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Methane Gas from Lake Kivu, a Permanent Risk and Danger for the Surrounding Population of the Region, particularly those of the City of Goma, RD-Congo

BOLONDA KABEMBASandrick ¹, BAKAMUBIA KANYINDA Simon ¹,
LANDU MANGAIseult¹, ZANA NDOTONI André ², NSAKALA TANDA Reddy-Andy ³,
MWAMBA KANDE Franklin⁴.

¹Researcher and Civil Engineer, Geophysical Research Center (CRG); Kinshasa - DR Congo;

²Professor, Département of Physics, Faculty of Sciences, University of Kinshasa (UNIKIN); Kinshasa - DR Congo;

³Researcher, National Remote Sensing Center (CNT); Kinshasa - DR Congo;

⁴Researcher, Health Science Research Institute (IRSS); Kinshasa RD-Congo.

ABSTRACT : The eastern part of the Democratic Republic of the Congo, in the aftermath of its political crisis that struck it, today aspires to a peace and a peace that all Congolese wish to see lasting. Although the border security problem is in the process of being resolved, given the efforts made on it, it is necessary to become immersed in and prevent problems linked to natural disasters which in the future could cause other crises. And social tensions. With the city of Goma recently surprised by the volcanic eruption of Nyiragongo, the Congolese government has taken certain measures to prevent such type of tragedy from happening in the days to come. But nevertheless, Methane Gas from Lake Kivu constitutes a permanent explosive danger and a sword of Damocles next to the Nyiragongo volcano. Methane gas from Lake Kivu is listed among the three most dangerous lakes on the African continent, containing a large amount of carbon dioxide or methane dissolved in their waters. However, measurements carried out on Lake Kivu have shown that the methane rate had increased by 15% over the past thirty years and that supersaturation would be acquired by the end of the century. This is why Lake Kivu represents a much greater enormous risk. This is why we researchers recommend preparing to exploit it while extracting this methane to reduce the risk and eliminate the danger in this region, in order to enhance

KEYWORDS: Methane gas, Lake Kivu, natural resource, exploitation, risk and danger, city of Goma.

I. INTRODUCTION

Between the Democratic Republic of Congo and Rwanda, the peaceful waters of Lake Kivu lie dormant in the middle of a volcanic chain at 1400 km altitude of methane gas. Today, they extend over an area of 2,700 km² and dive to a depth of 485 m. From the earliest African legends to current scientific researchers, to romantic accounts of late 19th century explorers, the lake has been the subject of much history. Yet for a very long time it did not interest men as much as other great lakes in Africa. Its food chain, at first, seems underdeveloped, and the biomass of the lake is not a priori sufficiently attractive to allow the development of a significant fishery. However, studies have identified approximately 60 km³ of methane (CH₄) and 300 km³ of carbon dioxide (CO₂). The two gases are trapped in the deep layers of Lake Kivu. Extracting this gas could be the first step in mass production of electricity, equivalent to more than 100 billion kilowatt hours. Beyond the economic aspect, another issue is pushing scientists to advocate the possible exploitation of methane because a very high concentration of this gas accumulates in the deep waters of Lake Kivu and could indeed cause an eruption.

II. RELATED WORK

II.1. Presentation of the study framework

Lake Kivu is one of Africa's large lakes and one of three meromictic lakes on this continent. It lies between the Democratic Republic of Congo and Rwanda, at coordinates $2^{\circ} 03'$ to $44' S$ and $29^{\circ} 07'$ to $24' E$ in the east. In addition, it is in this lake that we find Edjwi, the largest island in the interior of the African continent with a length of 40 km and an area of 285 km². Let us underline then that this lake covers the city of Goma, Bukavu on the Democratic Republic of Congo side and the towns of Gisenyi, Cyangugu, Kibuye in Rwanda. It is different from that of the other Congolese lakes which are mostly tectonic as shown by its morphological configuration, which is that of a dam lake: numerous bays and islands, the latter disappearing towards the north. It was the volcanoes of the virunga mountains that blocked the south-north flow of a hydrographic network that originated on the bafulero plateau near Mount Mulhi. This lake is characterized by a strong thermal and chemical stratification: (carbon dioxide CO₂ and methane CH₄ are quite strongly "trapped" in the deep waters, but could occasionally be suddenly released with serious risks for the population as well as the fauna.

The African continent has several very dangerous lakes because they contain a large amount of carbon dioxide or methane dissolved in their water. Those of Nyos and Monoum, in Cameroon, are unfortunately the best known, because they caused a total, in 1984 and 1986, the death of 1,800 people and many animals following the brutal emission of a large quantity of CO₂. Since then, to contain the risks, the two lakes have been fitted in 2001 for Nyos and 2003 for Monoum with an artificial degassing system developed by Michel Halbwachs, Professor of Physics at the University of Savoie, and the company Data Environnement, that he created. Another potentially very dangerous lake is Lake Kivu, located in the hollow of the African rift between the Democratic Republic of Congo and Rwanda. It contains a thousand times more dissolved gas than Lake Nyos and could cause a gas emission, in the event of destabilization of its stratified waters by a volcanic eruption for example. Studies made by Professor Michel Halbwachs, who is studying the site with international specialists. This threat weighs on the two million people living near the lake, and in particular the 400,000 inhabitants of the city of Goma. (See figure 01).

The Nyiragongo eruption spread towards the lake through eruptive vents along a tectonic fault, up to 5 km north of the lake. If this progression had continued 6 to 7 km further south, magmatic effusions would have occurred at a depth of 300 m, causing water laden with gas to rise.

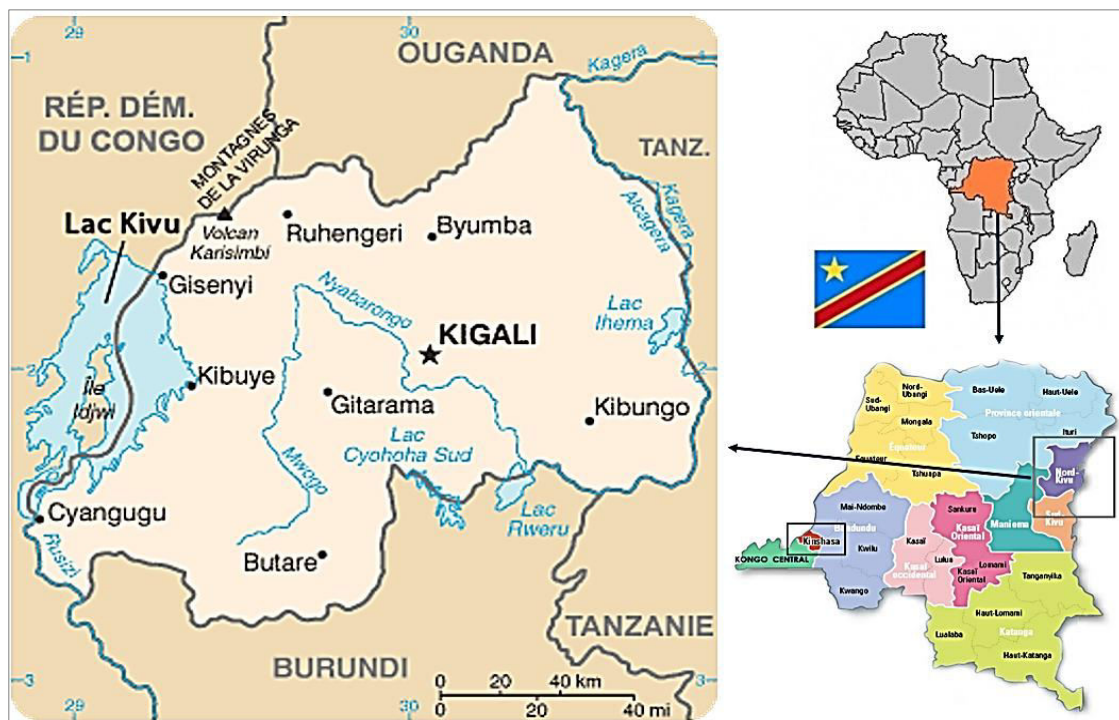


Figure 01: Presentation of the study area



II.2. From a geological point of view (Morphology and structural)

The morphology of the South Kivu rift is a fault staircase morphology made up of a succession either of fault blocks or of horsts and grabens progressively uneven from the outside to the inside of the rift. The study of rift faults in the Lake Kivu region shows that they are distributed in three main directions SW-NW, N-S and NW-SE. These normal faults, with significant vertical releases, determine by intercepting a complicated structure formed of polygonal blocks arranged "in stairs", or in "horst and graben". There is therefore not a single ditch but a tectonic zone, elongated N-S, 100 to 200 km wide, in which we recognize several tectonic ditches. Their "relay" arrangement gives the (false) impression of a single ditch moved transversely. Most of the regional fracturing seems to have taken place at the time of the first lake deposits and the first volcanic eruptions linked to the rift (in the Cenozoic) but the activity of these faults has continued to this day.

It appears dangerous to systematically link the formation or the replay of a fault having the orientation of one or the other of the three systems, to a generalized tectonic phase and to a given geological period, because we often observe, at the favor of earthquakes or volcanic eruptions, movements in faults having the orientation of any of the three main systems.

II.3. Description and origin of methane gas (CH₄ and CO₂)

Where do carbon dioxide and methane come from?

Currently, Methane and Carbon dioxide are dissolved and stored in the layers of water below this "cover". The CO₂ is hypothetically of volcanic origin. Five deep water sources have a sufficiently large flow to be observed, and they provide the majority of this gas. For Methane, it is a little more complex to determine according to scientists, CH₄ could, like CO₂, come from volcanic activity, but we have never been able to demonstrate it. Surface water sources are indeed not loaded with methane, so we can legitimately think that deep sources are not either. Methane (CH₄) must therefore be biogenic, ie of biological origin. The most likely hypothesis would be that this methane comes from the anaerobic decomposition of organic matter. We know that in anaerobiosis, organic matter, when it decomposes, will release carbon which, half of which turns into CO₂ and half into CH₄, according to the formula CH₃COOH (acetate) CO₂ + CH₄. This biogenic process of anaerobic degradation of organic matter is believed to be responsible for approximately one third of the formation of methane in Lake Kivu. The remaining two-thirds are believed to come from a bacterial reduction of CO₂ in the lake. "For this reduction to take place, there must be a reducing agent in the case of methane formation, most commonly hydrogen. This hydrogen, in Lake Kivu, could also have two origins. It could be volcanic, which would explain the formation of these two-thirds of methane without the addition of organic matter from the lake. The other and more likely hypothesis would come, once again, from the decomposition of organic matter in the formation of hydrogen, which could then produce methane via the reduction of carbon dioxide.

Thus, although two-thirds of the carbon incorporated in methane would come from volcanic activity, biological production of material would be necessary for them to appear. Around the 1950s and 1960s, Belgian researchers showed that this lake contained methane (CH₄) and carbon dioxide (CO₂) of magmatic origin. The genesis of this methane and the explanation for its accumulation have long been debated; in particular, it was thought that it was of volcanic origin and / or resulting from decomposing organic matter, and we are trying to better understand the functioning of methane sinks (in the upper oxygenated layers of the lake, certain methanogenic bacteria degrade the methane before it does not reach the atmosphere of the lake. However, the data provided by two expeditions conducted on the lake, as well as a reassessment of the data acquired previously, concluded that most of this methane is biogenetic and recent. Formed by organisms formerly classified as "Methanogenic Bacteria" and now reclassified among archaea, a group of prokaryotes distinct from bacteria and living in deep anoxic waters, belonging to the little known group. These bacteria are said to have synthesized methane from carbon dioxide and hydrogen (all of which are abiogenetic). It was then assumed that a small part of the methane would be thermo-catalytic, the rest resulting from a transformation of CO₂ into methane by methanogenic bacteria see Figure 02.

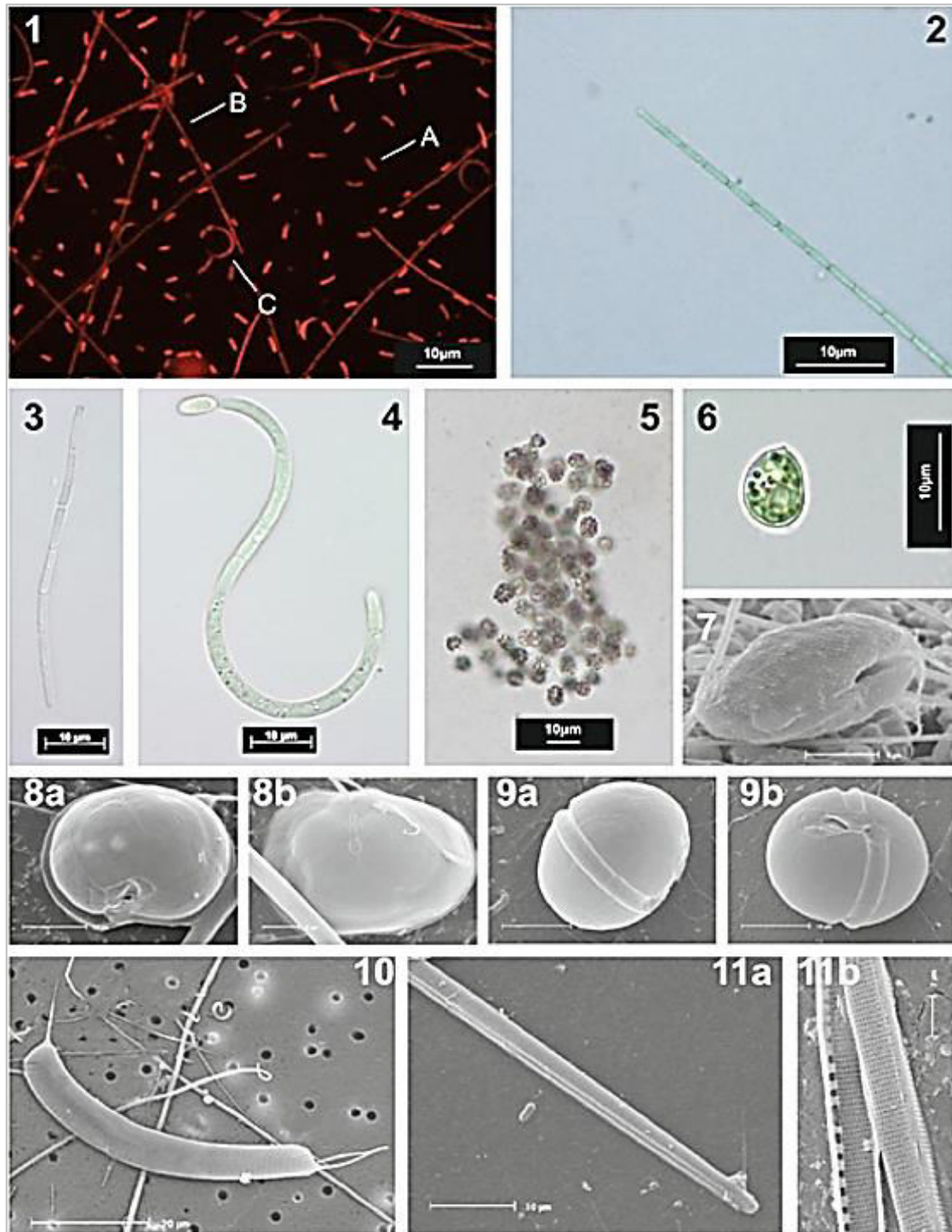
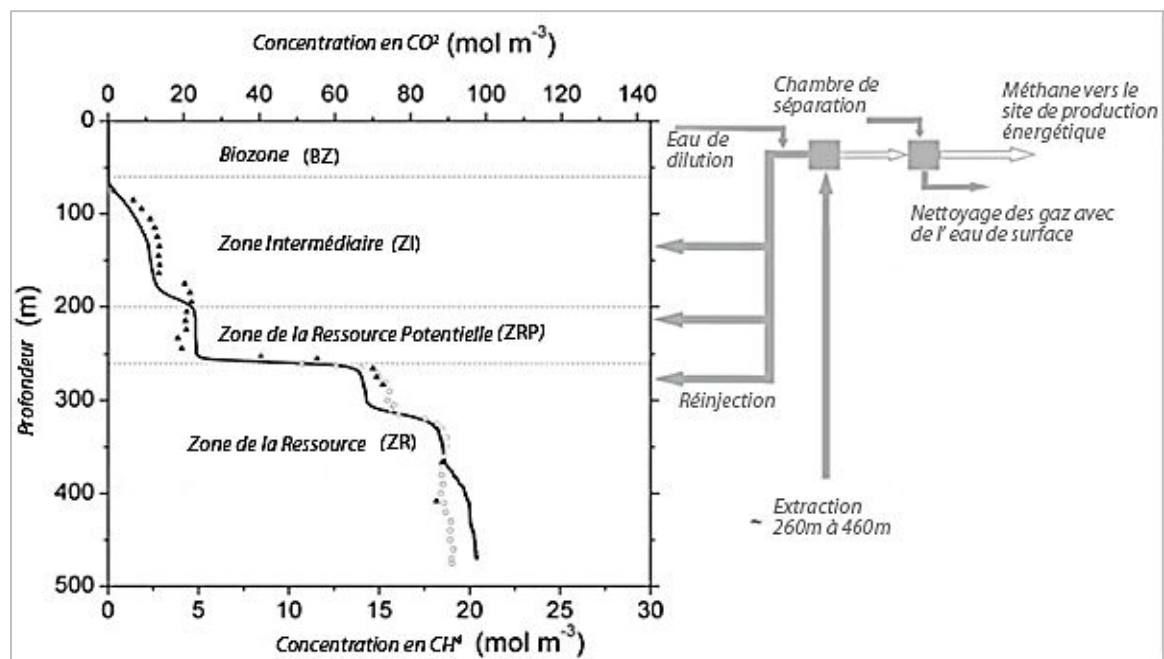


Figure 02: Presentation of the main kind of Phytoplankton found in Lake Kivu

It has recently been demonstrated that here at depth (from a depth of about 300 m), due to the local convection system, particular diffusion (superimpositions of convection cells maintaining a certain stability), characterized by a turbulent mixing low and a vertical transport by diffusion dominated by a phenomenon of double diffusion (from 120 m in February 2004) [2] Consequence of a high gradient of salinity, and therefore of density and entries of underwater sources at different depths, also responsible for an abnormal Zinc content in water, which unlike known systems of natural double diffusion are studied in the laboratory, dissolved CO₂ and CH₄, contribute significantly to stratification in layers, with unusual equilibria between the stabilizing effect of salts dissolved and the destabilizing effect of temperature. Mixed layers 0.48 m thick on average nevertheless appear to be in a state of active convection, the average thickness of the interfaces (0.18 m) being surprisingly constant and independent of large-scale stratification. Vertical heat fluxes correlate well with temperature measurements across interfaces. Changes are observed in the lake (warming of deep waters, reinforcement underwater, which could explain recent changes in the nutrient cycle and the production of methane from the lake. The potentially exploitable deposit of methane from the lake has been estimated at more of 50 (at ambient pressure and temperature, to 57 billion cubic meters); See Figure 03.

Figure 03: Methane formation diagrams in Lake Kivu

On



March 28, 2007, the Democratic Republic of Congo and Rwanda signed a memorandum of understanding for a team of scientists to study the feasibility of mining the deposit. Thus, provided that there is no disturbance of the effect of chemocline by exploitation, it is hoped to be able to both reduce the risk of exploitation and / or of asphyxiation by the rise of a large bubble of methane, for the benefit of fuel or electricity production.



II.4. Consequences and Risks of a Natural Disaster

The precise level of risk is not yet analyzed, but rather an imminent danger. But never mind, Lake Kivu is one of three identified lakes around the world susceptible to severe limnic eruptions. In 2005, geologists and geochemists estimated that some recent changes in lake behavior are indicative of an increased risk of an uncontrollable gas eruption and that "the release of a fraction of these gases, which could be triggered by an eruption magma in the lake, would have catastrophic consequences for the two million people living on these shores [3]. The first risk and safety assessments were based on the assumption that dissolved gas concentrations in deep water are in a state of equilibrium corresponding to a residence time of around 400 years, with turbulent transport considered the main route. vertical rise of Carbon dioxide (CO₂) and Methane (CH₄). However, recent measurements and the re-analysis of vertical transport processes have radically modified this hypothesis. The vertical turbulent exchange actually appears to be weak and negligible. The average residence time would not be 400, but 800 to 1000 years, while the available records show a recent trend towards an increase in the production of Methane in the sediments of the lake (more than 15% in thirty years according to a recent study which admits an increase in anthropogenic sources or causes, but invites not to exclude the hypothesis of a geogenic increase of H₂ and CH₄).

This leads to a build-up of gas, but the more gas-saturated the deep water, the less heat it needs to trigger a catastrophic release of devastating gas. If there is no error in the current production of Methane (CH₄) as estimated in 2005, the methane saturation of deep water could be reached before 2100. Global warming could be an anthropogenic source of 'aggravation of this risk (surface warming of 0.58 ° C in thirty years, but which could also be attributed to climate variability). A small amount of lava entering Lake Kivu is enough to cause a natural disaster. This lake is believed to be home to 300 km³ of carbon dioxide and 60 km³ of methane, which can rise through volcanic vents, which is more than 300 times the amount of gas contained in Lake Nyos causing more than 1,800 deaths during its eruption. However, Lake Kivu contains a thousand times more gas than Nyos, while being located in a very densely densified region, where more than two people live. And as the concentration of the gas increases over the years, the possibility of a limnic eruption increases, mechanically. Quoted by the weekly JeuneAfrique, Martin SCHIMID, researcher at the Swiss Institute for Research on Water and Aquatic Environments (Eawag), does not say anything else when he explains that (if the gases are allowed to accumulate for a long time, it will be necessary to wait at a time for a catastrophic gas eruption). And as if that were not enough, the proximity of the Nyiragongo volcano, one of the most active in Africa, further reinforces the plausibility of such a scenario, a volcanic eruption that could upset the stratification of the lake and could lead to a rise in gas uncontrollably.

III. METHODOLOGY

III.1. Methane extraction method

The extraction in itself turns out to be relatively simple, because naturally the water on rising to the surface, gradually regains an atmospheric pressure, which is no longer sufficient to maintain the dissolved gas at such quantities, and which at the like a soda bottle, the liquid escapes, decompresses to return to its normal volume, and carries the liquid upwards, which explains in particular the risk of a possible cataclysm. Harvesting enjoys the same natural process; "When you go up, the water degasses naturally, you just need to place a long tube in the lake. In addition, operators take advantage of what is called the siphon phenomenon. As the water rises, the bubbles created will themselves cause the water to rise, much like water filtration systems in aquariums. So all you need is a simple priming at the start, and then after a hundred meters of ascent, bubbles form, and the water rises on its own ". On the surface, there is a water - gas mixture in the ratio of one liter of water to 2 to 3 liters of gas. This means that these 2 to 3 liters of gas in deep water are compressed and dissolved in a single liter of water, and that they regain, on the surface, their volume in atmospheric conditions. But the mixture remains wet. It is therefore passed through a separator whose function will be to separate the gas from the liquid. The gas phase is preserved, the liquid phase rejected.

This gas phase contains 80% CO₂ (Carbon dioxide), 15% CH₄ (Methane) and 5% nitrogen. To obtain the greatest possible percentage of methane, this gas then goes through a leaching phase: the gas flow through a column of water in which the carbon dioxide (CO₂), which is extremely soluble, will redissolve naturally. At the exit, the resulting mixture contains between 80% and 90% methane and can be used as fuel to produce, for example, electricity. Extracting the gas would be almost childishly simple if it weren't for the green measures to consider. The real problem arises during the reinjection of wastewater. To return water to the depth where it was taken, it would have to be pushed back, an energy-consuming process that risks cooling down industrialists. The easiest and most economically profitable would obviously be to discharge degassed water on the surface, but such a practice would create a disastrous risk for the entire lake ecosystem. Confers Figure 04.

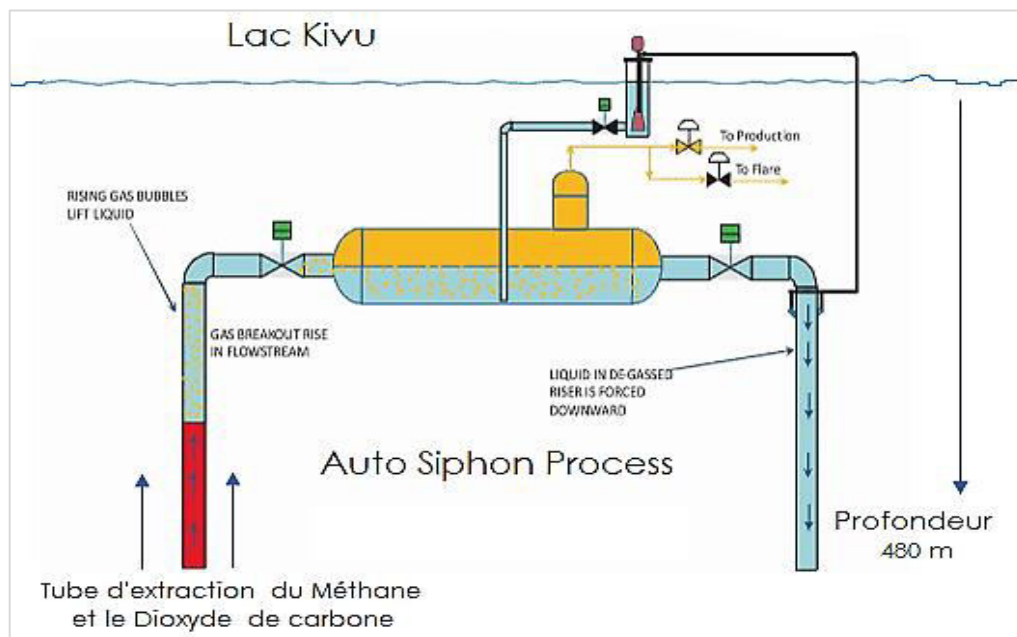


Figure 04: Methane extraction schemes in Lake Kivu

The lake is split in two by this "cover" at a depth of 250 meters, which allows the accumulation of gas at depth. A rejection of deeper surface water, more dense, could break the stratification of the lake and make it a lake with homogeneous waters. The gas would be diluted in a larger volume of water, therefore less concentrated and less easily exploitable. But the main risk would be eutrophication of the lake. Deep water doesn't just hold gas. They also retain anything that sinks from the surface, and is therefore extremely rich in nutrients, especially phosphate and ammonium. What we fear, in the event of water being released to the surface, is a sudden excess of nutrients in the ecosystem, which would cause a significant development of the phytoplankton. We can think a priori that this would be beneficial for the entire food chain of this lake, which is very poor in nutrients.

But this eutrophication could create harmful effects. Algae, when they die and settle, are subjected to bacterial decomposition, a process that consumes a lot of oxygen. More algae production which could lead to anoxia problems. Aerobic life already only develops in the first sixty meters of the lake, which is not huge. Simulations made from ecological models have shown that in the event of eutrophication of the lake, this oxygenated zone could be reduced in the first twenty meters of the lake, which would be catastrophic for all the species living there. The challenge for manufacturers will therefore be to find the fairest compromise between the economic profitability of gas extraction, maintaining the stability of the lake and the preservation of the lake's fauna is also of economic importance (see figure 05).

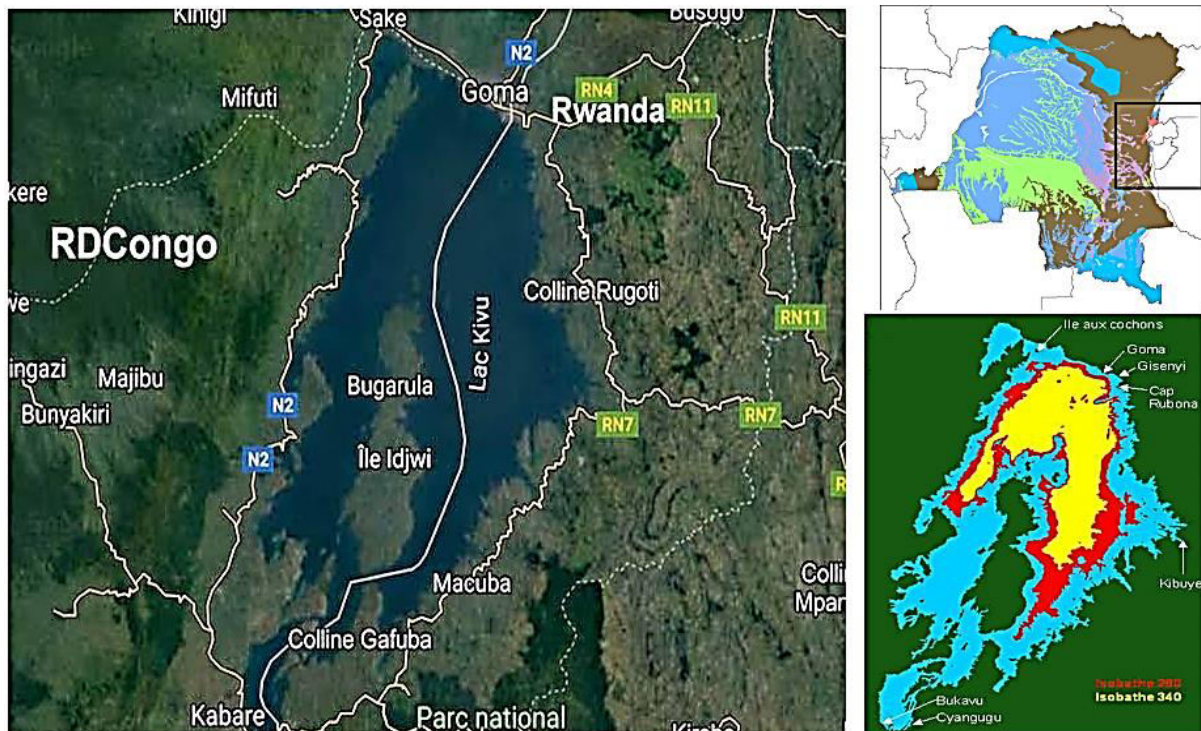


Figure 05: Satellite and geothermal image of Lake Kivu

IV. DISCUSSIONS AND RESULTS

Paradoxically, such a concentration of methane is also a chance and at the same time a natural wealth as we thought. The technological developments made in recent years make it possible today to exploit, distribute, manage and market gas from Lake Kivu. According to some estimates, it could thus produce up to 700 megawatts of electricity, nearly 4 times what Rwanda currently has (around 250 megawatts). What arouse the interest of certain private operators: the land of a thousand hills already has two companies (the Americans SYMBION POWER and CONTOUR GLOBAL). Which extracts gas from Lake Kivu to power power plants. The first initiative, launched in 2009 off the Rwandan city of Rubavu, is a pilot project called Kibuye Power 1 with a production capacity of 3.6 megawatts. Concretely, the floating platform, located three kilometers from the shore, pumps gas into the depths and then sends it via a gas pipeline to dry land, where three generators produce electricity. Explains Eric NSABIMANA, the operational manager of the facility, who also indicates; "That extracting methane from Lake Kivu helps stabilize this Lake from a possible cataclysm." See figure 06.

In short, gas exploitation kills two birds with one stone: it provides electricity while reducing the risk of untimely degassing. The second project, Kivu-watt, launched in 2016, is on a whole different scale since it currently generates 26 Mw, intended for the local network. A capacity which should eventually reach 100 Mw, distributed throughout the country. A real windfall for Rwanda, which aims for a rate of access to electricity of 100% of its population by 2025, against 30% today, according to the researchers. The profitability of the projects is still uncertain, with extraction currently only taking place on a small scale. When contacted, a source working in the finance department of one of the two aforementioned companies confirmed on condition of anonymity that the company does not currently make any money on the methane gas unit.



Figure 06: Satellite and geothermal image of Lake Kivu

A situation which, according to our interlocutor, the time to improve the extraction processes and increase the rates of population. One thing is certain: the bet on the exploitation of methane gas in the Kivu region continues to attract investors. In February, the Rwandan authorities validated the signing of a contract with a new private operator, the company Gas Meth Energy, for the production of bottled gas from the methane contained in Lake Kivu, for an amount ranging over 400 millions of dollars. But it seems that the potential of Lake Kivu has not finished talking about them. As no one knows to this day, the DR Congo is on the way to producing electricity from methane gas contained in Lake Kivu, in the east of the country. With this gas, Lake Kivu presents an immeasurable potential energy source for the province, Rwanda, which began exploration work at the same time as the DR Congo, had already set up its first gas plant which produces 26 Mw. But the DR Congo, the status quo seems to continue because of the issue of procurement for this operation. According to experts, there is already extraction technology that can properly separate gas from water and generate electricity without harming the ecosystem or the environment. The riparian populations of Lake Kivu only use firewood and charcoal for cooking as their main energy, thus exerting strong pressure on the islands of the forests that still exist during this period when the effects of climate change are very palpable throughout the world. On the other hand, civil society organizations keep alerting national and international opinions on the threats to the living beings that are around Lake Kivu, given the large amount of gas it contains. Within this lake are stored more than 57 billion cubic meters of methane gas which continues to accumulate at the bottom of the water. Faced with this situation, civil society actors in DR Congo say they do not understand the attitude displayed by the Minister of Hydrocarbons and his various services on the feasibility of exploiting this mantle gas, "While studies on the extraction of this gas have already been carried out and concluded more than 10 years ago. The Congolese government had launched calls for tenders," said Alain BOTOKO, president of the NGO ESSF (Environnement Sain Sans Frontières). The risk of a gas explosion, however, must be taken seriously, so gas extraction can defuse this time bomb. At the same time, the exploitation of such a quantity of methane offers assured prospects for profitability and some Rwandan and American industrialists are eyeing these waters with envy.



V. CONCLUSION

We are at the end of our reflection on the risk and permanent danger of methane gas from Lake Kivu; challenges of natural resource management concentrated in shared water. Our research aimed to demonstrate the issues while explaining national and international opinion that Lake Kivu represents a time bomb due to a large concentration of methane gas that has not been exploited for more than half a century. Although it is a natural energy resource on the border between DR Congo and Rwanda, Rwandan researchers have been able to set up a gas extraction power plant to produce electricity, but this represents only a small percentage of a control management of this methane gas which risks causing a possible natural disaster. And above all, geologically, during earthquakes or volcanic eruptions, movements in faults do not have a preferential orientation, because they are felt in the three main systems, which would still represent a danger.

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