# Report of a scientific mission to Japan

# 25 July to 11 August 2014


*By*

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***IRGM***

*August 2014*

**Outline of contents**

**List of Acronyms**

| | |
|---|---|
| AAS | Atomic Absorption Spectrometry |
| AIST | National Institute of Advanced Industrial Science and Technology (an institute of the Geological Survey of Japan) |
| AOGS | Asia Oceania Geosciences Society |
| CGMP | Cameroon Geochemical Mapping Project |
| GGBLTG | Global Geochemical Baseline Task Group |
| IAGC | International Association of Geochemistry |
| IGCP | International Geoscience Programme (formerly International Geological Correlation Programme) |
| IRGM | Institute of Geological and Mining Research (MINRESI) |
| IUGS | International Union of Geological Sciences |
| JICA | Japan International Cooperation Agency |
| JST | Japan Science and Technology Agency |
| MINRESI | Ministry of Scientific Research & Innovation |
| PDM | Project Design Matrix |
| SATREPS Ny-Mo | Science and Technology Research Partnership for Sustainable Development Nyos Monoun (Cameroon) Project |
| TIT | Tokyo Institute of Technology |

## 1 Introduction

During the 11th annual meeting of the Asia Oceania Geosciences Society (AOGS 2014), Prof. Takeshi Ohba of Tokai University and leader of the Cameroon – Japan SATREPS-NyMo project convened a session on '***Preventing limnic eruptions at Lakes Nyos and Monoun'.*** Within the framework of SATREPS-NyMo Project, Prof. T. Ohba invited two IRGM scientists, Mr. Djomou Bopda Serges Laurent (Assistant Researcher - AR) and Dr. Aka Festus Tongwa (Senior Researcher – MR) to take part in AOGS-2014. We thus undertook a scientific mission to Japan from the 25th of July to the 11th of August 2014, in order to:

(a) Participate in AOGS-2014 meeting that took place at the Royton Hotel in Sapporo (northern Japan) from the 28th of July to the 1st of August.

Mr. Djomou Bopda Serges Laurent

(b) Undertake training in Prof. Takeshi Ohba's laboratory at Tokai University (Japan) on the use of the Minoru Kusakabe (MK) method to quantify $CO_2$ in lakes;

Dr. Aka Festus Tongwa

(c) Visit Prof. Hasegawa of Ibaraki University to discuss Lake Nyos samples;
(d) Visit Prof. Yokoyama of Tokyo Institute of Technology (TIT) to discuss the on-going work of Mr. Asobo Elvis, SATREPS-NyMo PhD student at TIT;
(e) Visit Professors Asahara and Minami of Nagoya University to seek partnership for the Cameroon Geochemical Mapping Project.

This report gives the accomplishments of the mission. A separate report will be presented by Mr. Djomou Bopda Serges Laurent on his training at Tokai University.

## 2 Results

### 2.1 AOGS meeting in Sapporo

#### *2.1.1 Presentations*

On the afternoon of the 1st of August 2014, we and our Japanese counterparts and the SATREPS-NyMo PhD students in Japanese Universities animated AOGS-2014 session IG25 on '***Preventing limnic eruptions at Lakes Nyos and Monoun'.*** This session was convened by Prof. Takeshi Ohba, leader of the SATREPS-NyMo Project. Altogether, 7 oral and 3 poster () presentations were made (see Fig. 1, Table 1 & Appendixes 1 to III).

***Session: IG25***

***Topic: Preventing limnic eruptions at Lakes Nyos and Monoun (1 August 2014)***

***Convener: Prof. Takeshi OHBA (Tokai University Japan)***

*Table 1 Oral and poster presentations at AOGS – 2014 in Saporro Japan*

| N° | Presenter | Code | Title |
|---|---|---|---|
| 1 | Minoru KUSAKABE *(Invited Oral)* | IG25-D5-PM2-EB001 | Measures to prevent the recurrence of limnic eruption at Lakes Nyos and Monoun (Cameroon) |
| 2 | Festus Tongwa AKA *(Invited Oral)* | IG25-D5-PM2-EB002 | Preventing limnic eruptions in Lakes Nyos and Monoun within the framework of disaster governance, resilience and preparedness in Cameroon |
| 3 | Takeshi OHBA *(Oral)* | IG25-D5-PM2-EB003 | Temporal variation (2011-2014) of the amount of $CO_2$ dissolved in Lakes Nyos and Monoun, Cameroon |
| 4 | Issa ISSA *(Oral)* | IG25-D5-PM2-EB004 | Geochemistry of soil gas from Mount Manenguba Caldera, Cameroon Volcanic Line (CVL): Towards multipararmetric volcanic activities surveillance along the Cameroon Volcanic Line (CVL), West-Africa |
| 5 | Yosuo MIYABUCHI *(Oral)* | IG25-D5-PM2-EB005 | Pyroclastic sequence in and around Lake Nyos, north-western Cameroon |
| 6 | Asobo NE ASAAH *(Poster)* | IG25-D4-PM2-P006 | Geochemistry of volcanic rocks in Lakes Nyos and Monoun, including other lakes of the Oku Volcanic Group (OVG) on the Cameroon Volcanic Line |
| 7 | Kazuto SAIKI *(Poster)* | IG25-D4-PM2-P007 | Development of the Measuring Method of Dissolved $CO_2$ Concentration in Cameroonian Volcanic Lakes using Sound Velocity of Lake Water |
| 8 | Serges L. DJOMOU *(Poster)* | IG25-D4-PM2-P008 | Preliminary results from the Lakes Nyos and Monoun climate stations |
| 9 | Gregory TANYILEKE *(Poster)** | IG25-D4-PM2-P-009 | Results of phase I of the Lake Nyos dam reinforcement |

**Abstract published (see Appendix I) but poster not presented (so not shown in Appendix III)*

***Session HS1***

***Topic: Impacts, responses and risks on water recourses management (28 July 2014)***

| N$^o$ | Presenter | Code | Title |
|---|---|---|---|
| 10 | Mengnjo Jude Wirmvem (oral) | HS14-D1-PM1-CR005 | Hydrochemical and isotopic characteristics of groundwater in the Ndop plain, North West Cameroon: Resilience to seasonal climatic changes |

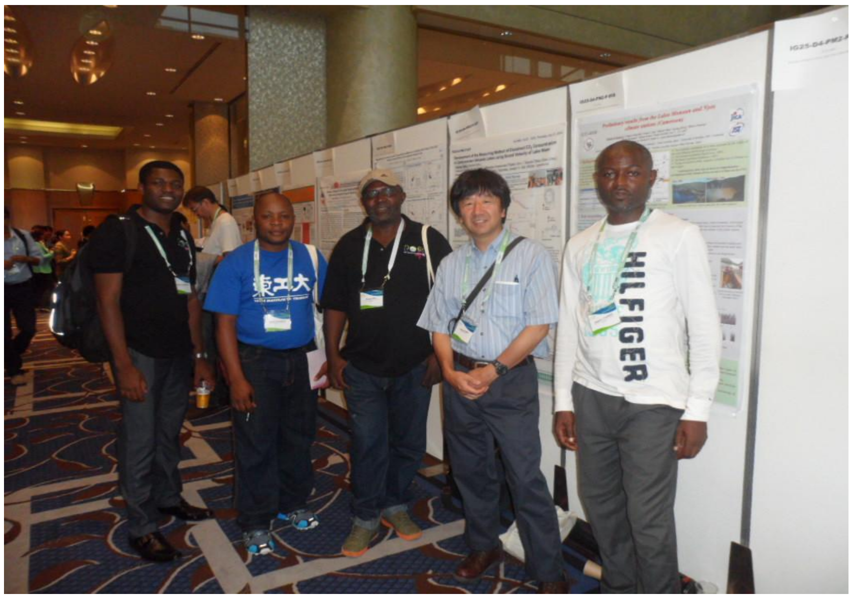

*Fig. 1 Poster session at the AOGS – 2014 meeting. L-R: Jude, Asobo, Aka, Ohba and Djomou*

## *2.2* Meeting of the SATREPS-NyMo Project volcanology group

On the morning of Friday 1st of August 2014, members of the volcanology group of SATREPS-Ny-Mo project who were attending the AOGS-2014 conference held a meeting at Royton Hotel where the conference was taking place. Present at the meeting were (Fig. 2):
Prof. Takeshi Ohba (Tokai University, Japan)
Prof. Minoru Kusakabe (Toyama University, Japan)
Prof. Yasuo Miyabuchi (Kumamoto University, Japan)
Prof. Takeshi Hasegawa (Ibaraki University, Japan)
Dr. Seigo Ooki (Tokai University, Japan)
Dr. Aka Festus (IRGM, Cameroon)
Prof. Tetsuo Kobayashi of Kagoshima University was scheduled to be at the meeting but he was unavoidably absent.

Table 2 shows the SATREPS Ny-Mo Project Design Matrix (PDM) output number 7 (magmatism of Oku volcanic zone & eruptive mechanism of Lake Barombi Mbo are understood). It can be seen that of the 3 activities of this output, activities 7.1 (Asobo PhD at TIT, Japan) and 7.3 (Chako PhD at Tokai University, Japan) are in good progress. Indicators of this are:

- Journal papers published by these 2 students (see references), and
- Their PhD theses work that are nearing completion (see below).

Activity 7.2 that concerns the geological maps of Lakes Nyos and Monoun areas have not had much progress after 3 fieldtrips by the volcanology group members.

It is with this background that the above meeting was held so as to:

- Evaluate how to realize some of the 6 indicators (see Table 2) of activity 7.2;
- Plan for the next fieldtrip in Cameroon by the volcanology group.

It was agreed as follows:

*Fig. 2 Meeting of some members of the SATREPS Ny-Mo project volcanology group (Royton Hotel Sapporo, 01 Aug 2014). L-R: Miyabuchi, Aka, Kusakabe, Ohba & Hasegawa. (Photo by Ooki)*

*Table 2 Output 7of the SATREPS Ny-Mo project design matrix (PDM)*

| Output number | Output Title | Activities | Objectively verifiable indicators |
|---|---|---|---|
| 7 | Magmatism of Oku volcanic zone & eruptive mechanism of Lake Barombi Mbo are understood | 7.1 Geological and petrochemical survey of rocks from Oku volcanic zone | 7.1.1) PhD thesis (petrogenesis of Oku volcanic zone)<br>7.1.2) Scientific journal papers<br>(Asobo PhD at TIT) |
| | | 7.2 Geological maps of the Lakes Nyos and Monoun areas are produced | 7.2.1) 1/25000 scale geological map of Lake Nyos area<br>7.2.2) Explanatory note for the 1/25000 scale geological map of Lake Nyos area<br>7.2.3) Scientific journal papers on lake Nyos plumbing system<br>7.2.4) 1/25000 scale geological map around Lake Monoun area<br>7.2.5) Explanatory note for the 1/25000 scale geological map of Lake Monoun area<br>7.2.6) Scientific journal papers on lake Monoun plumbing system |
| | | 7.3 Eruptive mechanism & hazard implications of Lake Barombi mbo are understood | 7.3.1) PhD thesis (lithostratigraphy & formation age of Lake Barombi mbo)<br>7.3.2) Scientific journal papers on Lake Barombi mbo<br>(Chako PhD at Tokai Univ.) |

1. At least 4 scientific papers will be prepared for Lakes Nyos and Monoun as follows:
   i) 1 paper on the petrology of Lake Nyos focusing on the newly discovered dikes;
   ii) 1 paper on the chemostratigraphy to elucidate the plumbing of lake Nyos
   iii) 1 paper on the eruptive history of Lake Nyos
   iv) 1 paper on the age of lake Monoun

For (i) above, both the geochemical and age data of the dikes need to be generated.

For (ii) above, geochemical data needs to be generated for the March 2014 samples.
For (iii) above, more data to be collected during the next field trip (see below) for the construction of an isopach map of Lake Nyos.

2. At least 2 of the above papers shall be ready for submission by December 2014, possibly to the Geological Society of London special publication;

3. Geological maps of Lakes Nyos and Monoun have to be produced using SATREPS Ny-Mo project counterpart funds provided by the Cameroonian side.

4. Since it is difficult to use conventional (K-Ar) methods to date Lake Monoun due to abundant granitic xenocrysts likely to carry exogenous argon, we have to think of a different dating method. On this vain, Dr. Aka was asked to discuss the use of U-Th disequilibria method with Prof. Yokoyama of TIT (see below).

5. For the next fieldtrip to Lake Nyos, the Japanese team arrives Cameroon on 26 December 2014, and leaves on the 4$^{th}$ of January 2015.

### *2.3* Visit to Prof. Nakano in Kyoto

My initial schedule approved by Prof. Ohba included a visit on Sunday 3$^{rd}$ August to Prof. Nakano at the Research Institute of Humanity and Nature in Kyoto. However, on the eve of the visit, Prof. Nakano sent a mail postponing the meeting to a later date in the near future.

### *2.4* Visit to Profs. Asahara & Minami of Nagoya University

#### 2.4.1 Reason for the visit - the Cameroon Geochemical Mapping Project

Within the framework of the SATREPS Ny-Mo Project, the Japan Science and Technology Agency (JST) has donated scientific equipment to IRGM (Cameroon), including:

- Picarro L2012-i water isotope analyzer,
- Milli-Q Direct 8 pure water maker,
- ICS-1100 ion chromatograph
- Analytikjena contrAA300 Atomic Absorption Spectrometer

We intend to use this equipment to establish a geochemical baseline map for Cameroon during which data and maps will be generated to document the concentration, distribution and significance of chemical elements and species in the near-surface environment of Cameroon that can be used for:

(i) Mineral exploration
(ii) Resource evaluation

(iii) Land use management
(iv) Environmental policy development, and
(v) Studies of the health and well-being of humans, animals and plants.

In this project, we will collect and analyze samples from the following sampling media:

- Soils
- Stream water
- Ground and surface waters
- Stream sediments, and (where possible)
- Off-shore marine and estuarine sediment in the coastal zones

This will be done according to the standards established by the Global Geochemical Baseline Task Group (GGBLTG) of the International Association of Geochemistry (IAGC) under the International Union of Geological Sciences (IUGS) (Darnley et al. 1995).

We would like to cooperate and draw from the experience and expertise that Japanese scientists have gained in Japan and other countries on geochemical baseline mapping regarding:

(i) Sampling equipment
(ii) Sampling methods
(iii) Field sample treatment
(iv) Laboratory sample preparation
(v) Sample analysis
(vi) Generation of geochemical baseline maps and geochemical atlases

*Fig.3 (Left): Prof. Asahara in his office with some stream sediment sampling equipment. (Right): Group photo with Prof. Masayo Minami (left) in her office.*

### 2.4.2 Results of the discussions at Nagoya University

I had very fruitful discussions with Profs. Yoshihiro Asahara and Masayo Minami (Monday 4th August 2014) regarding the geochemical mapping project. They were very interested in the project and it was:

- Suggested that Prof. Yoshihiro Asahara will contact Prof. Atsuyuki Ohta at the Geological Survey of Japan National Institute of Advanced Industrial Science and Technology (AIST) for cooperation. This group has done a lot of work on geochemical mapping in Japan (see Appendix IV)
- Profs. Asahara and Minami could visit Cameroon in 2015 for appraisal of the situation on the ground and some preliminary sampling.
- Since we already have a majority of analytical equipment (pure water maker, ion chromatograph and atomic absorption spectrometer), Prof. Asahara promised that he could set up a system in our laboratory (IRGM) to digest solid samples for analyses, and then train Cameroonian students/researchers on the use of such a system.

### 2.4.3 Immediate future plans regarding the CGM P

The Director of the Institute for Geological and Mining Research (IRGM) approves of the discussions as above and recommends that a full fledge project (with budget, collaborators, time lines etc) be provided and submitted (by IRGM) to the Ministry of Scientific Research and Innovation (MINRESI) for appraisal. This will be done in the coming months. In this way, a research convention can be signed between the Cameroonian side and our Japanese partners to carry out the Cameroon Geochemical Mapping Project for resource evaluation.

## 2.5 Visit to Prof. Yokoyama of Tokyo Institute of Technology (TIT)

On Tuesday 5th August 2014, I paid a visit to Prof. Tetsuya Yokoyama of TIT to discuss progress and the PhD work of Mr. Asobo (SATREPS Ny-Mo sponsored student) and also the possibility of carrying out U-Th series analysis on Lake Monoun samples to estimate the relative age of this maar (see indicators 7.2.4 to 7.2.6 in table 2).

### 2.5.1 PhD thesis pre-defense of Asobo at TIT

The PhD work of Mr. Asobo (petrogenesis of rocks from the Oku volcanic group) is going well. He has already published a referred scientific paper (see list of references), submitted 1 other manuscript and is programmed to do a pre-defense sometime between December 24th and 27th 2014. As an examiner of this thesis, I will be present at the pre-defense on the invitation of TIT Japan.

### 2.5.2 U-Th series analysis of Lake Monoun samples

Prof. Tetsuya Yokoyama accepted to carry out U-Th series analysis on Lake Monoun samples if appropriate samples are collected and the necessary sample pre-treatment done. We are looking at the possibility of collecting the samples during the December 2014 fieldtrip.

## 2.6 Visit to Prof. Ohba in Tokai University

On Wednesday 6th August 2014, I visited Prof. Takeshi Ohba (leader of the SATREPS Ny-Mo Project) at Tokai University to brief him on my activities so far, and also to discuss the PhD work of Mr. Chako.

### 2.6.1 Briefing report on my activities

I gave an account (Fig. 4) of my visits to Nagoya University and TIT and discussed my visit to Ibaraki.

*Fig. 4 Discussion with Prof. Ohba in his Tokai University office (6 August 2014)*

### 2.6.2 PhD thesis of Chako Boris

Prof. Ohba and I discussed the PhD work (lithostratigraphy of Barombi mbo maar) of Mr. Chako Boris at Tokai University. The candidate has already published a referred scientific paper (see list of references) and is programmed to do a pre-defense soon. Given my contribution to this work (teaching the candidate how to collect and label good samples on the field, sending him relevant literature, suggestions on dating and chemical analysis of some of his samples, detailed review of his manuscripts, supply of working templates to him, etc) I expressed the need for me to be mentioned in the thesis as a co-supervisor as was agreed before the start of the thesis. Tokai University, Prof. Ohba and the candidate have accepted this genuine request. I am now proof-reading the thesis.

## 2.7 Visit to Prof. Hasegawa in Ibaraki University

I visited Prof. Takeshi Hasegawa's laboratory in the Graduate School of Science and Engineering, Ibaraki University, from the 6th to the 10th of August 2014, and had discussions with him and Prof. Akihiko Fujinawa. This is a fully equipped petrological laboratory in which analyses spanning individual mineral compositions, and major & trace elements can be carried out.

### 2.7.1 Analysis of Lake Nyos samples collected in March 2014

During the March 2014 fieldtrip, 63 rock samples were collected from and around Lake Nyos. These included samples from 2 (newly discovered) dikes that intrude the granite on the northwest wall of the lake. We agreed that the dikes will be analyzed to prepare a manuscript for submission in December 2014. Arrangements have to be made to run isotopic analyses of the dike samples elsewhere.

### 2.7.2 Tour of Ibaraki University petrological laboratory

During a guided tour of the petrological laboratory, I was struck by their sample storage system. As shown in Fig. 5, such a system is recommended for storing samples in IRGM where it is presently highly needed

*Fig. 5 Rock sample storage system of the petrological laboratory of Ibaraki University*

### 2.7.3 Articles downloaded in Prof. Hasegawa's laboratory

I had access in the laboratory to Ibaraki University online library, and this gave me the opportunity to browse recent work published in my field of research (water/gas geochemistry, volcanology, geohazards) for Cameroon and other parts of the world. In all, I downloaded 635 relevant articles from 5 journals (Table 3).

*Table 3 Articles downloaded from Ibaraki University online library*

| N$^o$ | Journal name | No. articles downloaded |
|---|---|---|
| 1 | Applied Geochemistry | 118 |
| 2 | Chemical Geology | 73 |
| 3 | Earth and Planetary Science Letters | 179 |
| 4 | Journal of African Earth Sciences | 121 |
| 5 | Journal of Volcanology and Geothermal Research | 144 |
| **Total** | | **635** |

## 3. Conclusions and recommendations

(i) During the 11th annual meeting of the Asia Oceania Geosciences Society (AOGS 2014) that held in Japan from 28th of July to the 1st August 2014, Prof. Takeshi Ohba, leader of the SATREPS Ny-Mo project convened a session on '***Preventing limnic eruptions at Lakes Nyos and Monoun'***. Two IRGM scientists - Djomou Bobda Serges Laurent and Aka Festus Tongwa attended the AOGS-2014 meeting. Current results of the SATREPS Ny-Mo project including 7 oral and 3 poster presentations were given at the meeting by the project group members.

(ii) The volcanology group members of the SATREPS Ny-Mo project met during the AOGS-2014 meeting and agreed to speed up work on the volcanology of Lakes Nyos and Monoun (mapping & geological history - activity 7.2 of the PDM). At least 2 manuscripts, including one on the newly discovered dikes in Lake Nyos, shall be ready for submission by December 2014. Analysis of the rock samples will be done in Ibaraki University. The Japanese volcanology team arrives Cameroon on 26 December 2014 for the next fieldtrip to Lake Nyos, and leaves on the 4th of January 2015. To be able to have a first sketch of the geological map of Lake Nyos area, it is recommended that Cameroonian researchers remain in the field for another one week after the Japanese team leaves. We can use the U-Th series method to date Lake Monoun. Prof. Tetsuya Yokoyama will do the U-Th series analysis in his laboratory at TIT if appropriate samples are collected.

(iii) The work of SATREPS Ny-Mo PhD students at TIT (Asobo) and Tokai University (Chako) is going well. They have each published a referred paper and will soon do the pre-defence of their thesis. Dr. Aka Festus is co-supervisor for Chako's thesis and will visit TIT in December 2014 as an examiner for the pre-defence of Asobo's thesis.

(iv) Researchers in Nagoya University are willing to share their experience and expertise in our Cameroon Geochemical Mapping Project, and will seek further collaboration for the project from the Geological Survey of Japan. Since IRGM already has most of the analytical equipment in place, they are ready (Prof. Asahara) to set up a system in our laboratory to digest solid samples (soil & sediments) for analyses, and then train Cameroonian students/researchers on the use of such a system. Nagoya University researchers could visit Cameroon in 2015, before which date, the full Cameroon Geochemical Mapping Project will have been submitted to IRGM/MINRESI.

**Acknowledgments**
Our trip to Japan was approved and funded within the framework of the SATREPS Ny-Mo Cameroon - Japan cooperation project (IRGM – JICA – JST – Tokai University). We are thankful to Ms. Aya Inaba (Japanese administrative coordinator of the project in the Yaoundé JICA office) for her travel arrangements. Prof. Takeshi Ohba was the convener of the AOGS-2014 IG25 session and approved our schedule in Japan during the trip. The assistance and hospitality of Dr. Ooki & Mr. Yu (Tokai University), Profs. Asahara & Minami (Nagoya University) and Prof. Hasegawa & Fujinawa (Ibaraki University) are heartily acknowledged. We thank Dr. Tanyileke (SATREPS Ny-Mo project coordinator) and Dr. Hell (Director of IRGM) for their cooperation.

**Biblography**

Asaah, E.N.A., Yokoyama, T., Aka F.T., Usui, T., Wirmvem, J.M., Chako Tchamabe, B., Ohba, T., Tanyileke, G., Hell, J.V. (2014). A comparative review of petrogenetic processes beneath the Cameroon Volcanic Line: Geochemical constraints. Geoscience Frontiers, Doi; 10.1016/j.gsf.2014.04.012.

Chako Tchamabe B., Youmen D., Owona S., Issa, Ohaba T., Németh K., Ngapna M. N., Asaah, E.N.A., Aka F. T., Tanyileke G. (2013). Eruptive history of the Barombi Mbo Maar, Cameroon Volcanic Line, Central Africa: Constraints from volcanic facies analysis. Central European Journal of Geosciences 5(4) 480-496.

Darnley A. G et al. 1995. A Global Geochemical Database for Environmental and Resource Management: Recommendations for International Geochemical Mapping. Final Report of IGCP Project 259. Earth Sciences 19, UNESCO, Paris

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## Oral Presentations

**IG25 - Prevention of the Next Liminic Eruption at Lake Nyos and Monoun**
Friday, August 01, 2014 | Emerald Hall B | 16:00-18:00

1. **IG25-D5-PM2-EB-001** (IG25-A001)

### Measures to Prevent the Recurrence of Limnic Eruptions at Lakes Nyos and Monoun (Cameroon)

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The Lakes Nyos and Monoun (Cameroon) gas disasters in the mid-1980s claimed ~1800 casualties . The disasters received worldwide attention due to their uniqueness (preventable). Follow-up investigations revealed gradual and steady accumulation of magmatic CO2 in deep layers of these crater lakes . This led to sudden gas releases , called "limnic eruption". The steady gas input to the lakes after the catastrophes indicated the recurrence of similar events in the future if no preventive measures were taken. Artificial degassing of the lakes using a gas self-lifting technique that launched in early 2000s as an international project has worked well. At Lake Monoun the gas concentration in bottom water became too low to sustain the gas self-lift in 2009, resulting in cessation of gas fountaining. Based on this observation the Cameroonian Government declared the lake inoffensive in 2011. However, recent field surveys indicate resumption of gas build-up. Although the amount of gas revived was far below a risky level, resumption of gas buildup indicates the need for continuous monitoring of the lake. The same situation is expected at Lake Nyos within several years when it loses the gas self-lift capability . As such, the continuous monitoring of these lakes coupled with an in-depth geochemical understanding of the CO2 supply system beneath the lakes is going on as an activity under a JICA-JST sponsored project "Science and Technology Research Partnership for Sustainable Development (SATREPS), 2011-2016". Our SATREPS entitled "Magmatic Fluid Supply into Lakes Nyos and Monoun, and Mitigation of Natural Disasters through Capacity Building in Cameroon" is salutary . The essence of the project is capacity building in Cameroon, through measures to prevent the recurrence of limnic eruptions and actions by Cameroonians (independent of foreign support) to ensure the safe return of the survivors the Lake Nyos disaster to their homeland.

2. **IG25-D5-PM2-EB-002** (IG25-A002)

### Preventing Limnic Eruptions in Lakes Nyos and Monoun within the Framework of Disaster Governance, Resilience and Preparedness in Cameroon

Festus AKA1#+, Buh-Wung GASTON2, Issa ISSA3, Wilson Yetoh FANTONG1, Takeshi OHBA3, Minoru KUSAKABE4, Gregory TANYILEKE1, Joseph Victor HELL1
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The first world conference on disaster risk reduction held in Hyogo, Japan in 2005, in which 168 countries , committed themselves to take action before 2015 to reduce human and socio-economic disaster losses , what became known as the Hyogo Framework of Action (HFA). The United Nations Global Network for Disaster Reduction monitors national, regional and global progress towards attainment of goals of the HFA (UNISDR, 2011). This monitoring is done via its program called Views From the Frontline (VFL), the main goal of which is to support effective frontline implementation of the HFA to build the resilience of vulnerable people and communities at-risk to disasters . VFL has carried out 3 projects in the world to measure the level of progress in the implementation of HFA.

We conducted the 2011 and 2013 VFL surveys in Cameroon. In 2011, questionnaires of local governance indicators on disaster risk reduction were administerd in seven of the ten Regions , including the west and northwest that suffered devastating limnic gas explosions . In the 2013 survey questionaires were designed to probe frontliners ' views on everyday disasters , community resilience and disaster preparedness as an integral part of the UN poverty reduction strategy (UNISDR 2011).

We examine and attempt to explain the observed variations in the experiences of people on the frontline in 7 regions of Cameroon, with respect to how resilient their communities have become against natural disasters . Views observed in Cameroon in these surveys are compared with views from other West African countries and with the global average. Our results allow us to argue that for Cameroon to attain the main goals of the HFA by 2015 (which is directly linked to her becoming an emerging nation by the year 2035), she has to seriously consider mainstreaming disaster risk reduction into her short-term development program.

3. **IG25-D5-PM2-EB-003** (IG25-A003)

### Temporal Variation (2011-2013) of the Amount of CO2 Dissolved in Lakes Nyos and Monoun, Cameroon

Takeshi OHBA1#+, Issa ISSA1, Minoru KUSAKABE2, Yutaka YOSHIDA3, Akira UEDA2, Katsuro ANAZAWA4, Kazuto SAIKI5, Katsuya KANEKO6, Yasuo MIYABUCHI7, Festus AKA8, Wilson Yetoh FANTONG8, Gregory TANYILEKE8, Joseph Victor HELL8
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Introduction
In 1984 and 1986, abrupt discharges of CO2 gas (=limnic eruption) happened at Lakes Monoun and Nyos , respectively , killed 37 and 1746 of people living near the lakes . To prevent a recurrence of limnic eruption, the first degassing pipe was installed at Lake Monoun in 2003, and two additional pipes were installed in 2006. As a result, the lake was almost free of dissolved CO2 by 2009, and the degassing pipes lost their gas self-lifting capability . At Lake Nyos , one degassing pipe was constructed in 2001. Two additional pipes were constructed in 2011, accelerating the removal of CO2 gas . We observed the both lakes in 2011, 2012 and 2013 to estimate the CO2 amount left in the lakes .

Observation
We have estimated the CO2 amount in the lakes by a combination of two different methods . One is a kind of chemical analysis based on volumetric titration. We also obtained the temperature, pH and conductivity profile by use of CTD. Assuming the chemical equilibrium among CO2_aq, HCO3- and CO3–, we estimated the total CO2. Combining the above methods , we obtained a reliable profile of total CO2 along the depth, allowing the calculation of the total amount of CO2 in lake

water.

Result
The total $CO_2$ amount in the eastern basin of Lake Monoun was 101, 118 and 119 Mmol in 2011, 2012 and 2013, respectively, indicating a slight buildup of $CO_2$. The total $CO_2$ amount in Lake Nyos was 8.9, 7.8 and 6.5 Gmol, in 2011, 2012 and 2013, respectively. Although the decreasing rate of $CO_2$ amount in Lake Nyos is steady, the amount is as much as the half of it in 1998, when the amount was maximized after the liminic eruption in 1986 (Kusakabe et al. 2008).

4. **IG25-D5-PM2-EB-004** (IG25-A006)

### Geochemistry of Soil Gas from Mount Manenguba Cadera, Cameroon Volcanic Line (CVL)

Issa ISSA1#+, Takeshi OHBA1, Wilson Yetoh FANTONG2, Padron ELEAZAR3,4, Festus AKA2, Seigo OOKI1, Yutaka YOSHIDA5, Pedro HERNANDEZ3, Kuitcha DORIS2, Fouepe ALAIN2, Minoru KUSAKABE6, Boris CHAKO TCHAMABE1, Sighomnou DANIEL7, Gregory TANYILEKE2, Sigha NKAMDJOU2
*1 Tokai University, Japan, 2 Institute of Geological and Mining Research, Cameroon 3 Environmental Research Division, ITER, Spain 4 Volcanology Institute of the Canaries (INVOLCAN), Spain 5 Yoshida Consulting Engineer Office, Japan 6 University of Toyama, Japan 7 World Meteorological Organization, Switzerland*
*# Corresponding author: midissa17@yahoo.fr +Presenter*

This study reports the first results of diffuse gas survey from Mount Manenguba volcano caldera carried from December 2013 to January 2014. The total output from the caldera was estimated at 26.9 t.d-1 for the about 38.5ha area that had been surveyed. Extrapolating to the whole caldera (8.2km2) would yield 573t.d-1. Judging from the mean δ13C(CO2)=-8.6 ‰ vs PDB (-12.2 ‰ to -6.6 ‰) and the associated He with mean ∆He=332ppb (∆He=HeSoil-HeAtm), the soil $CO_2$ originates dominantly from magma with very small biogenic contribution. Argon isotopic ratio (mean 40Ar/36Ar=297) indicates little mantelic and/or crustal contribution. Nitrogen/36Ar points to an atmospheric source for the N2 in the soil gas although a small contribution from biogenic /organic is possible, especially from manure, since the place is known to host important cattle rearing activities. Based on a flux -soil temperature relationship, the soil gas emission is controlled by diffusion (instead of convection). The nature of the soil seems to play important role in the diffusion process.

5. **IG25-D5-PM2-EB-005** (IG25-A007)

### Pyroclastic Sequence in and Around Lake Nyos, Northwestern Cameroon

Yasuo MIYABUCHI1#+, Kobayashi TETSUO2, Takeshi HASEGAWA3, Katsuya KANEKO4, Festus AKA5, Takeshi OHBA6, Minoru KUSAKABE7, Gregory TANYILEKE5, Joseph Victor HELL5
*1 Kumamoto University, Japan, 2 Kagoshima University, Japan 3 Ibaraki University, Japan 4 Kyoto University, Japan 5 Institute of Geological and Mining Research, Cameroon 6 Tokai University, Japan 7 University of Toyama, Japan*
*# Corresponding author: miyabuchi@earth.email.ne.jp +Presenter*

Lake Nyos, which is a maar lake volcano in northwestern Cameroon, exploded in August 1986, releasing a large amount of $CO_2$ that killed about 1800 people and over 3000 cattle. Since steady input of gas to the lake after the disaster implied recurrence of a similar event in the future, artificial degassing of the lake started in 2001 as an international project. However, a large amount of $CO_2$ still remains in the lake, and a risk of further abrupt discharges of $CO_2$ gas (limnic eruptions) persists. We performed fieldwork in and around Lake Nyos to clarify an eruptive history of the Nyos maar volcano. The eruptive history and formation process of the maar provide valuable information for predicting future volcanic activity including limnic eruptions and hazard assessment around the maar volcano. We found that pyroclastic deposits derived from the eruption of the volcano directly overlie the Pan-African quartz monzonite basement rock. The deposits can be divided into lower scoria-fall deposits and upper pyroclastic -surge deposits. The scoria-fall deposits are recognized at the eastern to northeastern lakeshores. They include a homogeneous lava flow. The pyroclastic -surge deposits overlying scoria-fall deposits occur at the northern to eastern lakeshores, and are well-stratified and thickest of all the pyroclastic deposits. The pyroclastic sequence suggests that a series of eruptive events that formed the Lake Nyos maar started with a strombolian activity that produced scoria-fall deposits and lava flow, and was followed by explosive eruptions discharging multiple pyroclastic surges.

## Poster Presentations

**IG25-D4-PM2-P-006** (IG25-A004)

### Geochemistry of Volcanic Rocks in Lakes Nyos and Monoun, Including Other Lakes of the Oku Volcanic Group (OVG) on the Cameroon Volcanic Line

Asobo N.E ASAAH1#+, Tetsuya YOKOYAMA1, Festus AKA2, Mengnjo Jude WIRMVEM3, Boris CHAKO TCHAMABE3, Takeshi OHBA3, Gregory TANYILEKE2
*1 Tokyo Institute of Technology, Japan, 2 Institute of Geological and Mining Research, Cameroon 3 Tokai University, Japan*
*#Corresponding author: asoboasaah@gmail.com +Presenter*

The historical limnic eruptions of Lakes Monoun (1984) and Nyos (1984) alerted the international scientific community of the highly unrecognized potential natural hazards posed by volcanic lakes that trap and accumulate gas in their bottoms. Lakes Nyos and Monoun are two of the over 35 crater lakes located on the Cameroon Volcanic Line (CVL), West Africa. Numerous studies have suggested that the $CO_2$ gas that exsolved from these lakes and killed over 1800 people in the 1980s is of magmatic origin, with potentials of more explosions in the future if nothing is done. An artificial degassing process in the lakes started in 2001. Even though the $CO_2$ is of magmatic origin, little information exists on the geochemistry of the volcanic rocks around these maar lakes. Knowledge on the chemical composition of these rocks has a direct bearing on the nature of the mantle that underlies them, and may hold clues on why the mantle is $CO_2$-rich.

Twenty volcanic rocks were collected from 4 maar lakes in the OVG (8 from Nyos, 6 from Elum, 2 from Wum, and 4 from Oku). Samples were analyzed for major elements (XRF), trace elements (ICP-MS) and Sr-Nd-Pb isotopes (TIMS). The samples are basanites, basalts and trachybasalts, with magnesium number that range from 43 to 62. Lakes Nyos, Elum, and Wum are geochemically similar. Primitive mantle normalized multi-element diagrams show relative enrichment of LILE, LREE and depletion in HREE, indicating the presence of garnet in the mantle source. Variations in K/Rb, Ce/Yb and decreasing ratios of Ba/Nb, K/Nb, with increasing La and Nb suggest the existence of hydrous mineral phases. Radiogenic (Sr-Nd-Pb) isotope systematics indicates the involvement of the depleted mantle, focus zone, and an enriched mantle component derived from the metasomatized subcontinental lithospheric mantle (SCLM) beneath OVG.

**IG25-D4-PM2-P-007** (IG25-A005)

### Development of the Measuring Method of Dissolved CO2 Concentration in Cameroonian Volcanic Lakes Using Sound Velocity of Lake Water

Kazuto SAIKI1#+, Katsuya KANEKO2, Mitsuhisa SANEMASA1, Takeshi OHBA3, Minoru KUSAKABE4, Gregory TANYILEKE5, Joseph Victor HELL5
*1 Osaka University, Japan, 2 Kyoto University, Japan 3 Tokai University, Japan 4 University of Toyama, Japan 5 Institute of Geological and Mining Research, Cameroon*
*# Corresponding author: ksaiki@ess.sci.osaka-u.ac.jp +Presenter*

Limnic eruptions in 1984 and 1986 at Lakes Monoun and Nyos in Cameroon were caused by sudden degassing of magmatic $CO_2$ dissolved in the lake water. The disasters killed about 1800 residents around the lakes. To prevent further disasters, monitoring of $CO_2$ in the lake waters is essential. For frequent measurement, we developed a convenient method of $CO_2$ monitoring using sound velocity (SV) as part of SATREPS project supported by JICA and JST.

To estimate dissolved $CO_2$ ($CO_2$(aq)) concentration, we assume the following formula $v_+ = k_1[CO_2(aq)] + k_2[HCO_3^-]$, where $v_+$ is a term additional to SV due to dissolved matter, and $k_1$ and $k_2$ are the empirical coefficients. The $k_1$ was determined by laboratory experiment. SV sensor, thermometer, and pressure sensor were placed in a cylindrical stainless vessel filled with pure water. Then, high-pressure $CO_2$ gas was injected into the vessel to produce carbonated water. The result indicated that $v_+$ is proportional to [$CO_2$ (aq)], and $k_1$ was determined as a temperature (T) dependent function. The $k_2$ was determined by field data and $k_1$. Depth profiles of SV, pressure, T, and electric conductivity of Lakes Nyos and Monoun were measured in March 2012. Using these data, the profiles of [$CO_2$] determined by the syringe method, and the correlation between [$HCO_3^-$] and electric conductivity (Kusakabe et al., 2008), $k_2$ was determined to be 0.091 at Lake Nyos and 0.067 at Lake Monoun.

The difference of $k_2$ would be caused by the difference of cation species in the water and the stability of $k_2$ would mainly determine the accuracy of SV method. The $k_2$ obtained from 2012 data gives [$CO_2$(aq)] within the accuracy of +-10 mmol/kg. We will make the same kind of survey at Lakes Nyos and Monoun in

March 2014 and report the change of $k_2$ value at the meeting.

**IG25-D4-PM2-P-008** (IG25-A008)

### Preliminary Results from the Lakes Monoun and Nyos Climate Stations

Serges L DJOMOU1#+, Gregory TANYILEKE1, Festus AKA1, Takeshi OHBA2, George KLING3, Wilson Yetoh FANTONG1, Minoru KUSAKABE4, William EVANS5, Yutaka YOSHIDA6, Issa ISSA2, Joseph Victor HELL1

*1 Institute of Geological and Mining Research, Cameroon, 2 Tokai University, Japan 3 University of Michigan, United States 4 University of Toyama, Japan 5 U.S. Geological Survey, United States 6 Yoshida Consulting Engineer Office, Japan*

*# Corresponding author: serges.djomou@yahoo.fr +Presenter*

The phenomenon of lake-overturn is a common feature of some of the 40 crater lakes along the Cameroon Line (CVL) independent of size and depth. The timing of reported events (peak dry or peak rainy season), suggest a possible role of climate in their trigger. For example the deadly explosions of Lakes Monoun and Nyos occurred in August 1984 and 1986 respectively while Manengouba-female lake overturned in February 1992 killing fish. Unfortunately , there has been no comprehensive investigation of this climate-driven overturn of lakes on the CVL. Within the framework of the SATREPS/IRGM project, two new climate stations were installed at lakes Nyos and Monoun. Each station records 8 parameters (air temperature, relative humidity , wind speed/direction, incoming/outgoing solar radiation, barometric pressure, and rainfall). Also measured are water temperature, conductivity , and total dissolved gas pressure at two depths in each lake. The first set of data recorded by these stations (from June 2012 for Nyos and January 2013 for Monoun) show similar daily patterns of air temperature, relative humidity , wind speed and barometric pressure. There is a quasi-absence of rainfall and a drop in temperature and humidity between mid-December and mid-February . This is due to low atmospheric pressure from mid-October. Similar behavior is observed on previous climate data from both lakes (1989 - 2006), and is linked to the movement of the Inter-Tropical Convergence Zone (ITCZ) that shapes the climate of the whole region. Surface waters of both lakes record this climate variation, becoming cold during the rainy season and even colder during the passage of the monsoon. The month of August records the highest rainfall intensity (35 mm in 20 minutes at Nyos ). Wind speeds (maximum of 7.51 m/s and 9.37 m/s for Monoun and Nyos respectively ) show no discernable trend. This preliminary analysis will be improved as the new stations record more data.

**IG25-D4-PM2-P-009** (IG25-A009)

### Results of Phase I of the Lake Nyos Dam Reinforcement

Gregory TANYILEKE#+, Joseph Victor HELL, Sigha NKAMDJOU, Romaric NTCHANTCHO, Serges L DJOMOU

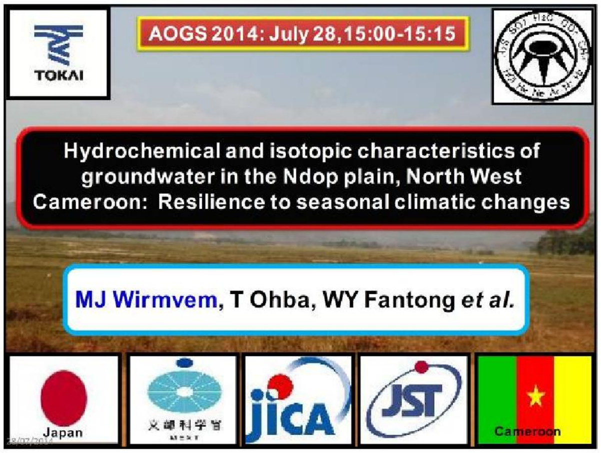
*Institute of Geological and Mining Research, Cameroon*

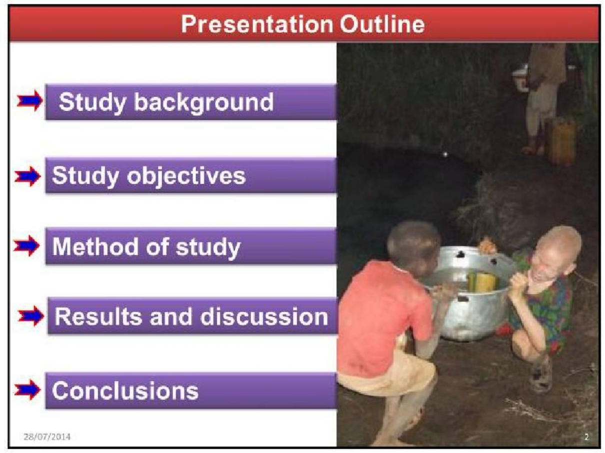
*# Corresponding author: gtanyileke@yahoo.co.uk +Presenter*

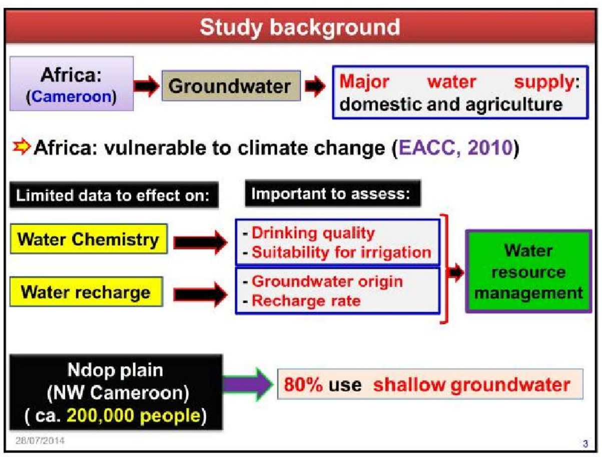
Lake Nyos is a huge freshwater resource but its security and that of nearby communities is threatened not only by the huge stock of $CO_2$ gas in its deep waters but also by the high potential of failure of the weak fragile natural dam at its outlet. Its collapse could result in the release of over 50 million m³ of water resulting in a major flood with severe damage to the environment and downstream communities as far away as neighbouring Nigeria. Geological, geotechnical, geophysical, topographical and bathymetric as well as hydrological studies suggested that this dam be reinforced by the jet-grouting technic so as to reduce infiltration and thus check erosion. The work plan entailed the construction of a 90 m long double screen impermeable wall of reinforced concrete down to the basement rock . Phase I of the work lasted from April 2012 to October 2013. The first screen made up of 130 pillars is 90m long while the second composed of 114 pillars is 80m long. Permeability measurements undertaken before work started varied from 10-7 to 10-4 m/s and from 10-8 to 10-7 m/s after the emplacement of the double screen wall.

To ensure effective follow up of the impermeable screen, 13 control piezometres were constructed on either side of the curtain wall. Phase 2 of this project which entails the construction of a concrete slap to check surface erosion and an overhead passage way for the population is yet to go operational; although the carrier beams (44) of the surface slap are already in place.

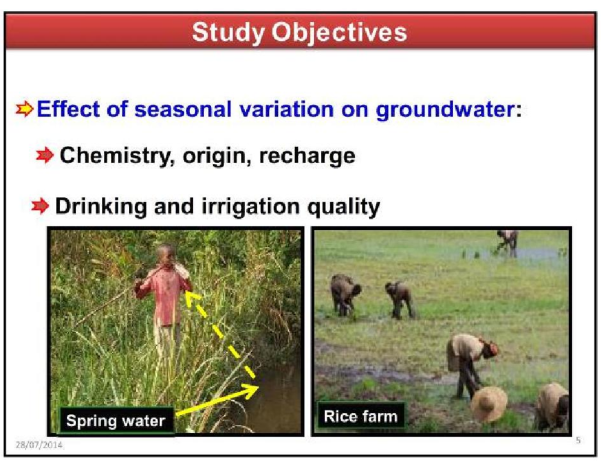
## Appendix II – Oral presentations at AOGS 2014

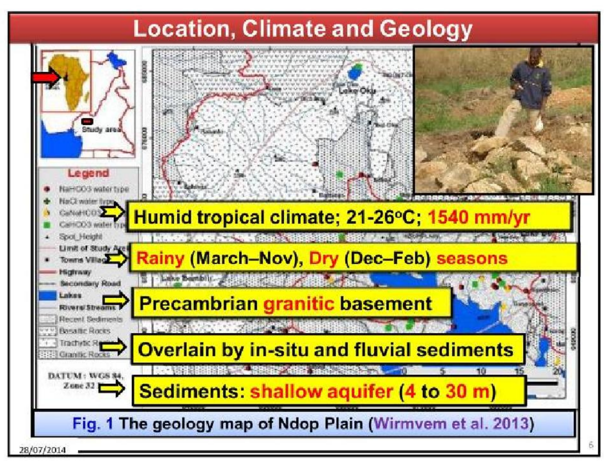


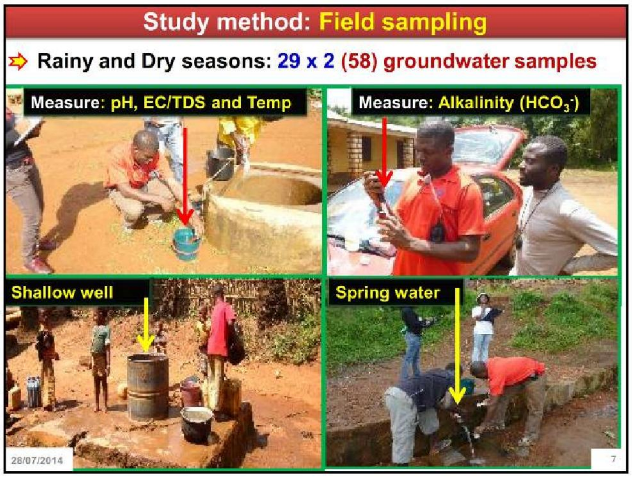



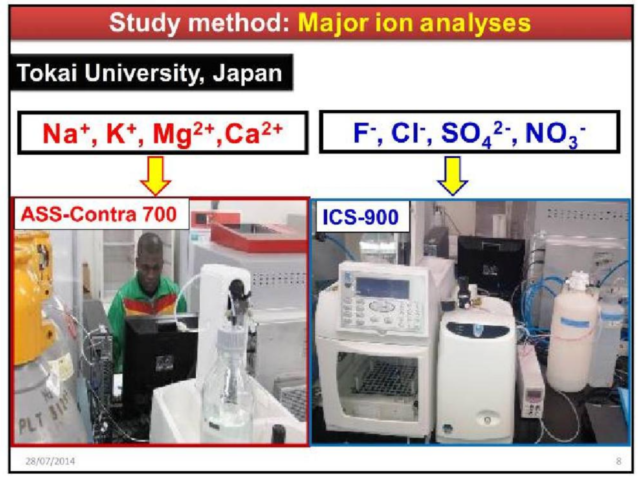



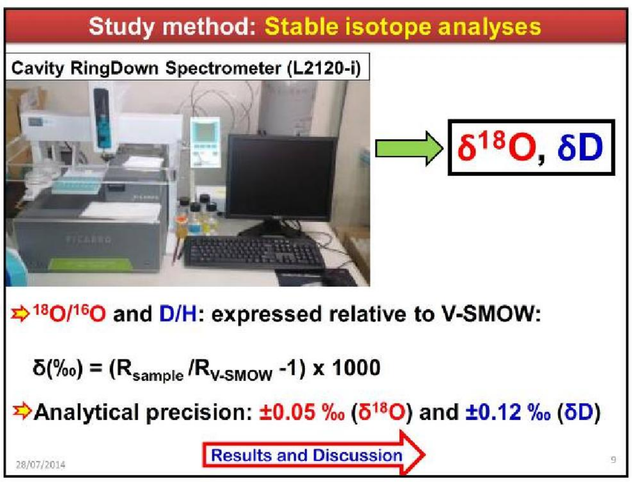


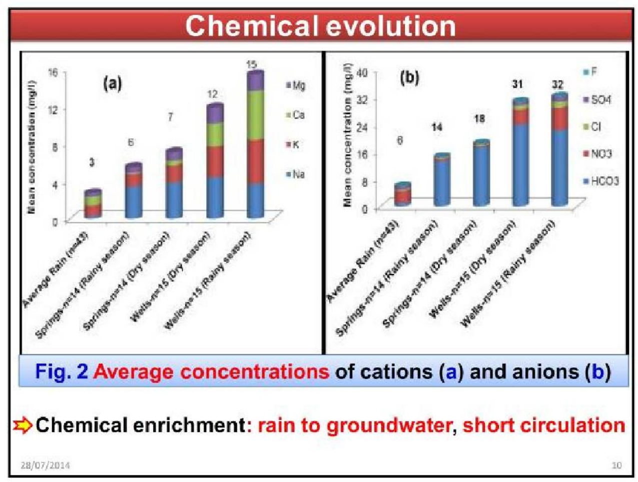


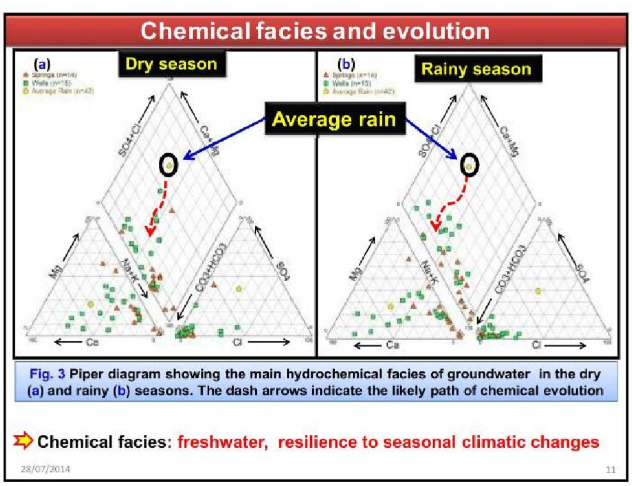




Study method: Field sampling
Rainy and Dry seasons: 29 x 2 (58) groundwater samples
Measure: pH, EC/TDS and Temp
Measure: Alkalinity ($HCO_3^-$)
Shallow well
Spring water
28/07/2014
7


Study method: Major ion analyses
Tokai University, Japan
$Na^+$, $K^+$, $Mg^{2+}$, $Ca^{2+}$
$F^-$, $Cl^-$, $SO_4^{2-}$, $NO_3^-$
ASS-Contra 700
ICS-900
28/07/2014
8


Study method: Stable isotope analyses
Cavity RingDown Spectrometer (L2120-i)
$\delta^{18}O$, $\delta D$
$^{18}O/^{16}O$ and D/H: expressed relative to V-SMOW:
$\delta(‰) = (R_{sample}/R_{V\text{-}SMOW} - 1) \times 1000$
Analytical precision: ±0.05 ‰ ($\delta^{18}O$) and ±0.12 ‰ ($\delta D$)
Results and Discussion
28/07/2014
9


Chemical evolution
(a)
(b)
Mean concentration (mg/l)
Mg
Ca
K
Na
F
SO4
Cl
NO3
HCO3
Average Rain (n=43)
Springs-n=14 (Rainy season)
Springs-n=14 (Dry season)
Wells-n=15 (Dry season)
Wells-n=15 (Rainy season)
Fig. 2 Average concentrations of cations (a) and anions (b)
Chemical enrichment: rain to groundwater, short circulation
28/07/2014
10


Chemical facies and evolution
(a)
Dry season
(b)
Rainy season
Average rain
Fig. 3 Piper diagram showing the main hydrochemical facies of groundwater in the dry (a) and rainy (b) seasons. The dash arrows indicate the likely path of chemical evolution
Chemical facies: freshwater, resilience to seasonal climatic changes
28/07/2014
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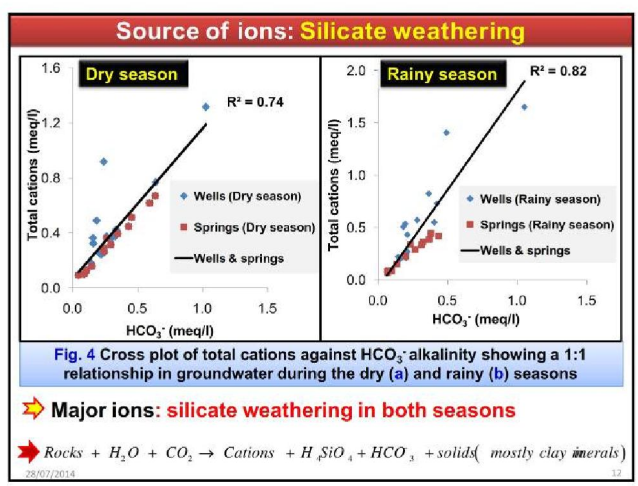
Source of ions: Silicate weathering
Dry season
R² = 0.74
Rainy season
R² = 0.82
Total cations (meq/l)
$HCO_3^-$ (meq/l)
Wells (Dry season)
Springs (Dry season)
Wells & springs
Wells (Rainy season)
Springs (Rainy season)
Fig. 4 Cross plot of total cations against $HCO_3^-$ alkalinity showing a 1:1 relationship in groundwater during the dry (a) and rainy (b) seasons
Major ions: silicate weathering in both seasons
$Rocks + H_2O + CO_2 \rightarrow Cations + H_4SiO_4 + HCO_3^- + solids(mostly\ clay\ minerals)$
28/07/2014
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## Source of ions: Ion exchange

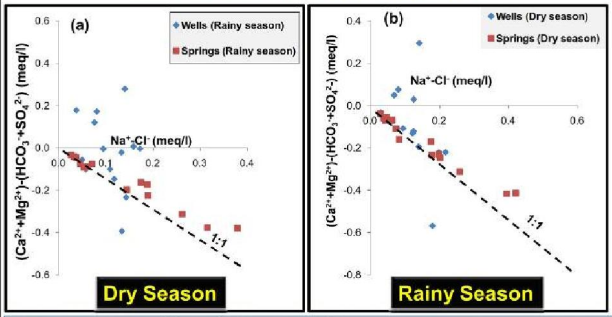


Fig. 5 $Na^+$-$Cl^-$ vs. $Ca^{2+}+Mg^{2+}-(HCO_3^-+SO_4^{2-})$ in groundwater: inverse relation

- Shallow aquifer: Ion exchange: (both seasons)
- $Ca^{2+}$ (aq) + 2Na (clays) = $2Na^+$ (aq) + Ca (clays)

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## Source of ions: Anthropogenic effect

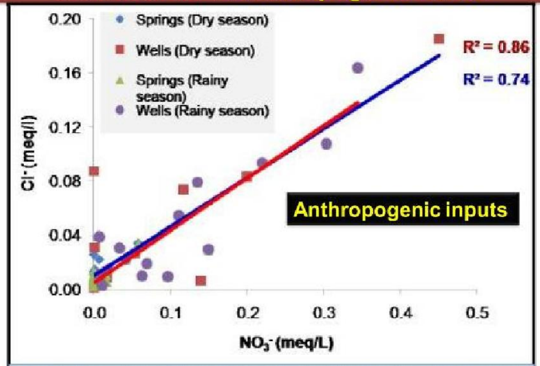


Fig. 6 Cross plot $NO_3^-$ and $Cl^-$: positive correlation in groundwater

- Low concentrations: Low anthropogenic inputs (both seasons)

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## Groundwater recharge: origin, timing and rate

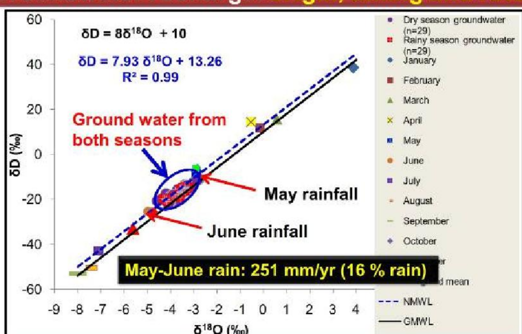


Fig. 7 Conventional $\delta^{18}O$-$\delta D$ relationship of groundwater and monthly $\delta^{18}O$-$\delta D$ ratios of precipitation in the Ndop plain

- Recharge: resilient to short term seasonal climatic changes

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## Recharge altitude

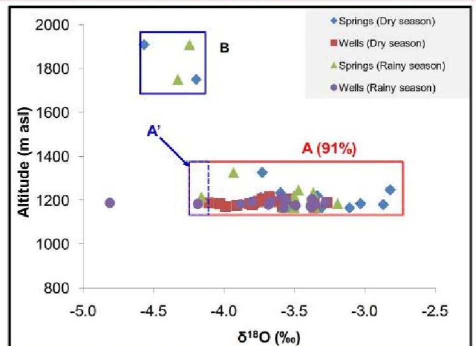


Fig. 8 Plot of $\delta^{18}O$ versus altitude

- Low altitude heterogeneous groundwater recharge

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## Recharge altitude

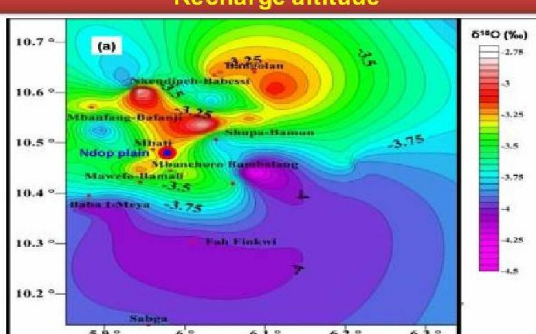


Fig 9. Spatial view of $\delta^{18}O$ showing depleted high altitude groundwater

- Insignificant groundwater recharge at high altitude

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## Origin: Relation to other studies in West Africa

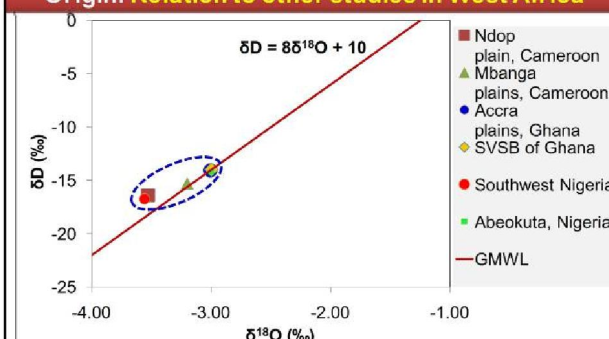


Fig. 10. Plot of $\delta^{18}O$ vs $\delta D$ of groundwater in some west African countries

- Meteoric recharge; rapid infiltration

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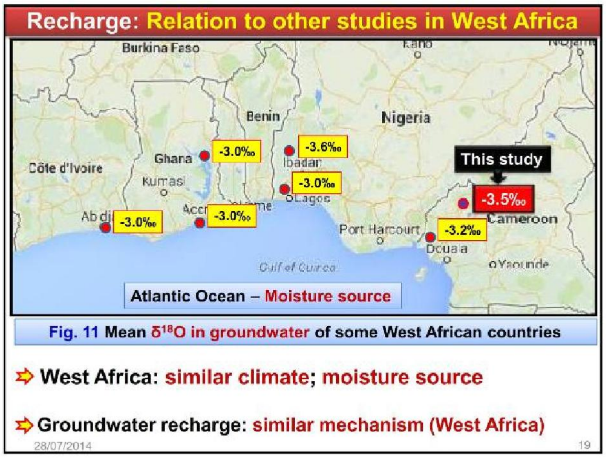
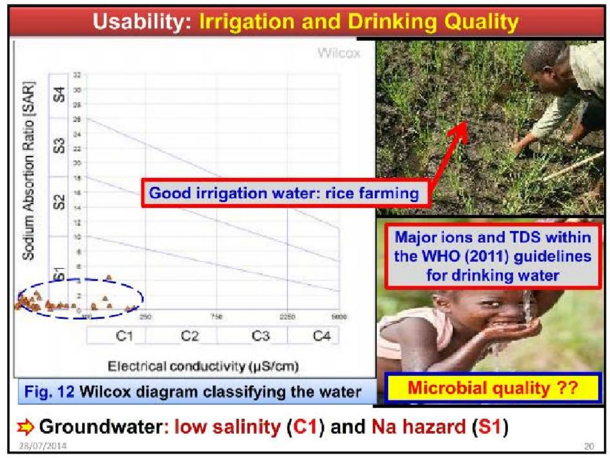

Recharge: Relation to other studies in West Africa
Burkina Faso
Benin
Nigeria
Ghana
-3.0‰
-3.6‰
Ibadan
This study
Côte d'Ivoire
Kumasi
-3.0‰
Lagos
-3.5‰
-3.0‰
-3.0‰
Port Harcourt
-3.2‰
Cameroon
Douala
Gulf of Guinea
Yaounde
Atlantic Ocean – Moisture source
Fig. 11 Mean δ18O in groundwater of some West African countries
West Africa: similar climate; moisture source
Groundwater recharge: similar mechanism (West Africa)
28/07/2014
19


Usability: Irrigation and Drinking Quality
Wilcox
Sodium Absorption Ratio [SAR]
S4
S3
S2
S1
Good irrigation water: rice farming
Major ions and TDS within the WHO (2011) guidelines for drinking water
C1
C2
C3
C4
Electrical conductivity (μS/cm)
Fig. 12 Wilcox diagram classifying the water
Microbial quality ??
Groundwater: low salinity (C1) and Na hazard (S1)
28/07/2014
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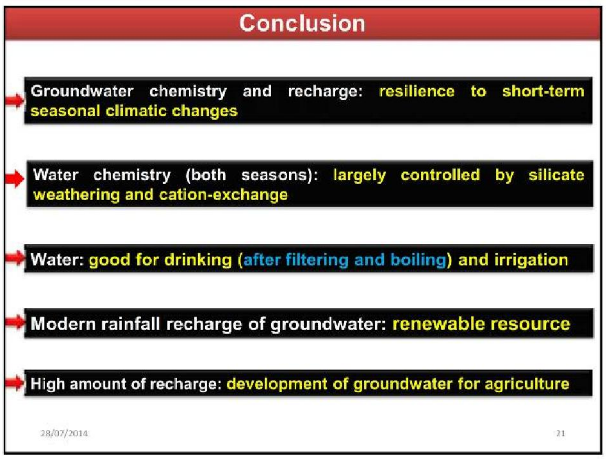
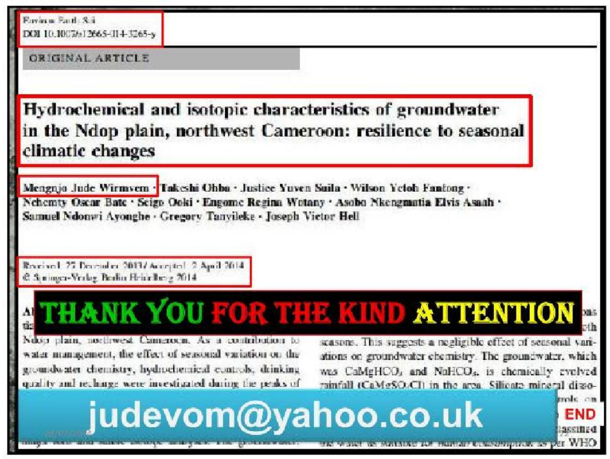

Conclusion
Groundwater chemistry and recharge: resilience to short-term seasonal climatic changes
Water chemistry (both seasons): largely controlled by silicate weathering and cation-exchange
Water: good for drinking (after filtering and boiling) and irrigation
Modern rainfall recharge of groundwater: renewable resource
High amount of recharge: development of groundwater for agriculture
28/07/2014
21


ORIGINAL ARTICLE
Hydrochemical and isotopic characteristics of groundwater in the Ndop plain, northwest Cameroon: resilience to seasonal climatic changes
Mengnjo Jude Wirmvem · Takeshi Ohba · Justice Yuven Suila · Wilson Yetoh Fantong · Nehemty Oscar Bate · Seigo Ooki · Engome Regina Wotany · Asobo Nkengmatia Elvis Asaah · Samuel Ndonwi Ayonghe · Gregory Tanyileke · Joseph Victor Hell
THANK YOU FOR THE KIND ATTENTION
judevom@yahoo.co.uk
END

Title

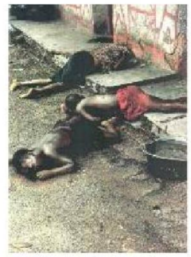
# Measures to Prevent the Recurrence of Limnic Eruption at Lakes Nyos and Monoun (Cameroon)

**Minoru KUSAKABE**

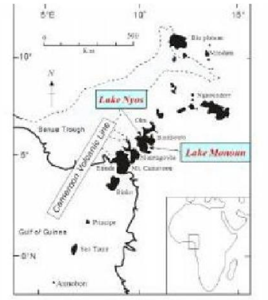
*University of Toyama, Japan*

**AOGS 2014 at Sapporo, Japan**
**28th July ~ 1st August 2014**

## Gas disasters at Lakes Nyos and Monoun

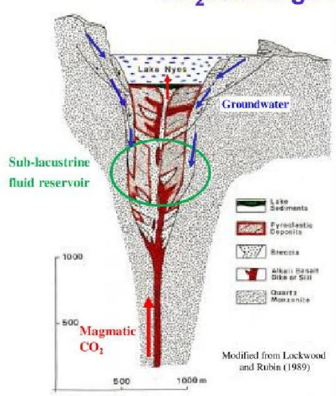


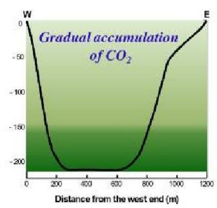
National Geographic Magazine (September 1987)




*Lake Nyos (August 21, 1986), 1746 casualties*
*Lake Monoun (August 15, 1984), 37 casualties*

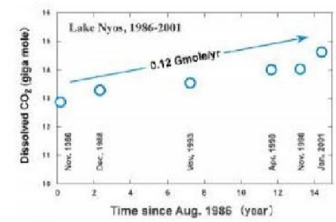
## $CO_2$ recharge model

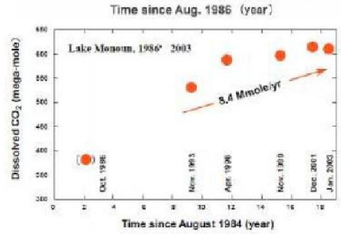



*These natural gas explosions may be repetitive, predictable and preventable.*

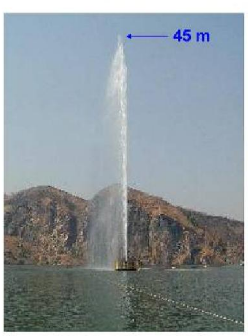
## Accumulation of $CO_2$ at NyMo




*$CO_2$ concentration was close to saturation at 50m in 2003.*

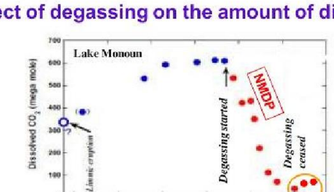
## Gas removal by NMDP



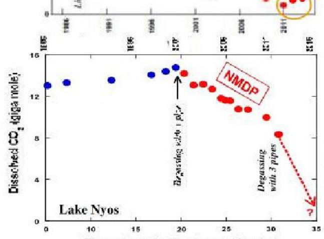

Lake Nyos, February 2001


Lake Monoun, January 2005

## Effect of degassing on the amount of dissolved $CO_2$

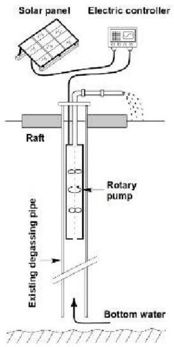



*~90% removed, but gas-buildup resumed.*




*~40% removed.*
*Requires ~5 years for gas removal.*
*Gas-buildup will resume.*

## Deep water removal system at Lake Monoun
**(installed in December 2013 by YY and MK)**





*Daily pumping rate of water: ~100 $m^3$/day*
*$CO_2$ removal rate: ~ 3.3 Mmol/yr*
*Two more systems are required to compensate the natural $CO_2$ recharge (~8.4 Mmol/yr)*

Yoshida et al. Mission Report to IRGM, March 2014)

## Comprehensive measures to mitigate gas disasters in Cameroon

1. Monitoring of the lakes should be continued.
2. Monitoring should be done by Cameroonian scientists (without support from foreigners).
3. Capacity building is required.

SATREPS-NyMo, 2011-2016

## SATREPS
**(Science and Technology Research Partnership for Sustainable Development)**

***International cooperation, addressing global issues, advancing science, and capacity development sponsored by JICA and JST***

*37 Countries where SATREPS is (was) running (since 2008)*

## Fields covered by SATREPS

1. *Climate change:* *17 projects in 12 countries*
2. *Global environmental issues:* *15 projects in 14 countries*
3. *Bioresources:* *15 projects in 15 countries*
4. *Natural Disaster Prevention:* *14 projects in 13 countries*
5. *Infectious Disease Control:* *14 projects in 14 countries*

## SATREPS-NyMo (2011-2016)
***"Magmaic fluid supply into Lakes Nyos and Monoun, and mitigation of natural disasters through capacity building in Cameroon"***
**T. Ohba (Tokai Univ.)**

*Capacity building*

- Donation of analytical equipment

  *IC, Laser water isotope analyzer, Laser $^{13}C$ analyzer, AAS, CTD, Multi-beam sonar, Auto observation buoy, Climate stations, Deep water removal system, associated consumables, etc.*
- 5 Cameroonian Ph.D. students and 4 technicians were invited to Japan for training.
- Joint researches including field work are going on.

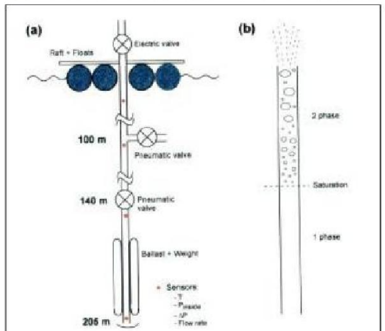
## Major goals of SATREPS-NyMo

1. *Independent scientific research by Cameroonian scientists.*
2. *Continuous monitoring of Lakes Nyos and Monoun.*
3. *Mechanism of limnic eruption.*
4. *$CO_2$ recharge system beneath Lakes Nyos.*
5. *Hydrology and microbiology around Lakes Nyos.*
6. *Volcanology/geochemistry of CVL volcanoes and lakes.*
7. *Utilization of the research outcomes for disaster management.*
8. *Sustainability of scientific research in Cameroon.*

**Thank you for your attention.**

## NMDP

(OFDA (USAID), Cameroon Government, French Government, and UNDP)

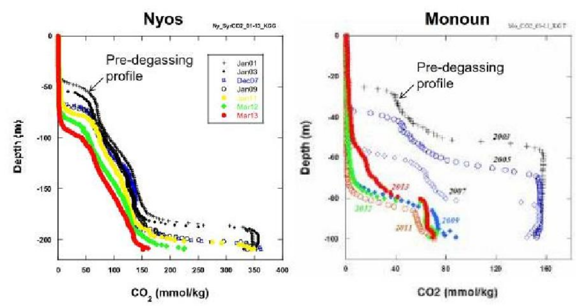



Schematic diagram of degassing pipe
(after Halbwachs, 2001)

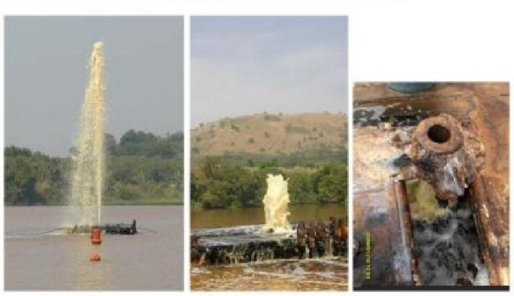
## Ongoing Joint Scientific Research

1. *Regular monitoring of Lakes Nyos and Monoun*
2. *Real time observation of T and conductivity at Lake Nyos*
3. *Continuous measurement of climatic parameters*
4. *Detailed bathymetry using a multi-beam sonar*
5. *$CO_2$ flux around the lakes*
6. *$CO_2$ determination by means of sound velocity measurement*
7. *3D distribution of $CO_2$ in the lakes to locate a $CO_2$ recharge point*
8. *Mechanism of limnic eruption – computer simulation –*
9. *$CO_2$ recharge system beneath Lakes Nyos and Monoun*
10. *Hydrology & microbiology around Lakes Nyos and Monoun*
11. *$CO_2$-rich fluid - rock interaction*
12. *Deep water removal system at Lake Monoun*
13. *Magmatism of the Oku volcanic zone*

### Change with time in $CO_2$ profiles during degassing at NyMo




### Degassing at Lake Monoun



January 2004 | January 2005 | January 2009

## Water & $CO_2$ removal rates

Daily pumping rate of water = ~100 $m^3$/day-time

$CO_2$ removal rate = Water flow rate x $CO_2$ conc.
= 100 ($m^3$/day) x 90 (mmol/kg)
= 3.3 Mmol/yr

Since the natural $CO_2$ recharge rate is ~8.4 Mmol/yr, we need to add 2~3 water removal systems to compensate the natural $CO_2$ recharge at Lake Monoun.

Yoshida et al. Mission Report to IRGM, March 2014)


**IG25-D5-PM2-EB-002**

**Preventing limnic eruptions in Lakes Nyos and Monoun within the framework of disaster governance, resilience and preparedness in Cameroon**

Festus AKA [1#+], Buh-Wung GASTON[2], Issa ISSA[3], Wi l son Yetoh FANTONG[1], Takeshi OHBA[3], Mi noru KUSAKABE[4], Gregory TANYILEKE[1], Joseph Vi ctor HELL[1]

[1]Insti tute of Geological and Mi ning Research, Cameroon, [2]Geotech. Env. Asses. Di sas. Ri sk Red., Cameroon, [3]Tokai Uni versi ty, Japan, [4]Uni versi ty of Toyama, Japan

[#]Correspondi ng author: akatongwa@yahoo.com [+]Presenter

**Institute for Geological & Mining Research (IRGM - Cameroon)*

## Outline

- Background
- Cameroon disaster profile
- Methods
- Disaster governanc, resilience & preparedness in Cameroon
- Results & discussion
- Conclusions

## Background

**Of the 8 MDGs (UN – 2005),**

**N°1: Eradicating extreme poverty and hunger**

**N°7: Ensuring environmental sustainability**

(i) Extreme poverty cannot be eradicated, and sustainable development cannot be attained unless <u>disaster risk reduction is mainstreamed into development policies, plans, and implementation</u>

(i) Disasters undermine the results of development and impoverish the community and the state

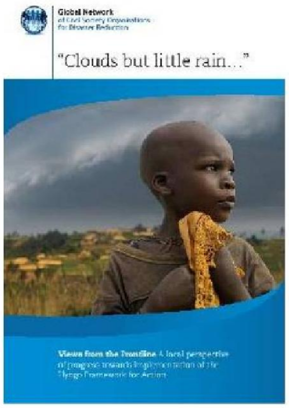
- Cameroon was among the <u>168 countries</u> that signed the 2005 <u>Hyogo Framework of Action (HFA) in Japan,</u> committing to take action within 10 years (up to 2015) to <u>reduce human and socio-economic disaster losses as a means to attaining the MDGs</u>.
- For HFA, DRR is central to development policy and a concern of multidisciplinary knowledge about humanity and the environment.

UNGNDRR monitors the attainment of HFA goals via a project called <u>Views From the Frontline (VFL)</u>

**Main goal of VFL:**

Support effective frontline implementation of the HFA to <u>build the resilience of vulnerable people</u> <u>and communities at risk to disasters</u>.

**We evaluate disaster governance, resiliance and preparedness based on the implementation of the VFL project in Cameroon**

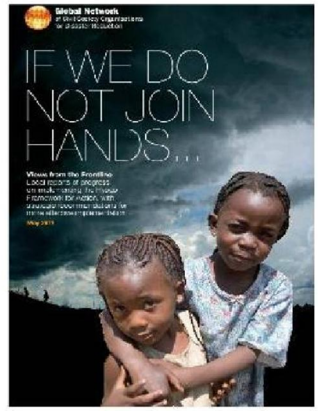



**VFL - 2009**

**In 48 countries across Africa, Asia and the Americas**

**400 CSOs**
**7000 respondents**

**Cameroon did not participate in VFL 2009**

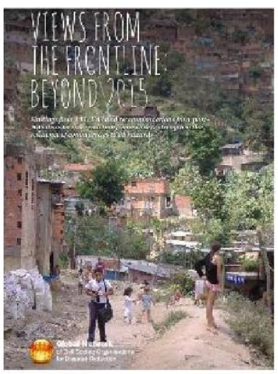



**VFL - 2011:**
**Local governance in DRR**

**69 countries**

**511 CSOs**
**20,290 respondents**

**57 video case studies**

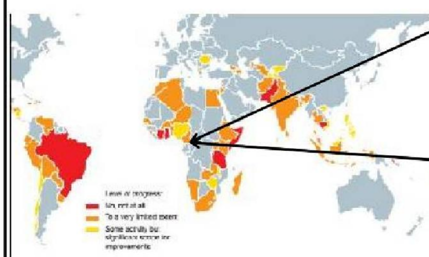



**VFL - 2013:**
**Community resilience and disaster preparedness**

**57 countries**

**450 CSOs**
**21,455 respondents**

**VFL world-wide coverage**

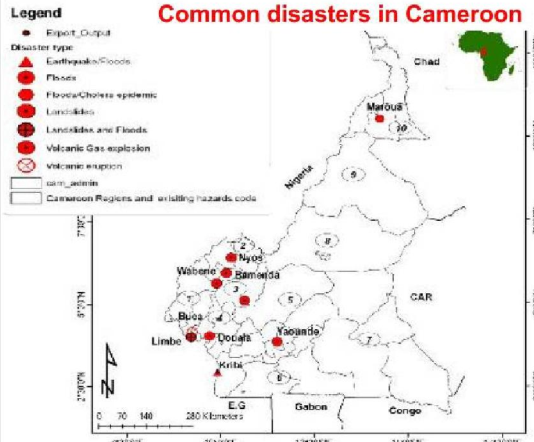


**VFL - 2011**
**7 CSOs in 7/10 Regions**
**300 respondents;**
**2 video case studies in in Limbe & Yaounde**

**VFL - 2013**
**7 CSOs in 7/10 Regions**
**356 respondents**

**Frontliners**
**People in at-risk zones**

**Common disasters in Cameroon**

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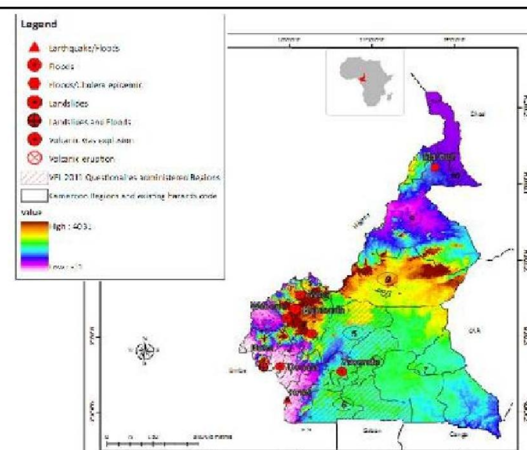


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## Survey methodology for VFL-2013
## Community resilience and disaster preparedness

1. Multi-risk resilience
2. Causes
3. Risk Assessment
4. Monitoring
5. Public awareness
6. Connecting
7. Learning
8. Negotiation
9. Conflict resolution
10. Partnership
11. Resources
12. Early warning
13. Local actions
14. Everyday disaster

Landslides, seasonal floods, droughts, fires, pests, food shortages, fluctuating prices, insecure land rights, conflicts, corruption......

## Targeted respondents

Frontliners (local government and community representatives/leaders)

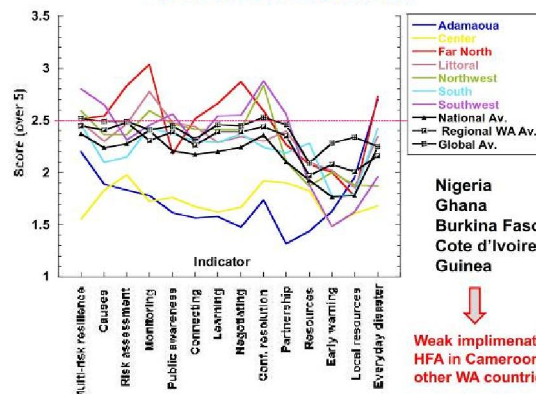
1. Divisional Officers
2. Sub divisional Officers
3. Police
4. Gendarms
5. Mayors
6. Chiefs
7. Village/quarter heads
8. Presidents of village/quater meetings
9. Civil society leaders
10. School teachers
11. Doctors/Nurses
12. Clergy

Focus groups & face-to-face interviews with people living in at-risk zones

## Survey rating

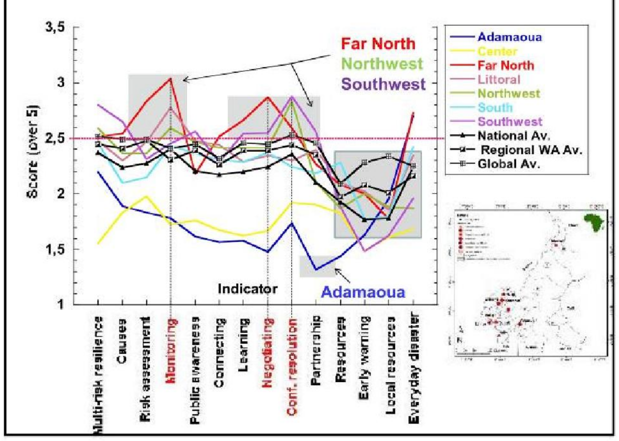
| Score | Meaning |
|---|---|
| 1 | No, not at all |
| 2 | To a very limited extent |
| 3 | Some activity but significant scope for improvement |
| 4 | Yes, but with some limitations in capacities and resources |
| 5 | Yes, with satisfactory, sustainable and effective measures in place |
| 6 | Don't know |

## Results and discussion

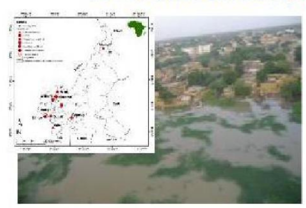



Nigeria
Ghana
Burkina Faso
Cote d'Ivoire
Guinea

Weak implimenation of HFA in Cameroon & other WA countries




## 2012 floods on the Far North Region of Cameroon

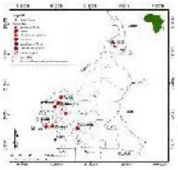


Vulnerable to natural disasters and climate shocks

2012 floods caused by collapse of Lagdo dam & overflow of Benue river

- 15 villages flooded
- 30 casualties
- 60 000 displaced

## Southwest Region – Eruptions of Mt. Cameroon & landslides



Fire fountains – 2000 eruption

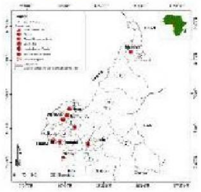
1999 - Oil palm plantation

1999 - lava cuts highway

Pre – earthquake destruction

2001 landslide on SW flank (24 casualties)

## Lake Nyos (Northwest Region) gas disaster of 21 August 1986



Limnic eruption = gas outburst from a lake

- $CO_2$ gas release
- 1800 casualties
- ≈ 3500 refugees
- >7000 cattle died

## Prevention of limnic eruption at Lakes Nyos & Monoun

(1) Gas removal via pipes

(2) $CO_2$ monitor

(3) Outreach activities (education for awareness & resilience)

## (4) SATREPS – NyMo Project

Magmatic fluid supply into Lakes Nyos and Monoun, and mitigation of natural disasters through capacity building in Cameroon

**Human capacity building**
- 5 PhD students now in Japan
- IRGM Techniciens in Japanese laboratoires
- Exchange of scientific visits

**Monitoring & dynamics of limnic eruptions In Lakes Nyos & Monoun**

**Institutional capacity building**
- Multi-beam sonar
- Observation buoy
- Ion Chromatography (ICS-1100)
- LI-820 soil $CO_2$ detector
- Picarro L2120-i isotope analyzer
- Milli-Q Direct 8 pure water maker

Analytikjena contrAA-300

Results to be presented during CVL9 (IAVCEI) in Cameroon in 2016 to mark 30th anniversary of Lake Nyos disaster ⟹ You are welcome!

## Conclusions

Sharing resources and a participatory approach between government, civil society, municipal and local stakeholders is an important vehicle for frontline progress in disaster risk reduction in Cameroon.

DRR in the country needs to include foundamental research and forecast, using space technology to establish the causative links between climate change and disasters.

The ongoing degasing of Lake Nyos, the installed CO2 early warning system, cooperation between Cameroon and Japan in the SATREPS NyMo project and emphasis on outreach and sensitization of the population around Lakes Nyos & Monoun will enhance mitigation of limnic eruptions.


## Acknowledgments

UNISDR – HFA (2005 – 2015)
Building the Resilience of Nations & Communities to Disasters (VFL 2011 & 2013 Projects)

GEADIRR

Geotechnology, Environnemental Assessement and Disaster Risk Reduction, & other CSOs in Cameroon for VFL 2011 & 2013 surveys

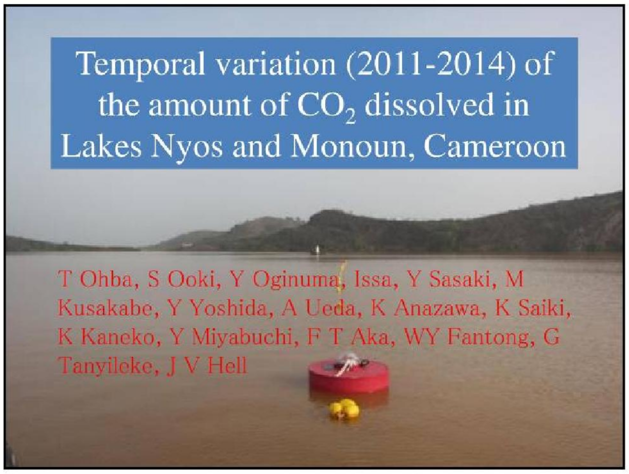
MINRES

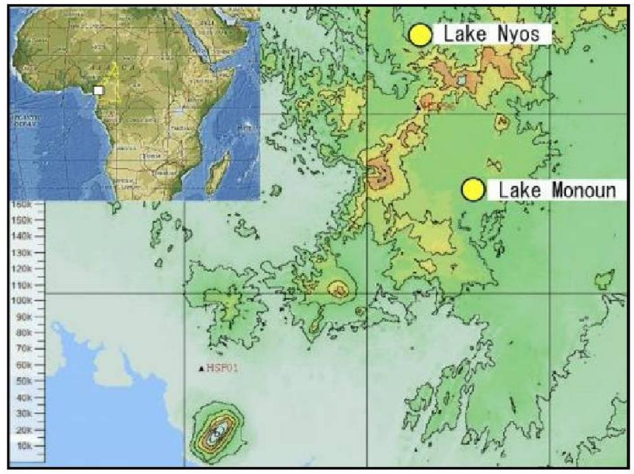
Cameroon Government for the SATREPS NyMo project via MINRESI & the Institute for Geological & Mining Research (IRGM)

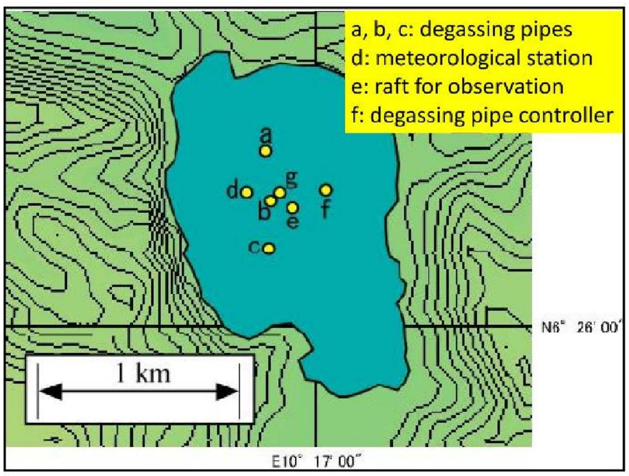
Japanese Government for the SATREPS-NyMo project via JICA (MOFA), JST (MEXT) and Tokai University

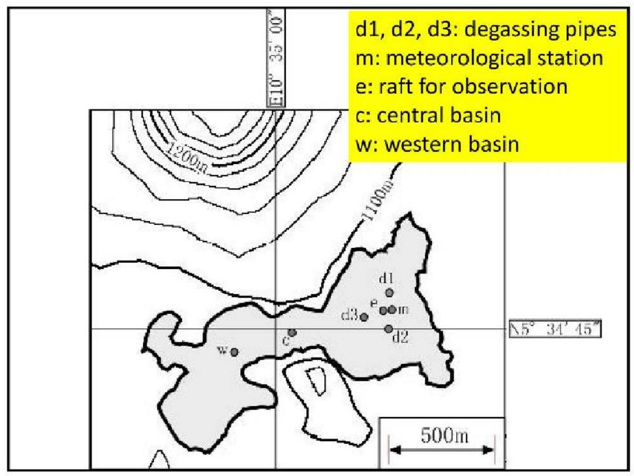
MOFA MEXT

JICA JST



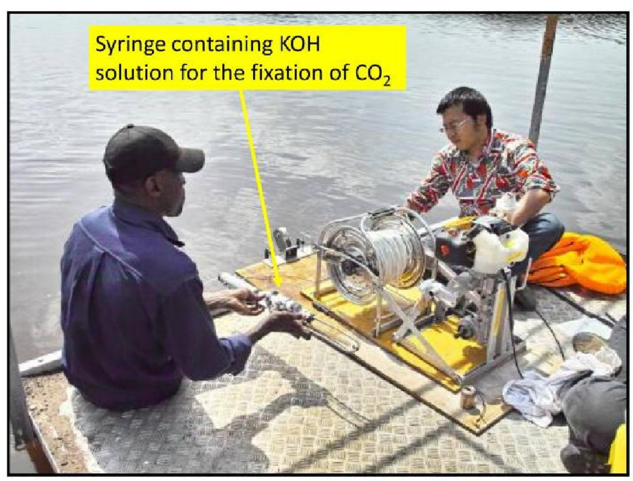




## The accurate estimation for the amount of $CO_2$ gas dissolved in Lake water

- Method-1 : MK-method ( in situ $CO_2$ fixation by KOH and subsequent Chemical analysis in Lab. Analytical error is less than ±1.5%)
- Method-2: CTD-method (Estimation by conductivity and pH, uncertainty = more than 20%)
- Combining the above two methods, the reliable and precise amount of $CO_2$ can be calculated.



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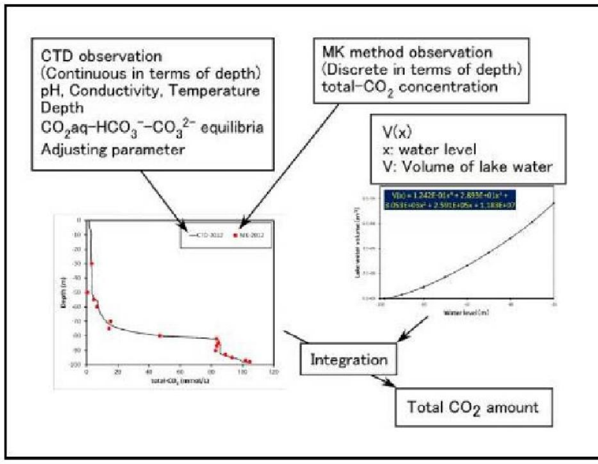
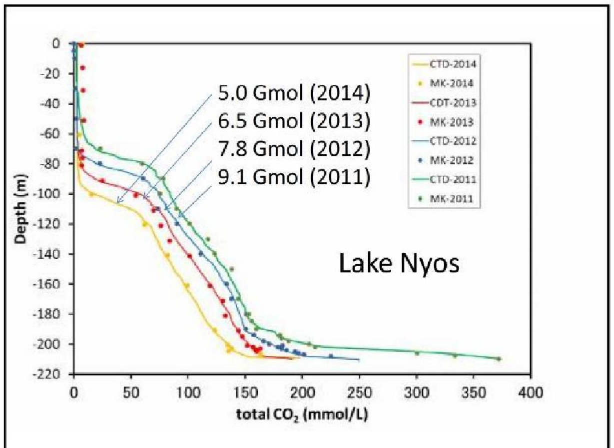
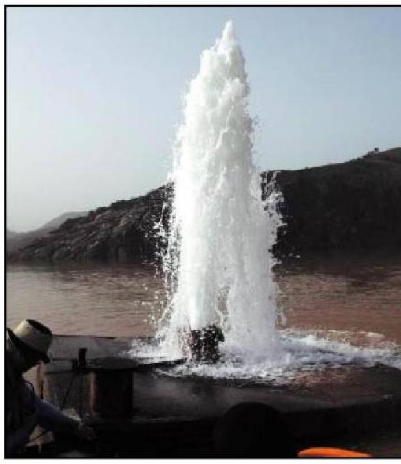
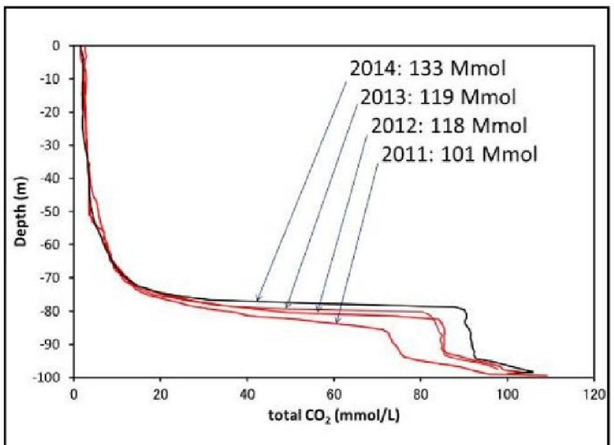


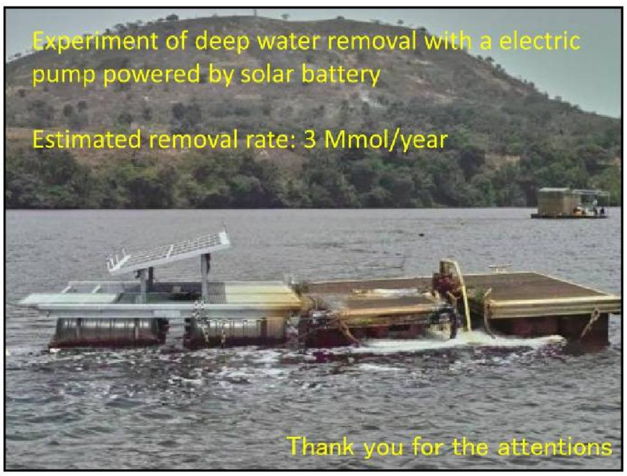
One of the three degassing pipes on Lake Nyos




One of the three degassing pipes on Lake Monoun

## Conclusions

- A steady decrease in the $CO_2$ amount continues at Lake Nyos due to the operation of three degassing pipes.
- The amount of $CO_2$ in Lake Monoun is increasing since 2011 due to the stop of degassing operation.
- The periodical observation at Lake Monoun is especially important to monitor the accumulated amount of $CO_2$.



# Geochemistry of soil gas from Mount Manenguba Caldera, Cameroon Volcanic Line (CVL): Towards multipararmetric volcanic activities surveillance along the Cameroon Volcanic Line (CVL), West-Africa

*[1,2]**Issa**, [1]Ohba T., [2]Fantong W., [3]Padron E., [2]Aka F.T., [1]Ooki S., [4]Yutaka Y., [3]Hernandez P., [2]Kuitcha D., [2]Fouepe A., [5]Minoru K., [1]Chako T. B., [6]Sighomnoun D., [7]Sigha Nkamdjou, [3]Tanyileke G.

[1]Tokai Univ., Japan;
[4]Yoshida Consulting Office, Japan;
[2]IRGM, Cameroon;
[3]ITER/INVOLCAN, Canary Islands, Spain;
[5]Univ. of Toyama, Japan;
[6]WMO Switzerland;
[7]CICOS, Republic of Congo.

Ohba Lab.





- *Volcanic gases carry useful messages on activities developing deep into the Earth*
  - *Magma body movements*
  - *Magma emplacement (Magnitude, composition and amount of degassing volatiles)*
  - *Etc.*

*Monitoring of such deep-derived volatiles have long served for volcanic activities forecasting*





- *The Cameroon volcanic Line (CVL) is volcanically and seismically active :*
  - *Mount Cameroon erupted 3 times within the last three decades*
  - *Several soda springs*
  - *Gassy lakes (Killer lakes: Nyos and Monoun)*
- *In spite of above, volcanic activity surveillance in Cameroon is still poorly developed*
  - ✓ *Only seismic method is used to monitor volcanic activities along the line (Mt Cameroon)*





- *Generate diffuse gas data to contribute achieving multiparametric volcanic activities surveillance along the CVL through:*
  - *Diffuse $CO_2$ flux survey*
  - *Soil gas composition*

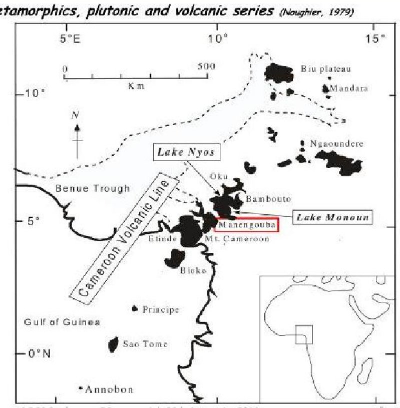




*<u>Geology:</u> sedimentary, metamorphics, plutonic and volcanic series (Noughier, 1979)*

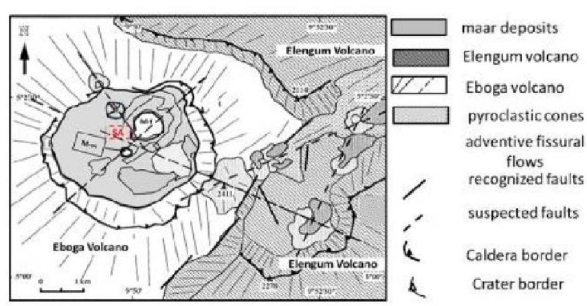
*Mt Manenguba Location: N5.04° E9.82°*

*<u>Ca 30km wind fly from Mt Cameroon</u>*



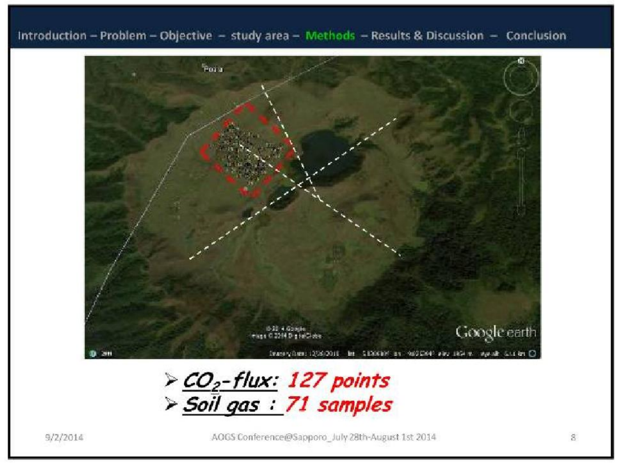


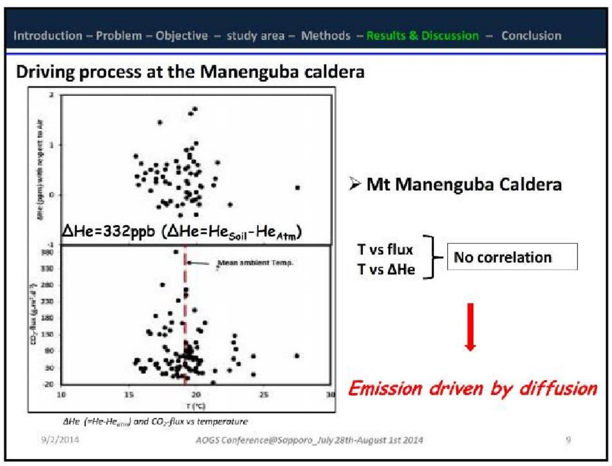


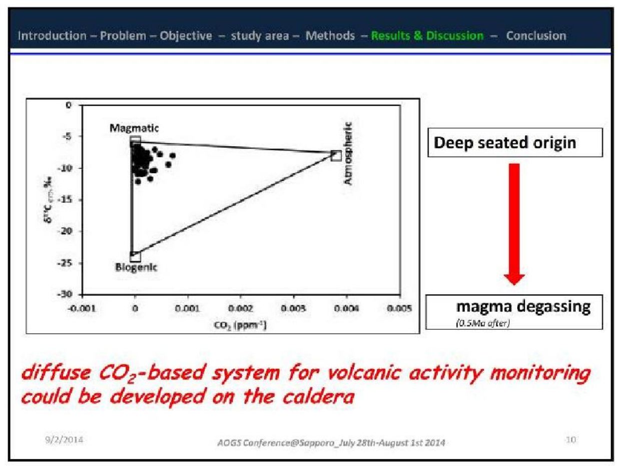



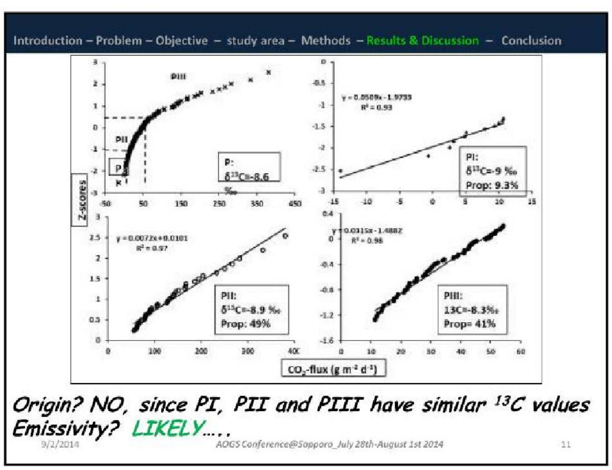

*Geologic setting of the Mt. Manenguba summit area containing its caldera and two twin lakes (Manenguba The area (SA) were the $CO_2$-flux survey was conducted is delineated by the dashed red rectangle (modified after Kagou et al., 2001)*


Introduction – Problem – Objective – study area – Methods – Results & Discussion – Conclusion
CO2-flux: AC: (e.g. Sorey et al., 1998; Bergfeld et al., 2001)
T0 (SATO SK-1110 thermometer); GPS (Hand held Garmin GPSmap 62s); Output (GsLib soft. (Deutsh and Journel, 1998) and Surfer 10)
Soil gas sampling: (Padron et al., 2013); He (± 300 ppb); 40Ar (±50 ppm) 36Ar (±5 ppm) N2 (± 1 %), CO2 (± 1 %); By QMS. Pfeiffer Omnistar 422 and micro-GC, VARIAN CP4900 at ITER (Spain)
Gas sampling and flux sur
9/2/2014
AOGS Conference@Sapporo_July 28th-August 1st 2014
7


Introduction – Problem – Objective – study area – Methods – Results & Discussion – Conclusion
Google earth
CO2-flux: 127 points
Soil gas : 71 samples
9/2/2014
AOGS Conference@Sapporo_July 28th-August 1st 2014
8


Introduction – Problem – Objective – study area – Methods – Results & Discussion – Conclusion
Driving process at the Manenguba caldera
ΔHe=332ppb (ΔHe=HeSoil-HeAtm)
Mean ambient Temp.
T (°C)
ΔHe (=He-HeAtm) and CO2-flux vs temperature
Mt Manenguba Caldera
T vs flux
T vs ΔHe
No correlation
Emission driven by diffusion
9/2/2014
AOGS Conference@Sapporo_July 28th-August 1st 2014
9


Introduction – Problem – Objective – study area – Methods – Results & Discussion – Conclusion
Magmatic
Atmospheric
Biogenic
CO2 (ppm-1)
Deep seated origin
magma degassing
(0.5Ma after)
diffuse CO2-based system for volcanic activity monitoring could be developed on the caldera
9/2/2014
AOGS Conference@Sapporo_July 28th-August 1st 2014
10


Introduction – Problem – Objective – study area – Methods – Results & Discussion – Conclusion
PIII
PII
P: δ13C=-8.6 ‰
PI: δ13C=-9 ‰ Prop: 9.3%
y = 0.0509x - 1.9733 R² = 0.93
y = 0.0072x + 0.0101 R² = 0.97
y = 0.0315x - 1.4882 R² = 0.98
PII: δ13C=-8.9 ‰ Prop: 49%
PIII: 13C=-8.3‰ Prop= 41%
Z-scores
CO2-flux (g m-2 d-1)
Origin? NO, since PI, PII and PIII have similar 13C values
Emissivity? LIKELY…..
9/2/2014
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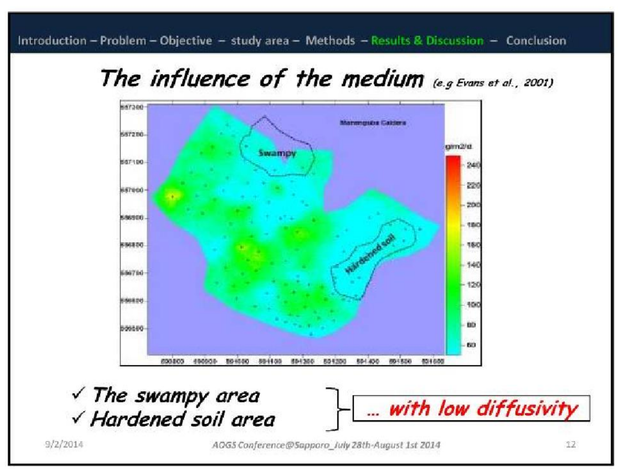
Introduction – Problem – Objective – study area – Methods – Results & Discussion – Conclusion
The influence of the medium (e.g Evans et al., 2001)
Manenguba Caldera
Swampy
Hardened soil
g/m2/d
The swampy area
Hardened soil area
… with low diffusivity
9/2/2014
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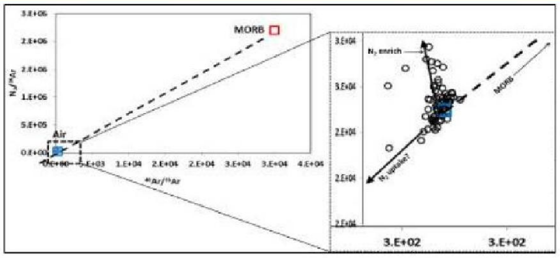



Plot of $N_2/^{36}Ar$ vs $^{40}Ar/^{36}Ar$ in soil gas at Manenguba caldera

- $^{40}Ar/^{36}Ar_{mean}$=297 similar $^{40}Ar/^{36}Ar_{air}$ 295.5 (Ozima and Podosek, 2002)
- $^{40}Ar/^{36}Ar_{Mgba} \neq {}^{40}Ar/^{36}Ar_{CVLmantle}$ >1650 (Barfod et al., 1999)
- *$N_2$ is of atmospheric origin*





## *Total $CO_2$ output*

- *We have surveyed 0.39 km²* (5%):
  - 26.9 (±1.4) t d⁻¹
- *Extrapolated to the whole caldera (8.2 km²)* :
  - 573 ± 23 t d⁻¹





- *First study on soil gas at Mt Manenguba was reported*
- *The $CO_2$ originates dominantly from magma*
- *Total $CO_2$ output has been estimated*
- *Origin and concentration of other soil gas has been determined*

*These data can make up a baseline for the assessment of future changes in that volcanic edifice*





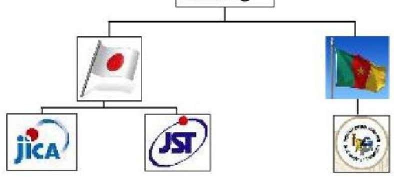
- *Soil diffuse emission surveys needs to be extended to other DDS (e.g: Mount Cameroon)*
- *Generate time series flux data to assess variation in magma degassing*
- *Couple diffuse gas geochemistry with geophysical methods (seismic methods) to enhance volcanic activity surveillance in Cameroon*



## *Acknowledgment: SATREPS-NyMo project*

*5-year project titled "Magmatic Fluids input in lakes Nyos and Monoun and Mitigation of Volcanic Hazards through Capacity Building in Cameroon" of SATREPS (also referred to as SATREPS-NyMo)*

Funding




engaged in the promotion of volcanic hazards mitigation and hazards governance in Cameroon



## *Thank you for your attention*

*(Issa et al., 2014a. doi: 10.4081/jlimnol.2014.966)*
*(Issa et al., 2014b. DOI: 10.1016/j.jvolgeores.2014.07.001)*
*(Issa et al., 2013, Geochem. J. 47, 349-362)*

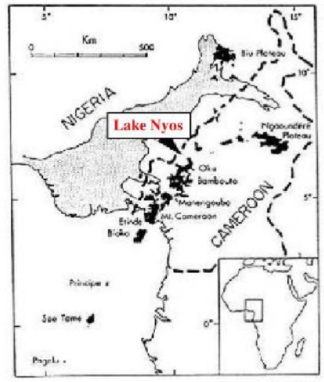
*AOGS 2014 in Sapporo (Aug 1, 2014)*

## Pyroclastic sequence in and around Lake Nyos, northwestern Cameroon


**Yasuo Miyabuchi[1], Tetsuo Kobayashi[2], Takeshi Hasegawa[3], Katsuya Kaneko[4], Festus T. Aka[5], Takeshi Ohba[6], Minoru Kusakabe[7], Gregory Tanyileke[5], Joseph Hell[5]**

*[1] Kumamoto Univ., [2] Kagoshima Univ., [3] Ibaraki Univ., [4] Kyoto Univ., [5] IRGM (Cameroon), [6] Tokai Univ., [7] Univ. Toyama*


## Location of Lake Nyos




Aramaki (1987)

**Cameroon Volcanic Line (CVL)**

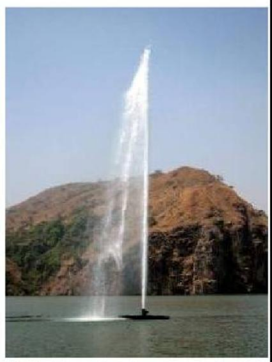
- A 1600 km-long chain
- Alkaline within-plate volcanoes
- Continental sector, four islands and seamounts in the Gulf of Guinea
- 0-9 Ma (almost <5 Ma)
- Mt Cameroon erupted in 2000

**Oku Volcanic Group**

- Four stratovolcanoes (Mts Oku, Babanki, Nyos and Nkambe)
- Young cinder cones and explosion craters (recent activity)

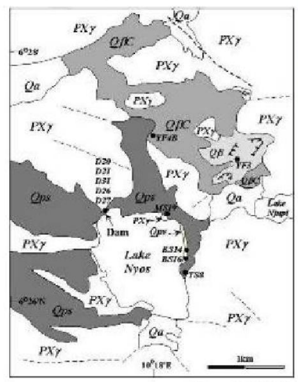
## Lake Nyos gas disaster on August 21, 1986


Releasing an estimated 3 million m³ of magmatic $CO_2$ killed approximately 1800 people and over 3000 cattle (Le Guern and Sigvaldason, 1989).



*Artificial degassing* *(photo January 13, 2011)*

## Geological map of the area surrounding Lake Nyos




Aka et al. (2008)

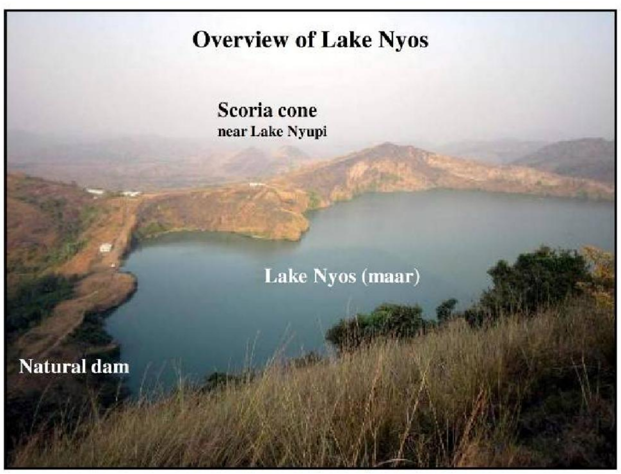

*Qa: alluvium*

*Qβ*: strombolian cones producing lava *QβC*

*Qps*: pyroclastic surge deposits

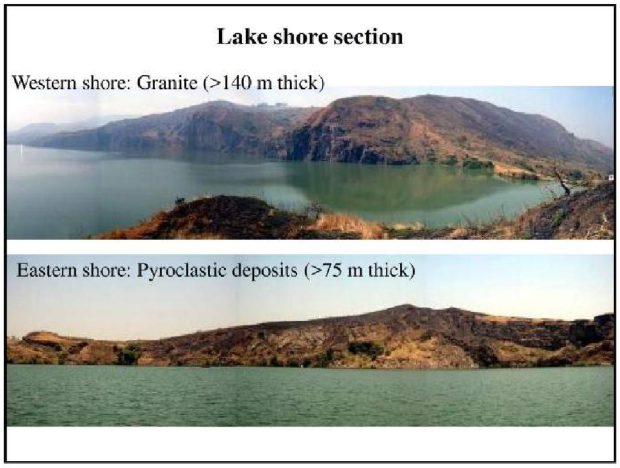
*Qpv*: pyroclastic scoria deposits and lava flow

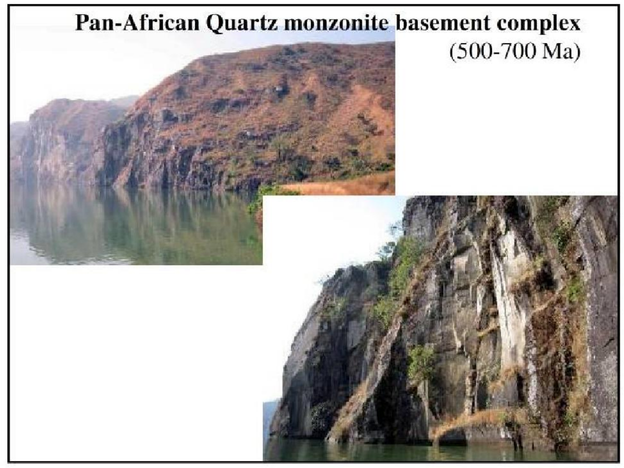
*PXγ*: Precambrian quartz monzonite basement complex

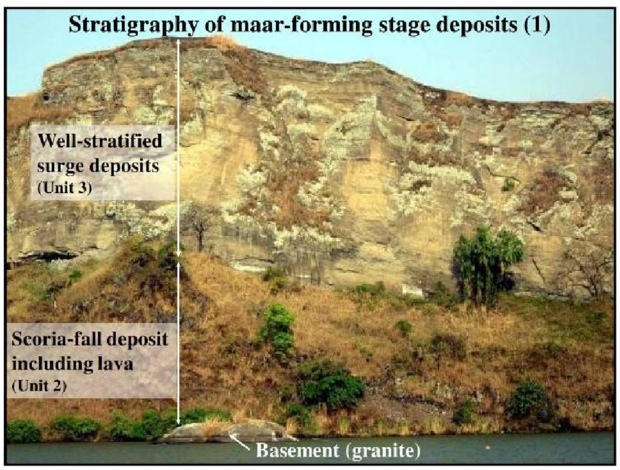


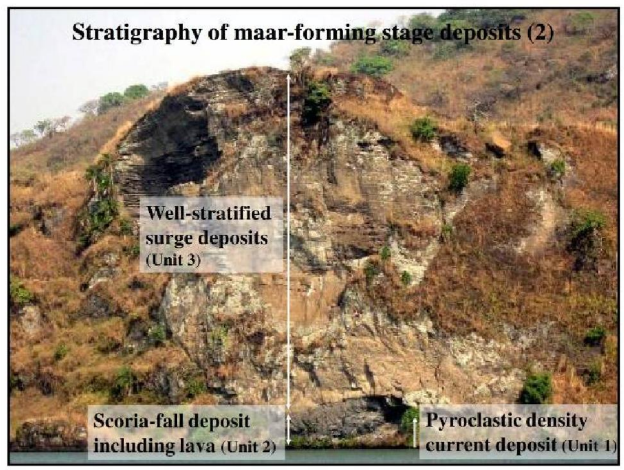

## Summary of pyroclastic deposits related to the formation of Lake Nyos

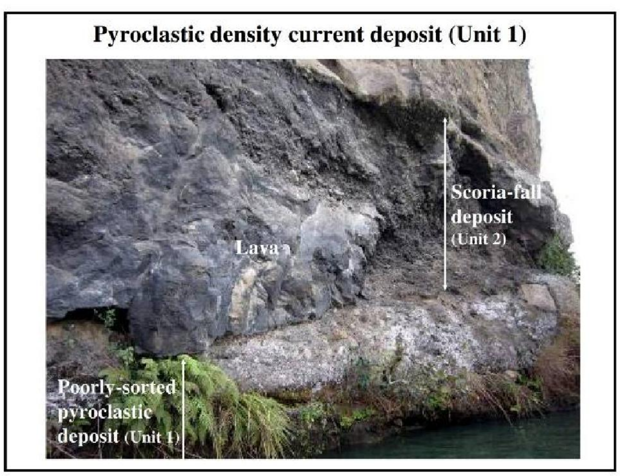
| Unit | Type of products | Eruption style | Vent location |
|---|---|---|---|
| Unit 4 | Scoria-fall deposits and Lava | Strombolian activity and Lava extrusion | Scoria cone near Lake Njupi |
| Unit 3 | Well-stratified pyroclastic surge deposits | Violent phreatomagmatic eruptions (main phase) | Lake Nyos |
| Unit 2 | Scoria-fall deposits and Lava | Strombolian activity and Lava extrusion | Lake Nyos (eastern part?) |
| Unit 1 | Pyroclastic density current deposits | Initial phreatomagmatic eruption? | Lake Nyos |
| Pan-African (500-700 Ma) Quartz monzonite basement complex | | | |

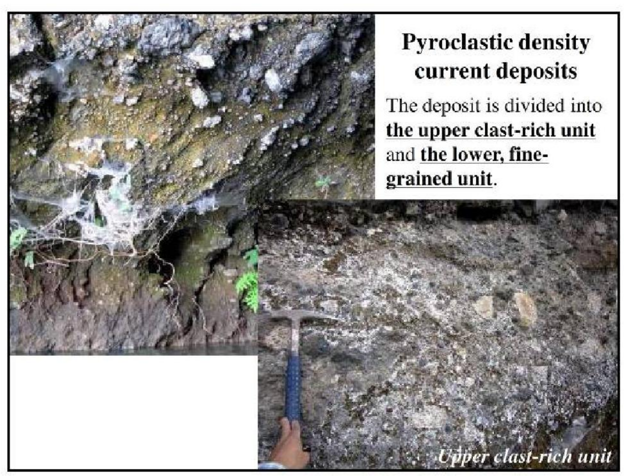

Lake shore section
Western shore: Granite (>140 m thick)
Eastern shore: Pyroclastic deposits (>75 m thick)

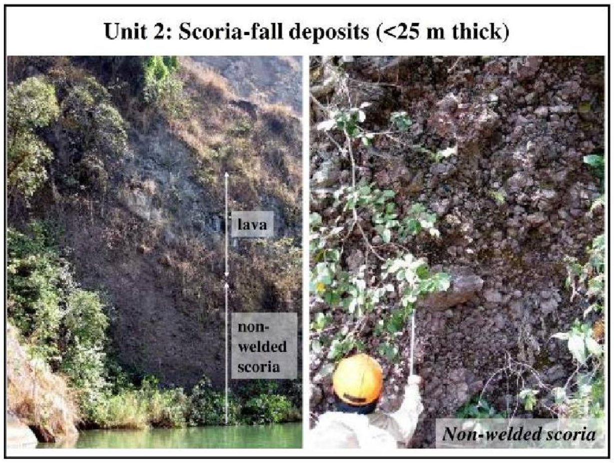

Pan-African Quartz monzonite basement complex
(500-700 Ma)

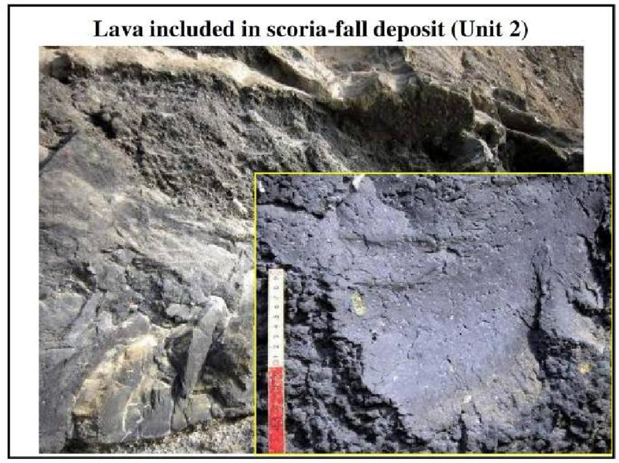

Stratigraphy of maar-forming stage deposits (1)
Well-stratified surge deposits (Unit 3)
Scoria-fall deposit including lava (Unit 2)
Basement (granite)

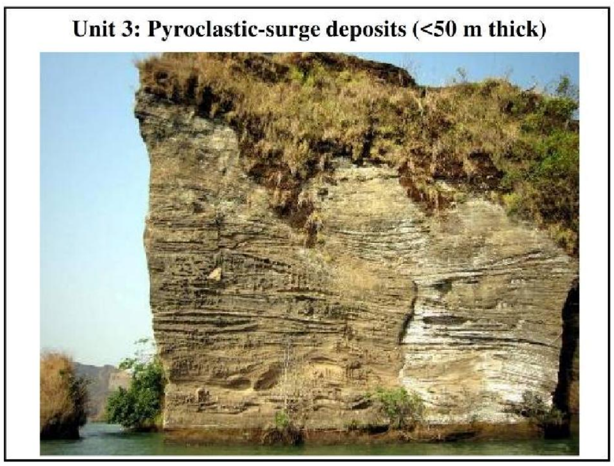

Stratigraphy of maar-forming stage deposits (2)
Well-stratified surge deposits (Unit 3)
Scoria-fall deposit including lava (Unit 2)
Pyroclastic density current deposit (Unit 1)

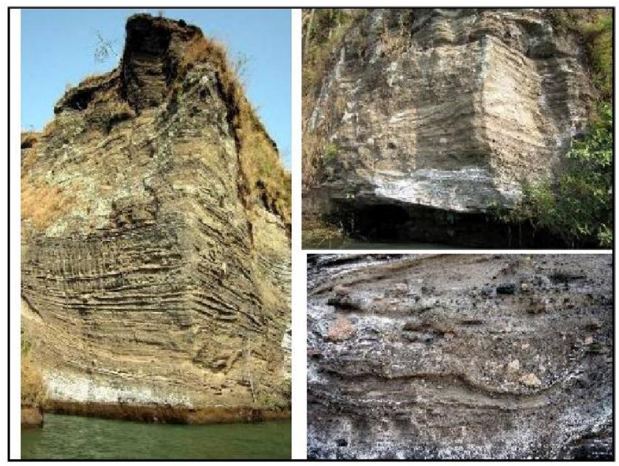

Pyroclastic density current deposit (Unit 1)
Scoria-fall deposit (Unit 2)
Lava
Poorly-sorted pyroclastic deposit (Unit 1)

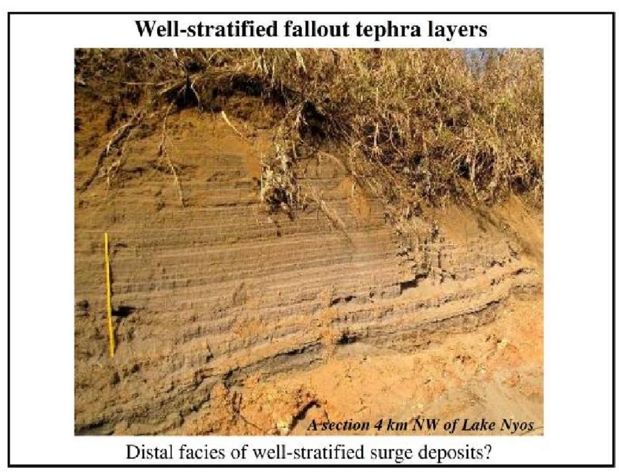

Pyroclastic density current deposits
The deposit is divided into the upper clast-rich unit and the lower, fine-grained unit.
Upper clast-rich unit

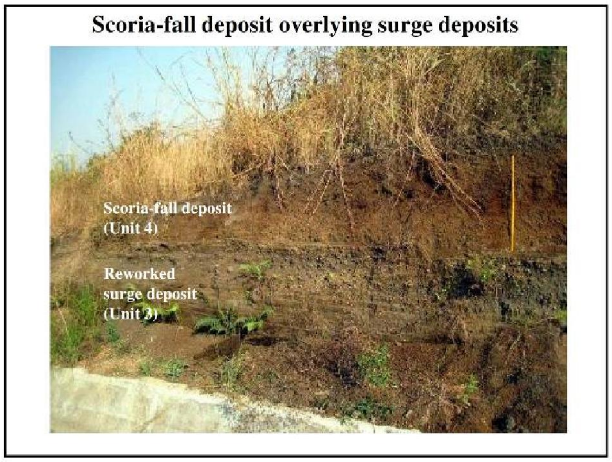

Unit 2: Scoria-fall deposits (<25 m thick)
lava
non-welded scoria
Non-welded scoria


Lava included in scoria-fall deposit (Unit 2)

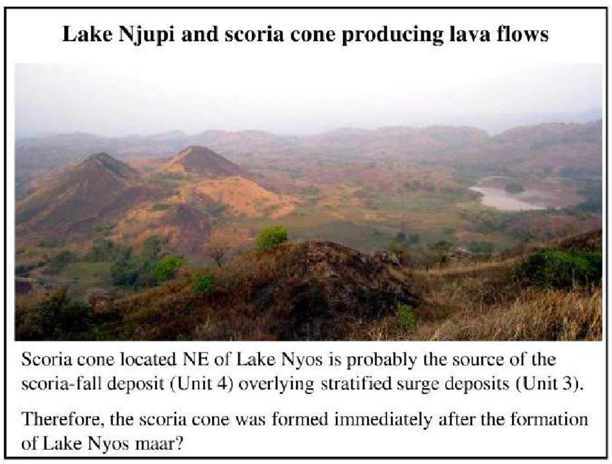

Unit 3: Pyroclastic-surge deposits (<50 m thick)

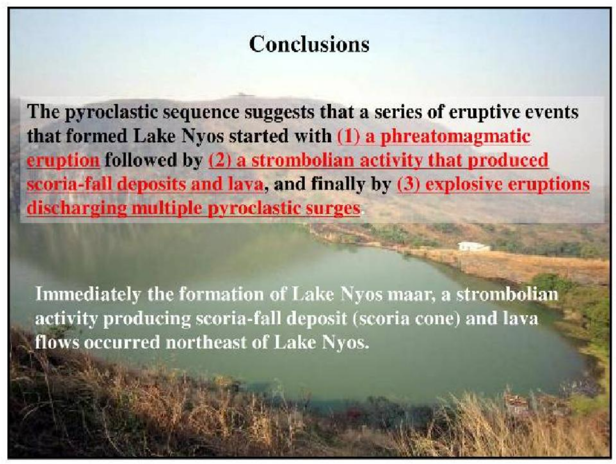



Well-stratified fallout tephra layers
A section 4 km NW of Lake Nyos
Distal facies of well-stratified surge deposits?


Scoria-fall deposit overlying surge deposits
Scoria-fall deposit (Unit 4)
Reworked surge deposit (Unit 3)


Scoria-fall deposit (Unit 4)
Reworked surge deposits (Unit 3)


Lake Njupi and scoria cone producing lava flows
Scoria cone located NE of Lake Nyos is probably the source of the scoria-fall deposit (Unit 4) overlying stratified surge deposits (Unit 3).
Therefore, the scoria cone was formed immediately after the formation of Lake Nyos maar?


Conclusions
The pyroclastic sequence suggests that a series of eruptive events that formed Lake Nyos started with (1) a phreatomagmatic eruption followed by (2) a strombolian activity that produced scoria-fall deposits and lava, and finally by (3) explosive eruptions discharging multiple pyroclastic surges
Immediately the formation of Lake Nyos maar, a strombolian activity producing scoria-fall deposit (scoria cone) and lava flows occurred northeast of Lake Nyos.

# Geochemistry of volcanic rocks in Lakes Nyos and Monoun, including other lakes of the Oku Volcanic Group (OVG) on the Cameroon Volcanic Line

A.N.E. **Asaah**[1*] T. **Yokoyama**[1], F.T. **Aka**[2], T. **Usui**[1], T. **Kuritani**[3], M.J. **Wirmvem**[4], T. **Ohba**[4]

## 1. INTRODUCTION

The Oku Volcanic Group (OVG) is one of the major volcanic centres along the continental sector of the Cameroon Volcanic Line (CVL, Fig. 1a)[1,2]. It host the infamous Lake Nyos that erupted tons of $CO_2$ gas killing 1750 people and over 3000 cattle. **However, the nature of the mantle beneath the OVG is still poorly constrained.** ***In this study, we use combined trace elements and Sr-Nd-Pb isotope evidence to characterize the mantle components involved in the generation of OVG magmas.***

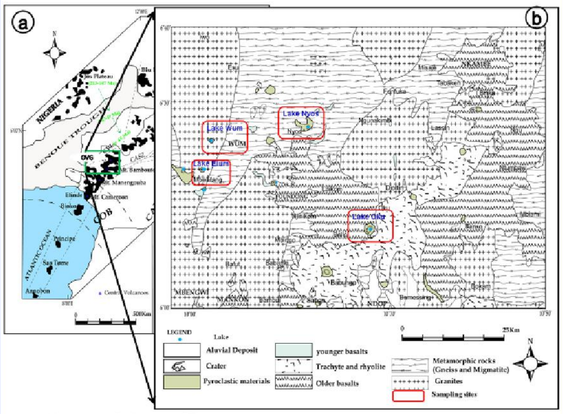



*Figure 1. Geologic map of the OVG*

**Volcanoes in the OVG cuts through Precambrian basement rocks of granitic composition** (Fig. 1b). Most alkali basalts host peridotite and crustal xenoliths. Large peridotite blocks of about 15 cm diameter are observed in the Nyos volcano.

## 2. Materials and methods

- Samples from the Lakes Nyos, Wum, Elum and Oku were analysed for **major elements, trace elements (37) and Sr-Nd-Pb isotopes (17) at TiTech**.
- Literature data for Isotopes in the OVG from Asaah et al., 2014 were used for comparison.

## 3. Results and Discussion

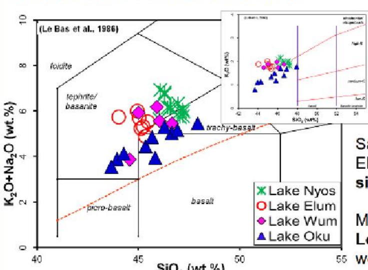



*Figure 2. TAS classification diagram*

### 3.1. Classification

Samples are classified as **basanite, basalt & trachy-basalt (Fig. 2)**

Samples from Lakes Nyos, Elum and Wum show much **similarity**

Mg# = 44 – 63

**Low Mg#** suggest the lavas were not derived from primary magma

### 3.2. Trace elements

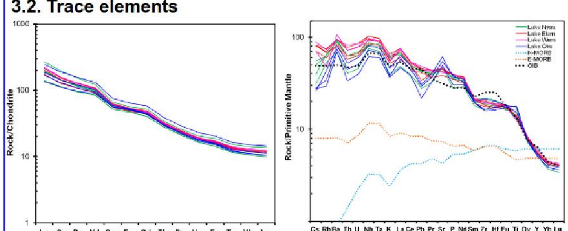



*Figure 3. a) CI normalized REE pattern and b) PM normalized multi-element diagram*

Significant HREE fractionation over LREE (Fig. 3a) with mean **$(La/Yb)_N$ of 15.5.**

Samples show patterns **akin to OIB** in PM normalized diagram (Fig. 3b). Depletions in HREE indicate the **presence of residual garnet in the source.**

### 3.1. Fractional Crystallization

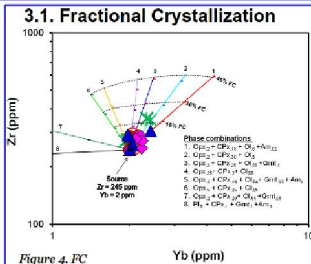



*Figure 4. FC*

Dominant minerals are Ol. Cpx, Opx. and Grnt. Insignificant Plg. fractionation

### 3.1. melting

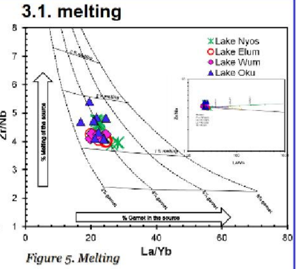



*Figure 5. Melting*

<2% partial melting of a mantle lherzolite with <6% garnet

### 3.3. Nature of Mantle component: DMM, FOZO, EM etc

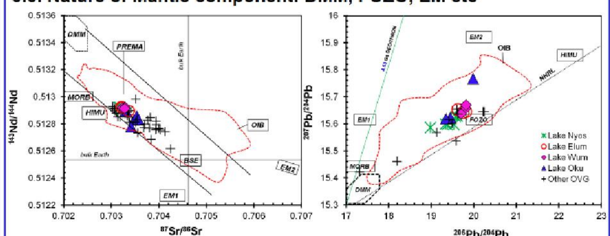



*Figure 6. a) $^{143}Nd/^{144}Nd$ vs. $^{87}Sr/^{86}Sr$, b) $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$*

Samples plot within the **quadrant of the bulk silicate Earth** (BSE, Fig. 6a) and on the **right of the Northern Hemisphere Reference Line** NHRL (Fig. 6b)[3].

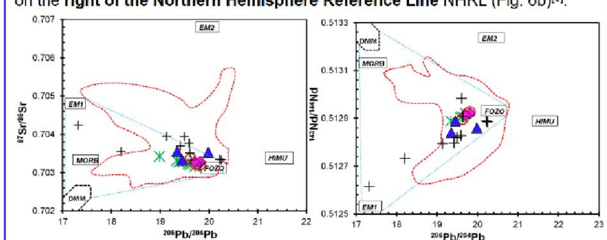



*Figure 6. c) $^{87}Sr/^{86}Sr$ vs. $^{206}Pb/^{204}Pb$, d) $^{143}Nd/^{144}Nd$ vs. $^{206}Pb/^{204}Pb$*

Patterns in Figs. 6c & d are suggestive of mixing of the **DMM and FOZO** with **involvement of a weak EM1** component [4]. However, the source of EM1 signature is still debated[5,6,7].

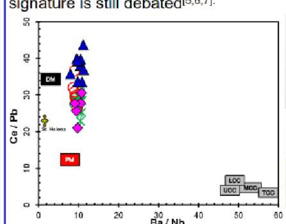



*Figure 7. Ce/Pb vs. Ba/Nb*

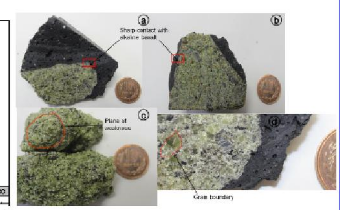


*Figure 8 . Mantle xenoliths from Lakes Nyos, Elum and Wum*

Trace element ratios **preclude significant role of crustal material** in the source of EM 1 component (Fig. 7). Sharp planar facets seen in xenoliths (Fig. 8) testify to brittle deformation in the lithospheric mantle. This enhance movement of fluids within the upper mantle. Evidence of mantle metasomatism in the OVG has been indicated by the **presence of hydrous minerals** in peridotite xenoliths from the Nyos volcano.

## 4. Conclusion:

- All lavas were derived from a **similar mantle source** with <6% residual garnet.
- Observed variations are due to differences in **depth of melt generation and lithospheric** thickness.
- Isotope compositions indicate **mixing of DMM and FOZO with the involvement of a weak EM1** signature resulting from metasomatism of the SCLM.
- the metasomatic fluids was rich in volatiles including $CO_2$.
- Planes of weaknesses in peridotite xenoliths influence fluid migration within reservoirs.

**References:** [1]Fitton and Dunlop, 1985, EPSL, 72, 23-38, [2]Marzoli et al., 2000. J.Petro.,41, 87-109 [3]Hart, S.R., 1984. Nature, 309, 753-757, [4]Zou et al., 2000. Chem. Geol. 171, 33 – 47, [5]Lustrino and Dallai, 2003. DOI: 10.1127/0077-7757/2003/0179-0085, [6]Willibold and Stracke, 2010, Chem. Geol. 276, 188-197. [7]Stracke et al., 2005. G3, 6, DOI: 10.29/2004GC000824

IG25-A008

# Preliminary results from the Lakes Monoun and Nyos climate stations (Cameroon)

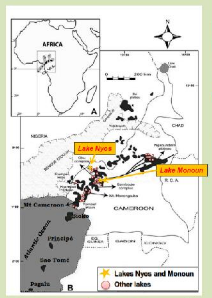
**Djomou B. Serges L.**[1], Gregory Tanyileke[1], Festus T. Aka[1], Takeshi Ohba[2], George Kling[3], Wilson Fantong[1], Minoru Kusakabe[4], William Evans[5], Yutaka Yoshida[6], Issa[1,2], J.V. Hell[1]
Correspondence to: Djomou B. Serges L., serges.djomou@yahoo.fr

[1]Institute for Geological and Mining Research (IRGM), Yaoundé, Cameroon - [2]Tokai University, Japan - [3]University of Michigan, USA - [4]University of Toyama, Japan - [5]U.S. Geological Survey, USA - [6]Yoshida Consulting Engineer Office Morioka, Japan

## 1. Background

- Over 40 lakes are located along the Cameroon Volcanic Line (CVL) .
- The phenomenon of lake-overturn is a common feature of some of them independent of size and depth.
- Gas explosions in Lakes Monoun (1984) and Nyos (1986), killed ($CO_2$ asphyxiation) about 1800 people and thousands of livestock.
- Degassing pipes installed in Lakes Nyos (2001 & 2011) and Monoun (2003 & 2006).

| Lake | Timing of reported events | Consequence |
|---|---|---|
| Monoun | August 1984 | Change in lake color and 37 people killed |
| Nyos | August 1986 | Change in lake color,1746 people and > 3000 livestock killed with about 3500 people displaced |
| Manengouba-female | February 1992 | Change in lake color and loss of aquatic life |
| Enep | July 2005 | Change in lake color and loss of aquatic life |
| Barombi Mbo | 1943, 1959 and August 2012 | Change in lake color and loss of aquatic life |
| Bambuluwe | Legend | Change in lake color and loss of aquatic life |
| Njupi | Yearly | Change in lake color |



*Location of Lakes Nyos and Monoun along the CVL*

- Two scientific hypotheses have been proposed for the origin of the Lakes Monoun and Nyos gas eruptions:
1) The volcanic hypothesis (Tazieff et al., 1987)
2) The limnic hypothesis (Sabbroux, 1987)
- Timing of reported events, suggests a possible role of climate in their trigger.

**Unfortunately, there has yet been no comprehensive investigation of this climate-driven overturn of lakes on the CVL**

*Photo of Lake Nyos before and after the 1986 eruption*

## 2. Data acquisition

Two new climate stations were installed at Lakes Nyos and Monoun (June 2012 and January 2013 respectively)

Each station measures and records the following meteorological parameters every 20 minutes:

- air temperature, relative humidity,
- wind speed/direction,
- incoming/outgoing solar radiation,
- barometric pressure
- rainfall

Also measured at two depths in each lake (Nyos: 5 m & 198 m; Monoun: 5 m & 91 m) are:

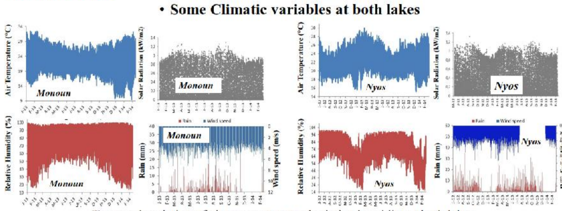
- water temperature,
- conductivity,
- total dissolved gas pressure

Here we present the results of preliminary data obtained at both stations from June 2012 to March 2014

*The two flaoting climate stations at Lakes Nyos and Monoun*

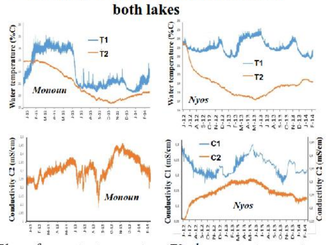
## 3. Results

- **Some Climatic variables at both lakes**



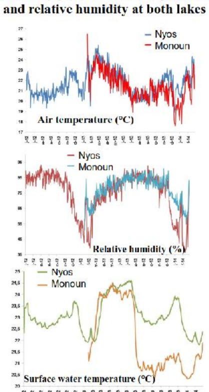
Temporal variation of air temperature and relative humidity at both lakes

- **Variability of some water parameters at both lakes**



*T1: surface water temperature; T2: deep water temperature*
*C1: surface water conductivity; C2: deep water conductivity*

- **Mean daily air & water temperatures, and relative humidity at both lakes**




*The data used for this study was generated within the framework of the SATREPS-NyMo project titled "Magmatic Fluid Supply into Lakes Nyos and Monoun and Mitigation of Natural Disasters through capacity building in Cameroon", jointly funded by the Governments of Japan and Cameroon (2011-2016).*

## 4. Discussion

***Seasonal variation of the climate***

Seasonal variation and similar patterns of air temperature, relative humidity, wind speed and barometric pressure at the both lakes, essentially due to seasonal movements of the Inter-Tropical Convergence Zone (ITCZ) that shapes the climate of the whole region.

***Water temperature***

Surface water temperature at both lakes shows:

i- two periods of cooling of surface water due to the movement of moisture loaded cool air masses from December to February (northern hemisphere winter) and the peak rainy season coupled with the effects of southern hemisphere winter

ii- a pronounced warming from March to May due to the warmest air temperatures coming out of the dry season.

The visible effect of climate observed on the epilimnion is not quite visible within the hypolimnion.

***Conductivity of water***

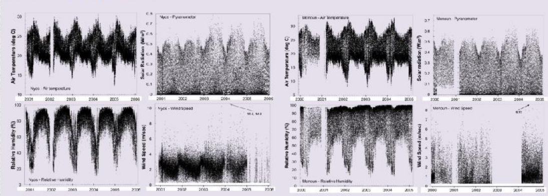
Current surface water conductivity is higher compared to observed values prior to upstart of the degassing process. This is due to input of charged deeper water resulting from degassing.

Its annual trend is induce by the annual variation of the surface water temperature.

At Monoun, a pronounced decreasing trend of conductivity who start in November is due to the reanimation of one pipe.


*A mini-fountain of bubbly flow at Lake Monoun, December 2013*

***Previous climate data***



- Similar behavior of climate is observed on previous climate data at both lakes
- No change in the climate since the start of degassing at the both lakes

## 5. Conclusions

1) The variations of climate and temperature/conductivity of surface water of both lakes is induced by seasonal movements of the Inter-Tropical Convergence Zone (ITCZ)
2) Surface water conductivity is also influenced by degassing process
3) No major observable change between the new (2012-2014) and previous climate data (1999-2006)
4) These preliminary results will be improved by continuous monitoring of theses climatic variables

IG25-D4-PM2-P-007

D4-PM2: 16:00 - 18:00, Thursday, July 31, 2014

# Development of the Measuring Method of Dissolved $CO_2$ Concentration in Cameroonian Volcanic Lakes using Sound Velocity of Lake Water

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## Introduction

### Limnic Eruptions in Lakes Nyos and Monoun

Limnic eruptions in 1984 and 1986 at Lakes Monoun and Nyos in Cameroon were caused by sudden degassing of magmatic $CO_2$ dissolved in the lake water. (e.g., Sigurdsson et al., 1987, Kling et al., 1987)

The disasters killed about 1800 residents around the lakes.

To prevent further disasters, monitoring of $CO_2$ in the lake waters is essential.

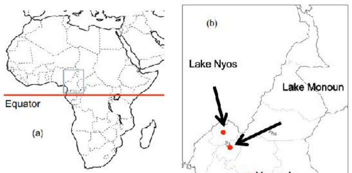


Fig. 1 (a) Location of Cameroon in Africa (b) Location of capital Yaounde, Lake Nyos, and Lake Monoun


Fig. 2 Degassing pipe of Lake Nyos.

### Sound Velocity (SV) of Solutions

- SV depends on material species and their concentrations
- Almost linear at low concentration
- Total change of plural salts is sum of those of each salts

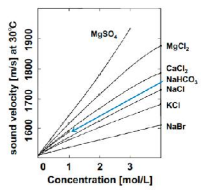


Fig. 3 Change of water sound velocity by solutes. (Weissler and Del Grosso, 1951)

### Why Sound Velocity (SV) Changes ?

Sound velocity of water ($v$) is expressed as equation (1). Configuration of water molecules around polar ions/ molecules may become rigid, and the compressibility of solution may decrease.

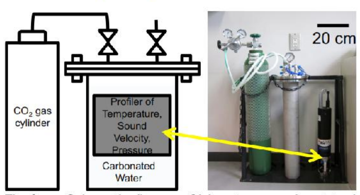
$$v = \frac{1}{\sqrt{\rho K_{ad}}} \quad \dots (1)$$

$\rho$ : Density
$K_{ad}$ : Compressibility

## Goal of This Study

To obtain the relation between sound velocity of water and $CO_2$ concentration of water and develop the new monitoring method for $CO_2$ in Cameroonian volcanic lakes.

## Laboratory Experiment




SV sensor, thermometer, and pressure sensor were placed in a cylindrical stainless vessel filled with pure water. Then, high-pressure $CO_2$ gas was injected into the vessel to produce carbonated water to measure SV under various $CO_2$ concentration.

Fig. 4 Schematic diagram of laboratory experiment to determine $K_1$.

$$\Delta V = k_1[CO_{2(aq)}] + k_2[HCO_3^-] \quad \text{(negligible)}$$

$\Delta V = V - V_{PW}$

$V_{PW} = 0.0002T^3 - 0.0532T^2 + 4.959T + 1402.84 + (0.000001T^2 + 0.0003T + 0.163) \times 9.87P$

V : measured sound velocity [m/s]

$V_{PW}$ : estimated sound velocity of pure water at same temperature T [°C] and pressure P [MPa] Based on Lubbers and Graaff (1998) and Chemical Society of Japan (1966)

### Results of laboratory experiment

The relation between $\Delta V$ and $CO_2$(aq) concentration was obtained.

$\Delta V = k_1[CO_{2(aq)}]$ $\quad k1 = 0.019$

$k_1 = k(T) = 0.033(\pm 0.003) - 0.0005(\pm 0.0001)T$

T : [°C]

k(T) : [m kg s$^{-1}$ mmol$^{-1}$]

## Field Survey

Nyos: 4-7 March 2012, 28 Feb. - 2 March 2014.
Monoun: 9-10 March 2012, 4-5 March 2014.


Fig. 5 The operation of the profiler at lake Nyos.

### Results of field survey

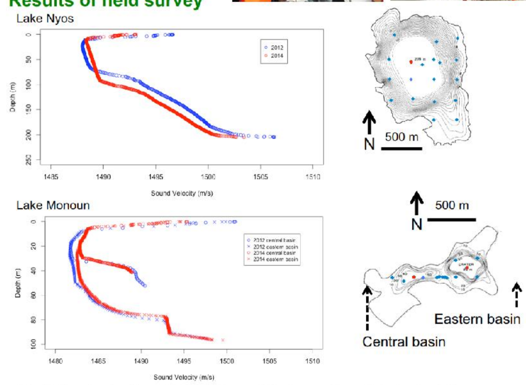


Fig. 6 Sound velocity vertical profiles and their sampling points (red point).

The results at Lake Nyos indicate the thickness of high $CO_2$ concentration layer at the bottom had reduced in comparison with the profile in 2012. The results at Lake Monoun indicate that (1) the sound velocity profiles at Lake Monoun are different between the central and eastern basins and (2) both profiles had slightly changed from 2012 but the depths where the profile branches are almost the same between the data in 2012 and 2014.

## Data analyses

[total $CO_2$] = [$CO_{2(aq)}$] + [$HCO_3^-$] + [$CO_3^{2-}$] (negligible)

$\Delta V = k_1[CO_{2(aq)}] + k'_2[Fe(HCO_3)_2] + k'_3[Mg(HCO_3)_2] + \dots$

$\Delta V = k_1[CO_{2(aq)}] + k_2[HCO_3^-] \quad \dots (2)$

$\Delta V = SV_{sample} - SV_{pure\ water}$ (Belogol'skii et al. (1999) (Accuracy : 0.2 m/s))

Depth profiles of $SV$, pressure, $T$, and electric conductivity of Lakes Nyos and Monoun were measured in the field survey.

Using these data, the profiles of [$CO_2$] determined by the syringe method, and the correlation between [$HCO_3^-$] and electric conductivity (Kusakabe et al., 2008), $k_2$ was determined by the equation (2).

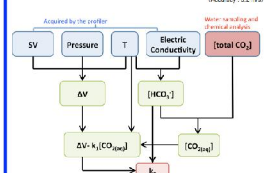


Fig. 7 Flow diagram showing how to determine $k_2$.

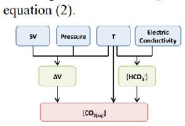


Fig. 8 Flow diagram showing how to estimate [$CO_{2(aq)}$] using the obtained $k_2$.

## Conclusions

- Sound Velocity (SV) is sensitive to $CO_2$ concentration and easy to measure, and therefore our multi-point measurement could discover the high $CO_2$ layer in the west part of Lake Monoun.
- SV Method was proposed assuming $\Delta V = k_1[CO_2] + k_2[HCO_3^-]$.
- $k_1$ was determined by the laboratory experiments as $k_1 = 0.033 - 0.0005\ T$ (m kg /s /mmol).
- $k_2$ was determined from field data as $k_2 = 0.091$ (Nyos), 0.067 (Monoun) in 2012, $k_2 = 0.079$ (Nyos), 0.054 (Monoun) in 2014.
- The difference of $k_2$ would be caused by the difference of cation concentrations in the water and the stability of $k_2$ would mainly determine the accuracy of SV method.

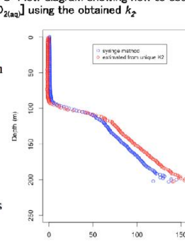


Fig. 9 Comparison between $CO_2$ concentration obtained by syringe method and those estimated from the unique $k_2$ in case of Nyos 2014.

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**Acknowledgement:**
This study is supported by Science and Technology Research Partnership for Sustainable Development (**SATREPS**)

SATREPS
Science and Technology Research Partnership for Sustainable Development Program

# Appendix IV
## Some bibliography acquired in Nagoya University on geochemical mapping

Asahara Y, Tanaka T, Kamioka H, Nishimura A (1995). Asian continental nature of $^{87}Sr/^{86}Sr$ ratios in north Central Pacific sediments. Earth Planet Sci Lett. 133, 105-116.

Asahara Y (1999). $^{87}Sr/^{86}Sr$ variation in north Pacific sediments: a record of the Milankovitch cycle in the past 3 million years . Earth Planet Sci Lett. 171, 453-464.

Mikoshiba M.U, Imai N, Terashima S, Tachibana Y, Okai T (2006). Geochemical mapping in northern Honshu, Japan. Applied Geochemistry 21, 492–514.

Ohta A, Imai N (2011). Comprehensive Survey of Multi-Elements in Coastal Sea and Stream Sediments in the Island Arc Region of Japan: Mass Transfer from Terrestrial to Marine Environments, Advanced Topics in Mass Transfer, Prof. Mohamed El-Amin (Ed.), ISBN: 978-953-307-333-0, InTech, Available from: http://www.intechopen.com/books/advanced-topics-in-mass-transfer/comprehensive-survey-ofmulti-elements-in-coastal-sea-and-stream-sediments-in-the-island-arc-region.

Ohta A, Imai N, Terashima S, Tachibana Y, Ikehara K, Takeshi Nakajima T (2004). Geochemical mapping in Hokuriku, Japan: influence of surface geology, mineral occurrences and mass movement from terrestrial to marine environments. Applied Geochemistry 19, 1453–1469.

Ohta A, Imai N, Terashima S, Tachibana Y (2005). Application of multi-element statistical analysis for regional geochemical mapping in Central Japan. Applied Geochemistry 20, 1017–1037.

Ohta A, Imai N, Terashima S, Tachibana Y, Ikehara K, Okai T, Ujiie-Mikoshiba M, Kubota R (2007). Elemental distribution of coastal sea and stream sediments in the island-arc region of Japan and mass transfer processes from terrestrial to marine environments. Applied Geochemistry 22, 2872–2891.

Ohta A, Imai N, Terashima S, Tachibana Y, Ikehara K, Katayama K, Noda A (2010). Factors controlling regional spatial distribution of 53 elements in coastal sea sediments in northern Japan: Comparison of geochemical data derived from stream and marine sediments. Applied Geochemistry 25, 357–376.

Ohta A, Imai N, Terashima S, Tachibana Y (2007). Preliminary study for speciation geochemical mapping using a sequential extraction method. Bulletin of the Geological Survey of Japan 58 (7/8), 201-237.

Ortiz E, Roser B. P (2006). Major and trace element provenance signatures in stream sediments from the Kando River, San'in district, southwest Japan. Island Arc 15, 223–238.

Reimann C, Matschullat J, Birke M, Salminen R (2010). Antimony in the environment: Lessons from geochemical mapping. Applied Geochemistry 25, 175–198.

Tanaka T, Kawabe I, Yamamoto K, Iwamori H, Hirahara Y, Mimura K, Asahara Y, Minami M, Ito T, Dragusanu C, Miura N, Aoki H, Ohta A, Togami K, Toriumi T, Matsumura Y, Sakamibara T, Tanimizu M, Mitutani Y, Miyanaga N, Murayama M, Takayanagi Y (1996). Geochemical mapping of the northern area of Toyota City, Aichi Prefecture, central Japan: District chemical characteristics of stream sediments between granitic and sedimentary rock areas. J Earth Planet Sci Nagoya Univ., 43, 27-47.

## *Appendix V*

Program of activities and places visited during my visit to Japan (25 July – 11August 2014)

| Date | From - To | Activity |
|---|---|---|
| Friday 25 July | Yaoundé to Istanbul (TK 669) | Travel |
| Saturday 26 July | Istanbul to Tokyo (TK 050) to Sapporo | |
| Sunday 27 July | | Stay at APA Hotel Sapporo |
| Monday 28 July | AOGS Meeting Sapporo | Mengnjo oral presentation |
| Tuesday 29 July | AOGS Meeting Sapporo | Participation in various sessions |
| Wednesday 30 July | AOGS Meeting Sapporo | Participation in various sessions |
| Thursday 31 July | AOGS Meeting Sapporo | Asobo, Djomou & Saiki poster presentations |
| Friday 1 August | AOGS Meeting Sapporo | Kusakabe, Aka, Ohba, Issa, & Miyabuchi oral presentations |
| Saturday 2 August | Sapporo to Tokyo | Stay in Toyoko Inn Hotel near Ueno Station |
| Sunday 3 August | Tokyo | Start report writing (missed trip to Kyoto) |
| Monday 4 August | Tokyo – Nagoya - Tokyo | Meet Drs. Asahara, Minami at Nagoya Uni. |
| Tuesday 5 August | TIT | Meet Prof. Yokoyama and Mr. Asobo |
| Wednesday 6 August | Tokyo – Tokai University | Meet and update Prof. Ohba about my activities so far |
| | Tokyo – Ibaraki | Stay at Ibaraki University guest house |
| Thursday 7 August | Ibaraki University | Work in Dr. Hasegawa's laboratory |
| Friday 8 August | Ibaraki University | |
| Saturday 9 August | Ibaraki University | |
| Sunday 10 August | Ibaraki – Narita – Istanbul (TK 053) | Travel |
| Monday 11 August | Istanbul – Yaounde (TK669) | |