CARBON DIOXIDE DISPERSAL AND ASPHYXIATION: SHARING COMPUTER SCIENCE WITH CULTURE, MYTHS AND LEGENDS.

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IMPACT OF THE VOLCANOES ON HUMAN ACTIVITIES

In spite of modern technology, it is still difficult to predict the beginning, the end, and the magnitude of a volcanic eruption. Ancient civilizations managed volcanic catastrophes using myths and legends. Concerning phenomena leaving no geological prints such as toxic gases, modern volcanology refers to phenomena having a recurrence time of centuries to millenia or more as evidenced by written texts a few centuries old. Considering the myths and legends around Lake Nyos (Cameroon) where cultural transmission is essentialy oral, and comparing testimonies of the August 1986 event with the data obtained by scientists, it has been possible to reconstruct the catastroph history. Scientific observations are used to define the boundaries of a computer modeling describing the toxic gas propagation. Testimonies and modern medical knowledge are confronted. This experience made it possible to reinterprete the plague killing the inhabitants of Arequipa (Peru) in 1718 as probably due to the emanation of toxic gases from Mt. El Misti volcano.

IMPACT OF THE VOLCANOES ON HUMAN ACTIVITIES.

The volcanic activity affects the atmosphere and ocean chemistry but often volcanoes destroy human goods in explosions, flows, avalanches, etc,. Since the middle of the last century, modern technologies has induced a tremendous expansion of the population . Major modern population centers were settled in complete ignorance of volcanic risks. Big cities like Naples, Mexico City, and Tokyo are in a situation where a small ash fall of few cm would dramatically affect the economy. Volcanic eruptions represent a significant hazard for civil air transport. Numerous encounters of aircraft flying through volcanic plumes have been reported in the past 15 years. These incidents were sometimes serious (US Geologicaln Survey 1991).

Up to now the major volcanic catastrophes have happened in deserts, national parks or sparsely populated areas affecting a few 100,000 people. But in January 1995, Mt. Popocateptl (Mexico), Mt Merapi (Java, Indonesia), and Mt Niragongo (Rwanda) threatened millions of people (Volcano Listserv 1995; Smithonian Institution 1995).

THE LIMIT OF VOLCANIC ACTIVITY FORCASTING

Using the up-to-date volcano survey equipement it is easy to detect data suggesting impending eruption. Detection has sometimes failed because rising magma suddenly stopped, soil inflation reversed, or a dramatic increase in gas temperature did not correlate with the volcano behavior. Prediction of the initial stage of an eruption is still difficult; but, it is impossible today to predict a volcano's magnitude and duration. (Tazieff and Sabroux 1983; McBirney 1983,Tazieff 1988;Tazieff and Derruau 1990, Shimozuru 1991). A dozen volcanologists were killed in the last decade in situations they could not completely predict.

In the last decade computer developpement made possible to simulate volcanic activity, lava flow developpements, gas trajectories... These models to be valid need to be tested on the real situations. Volcanology is only few centuries old and the informations are mainly transmitted by written traditions. Geological records are not enough to reconstruct past eruptions: Huge gas explosions leave very tiny geological prints.

Recently we have been involved in carbone dioxide outbursts dividing the scientific community and pointing out the necessity to share modern science and old traditions.

LAC NYOS (CAMEROON)

The Scientific debate:

The catastrophic event at Lake Nyos (Cameroun) has resulted in a major scientific debate. On August 31 1986, more than 1800 people, 6000 cattle, birds and wild animals were

asphyxiated by a toxic gas. Local authorities ask for help and scientists from the major developed countries were sent by their governements in order to determine the origin of the catastrophe, diagnose the possibility of a new event, and study the possibility of predicting and preventing such new events.(Tazieff *et al.* 1986; Le Guern and Sigvaldason 1989; Le Guern and Sigvaldason 1991)
Similar catastrophes occured in Indonesia in February 1979, and Lake Monoun (Cameroon) in August 1984. (Le Guern et al. 1982; Sigurdson et al. 1987).
The entire scientific community agreed that the catastrophe was due to carbon dioxide from a magmatic origin. Two scenarios have been used to describe the catastrophe:
(1) the volcanic origin scenario : a gas jet spitted across the lake water; or
(2) the limnic origin scenario: gases were stored in the lake water and an internal or external phenomena triggered the degassing.
In the volcanic scenario prevention of degassing is impossible. Any volcanic area can present this danger in, or outside lakes; prediction will proceed with usual methods. (Tazieff 1991)
In the limnic scenario both prediction and prevention are possible: The only dangerous area being located around lakes containing dissolved gases, prevention can be obtained by pumping the deep waters to the surface where they will naturally degassed.
This scenario has been presented as a new geological hazard.(Sigvaldason 1991)

SCIENTIFIC OBSERVATION AND COMPUTER SIMULATIONS.

Sent by the french government we arrived on the lake shore 4 days after the occurence and observed all the facts that could help to reconstruct the event:
Figure 1:
- bodies were found 23 km from the lake,
- dead animals were found on southern hills 120m above the lake surface
- a cliff on the lake shore had been washed and stipped from its all cover up to 80m elevation
- in situ measurements pointed out a huge CO2 flowrate from the ground all around the lake
- surface lake water were oxidized but deep waters were clear and undisturbed
- mechanical effects of strong wind were observed in valleys down slopes 3 km from the lake (Tazieff et al. 1986).

Taking into account the percentage of surviving people place by place in the all area it has been possible to draw a hazard map (Le Guern et al. 1992).
Reviewing what is mainly known about carbon dioxide intoxication it has been possible to evaluate the atmospheric carbone dioxide concentration and draw a map of carbone dioxide isoconcentrations deduced from the survival rate for human beings and dose effects relations (Faivre-Pierret and Le Guern 1983; Stupfel and Le Guern 1989)
A modelling has been carried out by using a three-dimensional thermohydraulic code (TRIO) . This code is qualified for modelling the dispersal of heavy gases and has been developed by the "Commissariat à l' Energie Atomique France" (Magnaud et al. 1987; C.E.A. et al. 1989)

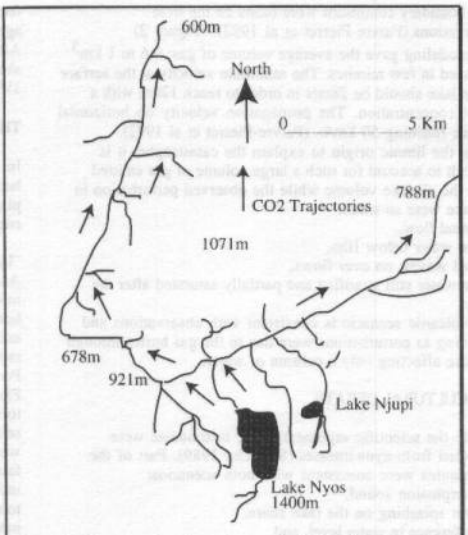

Figure 1: Map showing the carbone dioxide trajectories (After Tazieff et al. 1986)

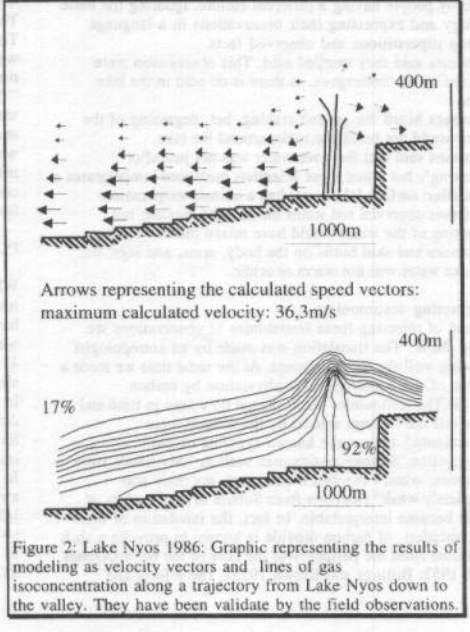

Figure 2: Lake Nyos 1986: Graphic representing the results of modeling as velocity vectors and lines of gas isoconcentration along a trajectory from Lake Nyos down to the valley. They have been validate by the field observations.

The boundary conditions were based on the field observations.(Faivre-Pierret et al 1992). (Figure 2)
The modeling gave the average volume of gas: 0.6 to 1 km^3 degassed in few minutes. The minimum velocity at the surface of the lake should be 28m/s in order to reach 120m with a lethal concentration. The propagation velocity on horizontal surface reaching 50 km/h. (Faivre-Pierret et al 1992).
Using the limnic origin to explain the catastrophe, it is difficult to account for such a large volume of gas emitted from the all lake volume while the observed perturbation in the lake were so small:
- no mud flow,
- clear water below 10m,
- small waves, no over flows,
- lake water still stratified and partially saturated after the event.

The volcanic scenario is consistent with observations and modeling as perturbations were due to the gas hurles through the lake affecting only a column of water.

THE CULTURAL DEBATE

Beside the scientific argumentation , testimonies were collected from eyewitnesses.(Shanklin 1989). Part of the testimonies were consistent with both scenarios:
- an explosion sound,
- water splashing on the lake shore,
- a difference in water level, and
- the existence of white clouds .

Other testimonies were rejected by our colleagues as they were made by people having a different culture, ignoring the basic geology and expressing their observations in a language mixing superstitions and observed facts.
Witnesses said they smelled acid. This observation were rejected by our colleagues, as there is no acid in the lake water.
Witnesses heard the ground craking, but, degassing of the water would not break the rocks around the lake.
Witnesses said that the river water was hot just after degassing": but when these scientists measured temperatures a week after: surface lake water had a normal temperature.
Witnesses observed red stains on the lake surface; but, degassing of the water would have mixed the entire lake.
Witnesses had skin burns on the body, arms, and legs; but, the lake water was not warm or acidic.

Interpreting testimonies:
Instead of rejecting these testimonies or observations we tested them . The translation was made by an antropologist knowing well the local language. At the same time we made a review of the pathology of asphyxiation by carbon dioxide.The testimonies were located on a map in time and place and the feelings related by the witness were reexaminated against the known syptoms of gas asphyxiation. Strange testimonies such as "My hands were all frozen; when I reached the hospital, my body was completely weak" (survivor from Subum in Le Guern *et al* 1992) became interpretable. In fact, the inhalation of high concentration of carbon dioxide is known to provoke a shift of plasma from the periphery to the core of the boby (Arends *et al.* 1952; Billings and Brown 1955). The effects and feelings are very similar to what occurs during a cold agression (Stupfel and Le Guern 1992).
After completing this work it was remarkable that we were able to reconstruct the event in space ad time (LeGuern *et al.* 1991).

THE PLAGUE OF AREQUIPA (PERU) IN 1718.

In 1991 when studying the eruption of Sabancaya (Peru) we had the opportunity to collect a text describing the general plague affecting in Peru the City of Arequipa in 1718 the english translation is as follows: (Huaman 1991)

"In July August and September 1718 people suffered in Arequipa from a very hot and fetid southern wind giving to the most aware the fear that something fatal happened. The heaviness and tightness of the wind spoiled the atmosphere, and short time after, the plague contagion disseminate rapidely, and at the end of September it spread all over. People in the city and suburbs were affected.
Places and streets stayed deserted, very few people being able to walk around. Food was lacking as no people were able to sell or buy wares. In this situation basic supplies and welfare were nonexistant. The illness consisted of a great dullness, fainting, feebleness in all the senses, a pain feeling indistinctly in the whole body, general lassitude, deafness, total prostation, fever, and lack of appetite with blood in mouth and nose .
"The people already sick, especially those suffering from chest ailments died quickly, as well as those using medications prescribed by doctors.
The strongest people were wearing a lot of cloth and sweated. They felt extremely heavy and ill, having bodies feeling very weak, being dim sighted and looking sad and drawn. A long time was necessary to dissipate the troubles of the disease.
"The major part of the city became deserted. There were so many dead that churches and cemeteries were not sufficient and it was decided to transport them on carts in the contryside where pauper's graves were especially dug. In the city the major part of the houses remained opened some were completely bewildered but nobody took care of the oufits and furnitures they contained."

PLAGUE OR CARBONE DIOXIDE ASPHYXIATION ?

When they diagnosed this catastrophe people ignored the intoxication by carbone dioxide. Plague was well known to have already killed millions of people in Europe. But today when we compare the testimonies collected in Arequipa in 1718 with those collected around Lake Nyos in 1986 they are similar.
In Arequipa people felt "a very hot fetid southern wind": Around Lake Nyos survivors said that they "heard something like a breeze or a wind like before the rain" and felt a heat impression.
In Arequipa able-bodied people wearing a lot of clothing were sweating
Inhalation of 6% carbone dioxide provoque an increase in the sweating rate.
In both places people were prostrated, "unable to walk even to talk..."

STRANGE IDIAN LEGENDS:

Other similar cases are reported in indian legends around Aconcagua in the Andes were a "bad wind" "The Puna" blows down the montain and legend says is produced by stones or vegetation . While studies on the role played by the respiratory sensation of low or high landers during high altitude hypoxia adaptation were carried out at base or altitude camp of the Aconcagua mountain (Plaza des mulas 4800m or Nido del Condor 5400 m), physiologists observed that altitude acclimatization did not present the classical or regular pattern as in other high altitude hypoxic situations (Andean or Himalayan ranges). Especially in area where CO_2 escapes from the ground (Noël-Jorand 1991personnal communication ; Noël-Jorand and Brunet 1994 A and B).

RISK MANAGEMENT FROM MYTHS AND LEGENDS :

Geologist are not usually aware from carbon dioxide; as usually emitted at great velocity and high temperature it mixes with the air and never reaches dangerous concentrations. But myths and legends contain strange stories in many places around volcanoes. When looking aerial photographs of Cameroon we can see that people settled around lakes since the last decade, when the unique voice of tradition has been replaced by multimedia and the multiple opinion of scientists.

KEEPING WITH ANCIENT CULTURES

We are trying to reconstruct natural phenomena having a reccurence of centuries or millenium on the basis of written documents. A huge amount of observations are conveyed by oral traditions in a language always including myths, legends and superstitions. We had with the Nyos case a good opportunity to correlate testimonies in local culture with scientific observations, measurements and knowledge. Modern developpement is uniformitizing cultures and it is urgent to collect these oral traditions before they dissapear . Degassing of toxic volcanic gases leave no readeable geological records; oral traditions can help to locate today's affected areas.
On Lake Nyos we were able to validate a model calculating the flow of carbon dioxide. It would be possible to simulate such a situatioon by calculating in other topographies.

THE COMMUNICATION PROBLEM

Leading volcanologists are proceeding to theoretical studies publised in specialized journals. They belong to the geology, chemistry, and physics communities. But, their opinions are now used by public authorities. Very few scientists are taking into account the social and legal problems induced by the transfer of their results to public officials, industries, and public services. Very often their statements are distorted or sensationalized by the media. In addition, there is no universal survey system, each volcano having its own specific behavior. Even when using the complete up-to-date set of geophysical, geochemical, and geological equipment, when computing simulations and models, the diagnosis will always be based on personal experience. This subjectivity sometimes induces conflicting opinions, especially when scientists sometimes try to seize the opportunity to highlight their activity and obtain more funds (McBirney 1983; Tazieff and Sabroux 1983)
In August 1994 Niragongo volcanic activity threaten one million refugees on its flanks. Experts from Zaïre, USA, Japan and France, claimed in October 1994 for cooperative studies and ask for an international meeting in Goma to plan monitoring efforts. (Goma Declaration). At Christmas time 1994 the head of the international humanitarian association "Médecin du Monde" Asked Dr H. Tazieff, President of the "Conseil Superieur d' Evaluation des Risques Volcaniques" to complete the international expertise wich described the situation in its volcanological aspect. Tazieff evaluates "the number of people that could be victims of the volcanoe and the number of refugees who should be badly exposed to death and serious diseases in case of a large scale transfer. (Tazieff 1995)

THE CULTURAL PROBLEM

When sharing our knowledge in the frame of scientific publications or international congresses we are using the same language and the same rules in the same culture. But when we are involved in the projection of our expertise in society, the conclusions we deliver to authorities can be completely different from one expert to another. Europeans, Asians, Africans, or Americans keep with their culture; the scheme they have to work in depends on the country in which they operate. In some the human life has no value; in others they cannot accept a death. This is a dimension of expertise that has not been usually taken into account.

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