be submitted in PostScript format.

S.J.F.

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The end of Volcanic Lakes Newsletter No. 9

M.K.

Current Research on Volcanic Lakes

Newsletter of the IAVCEI Commission on Volcanic Lakes

No.10 March 1997

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Editorial

Who would have believed in 1987 when a small group of us, at the "International Conference on Lake Nyos", in Yaoundé, discussed the setting up of a working group that ten years later the International Working Group on Crater Lakes would have been transformed into an IAVCEI Commission and the group's Newsletter would have reached its tenth issue. Over the years the Newsletter has expanded and changed - hopefully reflecting the changing needs of the group. The first few issues of the Newsletter averaged 3 contributions on recent research and contained around 25 pages each. Following the highly successful 1992 meeting in Misasa, which brought with it an increase in membership and a broadening of members interests, the number of contributions doubled and the size of the Newsletter went up to over 60 pages. Since then the number of contribution has continued to creep ever upwards and the number of pages has been kept to under 50, by ever stricter editing and by reducing the size of the type face. With this the 10th issue now is an appropriate time to look to the future. At our recent meeting in Crater Lake, Oregon I was greatly encouraged by the members who made a specific point of offering favourable comments on the content and presentation of recent Newsletters and gratified by the willingness with which members rushed to pay their subscriptions when asked to do so. Despite the number of members who paid at the meeting and the number of new and continuing members who have subsequently sent in subscriptions the Newsletter is running in deficit. I would therefore like to encourage those continuing 'members' who have not paid a recent subscription to do so (remember that 20 $ US or the equivalent in any European currency is equally acceptable - but currency *notes* only please), whilst recognising that for some members obtaining small quantities of hard currency may be unrealistically expensive. However, financial constraints are but a minor irritation and so long as I feel that my efforts as Editor are appreciated I will be happy to continue. At an informal committee meeting during the Crater Lake meeting there was general agreement that members of the committee should in future be elected for a limited period and there was a certain amount of inconclusive discussion as to whether or not this should also apply to the Secretary (Minoru Kusakabe indicated that he would probably wish to step down at our next meeting) and to the Editor of the Newsletter. I would certainly not wish to overstay my welcome as Editor (particularly since there seems to be no way of preventing it becoming an ever more time consuming task) but equally having built up the Newsletter I would not like to see it wither and die. I would therefore greatly appreciate it if the membership in general could let me know how they feel about this matter. It occurs to me that if the Newsletter is to expand and improve this might be an appropriate time to see whether there might be someone who might be willing to volunteer to act as Assistant Editor (possibly with a view to taking over as Editor at an appropriate time). Editing this Newsletter can be divided into a number of tasks; soliciting and collecting in contributions, editing text into a form which will be easily understood by the majority of members, converting text into a common format, compiling, printing and distributing the copies. Of these tasks by far the most time consuming (and intellectually challenging) is that which involves editing text into an understandable form. Virtually all contributions are written by members who are using English as a second language - this would not be a problem if everyone made the same, or similar mistakes, since everyone would presumably recognise the intended meaning. Unfortunately this is far from the case in that it has been my experience that the errors made by contributors with one linguistic background have little in common with the errors made by contributors with another background, so much so that I suspect they would be mutually unintelligible and therefore unintelligible to the membership in general. The 'errors' which arise tend to fall into a number of distinct categories: (1) minor errors of grammar and usage - these tend to be easy to correct but make a surprisingly large contribution to intelligibility, (2) words with roughly the right meaning but used in an inappropriate context - it can be a major challenge to figure out the intended meaning and (3) using an exceedingly obscure term which may be technically correct - but what is the point of printing something which only the author (and perhaps a few of his/her colleagues) can understand? Of these 'errors' the first presents few problems, the second can frequently be resolved by a certain amount of *creative* thinking (and by repeatedly editing until a logical meaning emerges) but the third can be difficult to resolve. There is also the occasional sentence which seems to be devoid of meaning! Editing can be an interesting challenge so if there is anyone who would like to Assist (perhaps by sorting out only a couple of papers each year) I would be very pleased to hear from them.

Last year's Newsletter looked forward the meeting in Crater Lake, Oregon. That meeting was a great success (see report on page 39) for which our grateful thanks must go to all the organisers but particularly to Joop Varekamp and Gary Rowe. And now we must look into a rather more uncertain future for our next meeting which is tentatively scheduled for 2000 in Indonesia.

S.J.F.

A note from Secretary

The fourth official meeting of the Commission on Volcanic Lakes (CVL) was successfully held as part of AGU's Chapman Conference from 4-9 September 1996 at Crater Lake, Oregon. The participants enjoyed not only science but also post-conference field trips and the beautiful nature of Crater Lake-Mt. Mazama area. The Conference report by the organizers will be found elsewhere in this Newsletter. They are calling for papers to a special issue of JVGR for the papers presented at the Conference. I would like to thank the organizers, Johan C. Varekamp and Gary L. Rowe, Jr. for their efforts that led to a very successful meeting and for organizing the special JVGR issue.

At the CVL's steering committee meeting and business meeting held during the Chapman Conference, the following was accepted;

1. Secretary, Editor of Newsletter, and other members (except John Fonji) of the steering committee of CVL remain as they are until the next CVL official meeting. Since John is now more or less engaged in administrative work, Greg Tanyileke replaces him as a Cameroon representative.
2. Considering that CVL affiliates to IAVCEI, it would be better to organize the fifth official meeting of CVL synchronized with the next IAVCEI General Assembly which will be held in the year 2000 in Indonesia. The 2000 IAVCEI General Assembly in Indonesia was just recently endorsed by the "Extended" Executive Committee of the 1997 IAVCEI at Puerto Vallarta, Mexico.
3. Considering that a period of four years before the next official CVL meeting may be too long, we may seek an unofficial CVL meeting in 1998. The Ninth International Symposium on Water-Rock Interaction (WRI-9) which is scheduled from 30 March to 3 April 1998 at Taupo, New Zealand, will be the best opportunity for us to present the latest studies on volcanic lakes. B.W. Robinson, Secretary General of WRI-9, invites us to one of the conference themes entitled "Magma - water interaction and volcanic gases". For further information on WRI-9, visit the World Wide Web page: http://www.ruamoko.gns.cri.nz/wri-9.html, or write to him at Wairakei Reserach Centre, IGNS, Private Bag 2000, Taupo, New Zealand (Fax: 64-7-374-8199).
4. The focus of interest on the Lakes Nyos/Monoun disasters has entered a new stage; the lakes can be made safe through artificial degassing, provided sufficient funding and technology are applied. To this end, it was proposed to set up an advisory committee specifically devoted to the Nyos/Monoun degassing project (NMDP). Such a committee would (1) advance scientific and technical opinions for degassing, (2) obtain advise and recommendations from outside our community about the degassing, (3) communicate with the funding agencies and Cameroonian authorities about the importance and necessity of degassing Lakes Nyos and Monoun, and (4) collect information on the funding efforts. Even though those who were present at Oregon generally agreed to the proposal, not much discussion was made on its necessity, functions and composition due to lack of time. For this reason, I distributed a letter to all the steering committee members for comments on the proposal and nomination for the NMDP advisory committee members in March. They generally agreed on the necessity and functions given in the proposal. The following 8 people, each supported by more than half of the 7 steering committee members, bocome member of the NMDP advisory committee; A. Bernard, W.C. Evans, M. Halbwachs, G.W. Kling, M. Kusakabe, J.-C. Sabroux, G. Tanyileke and K. Tietze. There is an important suggestion that the advisory committee should invite in future additional expert(s) in different disciplines such as fluid dynanics and physical limnology/oceanography.

At the Puerto Vallarta IAVCEI General Assembly, 19-24 January 1997, all the commission leaders were invited to the Executive Committee meeting. However my commitment to other things did not allow me to attend the meeting as Secretary of CVL. After exploration of some CVL members, Marino Martini kindly agreed to represent the CVL at the "Extended" Executive Meeting. He will tell us what was decided there.

The Oregon meeting was also a good opportunity to advertise the activity of CVL, resulting in increase of new members. Those who want to join CVL, just contact either M. Kusakabe (kusakabe@misaa.okayama-u.ac.jp) or S.J. Freeth (s.j.freeth@swan.ac.uk).

Minoru Kusakabe
Secretary
Commission on Volcanic Lakes
IAVCEI

Water and gas chemistry of the Lake Piccolo of Monticchio (Mt. Vulture, Italy)

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Introduction

The two Monticchio Lakes, known as Lake Piccolo, which is Italian for small, and Lake Grande, which is Italian for big, are located within two *maars* (Principe and Stoppa, 1994) that formed about 130 ka BP (Laurenzi et al., 1993) within the Vulture caldera (Fig. 1). The two lakes are connected by a channel discharging the water of the former into the latter.

Lake Piccolo has a maximum depth of 38 m, a volume of 0.0039 km^3 and a surface area of 0.16 km^2. Previous studies (Mongelli et al., 1975; Fornai, 1992; Martini et al., 1995) and our unpublished data indicate that the Lake Piccolo of Monticchio is a biogenic meromictic lake, with a chemocline at a depth of about 13 to 14 m.

In order to collect further data aimed at assessing the risk of gas accumulation and consequent limnic eruptions from Italian crater lakes, a gas geochemical survey was carried out in the monimolimnion of Lake Piccolo in July 1995.

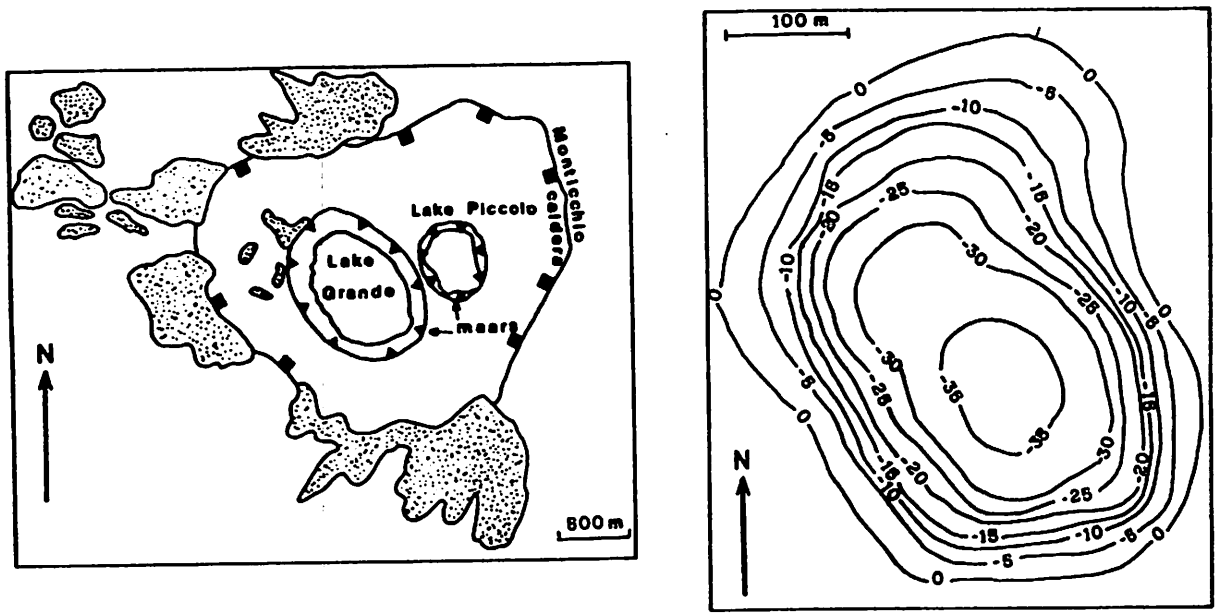

Fig. 1. Location and bathymetric map (from Hansen, 1993) of Lake Piccolo.

Sampling and analyses

Six samples of gases dissolved in lake waters were collected at different depths. Water samples were also obtained and alkalinity was measured immediately by acidimetric titration. Additionally, vertical profiles of temperature, dissolved oxygen, pH and electric conductivity (EC) were performed by means of an OCEAN SEVEN 401 manufactured by Idronaut (see below).

Gas sampling was carried out as follows. A polyethylene pipe was lowered at the chosen depth and the submerged end of the pipe was held close to the T-O_2-pH-EC sensors. A glass bottle with two Torion valves was connected to the surface end of the pipe. A three-way valve and a syringe were fitted downstream of the bottle, which was held vertical with the mouth downwards to allow gas accumulation.

Gas samples were analyzed for CO_2, N_2, CH_4 and Ar by means of gaschromatographic techniques. Results are reported in Table 1..

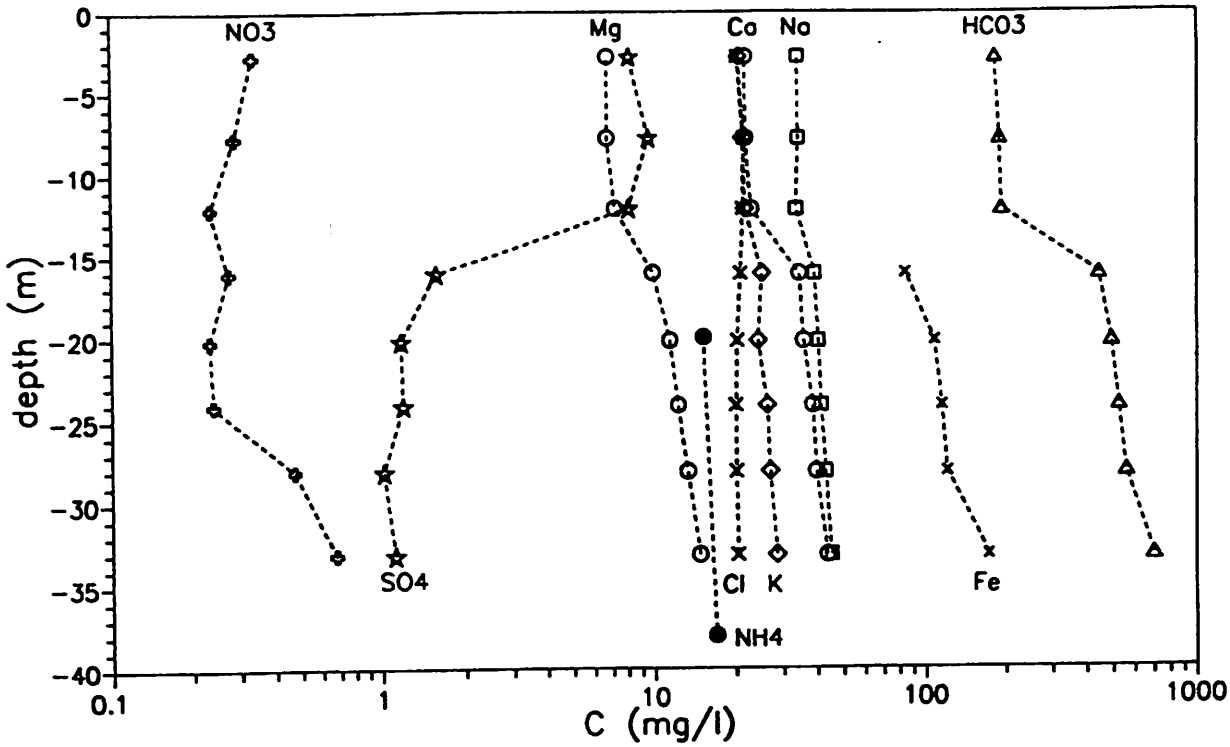

Fig. 2. Lake Piccolo: vertical profiles of major ionic species, i.e. Na, K, NH_4, Ca, Mg, Fe, HCO_3, SO_4, Cl, NO_3 in August 1992. Iron content is below detection limit (0.01 mg/kg) in the mixolimnion.

Gas chemistry

In order to calculate gas contents of deep lake waters it is convenient to refer to the following mass balance:

$$m_{i,d} = m_{i,s} + nx_{i,s} \qquad (1)$$

where m's and x's indicate molalities in the liquid phase and molar fractions in the gas phase of the i-th species, either at depth (subscript d) or at the surface (subscript s) and n stands for the moles of gas separated from 1 kg of water.

At surface conditions m's and x's are related by the Henry's law:

$$m_{i,s} = P_{i,s} / K_{H,i,s} = P_{t,s}x_{i,s} / K_{H,i,s} \qquad (2)$$

where $K_{H,i,s}$ is the Henry constant of species i at surface (sampling) conditions and $P_{t,s}$ is the sampling pressure. Substitution of equation (2) in (1) leads to the relationship we are looking for:

$$m_{i,d} = x_{i,s} (n + P_{t,s} / K_{H,i,s} \qquad (3)$$

Partial pressures of gas constituents in lake waters are then calculated by means of the Henry's law. Values of K_H at temperatures of interest are given by Wilhelm et al. (1977). Since sampling pressure and n were not measured, they must be calculated in some way. A suitable approach is to refer to the mass balances for CO_2 and Ar inserting proper values of $m_{CO_2,d}$ and $m_{Ar,d}$. The molality of CO_2 at depth is given by carbonate equilibria in the aqueous phase, whereas $m_{Ar,d}$ is assumed to be fixed by equilibrium with the atmosphere at the yearly average temperature of 11.8 °C. In our opinion this assumption is reasonable since even geothermal water discharges and magmatic vapours have Ar contents similar to those of air-saturated waters (Giggenbach, 1991).

Results are given in Table 2 and Fig. 4. Total gas pressures in the monimolimnion increases with depth from 1.9 bar at 18.3 m to 4.3 bar at 34.2 m. Gas pressures for all the samples are lower than hydrostatic pressures. However gas pressures approach and could even exceed hydrostatic pressures in the deepest parts of the monimolimnion. It seems possible, therefore, that gas bubbles form below 34 m. They cannot dissolve again in shallower lake waters because both these bubbles are strongly enriched in poorly soluble gases and their rise is too quick to allow significant re-dissolution. Intermittent gas bubbling is actually observed at the surface of Lake Piccolo.

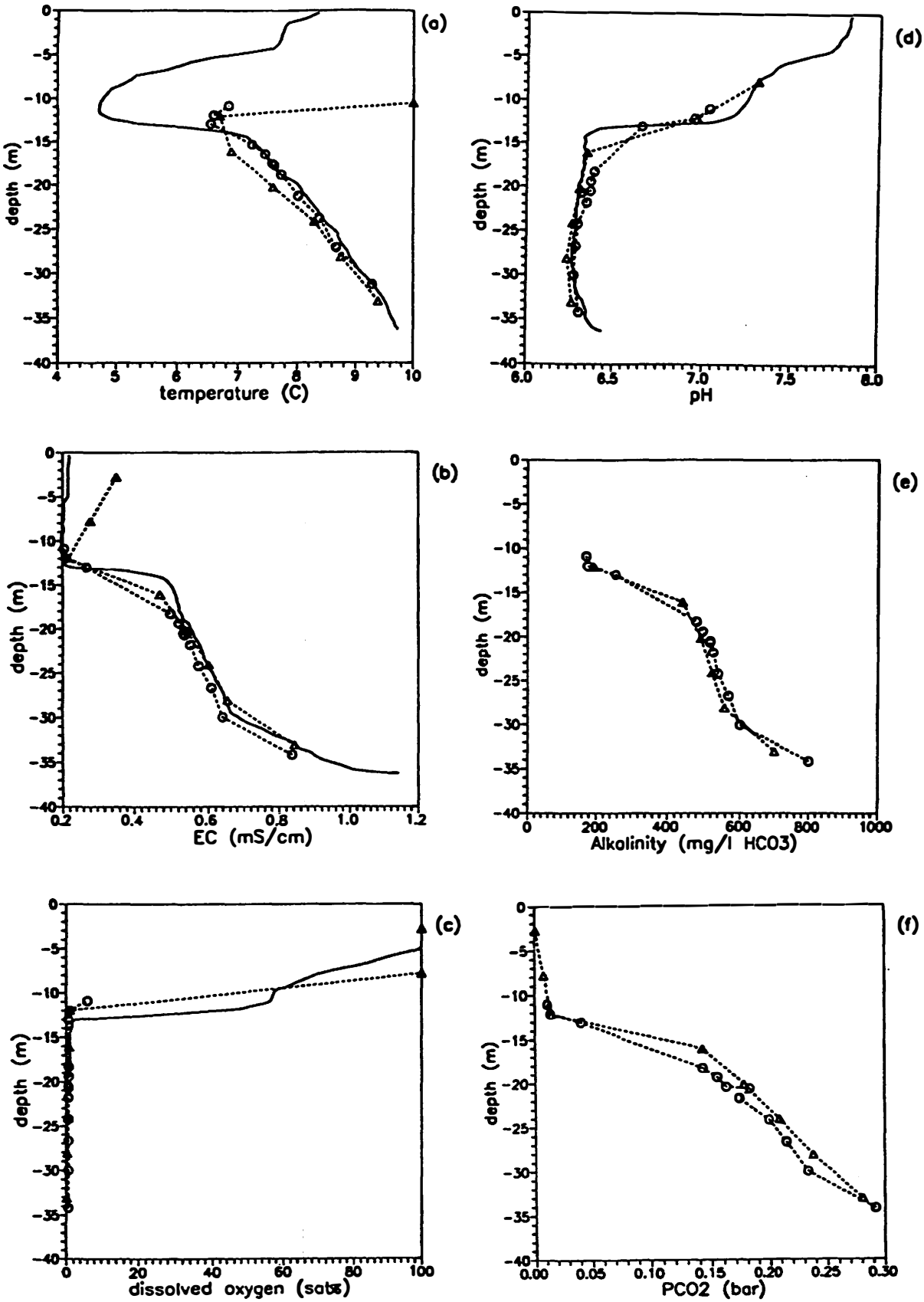

Fig. 3. Lake Piccolo: vertical profiles of (a) temperature, (b) electric conductivity, (c) dissolved oxygen, (d) pH, (e) alkalinity, (f) PCO_2 in March 1992 (solid curve), August 1992 (triangles) and July 1995 (circles).

Table 2. Calculated partial pressures and concentrations (mmol/kg) of gas species in deep lake waters

Depth	P_t	P_{CO_2}	P_{CH_4}	P_{N_2}	P_{Ar}	CO_2	CH_4	N_2	Ar
18.3	1.88	0.143	1.10	0.632	0.0084	8.37	2.28	0.565	0.017
20.5	2.08	0.162	1.26	0.648	0.0085	9.39	2.59	0.575	0.017
20.7	2.11	0.182	1.27	0.652	0.0085	10.5	2.62	0.578	0.017
26.7	2.61	0.215	1.72	0.662	0.0087	12.1	3.48	0.578	0.017
30.0	3.55	0.233	2.46	0.854	0.0087	13.0	4.92	0.741	0.017
34.2	4.29	0.292	3.36	0.627	0.0088	15.9	6.62	0.537	0.017

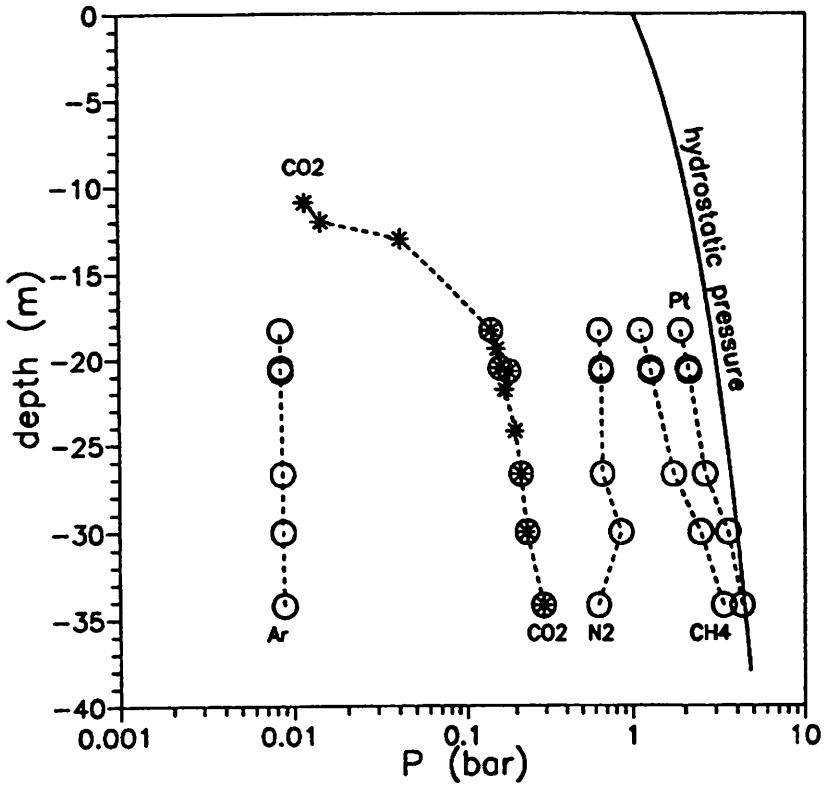

Fig. 4. Lake Piccolo: vertical profiles of partial pressures of CO_2, N_2, CH_4 and Ar, and total gas pressure in July 1995 (circles). The vertical profiles of PCO_2 calculated through water chemistry is also reported (asterisks). Hydrostatic pressures are shown for reference.

Although m_{CO_2}'s in the monimolimnion are 2.4 to 4 times higher than m_{CH_4}'s, and 15 to 30 times higher than m_{N_2}'s, the largest contribution to total gas pressures is provided by CH_4 and N_2, due to their low solubilities in water. The contribution of CO_2 to total gas pressures is subordinate, that of Ar is insignificant. The high proportion of CO_2 and CH_4 in dissolved gases suggests that they are at least partly of biogenic origin, thus confirming the proposed conceptual geochemical model. However, a possible contribution of inorganic CO_2 cannot be ruled out, especially in the first stages of lake formation.

Historical chronicles

According to a chronicle by Paolino Tortorella quoted by Ciarallo and Capaldo (1995), a series of gas emissions from Lake Piccolo took place in 1810, from 1 to 23 (or 24) June, on 31 July and again later in the same year. A flood, on 31 May, probably triggered the first series of gas emissions, described as short-lasting "pyramids of water" rising to a maximum height of 17 Parisian feet (5.5 m). The gas emissions of 31 July were of lesser intensity and duration than before. Water columns rose over the lake for 7 to 8 feet (about 2 to 2.5 m) but a strong, deep roar was felt for the first time by local people. Subsequent gas emissions were even lower in intensity.

According to both Tenore and Gussone (in Ciarallo and Capaldo, 1995) and Palmieri and Scacchi (1852), P. Tortorella reported the occurrence of other gas emissions in November 1820. Water columns probably reached 20 feet (about 6 m) in height and dead fish were thrown onto the lake shores.

Accepting the reliability of these chronicles, these events could be limnic eruptions driven by a gas largely made up of CH_4. Since CH_4 is lighter than air, the emission of a CH_4-rich gas would explain why it rose in vertical columns, contrarily to what occurs to CO_2-rich gases. Carbon dioxide is heavier than air and remains close to the Earth surface, as occurred at Lake Nyos (Giggenbach, l990) and Lake Monoun (Sigurdsson et al., 1987), both in Cameroun. Although available chronicles are somewhat imprecise, gas eruptions of Lake Piccolo were probably of short duration. This fact can be attributed to the low solubility of CH_4 in water, that limits the amount of gas involved in each event.

Conclusions

Available data on gas chemistry indicate that:

(1) gas pressures are less than hydrostatic pressures above 34 m, but they could exceed hydrostatic pressures in the deepest parts of the monimolimnion, where gas exsolution might occur; intermittent gas bubbling is actually observed at the surface of Lake Piccolo;

(2) if the deepest monimolimnion waters were suddenly brought to shallower depths (for instance close to the chemocline) by an external cause, their total gas pressures would exceed the degassing threshold by roughly 2 times; such a mechanism could explain the event that possibly occurred in 1810 and 1820, most likely a series of short-lasting limnic eruptions driven by CH_4-rich gases.

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Magma-hydrothermal systems below active crater lakes in view of sulfur and oxygen isotopic variations

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Sitting on top of volcanic conduits, active crater lakes act as condensers for magmatic gases. Through the studies of active crater lakes, it is possible to understand what is going on in the magma-hydrothermal system that develops below the lakes (Special Issue on: Geochemistry of Crater Lakes, 1994). Magmatic gases are composed of H_2O, CO_2, HCl, SO_2, H_2S, etc. which condense into the system to make it highly acidic, and thereby to promote rock-water interaction within the system. In the magma-hydrothermal system SO_2 will react with hydrothermal water to form sulfuric acid and elemental sulfur (or H_2S) as given below:

$$3\ SO_2 + 3\ H_2O \rightarrow 2\ HSO_4^- + S^\circ + H_2O + 2\ H^+ \quad (1)$$

$$4\ SO_2 + 4\ H_2O \rightarrow 3\ HSO_4^- + H_2S + 3\ H^+ \quad (2)$$

Disproportionation of SO_2 is often invoked to explain the highly acidic nature of hydrothermal water (e.g., Kiyosu and Kurahashi, 1983). Reaction (1) takes place under high total sulfur concentration and plays an important role in active crater lakes, since we often observe very high sulfate concentration and molten elemental sulfur.

It has long been known that there is extensive sulfur isotope fractionation between HSO_4^- and S° which form through reaction (1) (Robinson, 1973; Kusakabe and Komoda, 1992). Figure 1 shows how the sulfur isotope fractionation ($1000\ \ln\alpha_{HSO_4^- - S^\circ}$) changes, as the SO_2 disproportionation reaction proceeds, as a function of temperature. It is noted that considerable fractionation has been attained at the initial stage (initial kinetic fractionation, IKF) followed by gradual approach to the equilibrium fractionation (EF) at a given temperature, as indicated by the arrows in Fig. 1. Under the assumption that isotopic equilibration obeys the first order reaction with respect to the isotopic distance between EF and IKF and to the total sulfur concentration in the system, the rate of isotopic equilibration may be approximated by:

$$\log k = -6.19^*(1000/T) + 11.58 \quad (3)$$

where k stands for the rate constant of sulfur isotopic exchange between HSO_4^- and S°. From this kinetic approach, one can calculate the time for any disequilibrium HSO_4^- – S° pair to reach equilibrium under a given temperature and total sulfur concentration. For example, it will take 1 - 20 days for the HSO_4^- and S° pair to reach equilibrium with the fractionation of approximately 26‰ after SO_2 is injected into hydrothermal fluid at 250°C. Once sulfate ions are formed, they will exchange their oxygen very quickly with the surrounding acid water at a rate 2 to 3 orders of magnitude greater (Chiba and Sakai, 1985) than the sulfur isotope exchange mentioned above. At 250°C oxygen isotopic equilibration between hydrogen sulfate and water is almost instantaneous.

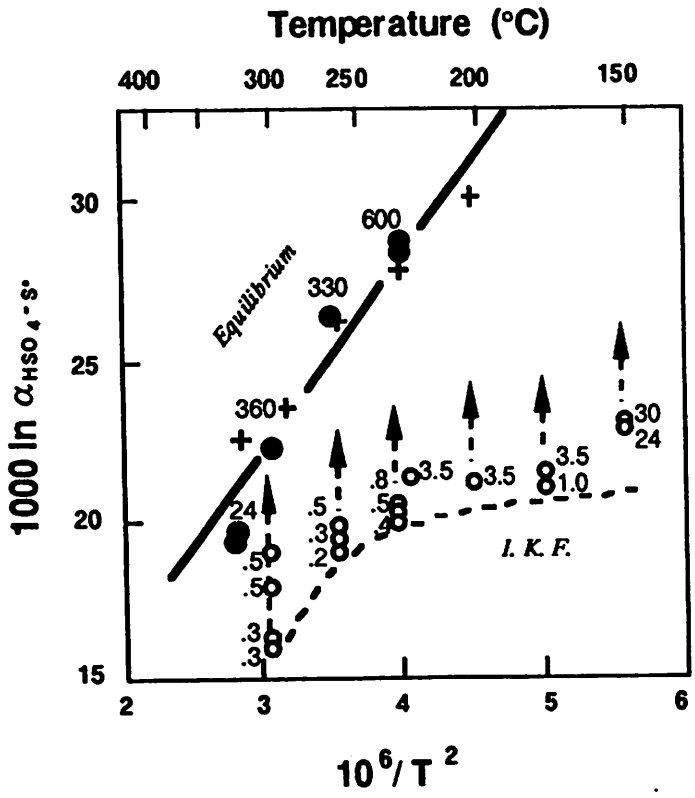

Fig. 1. Sulfur isotope fractionation between HSO_4^- and S° produced by the disproportionation reaction of SO_2. I. K. F. stands for the initial kinetic fractionation, which gradually approaches the equilibrium fractionation (E. F.) with time. The numbers by the data points indicate time (hr) after initiation of the reaction.

The sulfur isotopic ratios have been measured for dissolved hydrogen sulfate (HSO_4^-) and elemental sulfur (S°) from some active crater lakes (Fig. 2). In Fig. 2, the crater lakes studied are listed in increasing sulfur isotopic distance between HSO_4^- and S°. There is a clear tendency for the distance to become greater for more active crater lakes such as Yugama (Kusatsu-Shirane), Maly Semiachik, Poás, Crater Lake (Ruapehu) and Kawah Ijen. For these lakes, the value of $\Delta_{HSO_4^- - S^\circ}$ ($= \delta^{34}S_{HSO_4^-} - \delta^{34}S_{S^\circ}$) ranges from 21 to 26 ‰, suggesting supply of sulfate and elemental sulfur produced through the disproportionation reaction of SO_2 from a magma-hydrothermal system developing below the lakes at temperatures between 250 and 300°C. Direct injection of magmatic SO_2 into lake water whose temperature rarely exceeds 60°C, could produce HSO_4^- and S° with large $\Delta_{HSO_4^- - S^\circ}$ values as shown in Fig. 1. However, the oxygen isotopic ratios of dissolved hydrogen sulfate and lake water indicate that hydrogen sulfate underwent oxygen isotopic exchange with water at 100 to 170°C (Fig. 3), and do not support the hypothesis of direct SO_2 injection into the lake bottom. It is likely that the SO_2 disproprtionation reaction took place in the two phase (vapour-liquid) region where magmatic gases condense (Christenson, 1993). Relatively constant oxygen isotopic fractionation between dissolved sulfate and water gives strong evidence that lake water circulates through hydrothermal systems below those lakes.

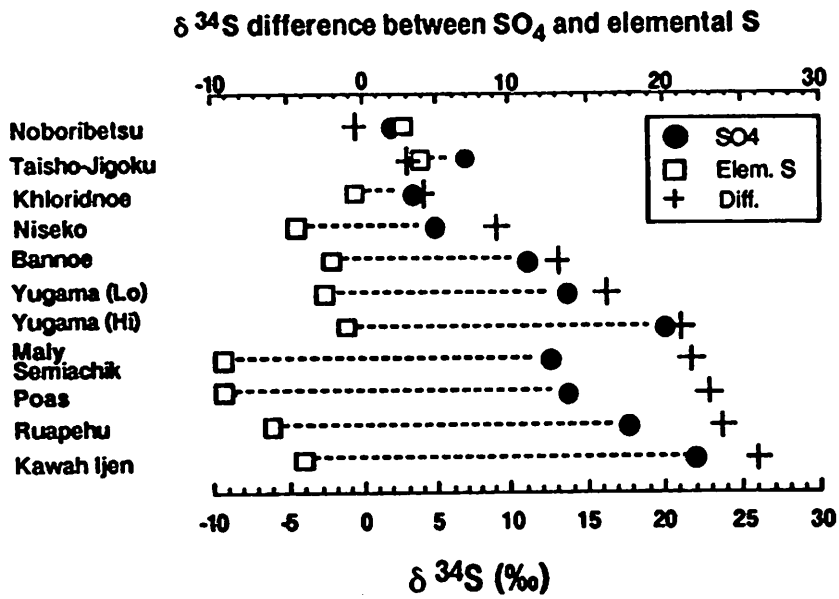

Fig. 2. Sulfur isotopic distance between dissolved sulfate and elemental sulfur from some active crater lakes. Samples were donated by T. Abiko for Niseko (Japan), by B. Takano for Yugama, Poás and Ruapehu, and by P. Delmelle for Kawah Ijen.

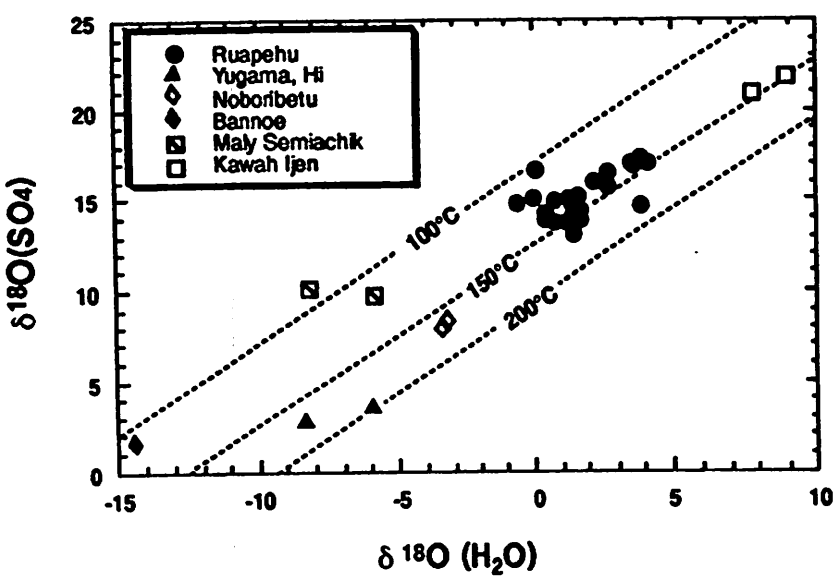

Fig. 3. Relationship between $\delta^{18}O$ values of dissolved sulfate and water from some active crater lakes. Note a positive correlation between them. Dotted lines indicate the equilibrium relationship (Mizutani and Rafter, 1969) at the temperatures indicated.

There are lakes whose $\Delta_{HSO_4^- - S}$ values are less than 10 (Fig. 2). The extreme case is found at Noboribetsu where the $\Delta_{HSO_4^- - S}$ value is almost 0, suggesting that most of the dissolved sulfate was derived from bacterial oxidation of sulfide and/or elemental sulfur and supplied to the lake through surface run-off. The lakes with $\Delta_{HSO_4^- - S}$ values smaller than 20 may have increasing contributions of sulfate produced by subaerial, bacterial oxidation of sulfide and/or elemental sulfur. For these lakes, increase in the $\delta^{34}S_{HSO_4^-}$ value may be considered to indicate an increased influx of magmatic SO_2. At Yugama where the contribution of magmatic SO_2 is significant, a decreasing trend of $\Delta_{HSO_4^- - S}$ values, i.e., 20‰ in 1973 to 13‰ in 1990, turned into an increase after a swarm of volcanic earthquakes coupled with a geomagnetic anomaly in 1990 (Yamazaki et al., 1992; Ohsawa et al., 1994; this study). This was interpreted as representing an increased supply of magmatic gases into the magma-hydrothermal system below Yugama.

An isotopic view of a magma-hydrothermal system below an active crater lake is summarized in Fig. 4.

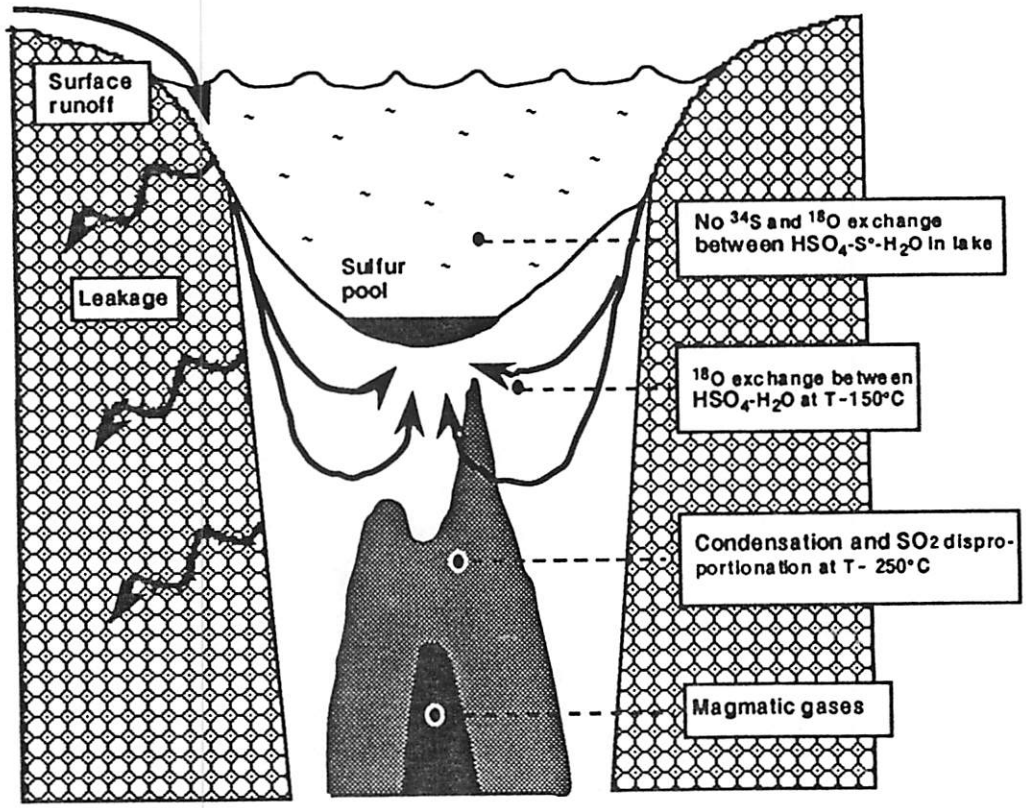

Fig. 4. Schematic presentation of a magma-hydrothermal system in view of sulfur and oxygen isotopic variations.

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Temperature and hydrochemical studies of Karymsky Lake (Kamchatka) during 1996

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General descriptions of an underwater eruption in the Karymsky lake in early 1996 have already been described in some publications (Fazlullin et. al., 1996; Fedotov, 1996; Karpov et al., 1996). That was a rare event. As a result of studies carried out during the eruption, its energetic effect and scales of water-soluble material supply were estimated.

Regrettably, hydrological and hydrochemical data on the Karymsky lake were extremely scanty. Only single measurements of the temperature vertical distribution and a few chemical analyses of the lacustrine water were made during different years. On the whole, before the 1996 eruption the lake was considered to be a typical mountain lake. It was covered with ice from late October to mid July, that is, it was ice-free only for about three months per year. During the period of maximum heating it had a slightly-developed epilimnion (Fig. 1) which did not sink down to 5 m (Kurenkov, 1985).

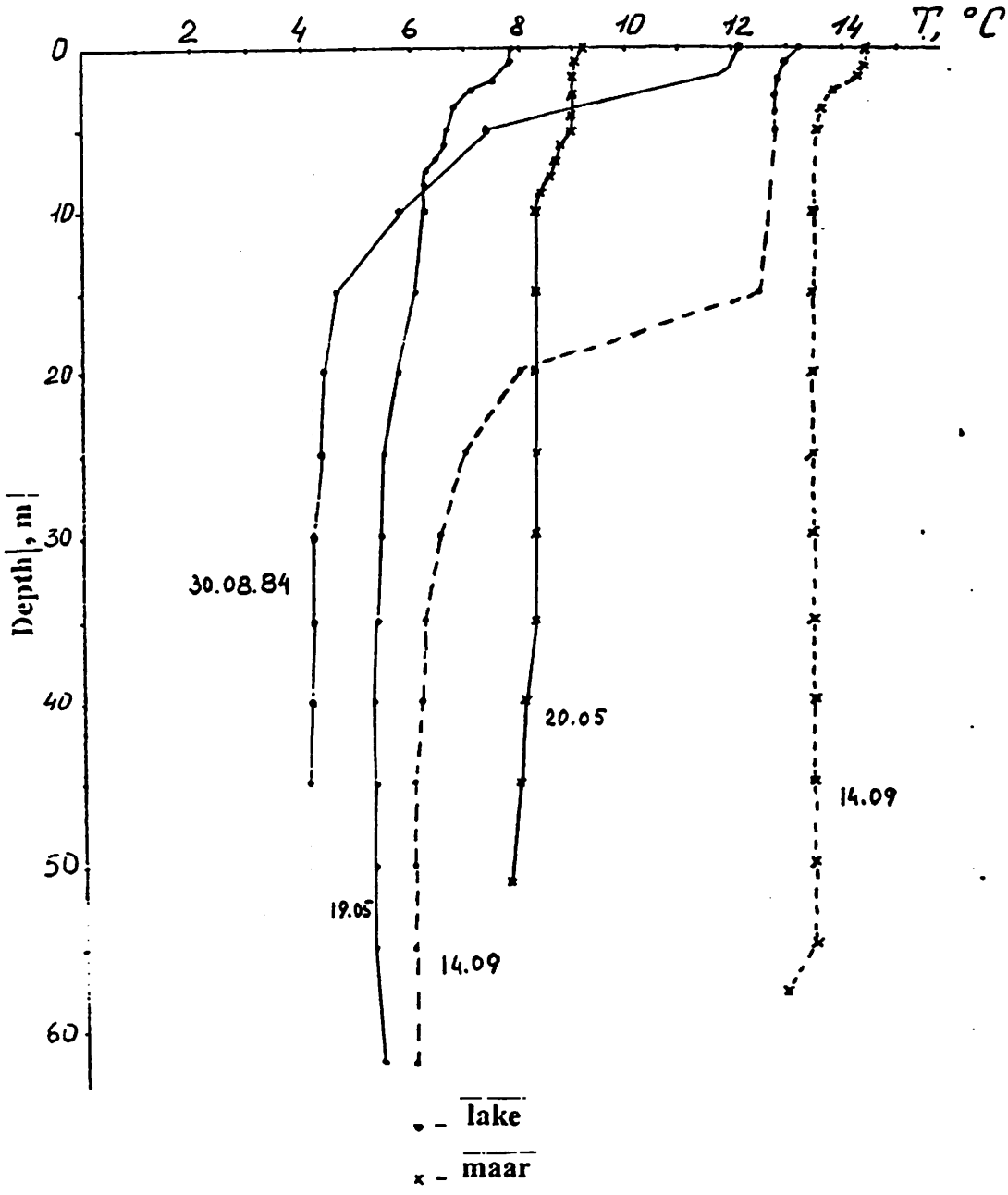

Fig. 1. Vertical distribution of temperature in Karymsky lake (based on data obtained during different years).

In the southern part of the lake, where hot waters of the Akadenia Nauk springs enter the lake, an unfrozen patch of water near the shore was observed during the winter, pointing, to the numerous underwater discharges. These discharges extended for 1 - 1.5 km distance (Ivanov, 1974). Later, during 1993, V. A. Droznin and I. K. Dublovskaya made the remote-sensing measurements of the temperature of water using "a thermal T V set" and corrected the position of underwater discharges near the southern shore. They were estimated to be as long as 2.5 km.

In addition three more unfrozen patches of water near the shore were described by G. F. Pilipelko (1989). The first patch found near the source of the Karymsky river, had a radius of the order of 100 m. The second unfrozen patch of water found near the eastern cape of the northern was 250 m long, and as wide as 50 m. The third patch extending for about 1 km was located along the western shore of the lake. The extension of the patch near the Akademia Nauk springs was estimated to be 1 km, and its width reached 50 m.

During the flight over the Karymsky lake on 3 January 1997 the entire surface of the lake was covered with ice except for small areas near the shore, where underground water discharges were detected. In addition to the unfrozen patches of water already known and described by G. F. Pilipenko, some patches of water were marked south of Karymsky creek confluence, at the site of Gremuchiy creek confluence and in the crater of the volcanic edifice. A scheme showing the location of hydrothermal springs before and after the 1996 eruption is shown in Fig. 2.

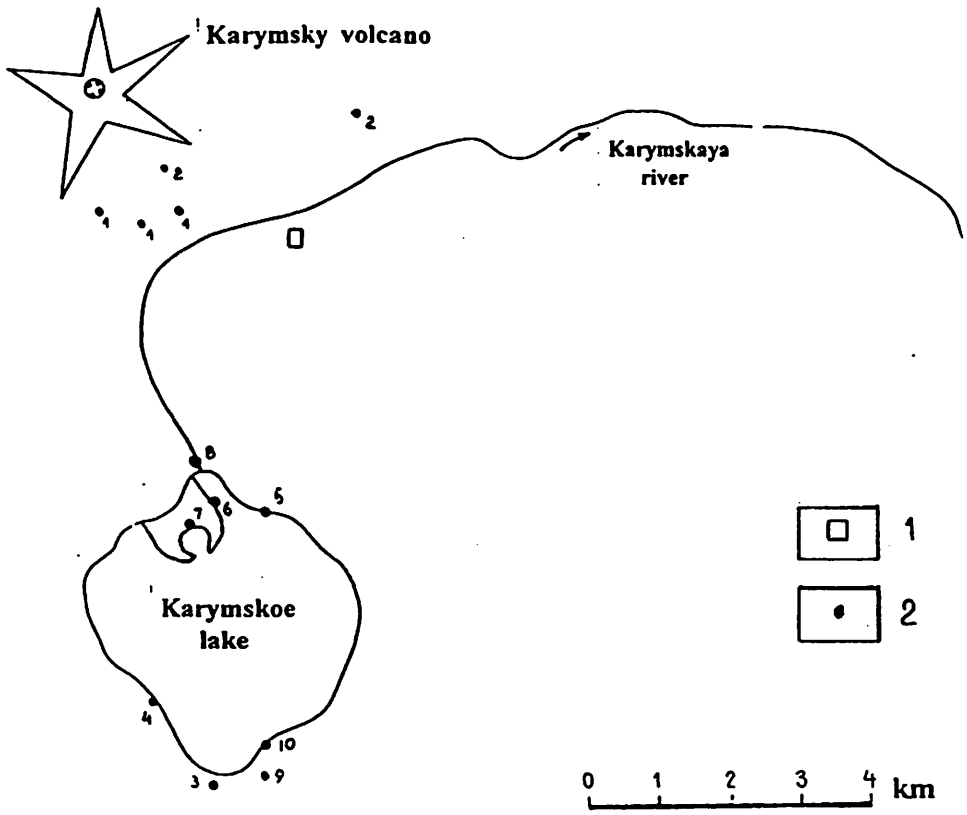

Fig. 2. Scheme of thermal water discharge in the region of Karymsky volcano.
1 = Location of the Karymsky volcanological station of the Institute of Volcanology.
2 = Groups of thermal springs known before the 1996 eruption:
1 = Karymsky high-magnesium springs;
2 = warm springs of the "Narzan" type from under the Karymsky lava flows;
3 = Akademia Nauk springs;
4 = Gremuchiy creek (discharge of abundant underground waters with the temperature of 10 - 11 °C;
5 = discharge of hot underground waters in the beach zone at the northern shore.
2b = Thermal springs discovered in 1996;
6 = hot springs flowing out from under outside the maar edifice;
7 = hot springs forming the lateral runoff in the crater bay;
8 = hot springs in the Karymskaya river-head;
9 = Ushakov thermal site;
10 = hot springs at the southern shore of Karymsky lake exposed after water level had fallen.

The chemical composition of waters from the caldera was commonly determined when recent hydrothermal activity was investigated. First information on the composition of thermal waters was given in Vlodavetz (1947). Later on some more samples were collected and analyzed (Ivanov, 1974). The composition of a sample of lacustrine water was studied in more detail in 1993 by Fazlullin.

In 1976 the employees of the KamchatNIRO moved the landlocked blueback salmon to the Karymsky lake. This was preceded by preliminary hydrobiological studies of the lake, which revealed a good food supply in the Karymsky lake. Migrants spawned rapidly. In 1979 one could catch the fish in the lake and it was not rarity. Since 1983 its quantity has greatly increased (Kurenkov, 1985).

The underwater eruption of 2-3 January 1996 entirely changed the chemical composition of water. The eruption produced the largest in the world depository of acidic water. The values of pH through the entire thickness of water became as low as 3.0-3.2. The total mineralization of waters sharply increased. In some samples it reached 780-800 mg/L. The change of the water mineralization during the underwater eruption has led to the increase of its density, which caused the vertical density convection enveloping the lake down to the bottom. Variations in temperature of water could not compensate for the changes in mineralization.

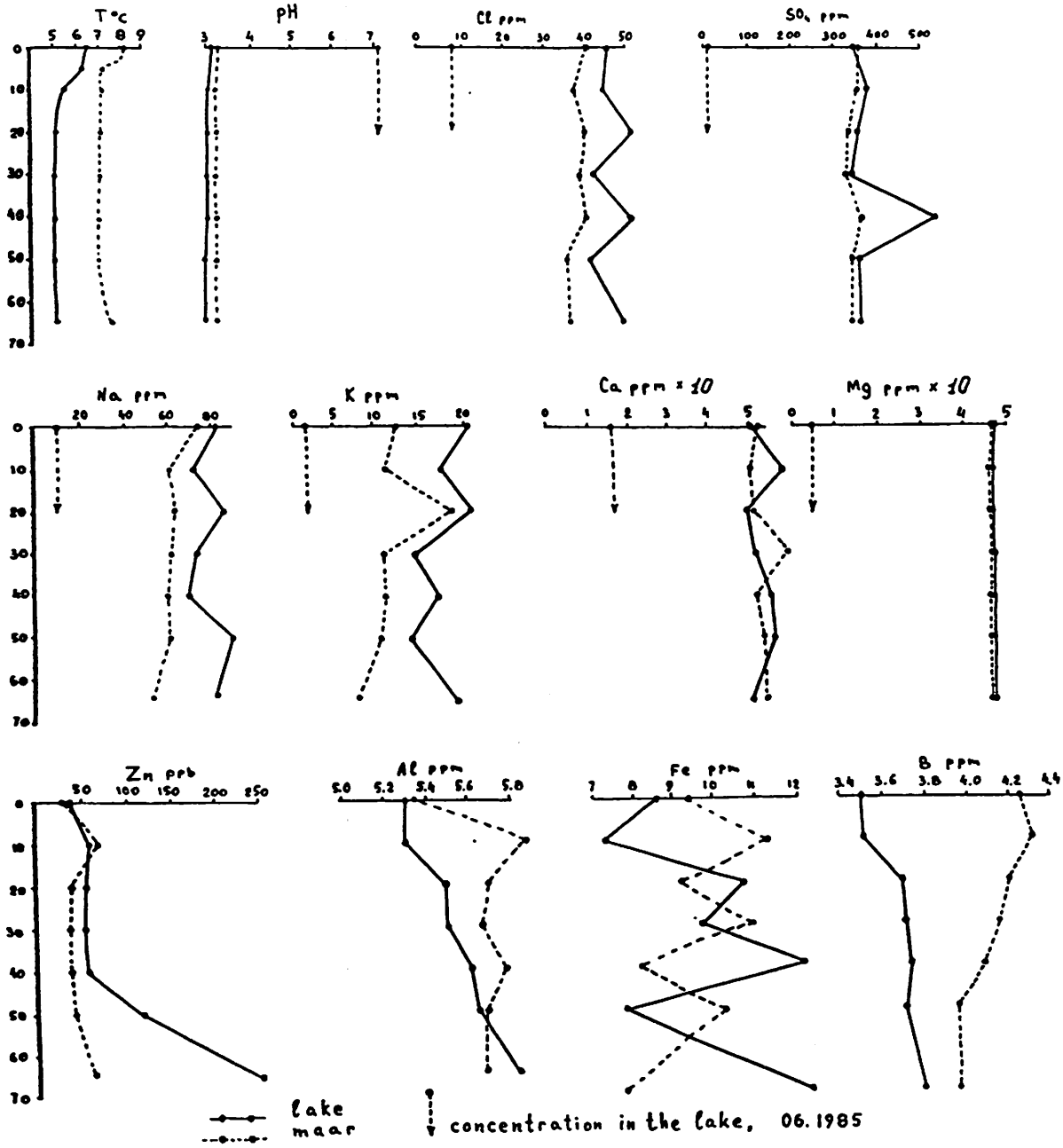

Fig. 3. Vertical distribution of chemical elements in Karymsky lake.

A volcanic edifice formed during the underwater eruption was composed of fresh ejected materials. Several groups of hot springs are located near it. The chemical composition of these springs is due to mixing of lacustrine and hot underground waters from deep-seated aquifers. Their mixing occurs simultaneously with the interaction of hot waters and fresh volcanic materials. This process results in increasing the content of some chemical elements, such as Fe, Al, B, Ni, and Mn, in waters from the flooded crater of the volcanic edifice.

The vertical distribution of chemical elements in the region of the flooded crater and in the centre of the Karymsky lake are given in Fig 3. There is a conspicuous difference in water composition of the lake and maar. Comparative analyses of chemical resources in the Karymsky lake before and after the underwater eruption are shown in Table 1.

Table 1. Chemical element resources (in tons) in the waters of the Karymsky lake before and after the underwater eruption.

Year	Cl	SO_4	HCO_3	Na	K	Ca	Mg	Al	Fe	Mn	Zn	Cu
1993	11 228	2 530	11 598	7 380	442	3.16	316	0.1	1.17	0.3	2.32	0.01
1996	24 460	216 730	- -	40 910	8 350	3.41	8 381	3 232	5 629	992	32.6	26.8

In addition to soluble salts, great amounts of heat were released to the lake during and after the underwater eruption. As follows from information obtained from the crew of a helicopter, the surface of the Karymsky lake was ice-free several hours before the beginning of the underwater eruption (at about 14:00 on 2 January). This indicates that the amount of heat, which had been released to the lake by the afternoon of 2 January, was sufficient to melt the ice cover. The heat was probably released along the fault zone which extends through the entire bottom of the lake and is the continuation of the subaerial series of fractures.

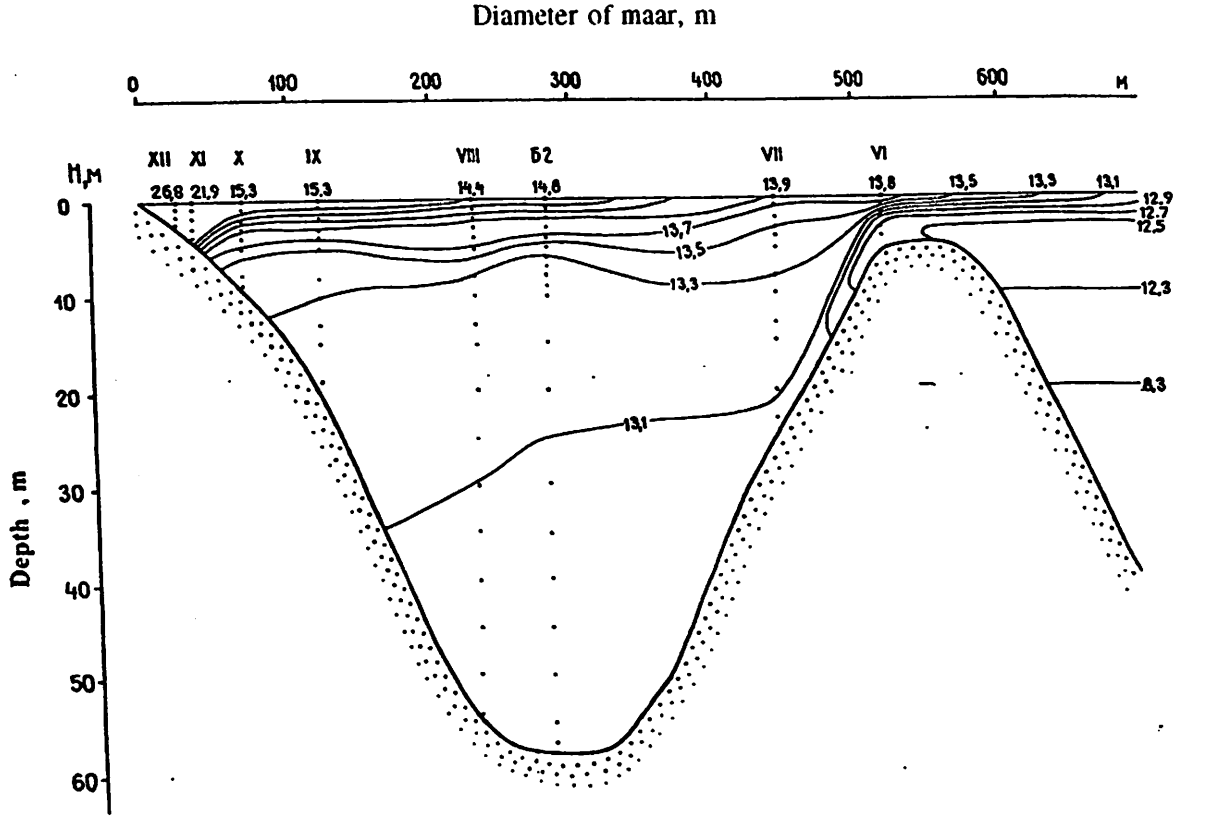

Fig. 4. Vertical distribution of temperatures in the maar crater (15 September 1996).

We have estimated the heat energy released during the first two days of the eruption. Amounts of heat needed for ice melting and water heating and released during the underwater volcanic explosions were taken into account. In total this value was at least 11.8×10^{15} J.

After the underwater volcanic edifice has been formed, the further heating occurred of only the upper 15-20-m-thick water layer. This was due to the fact that the heat discharge took place through the bottom and the shore line of the newly-formed edifice. Hot waters with lower concentration of salts and lower density entered the lake through the shallow strait from the region of the underwater eruption. Cold waters from the lake were supplied in place of hot waters to the near-bottom lavers of the volcanic crater. Waters flowing out from the lake could not penetrate deep water layers of the lake, and the density convection, caused by cooling (according to density calculations), enveloped only the upper 20-m-thick water layer. This is corroborated by peculiarities in temperature and chemical element distribution at observational points in the lake (Figs. 1, 3, 4).

Thus, during the first days after ceasing of the underwater eruption, a system of density circulation which was triggered by the water heating in the region of the underwater eruption, has set in there. The forming layer of warm water spread about the surface of the lake, creating the considerable temperature difference between the lake and the atmosphere. which led to significant heat losses through the surface of the lake.

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Morphometric studies of Karymsky Lake (Kamchatka) related to a subaqueous eruption

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Karymsky Lake is located near to the east coast of the central part of the Kamchatka Peninsula, 150 km to the north of Petropavlovsk-Kamchatsky. Its surface area, prior to the recent eruption, was 10.7 km^2 and its maximum depth varied within the range of 65 - 69 m (Ivanov, 1970).

On 2 January, 1996, between 12 and 15 hours (local time), a subaqueous eruption commenced in the northern part of Karymsky Lake and continued for 12 to 14 hours. Series of explosions (5-10 explosions/hr) occurred, with plumes rising to 8 km above the lake (Fedotov et al., 1996) generating 20 m-high tsunami waves and causing a high-flood in the valley of the Karymskaya river (Karpov et al., 1996).

Detailed studies in the region of a new volcanic edifice and approximately 40 km of echo sounding profiles, of the bottom of the lake, were carried out by staff members of the Institute of Volcanology in May and in August through September 1996. Figure 1 shows two of the more typical bottom profiles, extending roughly EW and NS. As shown in Figure 1 the depth of the lake increases sharply to 50 m at a distance of 250-300 m from the shore. The main area of the Karymsky lake bottom is a plain 60-61 m deep. Results from these investigations were used to plot the bathometry of Karymsky lake (Fig. 2) and the detailed bathometry of a new crater (maar) close to the northern shore (Fig. 3).

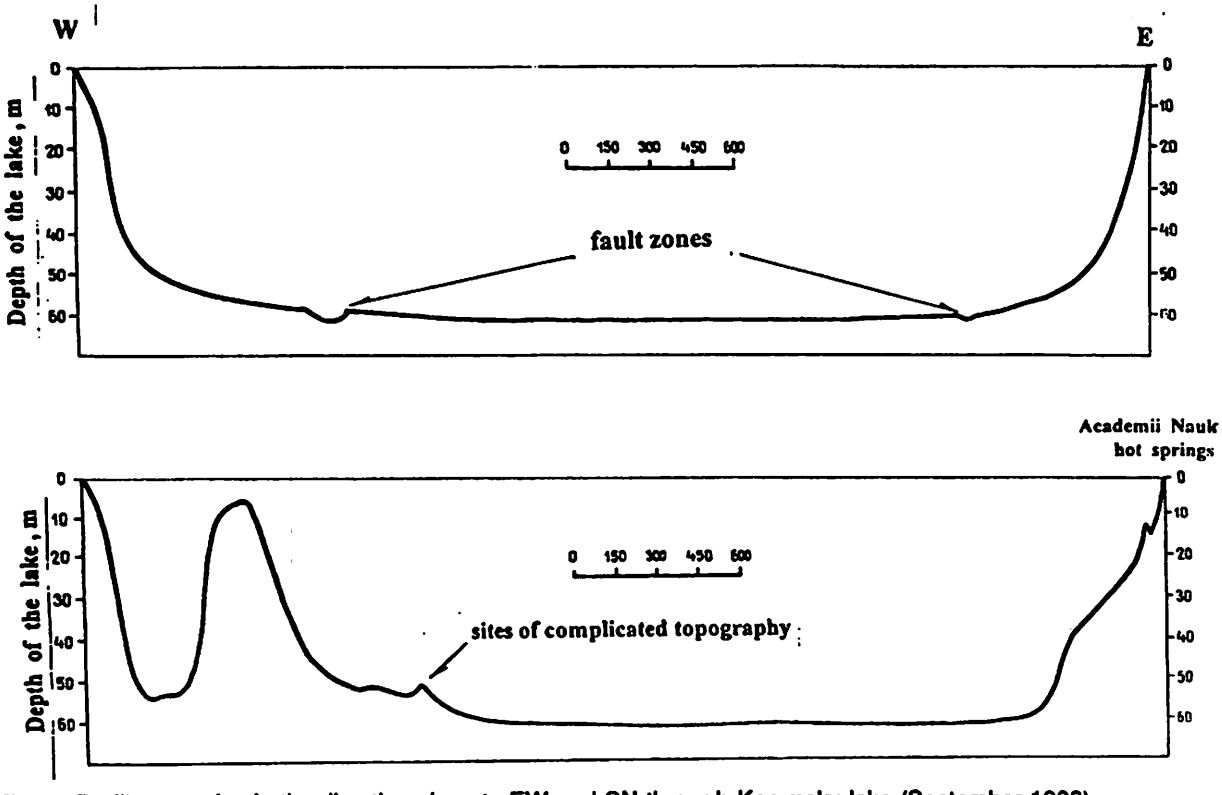

Fig. 1. Profiles passing in the direction close to EW and SN through Karymsky lake (September 1996).

The recalculated surface area is 9.8 km^2, the volume of erupted material was 60.11 million m^3 and the volume of Karymsky lake is now 461.58 million m^3. The mean inclination of the slope of the lake basin, within the depths down to 50-60 m, is 11-12 degrees and in the south-eastern part it increases to 15 degrees.

During the summer of 1996 staff members of the Institute of Volcanology prepared detailed maps of fault zones and made instrumental geodetic measurements in the region around Karymsky lake and Karymsky volcano. Their investigation revealed numerous fault zones (Leonov, 1997) and a zone of surface subsidence passing through a new volcanic edifice (Maguskin, oral communication, 1996). Two depressions, interpreted as continuations of fault zones detected on the ground surface, are distinctly identifiable on the east-west profile through Karymsky lake.

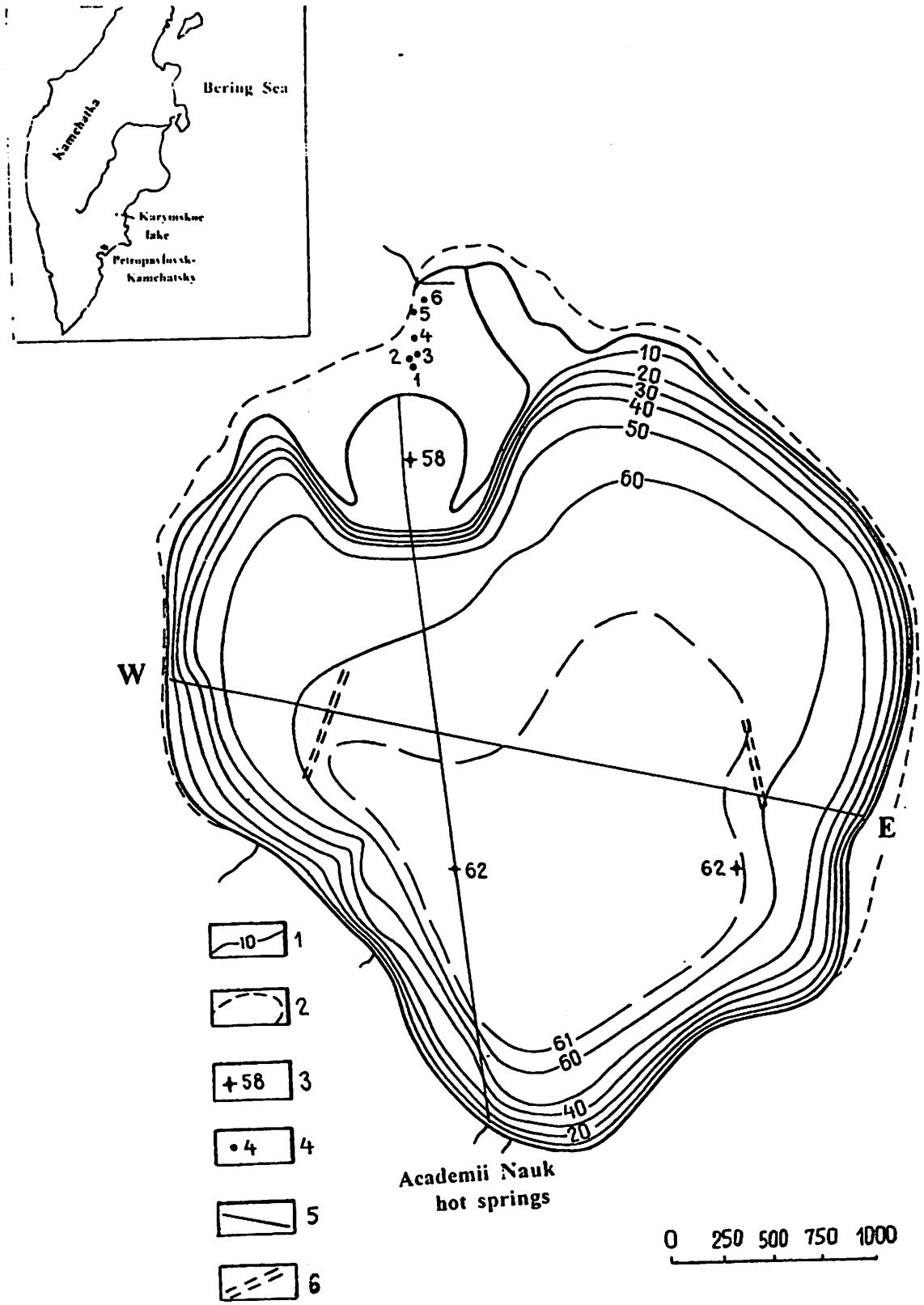

Fig. 2. Bathometry of Karymsky lake as shown by data from echo sounding profiling (conducted by S. V. Ushakov and Ya. D. Muravyev, September 1996).
1 = isobaths; 2 = 61 m isobath; 3 = points with maximum depths; 4 = small explosive vents at the surface of volcanic edifice; S = echo sounding profile; 6 = topographic depressions presumably related to fault zones;

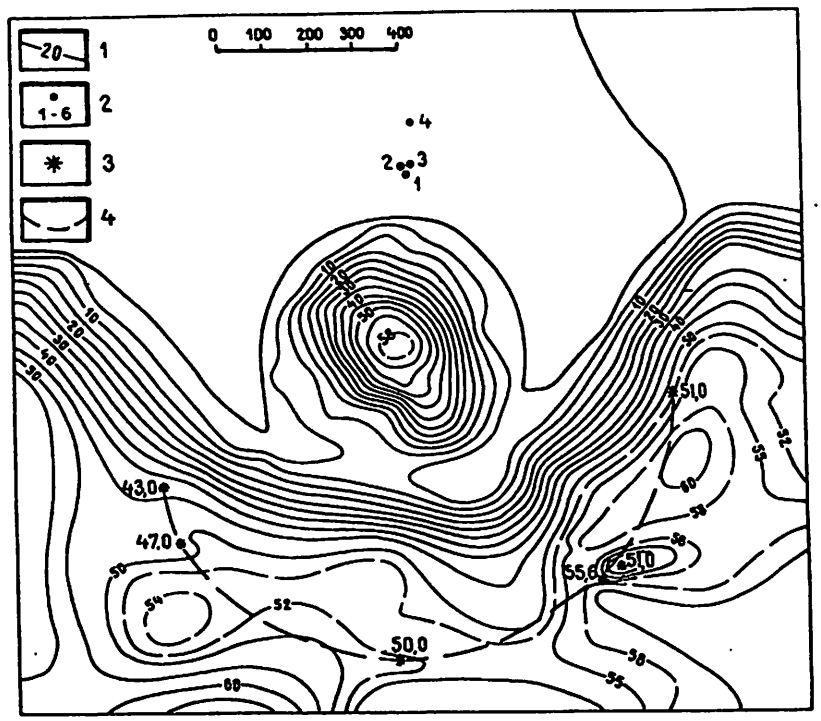

Fig. 3. Bathometry of the new crater of the maar.
1 = isobaths; 2 = small explosive vents at the surface of the volcanic edifice; 3 = sites of complicated topography presumably forming a part of the ancient volcanic edifice (4) (Leonov, 1997).

As a result of the eruption a new volcanic maar was created in the northern part of the lake and a peninsula, with an area of 0.4 km^2 (in February) and 0.95 km^2 (in September), with numerous explosive vents of differing diameters, was formed the by eruption products. The maar has an oval shape (600 x 650 m) elongated in a NW-SE direction. Its maximum depth is 58 m and the inclination of its floor is about 12 degrees. This inclination is also preserved outside the edifice. Echo sounding data show sites of complicated topography near the foot. This zone apparently is a fragment of the ancient volcanic edifice which is overlapped by a new one.

Thus, our studies have revealed noticeable changes in the morphometric characteristics of Karymsky lake caused by a subaqueous eruption, including the origin of a new volcanic edifice in the northern part of the lake, consequent variations in the volume of the lake, and fault zones complicating the bottom of the lake.

Acknowledgements

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Changes in the hydrobiological state of Karymsky Lake caused by a volcanic eruption

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The Karymsky Lake agloflora, in the caldera of the Akademia Nauk volcano (eastern Kamchatka), were first studied using samples collected in the 1960's and kindly presented by Dr.I.I.Kurenkov (Kamchatkan Fishery Research Institute - Kamchat N I R O). Diatoms dominated in the plankton of Karymsky and other large lakes of Kamchatka. They are the basis for food supply of zooplankton. Aulacosira italica (Kutz.) Simon. et var. subarctica (O. Mull.) Dav. et var. tenuissima (Grun.) Simon. were dominant in the overall phytoplankton biomass. Asterionella formosa Hass., Stephanodiscus cf. invisitatus Hohn et Hellerman were their associates (occasionally subdominant). The total quantity of Aulacosira and Asterionella reached 250 000 cell/L. Increased diatom abundance results, presumably, as reported by Kurenkov (1985), from lake fertilization by a continuous volcanic ash fall within the Karymsky Lake region.

The abundance of crustaceous zooplankters made it possible to introduce fresh water blueback salmon (Oncorhynchus nerka Walb), from Kronotskoe lake, into Karymsky lake, which was previously absolutely devoid of ichthyofauna, in September 1976. This introduced population successfully adapted itself to its new circumstances (Kurenkov, 1985).

Data from the 1996 monitoring survey show that sharp successive changes in the Karymsky lake algoflora were due to the subaqueous eruption, to an escape of a plankton diatomic component, and to scanty representatives of Chroococcales, Oscillatoriales, and Nostokales (Cyanophyta), not eaten by zooplankters, were conspicuous in the plankton in the open part of the lake and at the lake's shore. During the first ten months of 1996 the abundance of blue-green alga biomass was low, not exceeding 0.1 mg/L. The allochthonic character of phytoplankton is well established. No zooplankton, the basic food for young salmon was found in the samples collected during the above mentioned time interval. On the 2nd of January 1996 a subaqueous eruption killed approximately 5 million salmon. Similar data were obtained by algologists from Dr.G.A.Zavarzin's Laboratory at the Institute of Microbiology, Russian Academy of Sciences (Moscow) based on materials collected in 1996 by Academician S.V.Fedotov.

Determinative negative factors responsible for the rapid successive changes in algoflora and fauna of the lake are, in our opinion, the abrupt changes in the chemical composition of the lake's waters (pH decrease and the change of water type). These changes are given in detail in the paper by Fazlullin *et al.* (the present issue).

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The role of hydrothermal activity and plankton in the distribution of trace elements in the Tsentralnoe Lake (Uzon caldera, Kamchatka).

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Volcanic lakes are an integral part of volcanic processes. They often have specific fauna and flora which take an active part in the biochemical cycle. By studying the development of biological communities in modern volcanic lakes and their influence on the distribution of chemical elements it is possible to recognize the roles of exogenic and endogenic processes in the development of the chemical composition and hydrological structure of volcanic lakes, the bio-variety of hydro-biotas and the regularities of their distribution.

Thermal water discharges in the Uzon caldera are located along fractures which intersect fracture zones containing superheated chlorine-sodium rich fluids. During this process differentiation and near-surface hydrothermal-metamorphism take place when the deep fluids mix with infiltrating water, causing clear hydrogeochemical zoning. The recent hydrothermal activity is concentrated in the central area and towards the northern part of the caldera. The abnormally hot areas can be clearly distinguished, forming a wide (not more than 350m) zone of hydrothermally altered rocks, with thermal discharges, which stretches for five km in an east-west direction.

To the south of the main thermal areas, in the lowest and swampy part of the Uzon caldera, lies the largest of the caldera lakes - Tsentralnoe Lake - which acts as an intermediate sublimation basin for the whole caldera. Complex hydrochemical and hydrobiological investigations of Tsentralnoe lake water were undertaken to determine the role of the biota in the processes of the redistribution of metals from the thermal water discharge zone in the Uzon caldera to the head of the Shumnaya River, which drains the area.

Changes to the physical-chemical characteristics and chemical composition of the lake waters are controlled by the distribution of water flow draining the thermal areas, and by subactive discharge. Three compositional types of water from the lake area have been distinguished based on analyses of the distribution of physical and chemical parameters. We have shown that for each of the distinguished parts a specific diapason is characteristic of concentrates of dissolved trace elements, caused by the process of hydrolysis. The concentrating ability of plankton plays an important role in retaining trace elements in suspension.

Acknowledgments. This study was supported by INTAS Grant 94-3129.

Changes in the chemical characteristics of Poás volcano's crater lake between 1993-1996, Costa Rica

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Abstract

This paper presents the results of volcano monitoring at Poás Volcano, Costa Rica, between 1993 and 1996. The geochemical data includes magmatic anions like fluoride, sulphate, chloride, pH and also lake water temperatures collected before, during and after the enhanced activity period which occurred between April and August 1994.

This paper recognizes three stages in the evolution of the crater lake. During the first stage the water had high concentrations of chemical compounds and very high acidity, enhanced by evaporation of the lake. During the second stage dissolved chemical compounds (i.e. HCl, H_2S and other sulphur compounds) were forced to volatilized. Sub-aqueous fumaroles became sub-aerial and volcanic activity was enhanced, including several phreatic eruptions. Acid precipitation increased due to the dispersion of lake bottom dry sediments down wind from the volcano. During the third stage, the lake refilled. Fumaroles continued to deliver gases directly into the atmosphere and a dilution effect was introduced by the gradual growth of the volume of rain accumulated by the crater lake.

1. Introduction

Crater lakes in active volcanoes are unstable and changing systems when they interact constantly or intermittently with cooling shallow-magma bodies and magmatic hydrothermal systems located beneath them. Changes in heat flow and degassing patterns induce variations in the water temperature and chemical composition of crater lakes. Variations in chemical composition and other physical parameters of crater lakes located in active volcanoes make them suitable for volcano monitoring programs assuming that other external factors affecting them (e.g. rainfall) can be isolated. Reports from volcano monitoring programs at active volcanoes with crater lakes are common in the literature [e.g., Poás (Rowe et al., 1992a); Kusatsu-Shirane, Japan (Takano and Watanuki, 1990; Takano et al., 1994; Takano, 1987); Ruapehu, New Zealand (Takano et al., 1994); Azores and Italy (Martini et al., 1994); Kelut, Java (Badrudin, 1994)]. In these reports, changes in crater lake chemistry are related to volcanic activity and are used to predict periods of enhanced eruptive activity. We report the variations of sulphate, chloride, fluoride, pH's and water temperature from 1993 to 1996 corresponding to the period before, during and after the 1994 enhanced activity of Poás volcano.

OVSICORI's volcano monitoring program monthly reports, reproduced by the Smithsonian Institution (Bulletin of Global Volcanism Network), are regularly referenced in this paper, so that the reader can find broader information about the evolution of volcanic events at Poás Volcano, if desired.

2. Crater Lake

Poás volcano crater lake, 2700 m above sea level, is located 10° 12' 00" N and 84° 13' 58" W in the Central Cordillera of Costa Rica. Poás, one of the most active volcanoes of Costa Rica, is broad and well-vegetated, with a summit area containing two craters along a north-south line within eroded remnants of two caldera. The crater lake has an almost circular shape with an estimated diameter of 276 meters along the east-west axis measured on December 12, 1996 (Van der Laat, OVSICORI, oral commun., 1996) and an estimated average depth of 50 meters (Smithsonian Institution, 1996a). The crater lake consists of a body of hot, extremely acid (pH near zero) water, rich in chloride and sulphur compounds, like sulphate, due to the intense discharge from fumaroles located at the bottom and at the almost vertical walls that contain the lake. The locations of fumaroles, within the crater lake, change with time.

Since the major magmatic eruption of 1953-1955, Poás activity has been characterized by variable fumarolic discharge with periods of very intense discharge and intermittent phreatic eruptions generally through the

lake which fills the active crater (Malavassi and Barquero, 1982; Malavassi et al., 1993). During the eighties and in the early nineties, before 1994, fumarolic discharge was intense to very intense and the level of the crater lake often decreased to minimal depths during the dry season as a result of the strong fumarolic activity. There were constant emission of gases, particles and steam, which were dispersed by the wind mainly to the south-west and west of the volcano. The area where vegetation, infrastructure and human health was influenced by the volcanic emissions extended approximately 15 kilometres south-west of the crater lake (Barquero, 1992; Barquero and Fernández, 1990). The recent period of enhanced activity that occurred between May and August 1994, was accompanied by the disappearance of the crater lake due to the very intense, high temperature fumaroles that appeared at the bottom of the crater lake. A few weeks after the activity wanned in August 1994, the crater lake reappeared and steadily increased its level during 1995-1996, to its highest point since 1953.

The interaction between the lake's thermally and chemically well-mixed acid-sulphate-chloride waters of extremely low pH and the magmatic hydrothermal system of the volcano has been investigated by Brown et al. (1989, 1991), Rowe et al. (1992b), and others.

3. Experimental and methods

The crater lake temperature was measured using a thermocouple. The pH values of the water samples were determined in the laboratory by the electro-metric method using a Corning Potentiometer Model 10. For the determination of the anionic species, the crater lake water samples were diluted and filtered through 0.2 mm Gelman Sciences 48106 nitrocellulose filters. Fluoride, chloride and sulphate were analyzed using a Shimadzu HIC-6A ion chromatograph that has a Shimpak IC-A1 anionic exchange resin column and a Shimadzu CDD-6A conductivity detector. Analytical errors of the determinations were around 15%. The chromatograms were registered in a C-R3A Shimadzu Chromatopac data processor. A 2.5 mM phthalic acid and 2.4 mM Tris-(hydroximethyl) amino-methane (pH 4.0) solution was used as mobil phase. The chromatograph operating at 40°C with a flow-rate of 2.0 mL min^{-1}, in a range of measure of 0.1 mS cm^{-1}. The concentration of the analytes were calculated from the peak height, using calibration graphs.

4. Results

4.1 Geochemical characteristics and volcanic activity: 1993-1994.

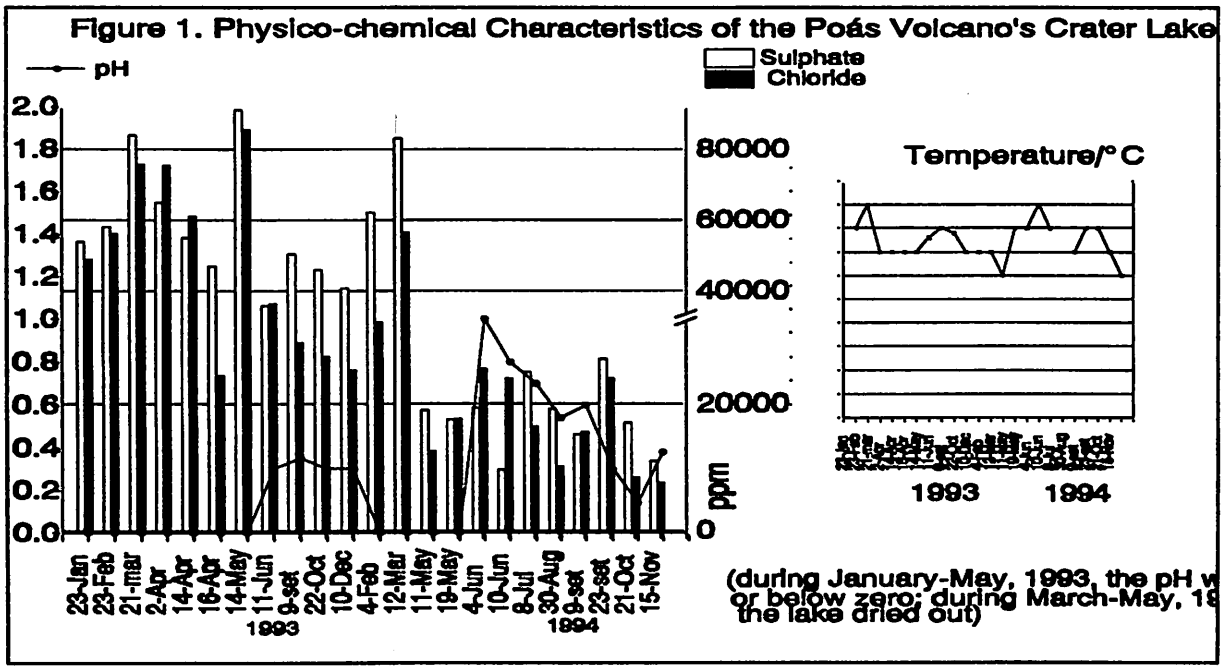
A review of the physico-chemical characteristics of Poás Volcano's crater lake water, 1993-1994 is presented in figure 1.

The most active fumaroles inside the crater were generally located on terraces near the north shore of the lake and produced sounds like that of a jet, other sub-aqueous fumaroles degassed into the crater lake. During the dry season (February to April, 1993) the lake level dropped. Boiling pots with abundant mud and sulphur formed on the SE, N and NW sectors of the partially exposed lake crater floor. These boiling pots permanently erupted gas bubbles and vapour and sporadically issued eruptions consisting of vertical columns of mud and sulphur with heights that ranged between 2-3 meters. After the rainy season started, the crater lake level started to raise gradually, covering all the boiling pots. Some of the boiling pots continue to produce sporadic very small phreatic eruptions. As the water level rose, the jet sounds produced by the fumaroles gradually decreased. Near the end of the rainy season (December 1993), both the very small phreatic eruptions and the jet sounds produced by the fumaroles had disappeared (Smithsonian Institution, 1993a).

With the beginning of the 1994 dry season, the water level of the crater lake dropped until, by late April, the lake had completely evaporated. Fumaroles, previously covered by water, were venting gases directly into the atmosphere. In March 1994 the almost dry crater lake floor displayed ponds which dried completely in April. Subaqueous fumaroles in the SE emitted small bubbles, but those in the lake centre produced weak phreatic eruptions several meters in height and gas plumes frequently rose 500 m above the crater lake floor. Also, the OVSICORI's seismic station adjacent to the active crater (POA2) registered an increase of the low (33% based on February events) and moderate (49% based on February events) frequency seismic events. During the month of April the low frequency seismic events maintained a similar behaviour and the mid-frequency events decreased, but at the same time high frequency events and a small tremor with low amplitude were registered. From March to July the mid-frequency seismic events increased about 400% and the low-frequency seismic events decreased 30%. Until July, the month in which the higher intensity eruption of all the eruptive process were produced both signals were registered continually (Barboza, V., OVSICORI, oral commun., 1997).

Between December 1993 and March 1994 sulphate and chloride concentrations increased in correspondence with the dry season and with the increase of the volcanic activity as indicated by the seismic activity recorded in March. During April fumaroles abounded on the dry lake bottom, chiefly in the central and northern parts of the crater. Escaping gases were audible (jet sounds) from Cerro Pelón, 2 km SW. Residents of several nearby settlements reported sulphur smells. On April 25 and 30, two phreatic eruptions occurred. Poás

vented a grey to clear coloured emission containing old lake-floor sediments. The emitted sediments were found over a significant area around the summit. Both eruption products reached Cerro Pelón, 2 km. SW, and the hut at the park entrance, 1.5 km South of the crater. Tourists came in contact with strong sulphurous gases on April 30, and suffered coughs and irritated skin and eyes. Repeated degassing caused new apparent damage to both wildlife of the Poás National Park and to the neighbouring farmland. Strong evaporation of the lake water, and the vigorous degasification produced in April gas columns of more than a kilometre in height above the crater floor and drastically effected the environmental conditions of an area located down wind from the volcano (Fernández et al., 1994; Sandoval, 1996). The apparent increase in sub-aerial (versus sub-aqueous) degassing translated to an increase in the acidity on material deposited (rain and lake sediments) at a network of collection sites around the volcano (Smithsonian Institution, 1994b).



In May 1994, dry weather and persistent fumarolic activity contributed to prevent the lake from forming. Fumarolic degassing persisted from a number of locations on the crater floor. In the absence of abundant water, volcanic gases continue to vent directly into the atmosphere, causing fumaroles to degas more vigorously and sometimes even to resemble low-energy explosions. Volcanic gas concentrations in the atmosphere rose in the area adjacent to the National Park (SE, S, SW and W of the main crater); residents in its vicinity reported a "strong sulphur odour". These odours forced the National Park Rangers to close the Park on May 26-27 and at least once in June. They were particularly strong at dawn, and some emissions showed yellow and bluish colours at the vent (sulphur combustion?). Acidic rainfall damage increased to a maximum since Poás crater lake level started to descend during the dry season in 1988. By 1994, economic losses were of the order of several million US dollars. Areas of loss encompassed timber, crops, machinery, grazing land, livestock, buildings, and human health. Health complaints included nausea, coughing, and irritated throat, eyes and skin (Smithsonian Institution, 1994a). From April to August the rains formed new ponds with temperatures of 90°C and vigorous degasification. In June, on the south and southwest parts of the lake floor, new fumaroles appeared, equal in size to those in the west and northwest. Some fumaroles were yellowish and reddish in colour suggesting sulphur deposition and melting. Phreatic eruptions resumed.

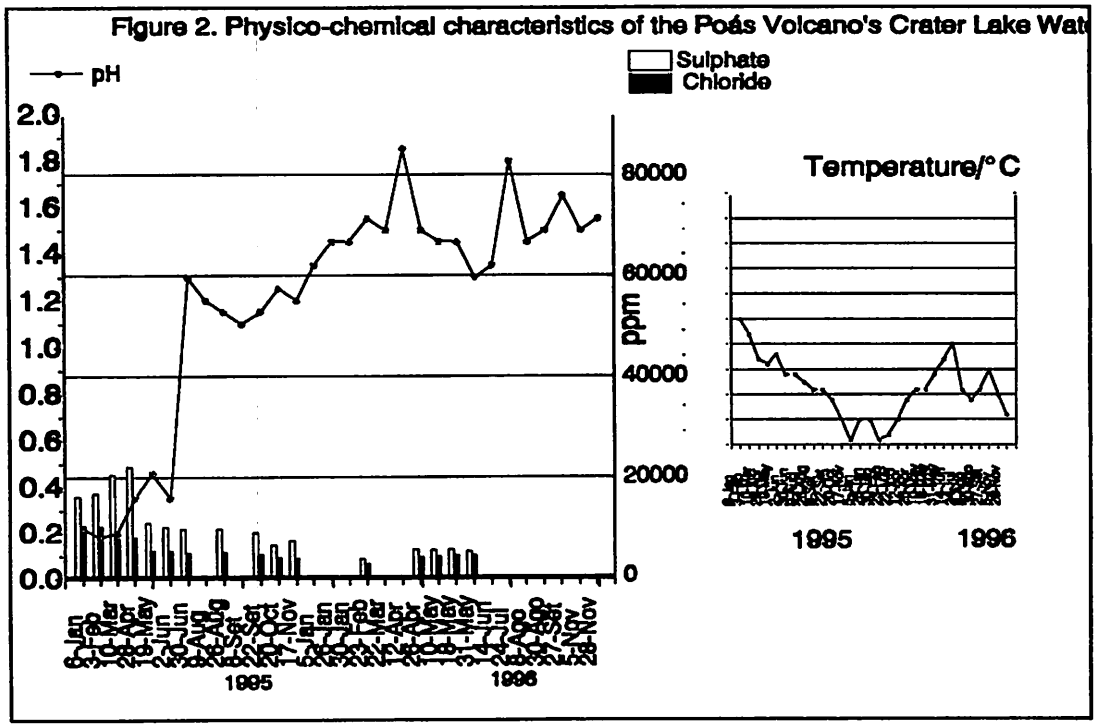
On June 3rd, visitors watched a phreatic eruption column grow to 2 km tall over a 10 minute interval. The dark grey column attained a mushroom-shape and deposited fine non-juvenile ash along the eastern border of the crater, at Laguna Botos, 1 km. SE and at the hut located at the National Park entrance, and at Cerro Pelón. Other phreatic eruptions occurred later that month.

During July, there were several phreatic eruptions of non-juvenile ash and blocks. They were accompanied or preceded by several near surface, high frequency rupturing events. The largest eruption occurred on July 31 (Barboza, V., OVSICORI, oral commun., 1996). Heavy rains caused the level of the nearly dry lake to rise gradually in September and October 1994 following the decline in eruptive activity in August (Smithsonian Institution, 1996b).

During 1993, the water of the crater lake was very acidic with pH values near zero. Moreover, the crater lake maintained a relatively constant water volume that was enriched by subaquatic fumaroles and this fact explains the higher concentration of magmatic chemical species contained in it. The chloride concentration ranged between 24,566 ± 1,400 ppm and 85,692 ± 1,584 ppm and the sulphate concentration ranged between 35,700 ± 1,745 ppm and 91,000 ± 5,573 ppm. The water temperature ranged between 60°C to 70°C. In contrast, during 1994, the concentration of sulphate and chloride in lake water decreased. Chloride concentration ranged between 7,641 ± 219 ppm and 56,598 ± 1,707 ppm and the sulphate concentration ranged between 9,630 ± 1,499 ppm and 83,100 ± 2,548 ppm. In March, 1994, the water lake temperature declined to 55°C and in May-June, 1994, it ranged between 65°C and 70°C. Those temperature changes correlate with the volcanic activity that took place in those months. In 1994, the lake acidity decreased and the pH values increased from near zero in May to 1.00 ± 0.05 in June. This increase in the pH was related to changes in concentration of the acid chemical species in the lake, produced by rain, phreatic eruptions and evaporation, where the fumaroles that used to enrich the lake were exposed directly into the atmosphere.

4.2 Geochemical characteristics and volcanic activity: 1995-1996.

Physico-chemical characteristics of the Poás Volcano crater lake water, 1995-96 are set out in figure 2.



During 1995 and 1996, the lake level continued to rise and the volcanic activity decreased. Seismic activity in 1995-96 at the volcano was less than in 1994; however, fumarolic degassing, the formation and migration of fumaroles and weak bubbling continued in the crater lake. The main source of fumarolic discharge was located on the southern rim of the lake on the 1953-55 pyroclastic cone. An accessible point on this region had a temperature of 94°C (Smithsonian Institution, 1996d; 1995; 1996c).

On April 8, 1996, a low-frequency signal that lasted 223 seconds, coincided with a small phreatic eruption (Smithsonian Institution, 1996a), otherwise, phreatic eruptions have been small and very unusual since 1995.

During 1995, the sulphate concentration ranged between 7,058 ± 456 ppm and 21,963 ± 980 ppm. The chloride concentration ranged between 3,717 ± 203 ppm and 10,284 ± 576 ppm. The temperature ranged between 26-50°C and pH ranged between 0.18 ± 0.05 and 1.25 ± 0.05.

During 1996, the crater lake level continued to rise to a maximum level since 1955. Fumaroles continued to migrate with time, several of them interact directly with the crater lake water, and the most active fumarole continue to be located at the Southern rim of the crater lake, only partially covered by the lake water (Smithsonian Institution, 1996c).

During 1996, the sulphate concentration ranged between 3,436 ± 427 ppm and 5,413 ± 613 ppm. The chloride concentration ranged between 2,554 ± 80 ppm and 4,336 ± 263 ppm. The temperature ranged between 26°C and 45 °C and the pH ranged between 1.30 ± 0.05 and 1.85 ± 0.05. Between 1993 and 1996 fluoride was never detected as free fluoride within the crater lake water.

5. Discussion and conclusions

Volcano monitoring of Poás Volcano crater lake between 1993 and 1996 captured three stages of evolution of a crater lake prior to, during and after a large increase in fumarolic activity.

Poás Volcano crater lake already had a low water level before 1993 due to the gradual evaporation of the lake induced by the robust fumaroles located at the crater floor. The water level fluctuated as a function of rainfall, with very low levels occurring every dry season (i.e. January to April). At the beginning of 1993, the lake had high concentrations of chemical compounds and very high acidity, which was enhanced by the gradual evaporation of the water due to the high heat flow originated in the fumaroles located at the bottom of the crater. Finally, the increase in lake temperature and acidity forced HCl, H_2S and other sulphur compounds to be volatilized into the atmosphere before the lake totally disappeared in April 1994.

About the reduction in crater lake chloride concentration observed during 1994, Rowe et al. (1992b) suggested that lake chloride concentrations declined due to the increased volatility of HCl as lake temperature and acidity increased. Due to the vigorous degasification, the sulphur compounds, like H_2S, are liberated into the environment in a direct form. This behaviour suggests and may explain the reduction in the crater lake sulphate concentration. After the lake disappeared, subaquatic fumaroles became sub-aerial, exchanging magmatic gases directly to the atmosphere, and rain water collected to reestablish the lake was not enriched in chemical compounds from the fumaroles. Between April and July, 1994, there was an increase in fumarolic activity that culminated with the occurrence of several phreatic eruptions in June and July.

The environmental impact of acid precipitation around the volcano's summit increased as sediments from the lake bottom were dispersed by phreatic eruptions, adding to other types of acid precipitation from water lake evaporation and the emission of magmatic gases through fumaroles. After the enhanced volcanic activity was over in August 1996, the lake reformed. Fumaroles that were previously subaqueous continued to deliver magmatic gases directly to the atmosphere, and a dilution effect, due to the gradual volume growth of the crater lake occurred.

Poás Volcano's Crater Lake has high concentrations of chemical compounds, whose presence gives its waters a high acidity. This shows that there exists an important discharge of fumarolic gases, in the crater lake water, which is the source of compounds, such as SO_2, H_2S, HCl, HF, $S_xO_6^{2-}$, CO_2, H_2O and other components of volcanic origin that affect its physico-chemical properties. The changes of the geochemical properties of the water in the crater during the period of study show a strong relation with the volcanic activity. Since the crater water covers the area of higher fumarolic activity, it is reasonable to expect that the changes registered are a direct effect of the variations of the volcano activity.

Acidic atmospheric conditions have also been a problem around Poás, particularly when the lake dried out in 1994, affecting the infrastructure, plants and animals.

The amount of precipitation and low activity of the Poás Volcano during 1995-1996 explains the increase of the pH of the crater lake water. Associated with this, the magmatic anion content diminished with respect to 1993-94.

Rowe et al., 1992b, suggested that more than 95% of the fluoride present in the water will be present as non-volatile Al-F (aluminum-fluoride) complexes and thereby the fluoride should not be detectable as free fluoride. Between 1993-1996 fluoride was not detected as free fluoride as no treatment was attempted to free this ion from the aluminum-fluoride complex.

Acknowledgments

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The Magmato-Hydrothermal System of Copahue Volcano, Argentina

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Copahue volcano in the eastern Andes (37 85 S, 71 17 W), Province of Neuquen, is characterized by an extensive acid hydrothermal system with a crater lake, acid drainage from the partially glaciated summit region, and a geothermal system on the NE flanks. No extensive magmatic eruptions have taken place this century, but repeated phreatic and phreato-magmatic explosions occurred (e.g., 1992, 1994-1995), sending lahars down the rivers and extensive falls of chilled sulfur fragments and pulverized lake deposits (Delpino et al., 1993, 1995; 1996). There was some evidence of new magmatic material in the late stages of these eruptions. We visited the region in March 1997 and sampled the waters of the crater lake, rivers, geothermal features and glacial lakes, and determined river flow rates. The volcano drainage system consists of the Rio Agrio (Fig. 1), which drains into a large glacial "two-finger" lake and the lower Rio Agrio carries off the overflow, to merge with the Neuquen River and draining into the Atlantic Ocean 1300 km to the east. The geothermal area consists of mud-pots, steam-vents and large bubbling pools, which drain into the Rio Blanco and into a series of dilute glacial lakes. A geothermal power plant produces electric energy for the hot spring resorts and spas of the villages Copahue and Caviahue.

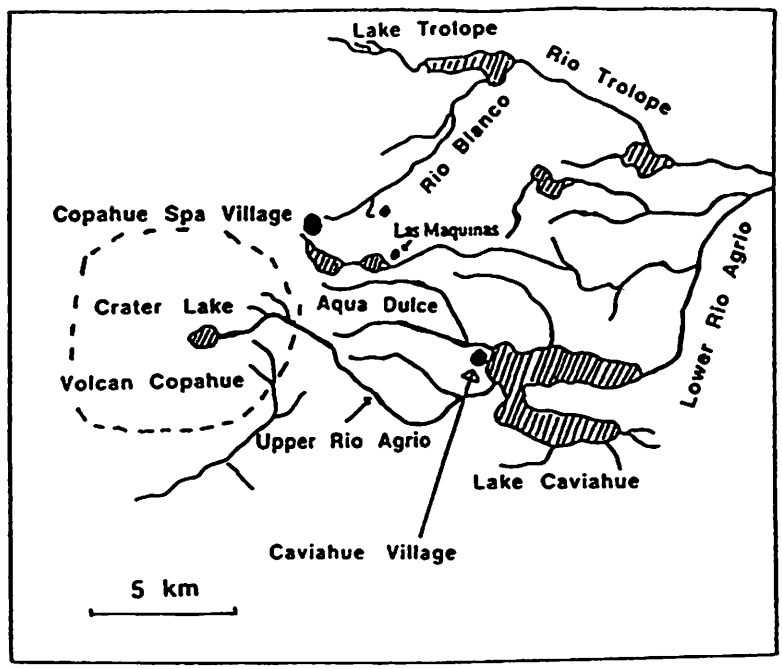

Figure 1. The hydrothermal features and drainage system of Copahue volcano.

The crater lake has an approximate diameter of 200m and sits in a crater cavity that is partially surrounded by a glacier. The water temperature was about 54 °C (March 1997) and the pH < 1; HCl fumes formed white clouds above the convecting lake waters that were highly turbid with finely suspended grey sediment. Earlier water analyses (Martini et al., 1997) indicate about 63,000 ppm SO_4 and 15,000 ppm Cl and some analytical data are given in Table 1. Before the 1992 eruptions, the lake drained into the headwaters of the Rio Agrio, but now the lake level is too low for that. About 50-100 m below the lake level, a series of cracks in the mountain leak hot (68 °C), bright yellow fluids of very low pH, forming the upper Rio Agrio, which also releases copious clouds of HCl vapour (Table 1). Hot springs below the glacier lobe mix with glacial melt water to form a small river, which at the foot of the mountain descends through a series of spectacular cascades of acids with a flow of about 0.3 m^3/sec. March is the end of the Argentinean summer when these Andean rivers have their lowest flow (little precipitation and most snow had previously melted away), so we sampled these rivers in their most concentrated stage. The upper Rio Agrio enters Lake Caviahue through a 1 km long floodplain that is totally "overgrown" with efflorescent salts, and a river plume of silt-laden, pH~ 0.8 water discharges into the lake.

The two fingers of Lake Caviahue (Fig. 1) are comparable in size (9.2 km^2 total lake surface area), each with a depth of about 90 m. The lake is thermally stratified, with water temperatures of about 7 °C at the bottom and 18 °C

at the surface. All water samples, taken at 10 m intervals, had a similar pH of about 2.5-2.6. There was no obvious evidence of any biological activity in the lake. Given the climate of the region, Lake Caviahue is probably dimictic, and presumably the epilimnion acidifies during the late summer. The dilution to pH 2.5 probably occurs during the spring-turnover when pulses of meltwater dilute both river and lake. The calculated *average* discharge of the upper Rio Agrio is about 3 m^3/sec, indicating a much larger flow during the spring season. Glacial meltwater and seeps dilute the lake (average flow of about 2m^3/sec), and the lower Rio Agrio forms from the lake overflow, again through a series of acid cascades with a March flow of about 0.5 m^3/sec (*average* discharge, over the whole year, is about 5 m^3/sec). The upper Rio Agrio waters were diluted in the lake by a factor of about 10 for most elements (Table 1) except for Fe, Al and K indicating mineral precipitation during mixing.

Combination of the river flow data and their water chemistry will enable us to estimate the cation flux from the mountain and some volcanic volatile fluxes. Analyses of the waters from its source to the region downstream will enable us to study the dilution and neutralization processes of this acidified river system. The Rio Agrio had acquired a pH of about 7.7 more than 100 km south of Copahue, where it had become a sizeable river. The bulk water chemistry will indicate in how far dilution and/or rock-water interaction played a role in the neutralization process.

The geothermal system is relatively sulfur-poor and the fluids are used in an extensive bathing and health spa complex. The pH of some of the larger geothermal pools was about 2.0, indicating the presence of acidifying gases (H_2S?) or an influx of acid fluids at the pool bottoms. The Rio Blanco has a pH around 7 and drains most of the geothermal fluids. The hot bath complex in Caviahue uses the hot headwaters of the upper Rio Agrio piped down through a plastic pipe system of a few km length, in about 5 % strength for therapeutic purposes: the ultimate cleaning experience! Air pollution by volcanic HCl is common in the region, dependent on wind and crater lake activity. We hope to characterize the volcano-hydrothermal system and the element fluxes through a detailed chemical and isotopic study. We plan to develop a theoretical model for the lake explosions as a form of volcano hazard planning to determine the magnitude of the trigger for these explosions, be it a thermal trigger or "decapitation" of the water column by catastrophic water loss (e.g. seismic events) or evaporation.

Table 1. Chemical analyses (ppm) of Copahue surface waters

	CPL	CP	RA	CVL
Na	544	713	159	13.9
K	530	775	122	6.7
Ca	768	666	211	21.2
Mg	410	506	143	14.7
Al	2000	2730	523	30.0
Fe	1150	1630	313	18.9
Mn	16	23.5	7.4	0.85
Zn	2.3	3.2	0.6	0.06
B	3.6	3.6	0.66	0.07

CPL: Copahue crater lake
CP: hot springs feeding the Rio Agrio
RA: upper Rio Agrio
CVL: Lake Caviahue, surface waters

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Progress towards a definitive list of volcanic lakes

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When the International Working Group on Crater Lakes (later to become the IAVCEI Commission on Volcanic Lakes) was set up one of the first tasks which it set itself was to compile a Catalogue of Crater Lakes. Initially the intention was to prepare a catalogue of crater lakes which possess limnological and volcanological similarities to Lake Nyos and Lake Monoun. These lakes had both released clouds of toxic gas in the mid-1980's and the primary purpose of the catalogue was to avoid similar tragedies by identifying other potentially hazardous lakes. This basic objective was extended, when the IWGCL became a Commission of IAVCEI (in 1991), to include all crater lakes and subsequently to include all volcanic lakes. Partial catalogues for specific geographical areas or for specific types of volcanic lake have been published but progress towards a comprehensive catalogue of volcanic lakes has yet to yield any tangible results.

As a contribution towards the eventual development of a comprehensive catalogue, an initial *list* of volcanic lakes of known depth was prepared for our Commission's 1996 Newsletter (*Current Res. Volc. Lakes* **9**, 30-37). Part of that list (the part covering West Africa and North America) was revised and updated for display as a 'poster' at the meeting in Crater Lake, Oregon. The interest engendered by the list in last year's Newsletter and the subsequent display was sufficient to make me feel that to continue revising the list would be a worthwhile exercise. The current list is still very far from complete but I hope that by printing a partial list members will be prompted to write in with corrections and with information on other lakes which can be added to the list.

One problem in preparing any list is to devise a logical order in which to present the data. The list of volcanic lakes printed in last year's Newsletter was arranged by continent (in alphabetic order) then by country (in alphabetic order). Within individual countries lakes were listed in depth order - reflecting the original intention "to prepare a catalogue of crater lakes which possess limnological and volcanological similarities to Lake Nyos" in that the deeper a lake the greater its capacity to contain dissolved gas and consequently the greater the hazard in the event of Lake Nyos type 'overturn'. The use of alphabetic order has an obvious simplicity but as more countries are added the list looses a sense of geographical coherence. For the purposes of this list I have divided the Earth into a series of north-south segments. This avoids the 'problem' of arranging all Asian countries in a single sequence and makes it easier to find a logical place for some of the oceanic islands. It also reflects geological reality in that most volcanic zones follow north-south plate boundaries. The segments selected are: 1. Europe and West Africa, 2. Asia Minor and East Africa, 3. Eastern Asia and Australasia, 4. Pacific Islands, 5. North and South America, 6. Atlantic Islands. These segments may need to be refined as more lakes are added and the scheme does throw up a minor problem with the Kurile Arc but in other respects it yields a logical order. Within each segment countries are listed in order from north to south. This has not yet thrown up any problems but as more lakes are added I suspect that some minor problems will emerge. And within each country lakes are listed from north to south (i.e. in numerical order of latitude).

The attached list gives whatever physical information (depth, area and volume) I have thus far been able to glean from the literature. However, I appreciate that this information is far from complete and any corrections or additional information will be more than welcome. To this I have added a limited amount of information on the chemistry of the lake water. The pH of the deep water, pH is not only a useful characteristic in itself but also tends to reflect the concentration of other ions. In some lakes the pH varies greatly and for these I have selected a 'representative' value. I have also listed the major cation (M^+) and the major anion (M^-) - in each case based on molar concentration. When I set out to create this list I thought that it might be useful to include the age of the lake, or more accurately the age of the most recent volcanic event to significantly affect the lake. The intention being to draw a clear distinction between mature lakes which had developed over a considerable period of time and lakes which had been modified by recent volcanic activity. However, in practice it proved to be impossible to compare like with like. For mature lakes it is sometimes possible to determine the age of the structure in which they reside whilst for lakes associated with historic volcanic activity it is usually possible to obtain the date of the most recent significant event. To avoid confusion I have therefore listed the age of lake basins in normal type and the *date* of recent volcanic activity in *italic type*. And where appropriate I have added a note by way of explanation. These notes have also been used to add other relevant information and to list alternative names and spellings.

Western Europe

Germany

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Laacher See	50° 24' N	7° 18' E	52	2210						crater

France

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Pavin	45° 55' N	2° 54' E	92	440						crater

Italy

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Bolsena	42° 36' N	11° 56' E	156	105 000		8.3	Na	HCO_3	350 ka	crater
Vico	42° 19' N	12° 11' E	48	12 100	261	8.5	Na	HCO_3	150 ka	caldera
Martignano	42° 07' N	12° 19' E	54	5300	151	8.0	Na	HCO_3	40 ka	crater
Bracciano	42° 07' N	12° 14' E	165	50 700		7.6	Na	HCO_3	40 ka	crater
Albano	41° 45' N	12° 40' E	177	4500		5.6	Na	HCO_3	36 ka	crater
Nemi	41° 43' N	12° 42' E	32	3800	65	7.8	Na	HCO_3	36 ka	crater
Averno	40° 50' N	14° 04' E	39	1300	38	7.2	Na	Cl	3.8 ka	crater
Monticchio-P	40° 55' N	15° 36' E	38	160	3.9	6.3	Fe	HCO_3	130 ka	caldera
Monticchio-G	40° 55' N	15° 35' E		500					130 ka	caldera

Notes
Albano and Nemi are lakes in the caldera of the Alban Hills volcano.
Monticchio - there are two Monticchio lakes in the caldera of the Mt. Vulture volcano: Lago Piccolo (Small Lake) and Lago Grande (Large Lake).

West Africa

Nigeria

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Maldau	10° 42' N	12° 06' E		35						caldera
Tilla	10° 33' N	12° 08' E	2	524					4.7 Ma	caldera
Oku	7° 56' N	8° 48' E	3	4000					6 Ma	crater

Notes
Oku - not to be confused with the lake of the same name in Cameroon. Although very shallow at the present time a core through the lake sediments revealed a 148 metre thick sequence dating back to the Late Miocene.

Cameroon

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Dang	7° 26' N	13° 33' E		799						
Mbalang	7° 19' N	13° 44' E	52	399						crater
Massot	7° 18' N	13° 41' E		48						
Tizong	7° 15' N	13° 35' E	48	44						crater
Baledjam	7° 08' N	13° 52' E	13	204						crater
Ngaoundaba	7° 08' N	13° 42' E	62	29						crater
Gagouba	7° 07' N	13° 41' E	104	103						crater
Boubala	6° 53' N	12° 38' E		267						
Assa	6° 50' N	10° 48' E		554						
Betolong	6° 43' N	9° 46' E		258						
Assom	6° 38' N	12° 59' E		1137						
Njupi	6° 27' N	10° 19' E	17	271					3.4 ka	lava dam
Nyos	6° 26' N	10° 18' E	208	1501	153	5.2	Mg	HCO_3	>4 ka	crater
Benakuma	6° 26' N	9° 57' E	138	1606		6.6	Ca	HCO_3		crater
Kuk	6° 24' N	10° 13' E	47	407						caldera
Wum	6° 24' N	10° 03' E	124	295			Mg	HCO_3		caldera
Elum	6° 20' N	10° 02' E	35	285						caldera
Enep	6° 18' N	10° 02' E	78	320						caldera
Oku	6° 12' N	10° 28' E	52	2271	71.6					caldera
Nkan	6° 08' N	11° 03' E		338						
Bambili-N	5° 56' N	10° 15' E		180						caldera
Bambili-S	5° 55' N	10° 15' E	4	417						caldera
Bambuluwe	5° 52' N	10° 12' E	58	184	7.2					crater
Ejagham	5° 45' N	8° 59' E	17	481						crater
Ménéné	5° 41' N	10° 28' E		35						
Pètponoun	5° 38' N	10° 39' E	12	408						
Ngouondam	5° 37' N	10° 33' E	49	135						crater
Monoun	5° 35' N	10° 35' E	96	565	14.0	6.2	Fe	HCO_3		crater
Nefo	5° 35' N	10° 27' E	64	40						crater
Mfou	5° 33' N	10° 42' E	58	76						crater
Negop Gbang	5° 33' N	10° 34' E	23	66						crater
Baleng	5° 33' N	10° 25' E	52	35						caldera
Mfouet	5° 32' N	10° 35' E	14	85						caldera
Beme	5° 10' N	9° 38' E	15	280						crater
Manengouba-N	5° 02' N	9° 50' E	168	293	18.6		Ca	HCO_3		caldera
Manengouba-S	5° 02' N	9° 50' E	93	60	3.4	6.6	Ca	HCO_3		caldera
Edib	4° 58' N	9° 39' E	13	95						caldera
Dissoni	4° 44' N	9° 17' E	81	1330	70.5					caldera
Barombi Mbo	4° 39' N	9° 24' E	111	3972	272	6.4	Na	HCO_3	>21 ka	caldera
Mami	4° 35' N	9° 37' E		271						
Barombi Koto	4° 28' N	9° 16' E	6	1260	4.8	8.8				caldera
Mbwandong	4° 27' N	9° 17' E		170						crater
Debundsha	4° 06' N	8° 59' E	14	96		6.1				crater

Cameroon (cont.)

Notes
Bambaluwe - although this is the name which appears on recent maps and in much of the scientific literature local scientists insist that its real name is Lake Awing.
Barombi Koto - or Lake Barombi ba Koto or just Lake Koto was called Rickards See (Rickards Lake) when visited by European explorers towards the end of the 19th century. Contains endemic fish.
Barombi Mbo - or Balombi Mbu was called Elefanten See (Elephant Lake) by late 19th centaury German explorers. Contains endemic fish.
Berne - or Bemin contains endemic fish.
Dissoni - or Lisoni was visited by a Swedish explorer in 1890 who called it Sodensjön (or Soden See) in honour of the then Governor of the German colony of Kamerun (Cameroon). Contains endemic fish.
Ejagham - contains endemic fish.
Kuk - or Nyi, recent maps use one or other of these names.
Magengouba - there are two crater lakes within the caldera of the Manengouba volcanic complex. The larger, more northerly, lake is generally known as the female lake and the smaller lake as the male lake, though whether it is the lakes which have gender or whether a more accurate translation would be the Men's Lake and the Woman's Lake is far from clear. When first visited by Europeans towards the end of the 19th century these lakes were described as "mysterious lakes in the Epocha crater".
Mbwandong - this is the spelling used on the 1987 map which differs from that used on the 1972 map (Bwando) and from the spelling used in the scientific literature (Mboandong) but they are presumably all transliterations of the same word.
Monoun - a cloud of toxic gas released from this lake in August 1984 killed 37 people.
Nefo - or Banefo - both names have been used for the lake but on government maps the lake is Lac de Nefo and Banefo is a nearby village.
Njupi - in Mmen (one of many local languages) njupi is the word for bad.
Nyos - sometimes spelled Njos or Nios was initially called Ilüi See by early German explorers (this name appears on later maps as Lake Lwi) but subsequently changed to Große Ndü See (Large Sacred Lake) in published reports. A toxic aerosol of water and carbon dioxide released from this lake in August 1968 1700 people.
Oku - not to be confused with the lake of the same name in Nigeria. When first visited by Europeans in the early years of the present century the local people apparently called it Lake Mauwe, but neither this name nor anything similar is to be found on recent maps.

Equatorial Guinea

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Lareto	3° 24' N	8° 41' E		270						caldera
Blaó	3° 21' N	8° 38' E		564						caldera
Fuego	1° 27' S	5° 37' E		289						caldera

Notes
Blaó and Lareto - Lago de Blaó and Lago de Loreto are both on the Gulf of Guinea island of Bioko (formerly Fernando Poo)
Fuego - there is a (?unnamed) caldera lake the highest point on the rim of which is the Pico de Fuego (Pinnacle of Fire - in Spanish) on the Gulf of Guinea island of Pagalu (formerly Annobon).

Asia Minor

Turkey

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Nemrut	38° 39' N	42° 01' E	167	11 000	980					caldera

East Africa

Kenya

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Simbi	0° 22' S	34° 38' E	25	49						crater
Green	0° 47' S	36° 16' E	5	141	0.5					crater

Uganda

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Bunyoni	1° 18'S	29° 54 E	39	51 500						lava dam
Mutanda			50	23 000						lava dam

Asia

Russia

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Bannoe	54° 32' N	160° 05' E	32	1		5.1				caldera
Klyuchoe	51° 50' N	157° 31' E	96	5400						caldera
Stubel	51° 50' N	157° 31' E	84	2500						caldera
Ebeko	50° 40' N	155° 56' E	20	30						caldera
Golovnin-1	43° 49' N	145° 31' E	62	2600						caldera
Golovnin-2	43° 49' N	145° 31' E	22	40						caldera

Japan

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Kussharo	43° 37' N	144° 19' E	118	79 700					7 ka	caldera
Mashu	43° 35' N	144° 32' E	212	19 600	2 860	<7	Na	HCO_3	1 ka	caldera
Toya	42° 32' N	140° 50' E	180	69 400						caldera
Kuttara	42° 30' N	141° 11' E	148							caldera
Osore-Yama	41° 19' N	141° 05' E	15	2300						caldera
Okama	39° 51' N	141° 00' E	14	2						caldera
Onasiroko	39° 51' N	141° 00' E	6	35						caldera
Gosikinuma	38° 09' N	140° 27' E	63	100						caldera
Yugama	36° 38' N	138° 32' E	27	68	0.8	1.2	Al	Cl	*1983*	caldera

Notes
Mashu - or Masyu was formed following a phase of volcanic activity which ended about 1000 years ago.
Okama - there are two volcanic lakes with this name, one which is also known as Lake Gosikinuma is in the caldera of Zao volcano and the other is in the caldera of Iwate volcano.
Yugama is in the caldera of the Kusatsu-Shirane volcano. There were a series of phreatic eruptions from a vent in the northern part of the lake in 1982-83.

Indonesia

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Klabat	1° 28' N	125° 02' E	20	5						crater
Gomkonora	1° 23' N	127° 31' E		12						crater
Todoko	1° 18' N	127° 26' E		1100						crater
Tampusu	1° 15' N	124° 49' E	25	40						crater
Sorikmarapi-1	0° 41' N	99° 32' E	150	30						crater
Sorikmarapi-2	0° 41' N	99° 32' E	50	2						crater
Tandikat	0° 26' S	100° 19' E	40	4						crater
Kerintji	1° 41' S	101° 10' E	200	49						crater
Burkit Dahn	3° 23' S	102° 22' E	150	65						crater
Kaba-L	3° 31' S	102° 37' E		18						crater
Kaba-B	3° 31' S	102° 37' E		10						crater
Dempo	4° 02' S	103° 08' E		110						crater
Telaga Bodas	7° 13' S	108° 04' E		160						crater
Galunggung	7° 15' S	108° 04' E			7.5	7.0	Ca	SO_4	*1983*	crater
Kelut	7° 56' S	112° 19' E	32	240	2.4	6.9	Na	Cl	*1990*	crater
Kawa Ijen	8° 04' S	114° 14' E	200	410						crater
Satonda	8° 07' S	117° 45' E	69	772	34					
Sirung	8° 31' S	122° 27' E		90						crater
Egon	8° 40' S	124° 09' E		210						crater
Wai Sano	8° 41' S	120° 02' E	>30	3900		3.0	Na	Cl		caldera
Keli Mutu-TiN	8° 46' S	121° 49' E	127	917	6.4	0.4	Al	Cl		crater
Keli Mutu-TAM	8° 46' S	121° 49' E	67	604	4.2	3.1	Ca	SO_4		crater
Keli Mutu-TAP	8° 46' S	121° 49' E	64	817	5.3	1.8	Al	SO_4		crater
Batur			80	15 000						caldera

Notes
Galunggung - on the island of Java has erupted twice this century most recently in 1982-83.
Kaba - on the island of Sumatra has two lakes, one in the Lama crater and the other in the Baru crater.
Keli Mutu - on the island of Flores is a dormant stratovolcano with three crater lakes: Tiwu Nua Muri Koohi Fah (lake of young men and maidens), Tiwu Ata Mbupu (lake of elders) and Tiwu Ata Polo (enchanted lake).
Kelut - on the island of Java has erupted five times this century most recently in 1990. In 1919 an eruption emptied the crater lake, which at that time had a volume of about 40 million cubic metres, generating a lahar which killed 5110 people.

Australasia

New Guinea

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Dakataua	5° 04' S	150° 07' E	111	48 000	3 300	7.8	Na	HCO_3	>1 ka	caldera
Wisdom	5° 20' S	147° 06' E	360	86 000	19 000	7.9	Na	Cl	*? 1699*	caldera
Sakar	5° 25' S	149° 05' E		250						crater

Notes
Dakataua is on the island of New Britain. The caldera itself is at least a thousand years old but there has been subsequent volcanic activity the most recent of which was a lava flow from a cone which rises within the lake. The chemistry of the lake water is most unusual in that it is near neutral at depth and increases in alkalinity towards the surface.
Wisdom is on Long Island. The caldera forming event has been variously dated to the late 17th or early 18th century but may well have been responsible for the exceptionally cold summer of 1699. More recently there have been frequent though minor eruptions from a cone within the lake.

Vanuatu

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Gaua	14° 15' S	167° 30' E	100	16 000						caldera

New Zealand

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Ruapehu	39° 18' S	175° 36' E	134	199	9.0	0.7	Al	SO_4	*1996*	caldera

Notes
Ruapehu - the lake in the caldera of the Mount Ruapehu volcano is also referred to, in the recent scientific literature, as the Crater Lake of Mt. Ruapehu and as Ruapehu Crater Lake. The information on bathometry and chemistry are for the lake as it was prior to the 1996 eruption.

North America

United States of America

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Surprise	56° 56' N	158° 07' W		2780					3.4 ka	caldera
Turbid	44° 32' N	110° 16' W								crater
Yellowstone	44° 27' N	110° 21' W								caldera*
Duck	44° 26' N	110° 35' W								crater
East	43° 43' N	121° 13' W								caldera
Paulina	43° 43' N	121° 13' W								caldera
Crater	42° 57' N	120° 06' W	590	53 200	17 300	6.9	Na	HCO_3	4.2 ka	caldera
Medicine	41° 35' N	121° 34' W								caldera

United States of America (cont.)

Notes
Crater Lake - Oregon is in the caldera of the Mount Mazama volcano.
Duck Lake and Turbid Lake - Wyoming are in explosion craters close to the margin of Yellowstone Lake.
East Lake and Paulina Lake - Oregon are both in the caldera of Newberry volcano.
Medicine Lake - northern California (not to be confused with the many other Medicine Lakes in the U.S.A.) is in the caldera of the Medicine Lake volcano.
Surprise Lake - Alaska is in the caldera of the Aniakchak volcano.
Yellowstone Lake - Wyoming, the lake basin is in a glacially modified caldera which was itself formed by a sequence of eruptions the last of which occurred about 600 000 years ago.

Mexico

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
El Chichon	17° 22' N	93° 14' W		140						crater

Guatamala

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Atitlan	14° 17' N	91° 11' W	341	137 000						caldera

Costa Rica

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Poás-C	10° 12' N	84° 14' W	60	67		1.6		Cl		caldera
Poás-B	10° 11' N	84° 14' W		100						caldera

Notes
Poás - there are two caldera lakes near the summit of Poás volcano: one of which, Lago Caliente (Hot Lake - in Spanish) is in the active crater and the other, slightly larger lake, is in the Botos Cone.

South America

Ecuador

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Quilotoa	0° 52' N	77° 55' W	>360	3000						caldera
Cuicachi	0° 19' N	78° 22' W	180	3000						caldera

Argentina

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Copahue	37° 45' N	71° 18' W	>40	71		0.1	Al	SO_4		caldera

Atlantic Islands

Iceland

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Grimsvötn	64° 25' N	17° 20' E	>350	2500						caldera
Öskjuvatn	63° 02' N	16° 45' E	217	10 700	1230	6.7	Na	SO_4	*1875*	caldera

Notes
Öskjuvatn - this lake is in the caldera of the Askja volcano which was formed by a cataclysmic eruption in 1875 and subsequently modified by a sequence of minor eruptions in 1921-26.

Azores (Portugal)

Lake	latitude	longitude	depth m	area 10^3 m^2	vol. 10^6 m^3	pH	M^+	M^-	Age	type
Sete Cidades	37° 52' N	25° 47' W	27			7.9	Na	Cl	*1444*	caldera
Fogo	37° 46' N	25° 28' W				8.5	Na	Cl		caldera
Furnas	37° 45' N	25° 20' W	10	1916		7.1	Na	Cl	*1630*	caldera

Notes
Fogo is in the caldera of the Agua de Pau volcano on the island of São Miguel.
Furnas and Sete Cidades (or Sete Sidades) are on the island of São Miguel.

Chapman Conference on 'Crater Lakes, Terrestrial Degassing, and Hyper-acid Fluids in the Environment', September 4-9, 1996, Crater Lake, Oregon, U.S.A.

Meeting Report by Joop Varekamp and Gary Rowe

The 4th meeting of the IAVCEI Commission on Volcanic Lakes was held from September 4 to 9, 1996 as part of an AGU-sponsored Chapman conference titled: Crater Lakes, Terrestrial Degassing, and Hyper-acid Fluids in the Environment. The meeting was held at Crater Lake, Oregon, USA, and brought together volcanologists, geochemists, microbiologists, limnologists and environmental chemists with interests in the physical and chemical characteristics of crater lakes, the geochemistry of hyper-acid fluids, mechanisms of shallow volcanic degassing, and geothermal/ore forming environments. The connecting theme of the meeting sessions was "exotic fluids at the earth's surface", thus a multidisciplinary set of talks and posters were presented which covered both theoretical and practical aspects of this range of topics. The first session focused on the geology. geochemistry and geophysics of crater lakes. It was followed by a session on the geochemistry of CO_2-rich lakes and current efforts to mitigate the hazards posed by such lakes. This was followed by sessions that focused on geochemical comparisons of hyper-acid fluids in crater lakes and acid mine drainage, the nature of magmatic-hydrothermal systems beneath crater lakes and their relation with epithermal acid-sulfate ore deposits, the isotopic characteristics of crater lake fluids, and the sulfur speciation in hyper-acid natural waters. Later sessions were dedicated to the surveillance of volcanic activity through crater lake monitoring, the quantification of volcanic volatile fluxes, and the occurrence of acid fluids in commercial geothermal fields.

The meeting was attended by 68 scientists from 13 countries and included a cruise on Crater Lake and a geological field-trip around the rim of Crater Lake. After the conference ended, some attendees participated in field trips to observe geothermal features of Lassen Volcanic Park, whereas others chose to see negative pH mine drainage at Iron Mountain near Redding, both in Northern California. The accommodation was simple, the meeting room basic, the program overfilled, but spirits were overall high, and the natural beauty of Crater Lake made up (we hope) for the occasional shortfalls in organization. A program overview is given below, listed by first author and title, in sequential order of presentation. A full scientific review of the meeting contents appears in EOS.

First author	Title
Varekamp	Exotic exhalations in the exosphere - where Hades meets Apollo.
Armienta	Geochemical trends of the lake water at El Chichon volcano since 1983.
Fazlullin*	Subaqueous eruption from Karymsky lake (Kamchatka) and its effects.
Martini	The influence of hydrothermal systems on volcanic activity: 20 years of investigations at Phlegrean fields and Vulcano (Italy).
Barbozo	Eruptive activity at Rincon de la Vieja Volcano, Costa Rica, November 6-13 1995.
Vandemeulebrouck	Degassing rate variations in a crater lake deduced from hydroacoustic noise level measurements.
Newhall	Early evolution of a caldera lake, Mount Pinatubo, Philippines.
Lopez	Seasonal variations in water chemistry and thermal regime at a tropical volcanic lake: Ilopango, El Salvador.
Delpino	Some characteristics of Copahue crater lake, Argentine.
Hayba	Magmatic heat and mass transfer into the crater lake on Mt. Ruapehu.
Kempter	Geological and geochemical influences on flank stability: the role of the crater lake system of Rincon de la Vieja volcano, Costa Rica.
Ohba	Changes in the crater lake on Kusatsu Shirane volcano, Japan: response to volcanic activity.
Sorey	Heat and mass discharge from thermal areas at Lassen volcanic national park, California, USA.
Sriwana	Volcanogenic pollution in west Java, Indonesia: the acid crater lake of Patuha volcano and impact on local surface water.
Taran	El Chichon: Chemistry of crater lake, fumarolic gases and thermal waters.
Ushakov	Automatic monitoring of heat flow through Bannoe lake (Uzon caldera, Kamchatka).
Kusakabe	pH and CO_2 profiles at lakes Nyos and Monoun, Cameroon.
Bernard	Geochemical evolution of Lake Nyos and Lake Monoun, Cameroon.
Evans	Hazard mitigation at Nyos, removing gas and water from the lake.
Kling*	The exploding lakes of Africa: from loss to wonder to understanding.
Evans	Cold CO_2 flux at Mammoth mountain, California.
Kantha	Numerical models of mixing processes in Crater Lake, Oregon.
Freeth	What triggered the 1986 lake Nyos disaster?
Rice	Rollover in volcanic crater lakes: a possible mechanism for the Lake Nyos disaster.
LeGuern	Crater lakes eruptions: chemical and physical modelling.
Fessenden	Degassing of magmatic CO_2 recorded in tree rings at Mammoth Mountain, California.

First Author	Title
McCord	Application of lake hydrodynamic simulation modeling for CO_2 degassing of Lake Nyos.
Staples	Theoretical geochemical interactions resulting from carbon dioxide disposal in deep ocean trenches.
Bacon	Mount Mazama and Crater Lake caldera, Oregon: a geological-limnological overview.
Molling	Analysis of volatile chloride production using chemical equilibrium of brine-rock-steam at the Geysers Geothermal Field, California.
Fournier	The generation of HCl in volcanic environments by hydrolysis of salts.
Rowe	Chemical systematics of crater lakes: the crater lake data base.
Schuiling*	Self-sealing of the waste acid lake at Armyansk.
Nordstrom*	Measurement of negative pH in ultra-acidic mine waters at Iron Mountain, California.
Ptacek	Use of the Pitzer model to describe highly acidic mine drainage.
Xu*	Formation, reactivity, stability and analysis of thiosulfate and polythionates in hydrothermal waters.
Oday	Constraining geochemical models at acid mine sites using molecular information from synchrotron X-ray absorption spectroscopy.
Rodgers	Microbial weathering of metal sulfides: initial analysis of bacterial diversity by ribosomal DNA sequencing.
Robbins	Microbial and mineralogical analysis of flocculates that occlude porosity in failed anoxic limestone drains fed by acid mine waters.
Kusakabe*	Sulfur isotopic distance between sulfate and elemental sulfur from some hot crater lakes.
Tedesco	Long term variations of helium, neon and argon at Vulcano Island: how the volcano works.
Alpers	Stable isotope systematics of S and O in aqueous and mineral sulfates from hyper-acid environments.
Cunningham	Formation of coarse-grained vein alunite by degassing of an epizonal stock.
Fehn	Potential of ^{129}I and ^{36}Cl as tracers in volcanic fluids.
Taran	Hyper-acidic waters at Baransky volcano, Iturup, Kuril Islands, sulfur isotopes and volcanic activity.
Africano	Acid alteration in fumarolic environment and its importance in the fluorine enrichment of altered volcanic rocks.
Aoki	From crater lakes to gold cradles.
Chastain	Rock water reactions within the crater lake of Poas volcano, Costa Rica: a preliminary report.
Martinez	Changes in the chemical characteristics of Poas volcano crater lake, 1993 to 1996.
Delmelle	Isotopic geochemistry of the hydrothermal system of Kawah Ijen, Indonesia.
Magenheim	Proposed survey of the chlorine stable isotope composition of crater lake HCl: potential for estimating the isotopic ratio of the volcanic chlorine flux.
Varekamp	A search for recycled sediments in volcanic arcs: ^{36}Cl, ^{129}I and $\delta^{11}B$ in crater lakes.
Zimbelman	Importance of glaciers to the geologic and geochemical evolution of Mount Rainier volcano, Washington.
Truesdell*	Volcanic degassing-geothermal consequences.
Qun*	A telemetering system for monitoring polythionates in active crater lakes.
Symonds	The interaction of magmatic gas with cold meteoric water: numerical modelling and implications for gas monitoring of volcanoes.
Lowenstern	Modes of degassing for subvolcanic magmas.
Andres	The use of COSPEC for monitoring terrestrial degassing.
Koepenick	Volatile emissions from the crater and flank of Oldinoye Lengai volcano, Tanzania.
Varekamp	Volatile element budgets of explosive eruptions: contributions from volatiles adsorbed on fine ashes.
Collier*	Hydrothermal inputs to Crater Lake, Oregon.
Fazlullin	Hydrochemistry and the behaviour of microelements in the estuary zones of recent volcanic regions (with reference to the Kurile-Kamchatka region).
Fisher	Chemical and isotopic composition of fumarole gases and spring discharges from Galeras volcano, Colombia.
Freeth	Towards a definitive list of volcanic lakes.
Kyle	Degassing of an anorthoclase phonolite lava lake at Mount Erebus, Antarctica.
Mastin	A new database on eruptions through lakes and shallow water bodies
Pasternack	Process framework for understanding volcanic lakes.
Takano	International analytical cross check of crater lake water.
VanBergen	Degassing of sulfur and chlorine during the 1982-1983 eruptions of Galunggung.

Field trips:

I: Volcanology and petrology of Mount Mazama and Crater Lake caldera, Charles R. Bacon, USGS

II. Hyper-acid fluids at Iron Mountain, California, Kirk Nordstrom, USGS

III. Geothermal features and volcanology of Lassen Park, California, Michael Sorey, USGS

A personal perspective by Sam Freeth

Selecting exotic venues for future meetings is an entertaining but frequently fruitless occupation. I therefore well remember the feeling of anticipation mixed with cautious realism when the suggestion that Crater lake, Oregon might be an appropriate place for a future meeting was discussed over a glass (or three) of saki in a ski lodge (or more accurately a pre-stressed concrete ski bunker) on top of Mt. Tatayama as we 'wound down' after the Misasa meeting. But the plans slowly took shape and four years later I found myself flying into Portland, Oregon after yet another 20+ hour journey. Unfortunately for me I had had to delay my flight at short notice so I was arriving the evening before the meeting (though in *real time* it was actually the following morning) but I had managed to wangle an upgrade so things could have been a lot worse! Anyway there I was at Portland Airport trying to find my way out of yet another car park in yet another rental car - I don't mind so much that Americans drive on the wrong side of the road but in the early hours of the morning it always seems a little perverse that they should insist on having their cars on the wrong side of the steering wheel.

After a night in an American 'motel' and an American breakfast at a 'truck stop' the world started to look far more civilised. Before long I was cruising south on Route 5 and watching the world go by - which it was doing in an all too literal sense - the occasional house flashing past in one direction and a steady stream of giant trucks, frequently with one if not two trailers, rolling past in the outside lane! I had taken the precaution, when picking up the car, of asking what the 'actual' speed limit was - having discovered in other States that what is written on the signs and what is enforced in practice was not necessarily the same. Obviously it was a silly question since no rental company is going to acknowledge that there is a difference between theory and practice but I soon noticed that nobody but nobody was taking *any* notice of the signs. So I speeded up and soon the miles were ticking past with monotonous regularity. A couple of hours or so down the highway then up into the hills. The Cascades were fantastic - seemingly endless pine forests with only the occasional sign of habitation. And hardly any traffic - which was a good thing since an underpowered rental car with automatic gears is my idea of frustration on wheels. Anyway, to abbreviate a long drive, and a few thousand million trees, the morning slid past and there I was at Crater Lake State Park just in time for lunch.

After an all too brief opportunity to greet colleagues whom I had not seen since the Lakes meeting in Boulder (Misasa / Nancy / Yaoundé) it was time for the afternoon session. Unfortunately, for the other participants, I had been asked to act as chairman for part of the session - unfortunately because for me it was now the middle of the night and not only was I in no fit state to chair anything but I did not even have the sense to ask someone else to do it for me. Consequently it was a total disaster and will I am sure be talked of in years to come as a prime example of how not to do the job. That evening there was a barbecue - or at least I think it was a barbecue and I think it was that evening - but I was on autopilot so if anyone thought I was a complete idiot they now know why.

As is the way with such things I woke late the following morning, late G.M.T. but at about 5 a.m. Pacific Time! So after a while watching the dawn light creep in I crept out trying vainly to avoid disturbing the unfortunate colleague who had been allocated to share a chalet with me. Once out there was ample time to survey my surroundings. Accommodation had been arranged in Mazama Village, not an actual village in the normal sense but a collection of spacious chalets set in a pleasant wooded area close to the park entrance. In other respects the area was unremarkable - except for the notices warning against feeding the bears. About 4 miles up the road was the Park Headquarters, a permanent village for park staff with a community hall which was being used for our meeting. The buildings could perhaps best be described as functional though I was immensely impressed by the ingenuity with which the bear proof waste disposal units had been designed - even Yogi Bear would have had trouble with some of them. A further 3 miles up the road was Crater Lake itself with Crater Lake Lodge an historic* hotel perched on the edge (* as far as I can make out 'historic' in the U.S.A. means that only a few old people can remember it being built) and the obligatory souvenir supermarket. I had caught only fleeting glimpses of Crater Lake the previous day but contemplating it at leisure in the cold light of morning it was a truly impressive sight. And the Lodge provided an impressive breakfast - if I could live by breakfast alone I could eat well in North America.

Facilities in general were excellent - but why is it so difficult to make telephone calls in the United States? Of all the countries I've visited the United States is the only one which seems to have a telephone system specifically designed to make life difficult for foreigners. In some countries the lines are forever busy but at least you know that when (of if) you get through they will be pleased to take your money. Only in the United states could it be possible to have a major credit card issued by the wrong bank! And just try making an overseas call from a pay-phone. Finding one was no problem, though it seemed strange to discover one on a post in the middle of the forest - perhaps it was intended for the bears - but since the company which owned it did not like any of my credit cards it had to be cash!! So first ask the disembodied voice how much a call to Europe costs, ($11), then collect a sack of 25¢ coins, then try again only to be quoted a different (higher) price - so give up in disgust. Everyone was ever so 'helpful' and anxious that I should "have a nice day" but found it impossible to put me through. Eventually, refusing to give up, I found myself talking to an International Operator in Scotland who was more than happy to charge a call to me home number - but of course my wife was out!

The sessions went well and there were two excellent local field trips. The first, a trip around the crater rim, presented a wealth of information and was run by someone who had obviously been studying the area for 35 years. The second, a rather more relaxing cruise around the lake with an all too (check) brief stop at Wizard Island provided everyone with memories to recall in years to come. Field trips can be an object lesson in national characteristics and these were no exceptions. The Americans, as always, behaved in an exemplary fashion - parked where they were told, paid careful attention and asked polite questions at appropriate times. The Europeans, quite the other way around, parked all over the place and tended to wander off to examine the wrong section or even worse stayed and asked loaded questions which implied a thoroughly unwarranted degree of scepticism. The Rest of the World tended to look on with varying degrees of confusion and of course the Japanese agreed with everyone.

All too soon the sessions came to a close and many of the participants headed south to Mount Shasta City prior to the start of the post-meeting field trips. I had the good fortune to select the Lassen Peak field trip which was quite brilliant - the area, the organisation and everything. I would like to summarise what we saw but I doubt I could do it justice so could I recommend to anyone who visits California that they visit Lassen Peak State Park and see the area for themselves - it is only 240 miles from San Francisco and well worth the trip.

I would like to thank Joop Varekamp for 'encouraging' me to write these comments.

The Science of Volcanic Lakes - WWW Site

G. B. Pasternack,
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In the last ten years scientists, including many members of the Commission on Volcanic Lakes (CVL), have made significant strides in understanding how volcanic lakes work and how to use these lakes as windows into underlying volcanic processes. Despite this advance, information about volcanic lakes is only very slowly trickling down to the science community at-large and ultimately to the general public. While the results of more than one hundred volcanic lake studies have been successfully published in a range of traditional peer review journals, conference proceedings, government reports, and general readership science magazines, 53% of papers are concentrated into just two volcanology-oriented journals. Rarely do I find other earth scientists who know anything about volcanic lakes except that a lake somewhere in Africa exploded a few years back.

During the recent CVL meeting in Crater Lake, Oregon, members conversed about new options for broadening the educational outreach of the organization. Video documentaries, lake catalogs and picture books, databases, and internet information sites are specific examples of new approaches that were discussed. While any of these may be pursued by CVL members, the diversity of these media indicate that a multi media approach capable of transmitting video, text, data, and computer programs to an audience would be ideal. In fact such an approach is now possible via the World Wide Web (WWW) component of the internet. After the CVL meeting, a WWW site devoted to the science of volcanic lakes was established at Johns Hopkins University. The web address (URL) for the site is "http://jhunix.hcf.jhu.edu/~gpast/lakes.html" (not including the quote marks). The site is also reachable using most WWW search engines.

"The Science of Volcanic Lakes" web site is presently divided into 5 main sections. The first section is an introduction that lays out the subject matter in general terms that anyone can understand. The second section explains the scope of volcanic lake systematics using the process-based volcanic lake classification of Pasternack and Varekamp (in press). The third section is devoted to individual lakes. Ideally each lakes web page should have a description of the lake, a summary of research done on that lake, pictures or video, and links to other sites with more information on it. Keli Mutu (Indonesia) has the most extensive information because that is where I have worked, but the Crater Lake at Ruapehu, Crater Lake National Park (USA), and Lake Nyos (Cameroon) also have substantial information. Other lakes that are listed include Yugama Lake (Kusatsu-Shirane), Laguna Calientes (Poas), Taal Lake, El Chichon, Soufriere, and Sun and Moon Lakes (Nevado de Toluca). However, the information for these lakes is limited to that which is available through other web sites such as Volcano World (^Ahttp://volcano.und.nodak.edu^A). The fourth section of the web site is a space for on-line research summaries where scientists can report on new work that is in progress. The fifth section is a simple listing of web sites with related information that can be reached via a single click on the sites name.

So far the volcanic lake web page has received a lot of positive feedback from CVL members and web surfers at-large. One criticism has been the selection of links, particularly with respect to Lake Nyos. This problem reflects the best and worst of the WWW as a medium- anyone can put up material about any subject on their own web site, regardless of credentials. To alleviate this problem, a simple rating system has been initiated in which links with a good overview of a lake are marked with an orange symbol. Also, links with large, slow-loading pictures are marked with a distinct blue symbol. The alternative to this approach, leaving bad links with outdated, wrong, or slow-loading information off the site altogether, was decided against because people will find and peruse them anyway using WWW search engines. With the rating system we can show this information and bring out its faults directly, perhaps with forced links to rebuttals and the like.

Besides controlling the quality of content, the next biggest problem we face right now is a lack of material. In the near future a complete searchable bibliographical database will be added to the page with over two hundred papers and abstracts listed. This feature will be extremely useful for students and scientists who are looking into volcanic lakes for the first time. It will also showcase new listings so we can learn about new publications and where to find them more efficiently. Web surfers will have the ability to suggest additions to the bibliography in case they know of unlisted relevant publications. A second new feature that is coming is a "guestbook" in which visitors can make public comments about the page for future visitors to read and reply to. This will allow students to ask questions and engage in a public dialogue with interested volcanic lake researchers directly on the volcanic lake web site. In the longer term, there are plans to include lake video clips, animations of theorized lake processes, and interactive volcanic lake physical and chemical models.

The volcanic lake worldwide web site is off to a solid, promising beginning. Ultimately, the success of the site is dependent on the contributions of CVL members. All members of the volcanic lake research community are encouraged to submit research summaries, lake descriptions, pictures, data, web links, and other forms of content to be included in the site. Such contributions may be submitted via e-mail to gpast@jhu.edu. Together we can forge a multi media learning center that will help educate our fellow scientists and the public at large about these most exotic and unique phenomena.

Reference:

Pasternack, G. B. and Varekamp, J. C. in press. Volcanic lakes systematics I. physical constraints. *Bull. Volcanol.*

Guidelines for Authors

1. Submission - contributions should if possible be submitted in electronic form, either by e-mail or on a 3.5 inch disk in an IBM compatible format (MS-DOS or in a commonly used word processing format such as WordPerfect or Word) but ***not*** in Macintosh. Where electronic submission is not practicable contributions should be sent as camera-ready copy.

2. Format - the Newsletter is printed on A4 paper, copy should be prepared with this in mind and contributions should preferably be designed to occupy one or more full pages.

3. Layout - the title of the contribution should be followed by the name of the author and the author's full address.

4. Text - copy should be designed to be printed using a 10 point type face (these guidelines are printed in 10 point Times Roman). Camera-ready copy should be double spaced using any type face which clearly separates individual letters.

5. Tables - where appropriate small tables should be incorporated within the text. For preference, large tables should use the same type face as the text and, if possible, be prepared so that they can be read in the same orientation as the text.

6. Figures - line drawings should be in black on white and the lettering should be either 10 point or slightly larger. The text occupies an area which measures 160mm x 250mm - this also applies to figures so please design them accordingly. Please note that half tone illustrations cannot be printed. For preference figures should be submitted in PostScript format.

S.J.F.

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The end of Volcanic Lakes Newsletter No. 10.