Lake Kivu and its problems

A tribute to H. Damas, professor at University of Liège and explorer of Rwandan lakes, who wrote "les lacs du Ruanda et leurs problèmes" (Damas, 1953)

Résumé

Situé dans le Rift Est-Africain, le lac Kivu est depuis quelque temps l'objet d'une certaine attention médiatique, du fait que le Rwanda a commencé l'exploitation de l'énorme quantité de méthane dans ses eaux profondes à des fins de production d'électricité. Cette exploitation est souvent présentée comme une solution « win-win », du fait qu'elle contribuera à réduire le risque d'éruption gazeuse … mais qu'en est-il réellement ?

Cet article présente un résumé des recherches, notamment par des scientifiques belges, depuis le début du XXe siècle, qui ont permis de mettre en évidence la structure physique unique du lac Kivu et les énormes quantités de CH_4 et de CO_2 contenues dans les eaux profondes. La question des risques liés à ces gaz est envisagée, dans le contexte de l'exploitation du méthane, notamment pour l'écosystème des eaux de surface (« biozone » ou « mixolimnion »). Cet écosystème a par ailleurs été modifié par l'introduction d'un poisson, qui a permis le développement d'une pêcherie importante pour la population humaine locale. Dans ce contexte, bien que l'exploitation industrielle du méthane soit soumise à des règles bien définies, une surveillance de l'état de l'écosystème est nécessaire afin de vérifier que l'extraction du CH_4 n'est pas nuisible aux ressources du lac.

Abstract

Located in the East African Rift, Lake Kivu has attracted media attention for some time, as Rwanda has begun exploitation of the enormous amount of methane stored in its deep waters for production of electricity. This exploitation is often presented as a "win-win" solution, as it will contribute to reduce the risk of gas eruption …. but is that true?

This paper presents a summary of research, notably by Belgian scientists, since the beginning of the XXth century, which allowed to put in evidence the unique physical structure of Lake Kivu and the enormous amount of CH_4 and CO_2 contained in its deep waters. The issue of the risk linked to these gases is considered, in the context of methane exploitation, notably for the surface-water ecosystem ("biozone" or "mixolimnion") historically modified by a fish introduction which developed into a fishery of economic importance for the local human population. In this context, although the industrial methane exploitation is submitted to strict

rules, monitoring ecosystem status is necessary, to verify that CH_4 extraction is not detrimental to the lake resources.

Introduction

A bit of history: studies on Lake Kivu in the XXth century

Lake Kivu is one of the great lakes located in the Western branch of the East African Rift. These great lakes – from North to South: L. Albert, L. Edward, L. Kivu, L. Tanganyika and L. Malawi – are among the largest and deepest lakes on Earth, together containing more than 20% of its surface freshwater. They harbor a remarkable vertebrate (mainly fish) and invertebrate (e.g., mollusk, ostracod) diversity, with numerous endemic species, and have attracted interest from scientists worldwide.

Speke (1864), one of the famous explorers looking for the source of the Nile, first reported the existence of Lake Kivu, but the first European to see the lake was von Götzen (1895). Scientific investigation of the African great lakes began in the early XXth century with the 'Cambridge expeditions' (Cunnington, 1920), which pointed out that L. Kivu, contrary to the other lakes, presented a very low fish diversity, with only 23 species recorded at that time. The first comprehensive limnological studies were carried out by H. Damas - to whom this article is dedicated - in the 1930s. Damas (1937) was the first to describe the meromictic character of the lake, to establish its bathymetry and its unique thermal profile and to provide evidence of the presence of large amounts of dissolved gases and nutrients in the deep waters. Damas' work was remarkable in many respects: unlike most other scientists at the beginning of the XXth century who were largely motivated by making inventories of the flora and the fauna, Damas - a zoologist from the University of Liège, Belgium - was interested in investigating the conditions in which animals lived and developed. Among other things, his observations, combined with geological evidence, contributed to confirm that present Lake Kivu originated from volcanic eruptions in the Virunga mountain chain in the late Pleistocene, i.e. some 12,000 years ago. Damas understood the meromictic nature of the lake, i.e. separation between a surface mixed oxic layer, the mixolimnion, and the deep anoxic layer (fig. 1). He also understood that the stability of its water-column stratification was due to the increase in salinity below 70 m depth, but he could not fully explain the associated increase in temperature.

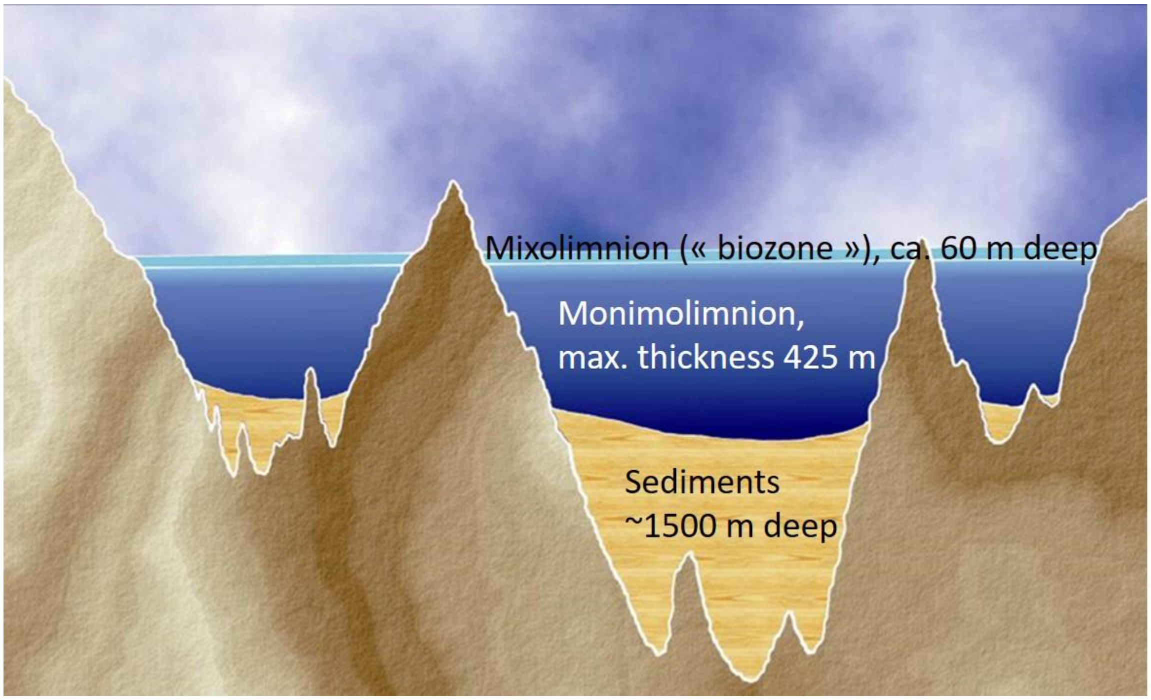

Fig. 1. A simplified view of the structure of the water column of Lake Kivu. Adapted from Sarmento (2006).

It were other Belgian scientists, Capart and Kufferath (1956) who identified the gases as carbon dioxide (CO_2, 73.4 %) and methane (CH_4, 24.8 %), with small amounts of hydrogen sulfide, nitrogen and argon. Schmitz and Kufferath (1955) estimated the total amount of methane to be 57 km^3, and proposed to exploit this enormous source of energy.

A subsequent Belgian expedition, the KEA (i.e. Kivu, Edward and Albert) mission led by André Capart, head of the 'Institut National des Sciences Naturelles', completed the data reported by the Damas' mission, with an emphasis on the littoral flora and fauna of the surface waters, particularly of invertebrates (Verbeke, 1957). Capart and others had practical objectives regarding the exploitation of the resources of the large lakes. They contributed to development of the pelagic fishery of Lake Tanganyika (Capart, 1959), and then promoted the introduction of the 'Tanganyika sardine' into the then fishless pelagic waters of Lake Kivu (Collart, 1960). The introduction was a success, as one of the two sardine species, *Limnothrissa miodon*, survived and adapted to Lake Kivu (Spliethoff et al., 1981), allowing the development of a pelagic fishery that since then has provided the local human population with a precious source of food. Another project of Capart and co-workers was to exploit the methane of the deep waters (Capart and Kufferath, 1956), and to increase the productivity of the fishery by releasing the nutrient-rich degassed waters into the surface waters. A small pilot plant for methane extraction was constructed by the Union Chimique Belge at Cap Rubona south of Gisenyi in 1962.

The scientific investigations that followed were led by American and German scientists and were devoted to understanding the unique physical structure of the lake and the processes leading to the formation of the gases in the anoxic deep waters (monimolimnion). Degens et al. (1973) and Tietze (1978, 1981) provided a detailed description of vertical profiles of temperature and chemical properties of the lake water. Particularly, a strong salinity increase between 255 and 262 m creates a density gradient, which is maintained by subaquatic springs entering the lake at the top of the gradient (Schmid and Wüest, 2012). The geochemists introduced the term 'biozone' to designate the 60 m deep surface waters, which are oxygenated through exchange with the atmosphere and phytoplankton photosynthesis, and supporting an ecosystem with various forms of life, as bacteria, phytoplankton, zooplankton and fish. The transition from the oxygenated surface waters to the anoxic deep waters is characterized by a redox gradient, where various biogeochemical processes supported by microbial communities take place, such as CH_4 and ammonium oxidation (Llirós et al., 2012). These processes control internal nutrient loading (of N, P, Si, see Pasche et al., 2012) from the deep to the surface waters which largely determine lake productivity, as well as greenhouse gas emissions to the atmosphere (Borges et al., 2011).

The killer lakes

As it contains very large amounts of CO_2 and CH_4 in its deep, anoxic waters, Lake Kivu is considered by some as a "killer lake". It has been compared to lakes Nyos and Monoun, whose gas eruption caused large-scale animal and human death in Cameroon (Zhang and Kling, 2006). The deep waters of these lakes are fed by underwater springs containing large concentrations of dissolved CO_2. Because of the permanent stratification, the gases cannot escape to the atmosphere, and the lakes are continuously charged with CO_2-rich water until the gas pressure reaches the hydrostatic pressure at some depth (Tietze, 1992). At this point, CO_2 bubbles can form and lead to a gas eruption from the lake (Zhang and Kling, 2006). As CO_2 is heavier than air, it remains at ground level, asphyxiating people as well as animals.

In Lake Kivu, the gas pressure is mainly due to the dissolved CH_4 which is much less soluble than CO_2, so that a gas eruption would be caused primarily by the dissolved CH_4. So, the risk of gas eruption is limited, as currently the total gas pressure in the lake reaches only about 55% of saturation (Schmid et al., 2005). However. Schmid et al. (2005) suggested that both CO_2 and CH_4 had increased within the 30 years since the previous measurements by Tietze (1978). Even though the increasing trend was not confirmed by a recent measurement campaign (Schmid, pers. com.), the prospect raised awareness that in the future a catastrophe caused by a 'limnic eruption' might occur, liberating large amounts of CO_2 into the atmosphere and causing the death of potentially up to 2 million people living around the lake. Moreover, the eruption of the Nyiragongo volcano in 2002, with a lava flow reaching the lake, has revived the fear that a major volcanic eruption might cause complete overturn of the lake water column that would likewise result in a massive gas outburst. Lorke et al. (2004), who studied the effects of lava flow penetration into the lake, concluded that a much greater volcanic event would have been necessary to disrupt the lake stratification. Nevertheless, recent studies on the sediments suggest that deep mixing, potentially causing gas release from the lake, may have occurred in the past (Zhang et al., 2014). However, another study also based on sediment analyses insisted on the complexity of the system linked to variability of hydrothermal springs, which makes prediction difficult (Votava et al., 2017).

Methane exploitation and its possible consequences

Wüest et al. (2012) provided a comprehensive account of the process of gas extraction, and considered different scenarios, taking into account the need to maintain the salinity gradient and to protect the ecosystem of the surface waters. The principle of gas extraction is presented in fig. 2: from a floating platform, a tube descends into the lake to a depth > 260 m, where the highest gas concentration occurs. As the gas-rich water is lifted upward, the hydrostatic pressure decreases and the gas pressure reaches supersaturation, allowing gas bubbles to form as the flow is driven to the surface. The gases are stripped from the water in a separation chamber and the CH_4 is piped to the shore where it is converted into electricity. The remaining soluble gases (chiefly CO_2 and some other gases, as H_2S) are washed with surface water, generating washing water, which is released around 60 m depth. The degassed water is re-injected deep into the lake: it must return there, because it contains dissolved salts and high concentration of nutrients. Returning the degassed water at depth is necessary to maintain the salinity gradient, which is the main factor determining the lake density profile which ensures the stability of the water column.

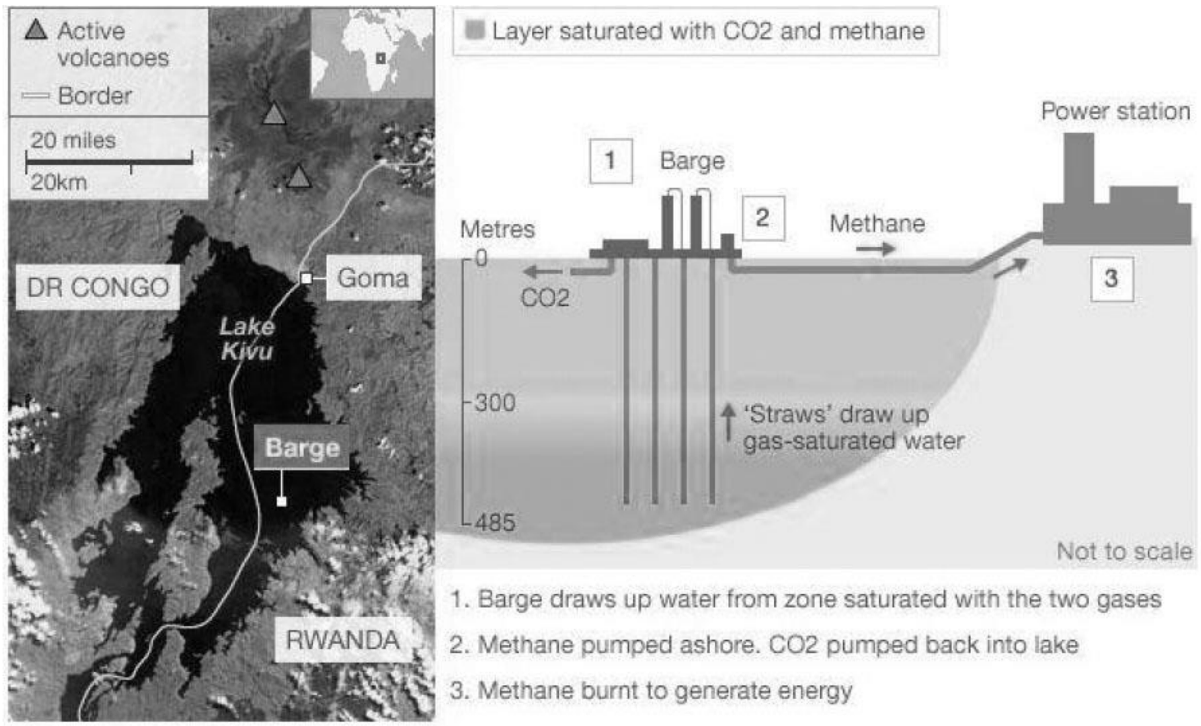

Fig. 2. Aerial view of Lake Kivu and simplified view of a gas extraction facility (source: BBC).

In addition, releasing the nutrient-rich water to the biozone would trigger a potentially catastrophic eutrophication, detrimental to the ecosystem. Hence, the exploitation scenarios tested by Wüest et al. (2012) considered three major objectives: 1) safety, by maintaining strong density stratification and avoiding critical gas concentration, thereby reducing the risk of gas eruption; 2) ecosystem integrity, by avoiding the modification of the chemistry and of the nutrient cycles in the biozone; 3) economy, by optimizing the yield of CH_4 harvest. Simulations were run over 50 years and established that reaching the three objectives would require re-injection of degassed water at a depth > 200 m (see Wüest et al., 2012). This conclusion should be reflected in the management prescriptions for the extraction of CH_4 from Lake Kivu (Expert Working Group on Lake Kivu Gas Extraction, 2009).

The need to monitor Lake Kivu and ecosystem resources

Large-scale exploitation of the gas resource in Lake Kivu started at the end of 2015, with phase 1 of the KivuWatt project, generating 26 MW of electricity, and there are prospects of further extension up to 100 MW. There is, of course, a need to monitor the deep waters. For instance, to control at which depth the re-injection of degassed water occurs, what is the dispersion of the plume, or the change in CH_4 concentration in the resource zone as a result the exploitation. Another concern is the conservation of the biozone ecosystem integrity, which includes all goods and services this ecosystem provides.

Among the uses of the lake resources, the fishery, mainly based on the Tanganyika sardine, is of particular importance. Since it developed in the 1960s, the fishery has become a key resource for the human population, with a yield reaching 10,000 ton/year for the whole lake. This figure is close to the annual production of the sardine, *Limnothrissa miodon*, estimated to be in the range of 8000–9600 ton (~38 kg ha^{-1} $year^{-1}$) from recent hydroacoustic surveys (Guillard et al., 2012, Snoeks et al., 2012). Compared to the sardine production in Lake Tanganyika (~200 kg ha^{-1} $year^{-1}$), this fishery yield in Lake Kivu is low, for several reasons discussed by Descy et al. (2012). One of those is that the lake is oligotrophic, with a long stratification period during the rainy season: in this period, nutrient supply to the euphotic zone where phytoplankton production takes place is reduced, and the water layer between 30 and 60 m may become oxygen-depleted, reducing the range in which the fish can live and feed on zooplankton. Nutrient enrichment resulting from release of degassed water in the biozone might boost phytoplankton production, but that would further increase the oxygen depletion when the surface waters are stratified. And of course, release of salts would profoundly alter the water chemistry, and likely be detrimental to the biota. This is precisely one of the reasons why the degassed water must be re-injected deep enough, well below the biozone. Moreover, the underwater springs generate an upwelling – i.e. upward transport of water and dissolved substances – that slowly brings deep water and solutes toward the biozone. If this "upwelling zone" (Schmid et al., 2012) becomes enriched in nutrients, it may increase the nutrient flux to the biozone, triggering in the long term lake eutrophication, with likely adverse effects to the biota.

Therefore, in the context of methane exploitation, monitoring the lake's physical and chemical properties, plankton biomass and composition, as well as fish stocks, is a necessity. This is why the Rwandan authorities set up the Lake Kivu Monitoring Program (LKMP) in 2008, which was later supported by the Belgian Technical Cooperation, which financed the 'Biological Baseline of Lake Kivu' (Descy and Guillard, 2014), and subsequently by the Dutch Cooperation. A long-term planktological and limnological data base is already available, creating a valuable reference frame to monitor the changes occurring in the pelagic zone of the lake. So far, observations have mostly revealed ecosystem changes related to inter-annual variability in climate (e.g. Darchambeau et al., 2013, Katsev et al., 2014, Thiery et al., 2014).

Conclusion

Research on Lake Kivu dates back to the 1920s, with a substantial involvement of Belgian institutes, universities and scientists, and with during the last two decades growing collaboration of Rwandan and Congolese institutions. Lake Kivu is unique in many respects: in particular, by its meromictic character generated by intense hydrothermal activity in this volcanic region and by the very large amounts of CO_2 and CH_4 stored in its deep waters. Although the risk of limnic eruption seems presently remote, the gases need to be removed from the lake to avert the danger of an eruption. The present view, with development of an industry harvesting CH_4 for electricity generation, is that removing the gas from the lake is an opportunity that will contribute to development of the neighbouring countries, and will ensure safety for the population surrounding the lake.

At the same time the goods and services provided by the Lake Kivu ecosystem, in particular the fishery, need to be preserved. This is a complex matter, because Lake Kivu is also unique in its limnological and geochemical features, and, like all the East African Great Lakes, is submitted to human disturbance and the impacts of climate change. A thorough understanding of these complexities – through continued scientific research and adequate monitoring of the lakes properties and resources – is essential as a basis for sound and sustainable management.

Further readings and sources of information

https://www.contourglobal.com/asset/kivuwatt

https://cleantechnica.com/2013/03/13/electricity-from-lake-kivu/

http://www.lake-kivu.org

https://www.belspo.be/belspo/fedra/proj.asp?l=fr&COD=SD%2FAR%2F02A

Acknowledgements

The authors is grateful to the two reviewers who helped improving the manuscript

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