MONITORING THE SAFETY LEVEL OF THE LAKE DURING THE DEGASSING PROCESS

Parameter of stability of the lake

The fundamental criterion which controls the stability of the layer of water in a lake can be presented as the vertical variation of liquid density. In a general way, density variation is an increasing function of depth.
The density parameter is a function of physical and chemical factors.
The water density:

- decreases with the temperature as an effect of the dilatation process,
- increases with depth as an effect of water compressibility,
- increases with the concentration of dissolved ions,
- varies (and generally increases) with the dissolved gas content.

From a quantitative point of view, the characteristic parameter of stability is given in the standard expression:

$$\mathbf{E=1/\rho\ d\rho/dz\ (m^{-1})}$$

ρ(z) being the density at a given depth z.
When the density gradient decreases towards zero, the corresponding layer becomes unstable.
Conversely, a layer will be as stable as the density gradient is high.

On the following figures (fig. 1 and 2), we calculated the density versus depth curves as a function of the various parameters for the cases of Nyos and Monoun.
- curve 1 is the density variation ρ(T) of pure water with the measured temperature, without taking into account the effect of pressure,
- curve 2 is the density ρ(T+I) of the water taking into account the temperature and the effect of the dissolved ion concentration,
- curve 3 is the density ρ(T+I+C) of the water taking into account the temperature, the dissolved ions and the dissolved CO_2,
- curve 4 is the density ρ(T+I+C+P) : the effect of pressure is simply added to the previous curve.

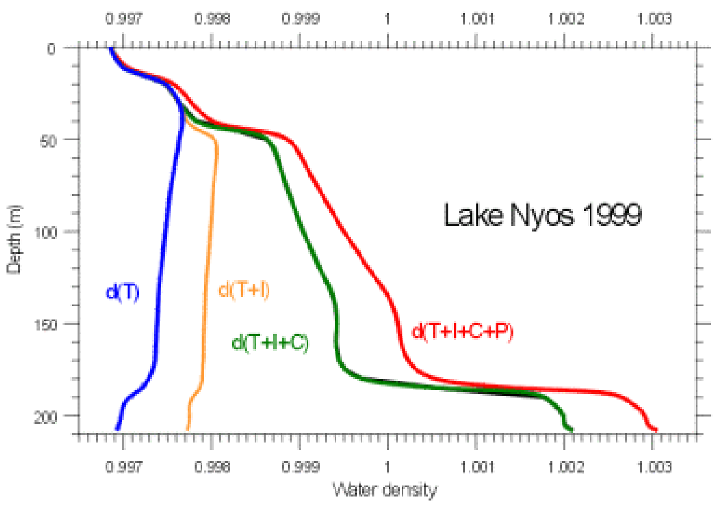

fig 1

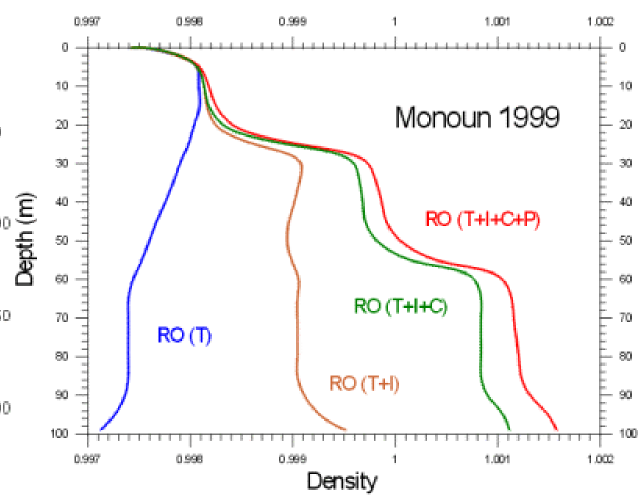

fig 2

The above description results from measurements taken during experiments:
Temperature and CO2 concentration: G. Kling et al., preliminary report of the US OFDA technical project, October-December 1999,
Ion concentrations: Gregory Tanyileke, Thesis, Okayama University, (1992)

The effect of the ion concentrations on the density was calculated by professor Gil Michard of the Laboratory of Water Geochemistry, University of Paris VII,
The CO_2 concentration effect was inferred from the mean partial molal volume for CO2.

The stratification of the Nyos Lake can be simply described as far as density is concerned Fig. 3:

- 0 – 45 m : a first degassed water layer,
- at 45/50 m a sharp density gradient layer,
- 50 – 170 m: a water layer indicating a slow and rather regular increase of dissolved gas,
- at 170/190 m , a high density gradient layer,
- 190 - 208 m: a quite homogeneous layer.

This lowest layer becomes more and more enriched with dissolved CO2 as time elapses and will probably reach the over-saturated level in under three decades.

The characteristics of Monoun Lake are not very different Fig. 4 :
- 0 – 20 m: a degassed water layer,
- 20 – 60 m: increasing dissolved CO2 content,
- 60/65 m: a high density gradient layer,
- 60 – 99 m: a very homogeneous water layer.

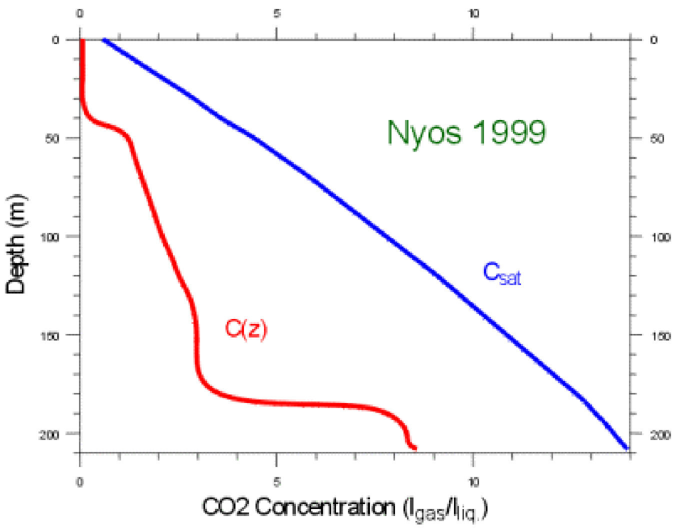

Fig 3

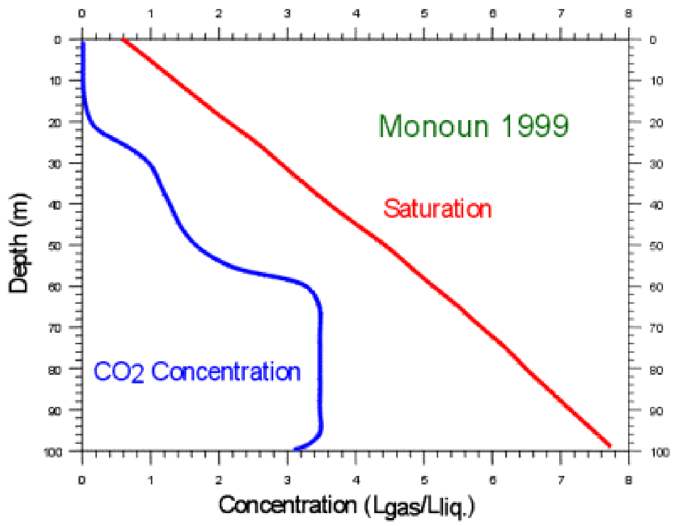

Fig 4

The stability coefficient is drawn on the following figures (fig. 5, 6) for both lakes. The high gradient zones indicate that mixing between the different layers is difficult.

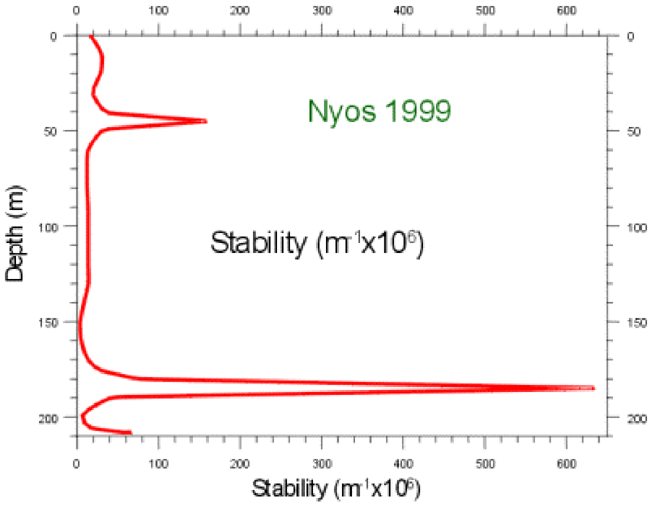

Fig 5

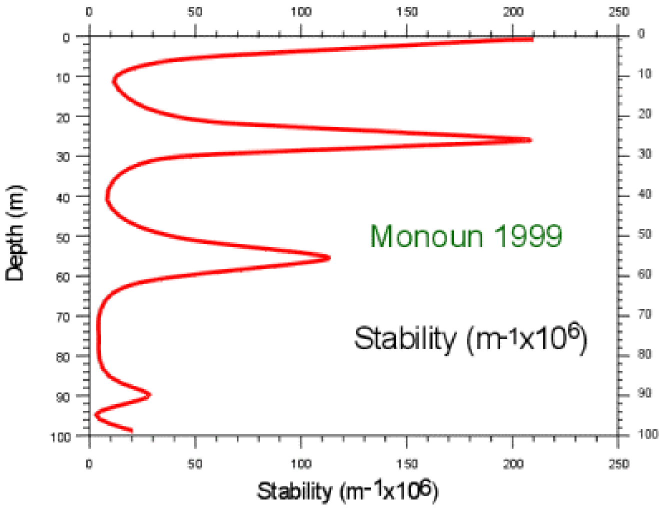

Fig 6

The safety parameter

It is necessary to differentiate between two distinct assumptions:

1) the CO_2 concentration enrichment increases regularly until over-saturation takes place at some depth of the lake,
2) some external source can set off a localised welling-up of a CO2 rich water body and consequently trigger the avalanche process before the normal occurrence of over-saturation.
Following the first assumption, the gas explosion will occur only after over-saturation is reached. The safety parameter can thus be described as the distance between the existing CO2 concentration curve and the over-saturation curve. We plotted on fig. 7 and the vertical distance $z\text{-}z_{sat}$ versus depth in the cases of both Nyos and Monoun.

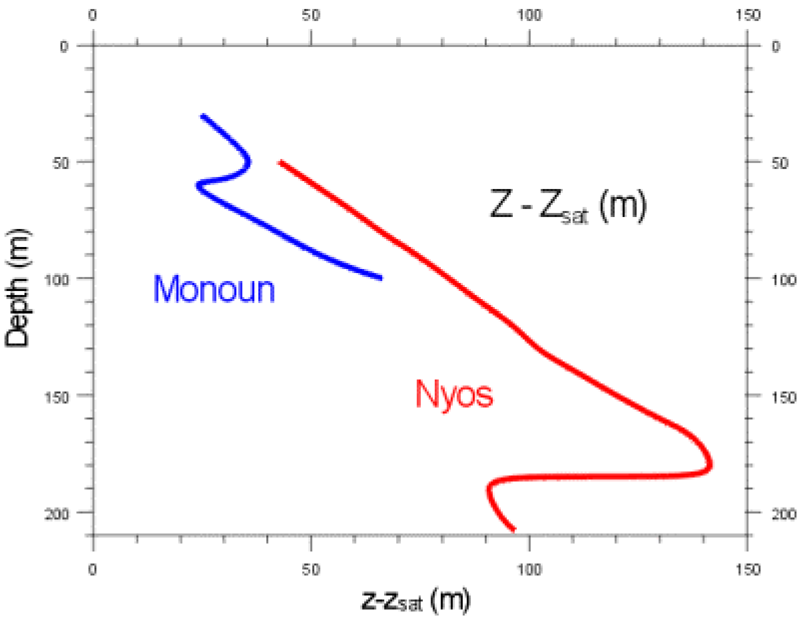

Fig 7

In the case of Lake Monoun, it appears that the most dangerous layer is located at a depth of 60 m whereas in the case of lake Nyos, it seems that the upper-most layers (50 – 100 m) are more dangerous.
In our opinion, this safety factor evaluation is not reliable since it implies that no external events can appear and trigger the gas burst before the critical saturation point is reached.

In case of a landslide or rock fall, the disturbance in the deep water could give rise to a kinetic energy in the water that in turn would be able to overcome the potential energy due to the density difference at z and $z_{sat.}$

We have defined a new "safety parameter" as follows (Fig. 8).

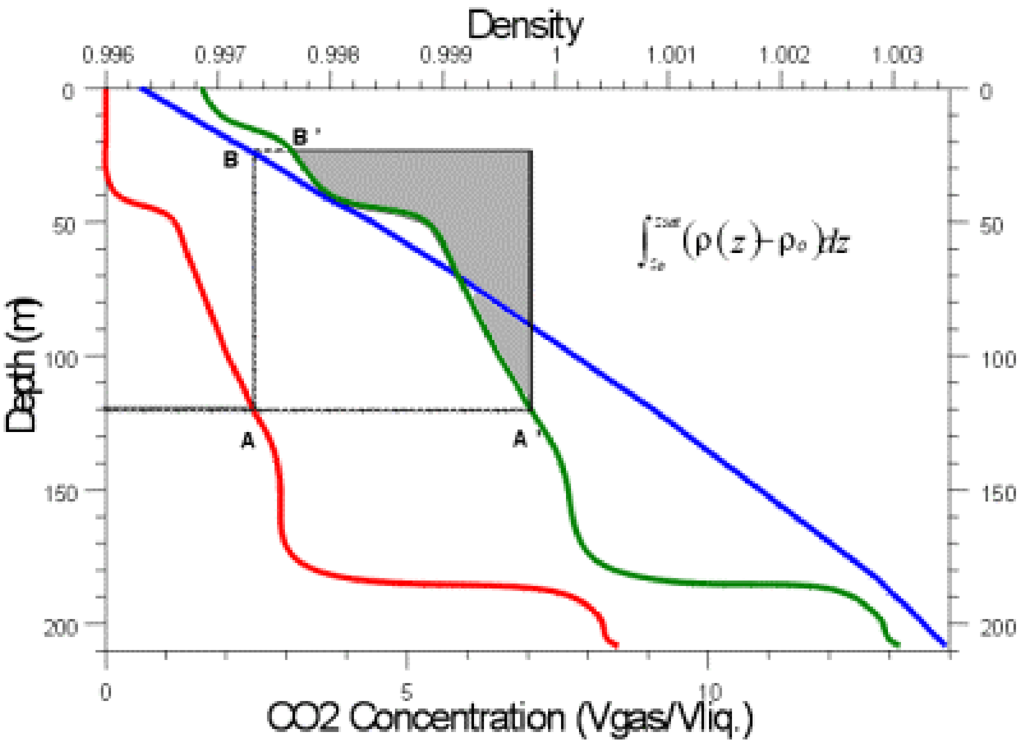

Fig 8

We have plotted on the same figure: i) the gas concentration (in red), ii) the saturation curve (in blue) and ii) the calculated density profile (in green).

We aim to estimate the safety level at a given depth z_0. The gas concentration is drawn as A and the density as A'. If one imagines a water unit volume at a depth z_0 and moves it upwards, this water will become over-saturated at a depth z_{sat} (point B). This body of water has a density $\rho(z_0)$, point A'. In order to move this water body upwards, it is necessary to overcome the Archimedean forces since the density of the surrounding medium is lower than $\rho(z_0)$, decreasing from A' to B'.

The potential energy required to move the water body from A, A' to B, B' (from a depth z_0 to a depth z_{sat} where it become over-saturated) is easy to calculate. The corresponding mathematical expression is presented below and corresponds to the shadowed area on the figure.

$$S=\int_{z_o}^{z_{sat}}(\rho(z)-\rho_o)dz$$

So, if we perform such calculation for different depths, we should get a good estimation of the safety parameter versus depth.

The results for lake Nyos and Monoun are reported in Fig. 9. It can be seen that, at the present time, the deepest layers are the safest in both lakes. It is particularly evident for the case of Lake Nyos where the very dense 190 – 208 m layer is confined under a lower density medium.
The above finding is of particular interest since it indicates that the safer way to degas the lakes is to begin with the upper layers.

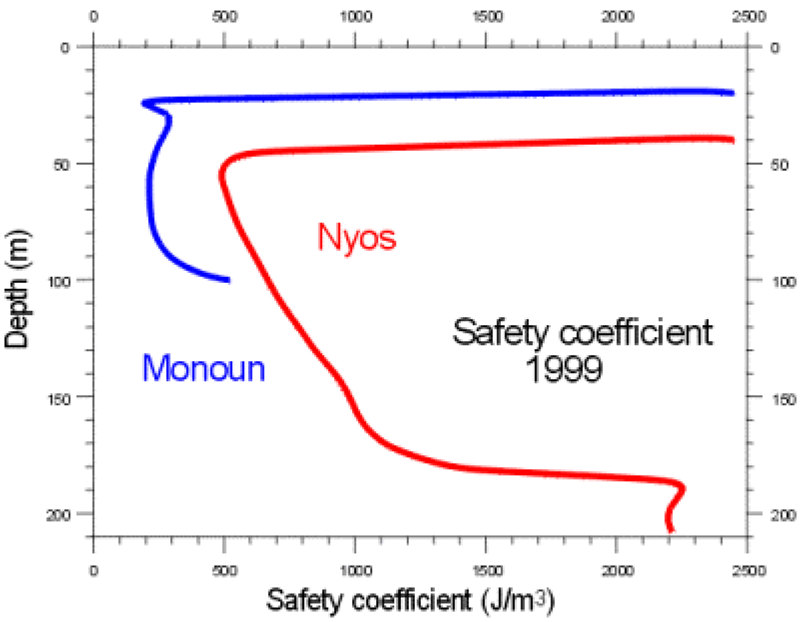

Fig 9

In conclusion, the zz_{sat} coefficient represents the safety parameter without taking into account any external event possibility. Our calculated safety coefficient seems to be a much more appropriate way of monitoring the situation in the lakes during the degassing process.

Michel Halbwachs
Chambéry July 1999