Case Teaching Notes for "A Killer Lake"

Thomas Horvath, Biology Department, SUNY College at Oneonta

Introduction / Background

In this case study, students are presented with data on a particular lake that they must synthesize in order to determine the cause of an event that occurred in 1986 in Cameroon, Africa. Because this case is a dramatization of an actual event (all the names used in the case are fictitious), the horrifying result—over 1,700 people dead—is the intended "hook" into the case material. Thus, I have intentionally played up the emotions associated with the deaths that occurred.

The case is intended for use in a limnology or an aquatic biology course. Ideally, students would have been introduced to a few key concepts about lakes, including lake formation, thermal stratification (particularly in meromictic lakes), and dissolved gases. This background knowledge allows students to put together the necessary pieces of information. Thus, in a limnology course that follows the common textbook chapters (e.g., Wetzel, 2001; Goldman and Horne, 1994; Kalff, 2001), students learn about geomorphology/basin morphology in the first few lectures, then move on to other physical topics (water properties, movement, light and thermal aspects). If this progression is followed, this case could be used after thermal aspects are covered. Conversely, the case could be used to introduce any of these concepts, in which case the students would read the case study without any previous exposure to the limnological concepts involved.

The original intent of the case was to introduce and reinforce the concepts of thermal stratification and use students' curiosity about this event to get them to think about how layers of water develop. The case could also be extended to cover or review other concepts such as lake formation (in this case, volcanism as a lake-forming process) or gas solution (in this case, carbon dioxide solution). The case could also be used throughout a limnology course because it deals with many aspects of the subject: lake origins, thermal stratification, gases, water movements, and applied limnology (remediation of problems). Instructors can introduce the case early in a course and refer back to it when each new topic comes up. The case also allows students to synthesize different types of limnological data to solve a serious problem.

Objectives

Upon completion of this case, students should be able to:

- List the types of lakes that can be formed through volcanic activity and identify the characteristics of such lakes.
- Distinguish between holomictic and meromictic lakes.
- Describe the limnetic conditions necessary for meromixis to form in a lake.
- Identify the vertical zones of a meromictic lake.
- List the possible dissolved gases associated with lakes.
- List the sources of and factors affecting the quantity of dissolved gases in lakes.

Classroom Management

The case is intended to be covered in a typical 50-minute lecture period but could be expanded into a 75-minute lecture period. Because the case narrative is not particularly long, it can be handed out for students to read in class. My limnology courses never have more than five students, but if your class is large enough, small groups may be used.

Students are given approximately seven to 10 minutes to read the case. Then, with the instructor's help, they are asked to identify the facts in the story. Board work from the instructor becomes important here. I recommend that you list the facts on the board under a heading such as "What We Know." If students are having trouble generating the facts, the instructor may ask leading questions, such as:

- In what part of the world is the lake located?
- What is this particular region's dominant geologic characteristic?
- Besides the villagers, what was affected by the event?
- What was the weather like at the time of the event?
- Why are the elders focusing on the lake as a cause?
- What samples were taken by the team of limnologists?
- How deep is the lake?
- Describe the water that came from the lake's depth.
- Describe what the lake looked like when the limnologists arrived.

After about 10 minutes, ask the students what data they want to have that will help them determine the cause of the event. Ideally, they will ask for the limnological data being collected, specifically the vertical profile data. The instructor can then hand them the graphs of temperature, dissolved oxygen, pH, and conductivity (see handouts below) depending on what variable they want to see; *do not give out data that they have not asked for, however.* This is the point in the class where the instructor will see if students are able to connect various types of concepts to actual data (connecting theoretical and applied concepts).

- **Handout I**—Continuous Temperature Profile in Lake Nyos and Lake Monou, November 1999
- **Handout II**—Selected Data on Water Chemistry for Lake Nyos, November 1999
- **Handout III**—Temperature and conductivity profiles
- **Handout IV**—Analytical results of dissolved chemical components except carbonate species, 17–18 December 1988
- **Handout V**—Concentrations of CO_2 species, hydrogen ion (pH), and TDS, 17–18 December 1988

Give the students several minutes to look at the data, and then ask them for their interpretations. The instructor may want to start another list on the board under the heading "Limnological Data Interpretation." If students do not respond without prompting, ask questions such as:

- Is the lake stratified?
- What type of stratification do the data suggest?
- Which data are you using to determine this?
- What do the pH data tell you?
- What was the significance of the lake's color?
- What is the origin of the gas in the deepest water layer?

Depending on time, each answer could be followed up with probing questions to make the students reveal that they understand (or don't) the physical properties involved. For example, the instructor can ask, "What type of stratification do the data suggest?" to which students would correctly answer, "Meromictic stratification." The instructor can ask, "How is meromictic stratification maintained?" to which the students would correctly answer, "Through density differences." The instructor can ask, "What is causing the density difference in that deepest layer?" to which the students would correctly answer, "Often chemicals dissolved in the water, such as salts, increase the density." Or the instructor can ask, "What is maintaining the density in this situation?" to which the students would correctly answer, "Probably something to do with the gas that is bubbling out of solution, likely very high carbon dioxide concentrations. Soda water is denser than regular water."

Assessing the limnological data can take the remaining class period, but leave at least 10 minutes for a conclusion.

To conclude, when you feel that the students have enough information present on the board, ask the million dollar question: *What happened here? Gases built up in the hypolimnion due to the meromictic stratification, but why did it bubble out of solution and eventually "burp" a huge cloud of carbon dioxide?* If students are having trouble, ask them: *Why is this event called a limnic eruption, and a violent one at that?*

Possible Follow-up Assignments

The assignments described below would be given to students to do outside of class. The instructor may devote another class period to discussing their answers, as both assignments can be used to further discuss limnology topics (tectonic lake versus glacial lake limnology). Assignment 2 can be used to bring in the concepts of applied limnology and engineering.

> ***Assignment 1:***
> Have students find other regions of the world where lakes are formed predominately from a type of geologic process. For example, the big lakes of the African Rift Valley (Victoria, Tanganyika, Nyasa) are mostly of tectonic origin; they are all graben* lakes. How does the origin of lakes affect limnological properties? Give specific details and examples to support your answers.
>
> ***Assignment 2:***
> Given the fact that follow-up sampling indicated that gases are continuing to build-up in the lake and the very possible repeat of this tragic event, how might scientists and engineers help the people around Lake Nyos? [Instructors can refer to the Answer Key for information on how the Lake Nyos problem was solved.]

Answer Key

Answers to the questions posed in the case study are provided in a separate answer key to the case. Those answers are password-protected. To access the answers for this case, go to **the key**. You will be prompted for a username and password. If you have not yet registered with us, you can see whether you are eligible for an account by reviewing our **password policy and then apply online** or write to **answerkey@sciencecases.org.**

References

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Further Reading

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End Note

* A graben is the depression left by a shift in land due to tectonic movements. Graben lakes are lakes formed by the filling in of these depressions.

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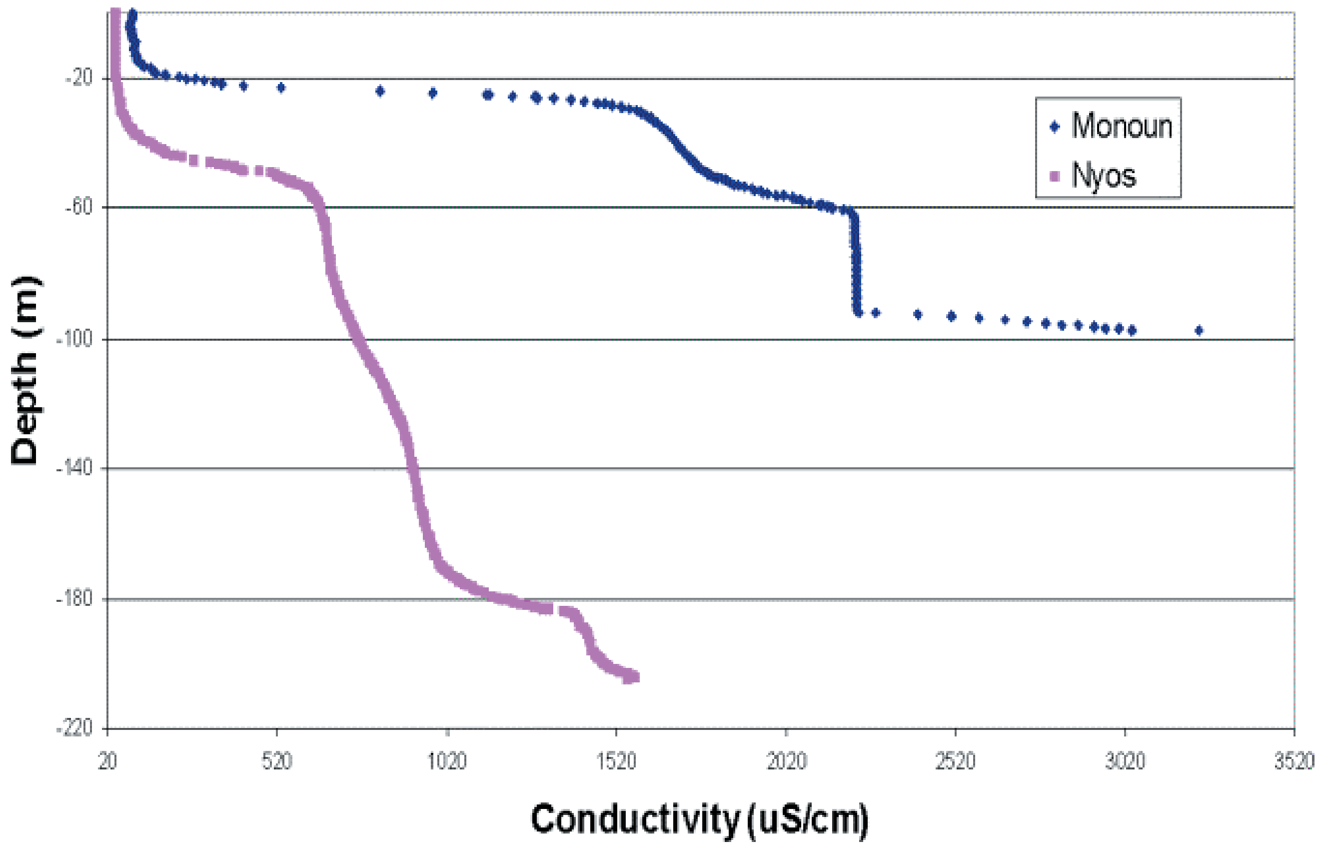
Handout I—Continuous Temperature Profile in Lake Nyos and Lake Monou, Nov. 1999



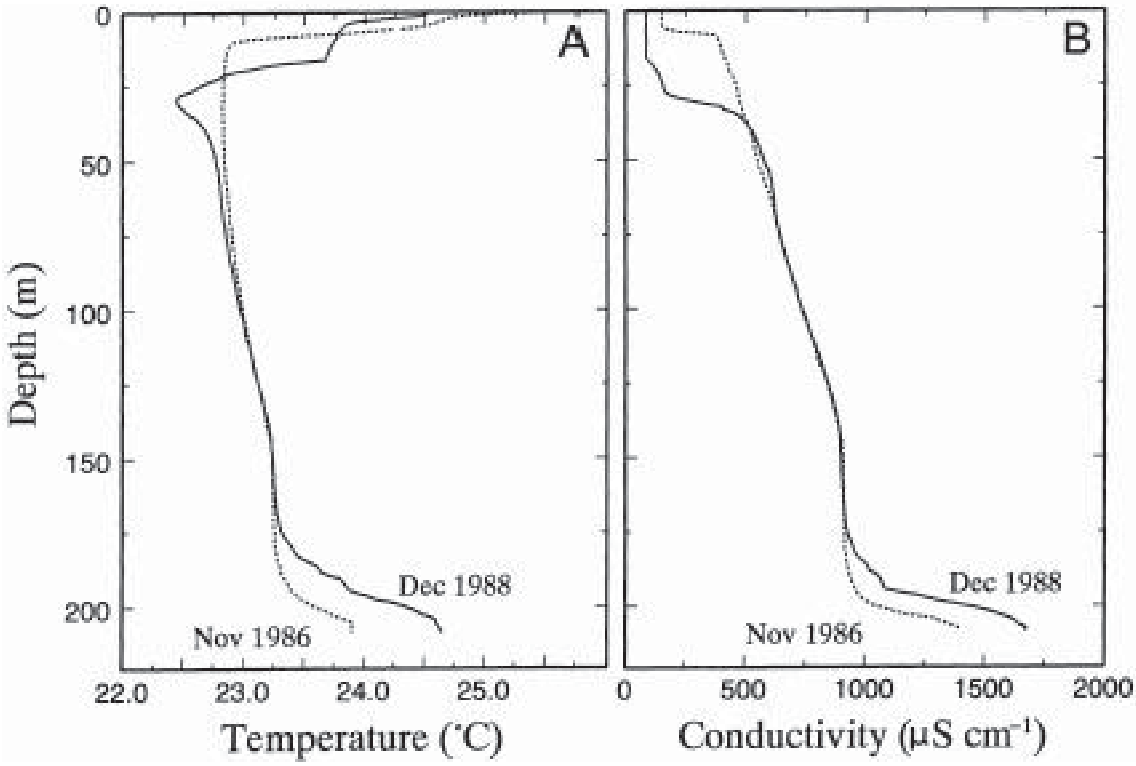
Data from "The Nyos-Monoun Degassing Program: Preliminary Report of the U.S.-OFDA Technical Project, October–November 1999." 9 November 1999, Yaounde, Cameroon. G. Kling, W. Evans, G. Tanyileke, M. Kusakabe, and Y. Yoshida.
http://www.biology.lsa.umich.edu/~gwk/research/nm1999_report.htm.

Handout II—Selected Data on Water Chemistry for Lake Nyos, November 1999

Depth (m)	Conductivity (µ S/cm)	pH	Bicarbonate (mg/L as HCO3-)
0.5	39	7.40	23
1	40	7.06	24
10	41	6.90	23
20	45	7.01	27
30	64	6.19	38
40	129	5.80	78
198	1460	4.81	1045

Data from "The Nyos-Monoun Degassing Program: Preliminary Report of the U.S.-OFDA Technical Project, October–November 1999." 9 November 1999, Yaounde, Cameroon. G. Kling, W. Evans, G. Tanyileke, M. Kusakabe, and Y. Yoshida. **http://www.biology.lsa.umich.edu/~gwk/research/nm1999_report.htm**.

Handout III—Temperature and conductivity profiles



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Handout IV—Analytical results of dissolved chemical components except carbonate species, 17–18 December 1988

Concentrations are given in mmol kg^{-1} of the sample water after exsolution of excess CO_2, during storage. Numbers in the second row for each depth indicate analytical error with respect to the last digit(s) of the value in the first row.

Depth (m)	Mg^{2+}	Fe^{2+}	Ca^{2+}	Na^{+}	NH_4	K^{+}	Mn^{2+}	Cl	NO_1	NO_2	SO_4	Si	O_2	TDS
Inflow water*	0.058	0.007	0.063	0.14	—	0.082	0.0002	0.016	—	—	0.002	0.435	—	—
0	0.245	0.0003	0.147	0.146	0.002	0.032	0.0002	0.005	0.000	0.000	0.002	0.243	7.0	94
	1	0	2	1	0	1	0	0			0	1	1	1
10	0.248	0.0004	0.147	0.153	0.002	0.034	0.0002	0.005	0.000	0.000	0.001	0.242	7.0	95
	1	0	1	3	0	1	0	0			0	1	1	1
20	0.359	0.0011	0.203	0.186	0.000	0.041	0.0009	0.005	0.022	0.000	0.001	0.274	0.7	127
	1	2	2	1		1	1	0	1		0	1	1	1
30	0.601	0.0056	0.322	0.255	0.042	0.053	0.0191	0.006	0.007	0.012	0.000	0.337	0.0	202
	2	1	3	1	3	3	1	0	0	0		1		2
50	1.43	0.894	0.710	0.482	0.068	0.095	0.0196	0.006	0.001	0.000	0.000	0.570	0.0	587
	2	6	6	13	1	2	1	0	0			4		7
75	1.63	1.01	0.794	0.543	0.240	0.098	0.0208	0.006	0.000	0.000	0.000	0.595		671
	2	1	6	14	18	2	1	0				4		9
100	1.87	1.18	0.904	0.605	0.268	0.106	0.0233	0.007	0.000	0.000	0.000	0.662	0.0	768
	3	1	8	13	21	1	1	0				9		11
125	2.16	1.40	1.037	0.694	0.331	0.124	0.0266	0.007	0.000	0.000	0.000	0.741	0.0	892
	7	2	7	12	6	1	2	0				10		17
150	2.34	1.52	1.115	0.745	0.369	0.133	0.0282	0.007	0.000	0.000	0.000	.780	0.0	964
	7	2	8	24	26	1	3	0				12		20
175	2.38	1.53	1.122	0.743	0.359	0.134	0.0281	0.007	0.000	0.000	0.000	0.794	0.0	973
	7	2	6	15	6	2	2	0				10		18
190	2.51	1.49	1.159	0.746	0.345	0.137	0.0263	0.008	0.000	0.000	0.000	0.840	0.0	994
	8	2	10	20	16	1	1	0				11		20
190†	2.71	1.69	1.28	0.829	—	0.150	—	—	—	—	—	0.869	0.0	1,093
200	3.73	2.28	1.73	1.10	0.436	0.198	0.0313	0.007	0.000	0.000	0.000	1.093	—	1,470
	11	3	2	4	34	2	3	0				11	0.0	32

* Taken from Kusakabe et al. 1989.

† Corrected for contammation of surface water wth the CTD conductivity-TDS relationship.

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Handout V—Concentrations of CO_2 species, hydrogen ion (pH), and TDS, 17–18 December 1988

Depth (m)	Temp. (°C)	Total CO_2	Free CO_2	HCO_3	pH	TDS (mg kg^{-1})
0	24.53	0.98*	0.03*	0.95 1	7.9 1	94 1
10	23.75	1.01*	0.04*	0.97 1	7.7 1	95 1
20	22.91	1.90*	0.58*	1.32 1	6.7 1	127 1
30	22.45	2.98*	0.77*	2.21 2	6.8 1	202 2
50	22.78	61 1	54*	6.72 8	5.42*	587 7
75	22.86	81 2	72*	7.76 11	5.35*	671 9
100	22.98	105 2	96*	8.89 13	5.28*	768 11
125	23.13	126 3	116*	10.35 21	5.26*	892 17
150	23.24	145 3	134*	11.22 25	5.23*	964 20
175	23.33	152–155*	141–144†	11.32 22	5.22*	973 18
190	23.80	222–241*	209–228†	12.73‡ 26	5.09–5.05*	1,093‡
200	24.37	433–500*	416–483†	17.19 40	4.91–4.84*	1,470 32

* Calculated assuming carbonate equilibria.

† Estimated assuming a linear correlation between TDS and free CO_2. Total CO_2 was given as a sum of the estimated free CO_2 and measured HCO_2 .

‡ Corrected for surface water contamination with the measured TDS and conductivity relationship.

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