GEOLOGY

Dissolved Gases in East African Lakes

According to the knowledge we have concerning the volcanic gases of Nyiragongo, the nearest volcano to the Lake Kivu of all the volcanoes of the Virunga Range, which constitutes the natural dam behind which Lake Kivu has formed, I cannot agree completely with Dr. Kevin Burke's and Prof. G. Mueller's views regarding the origin of the dissolved gases of this Lake (*Nature*, 198, 568; 1963).

In 1959, we were able to collect gases close to, and even on, the permanent lava lake of Nyiragongo volcano[1]. The sampling conditions were exceptionally good, in fact the best available so far with similar ones encountered by Shepherd[2] and Jaggar[3] in 1919 at the Halemaumau lava lake of Kilauea (Hawaii). Our own analyses, like those of Shepherd, showed no trace of methane. But all of them disclosed relatively high contents of unoxidized gases: carbon monoxide (average amount) 1·7 per cent of the 'active gases' (other than water, nitrogen + argon, oxygen) at Kilauea, 5·2 per cent at Nyiragongo and hydrogen (1·9 per cent for both Kilauea and Nyiragongo); moreover, Kilauea had also a sulphur content attaining 3·6 per cent of the 'active gases'.

The nitrogen/oxygen average ratio in our four best Nyiragongo analysis is 10/1·5, and the nitrogen content (1·65–14·5 per cent) is quite different from that which should be expected should atmospheric oxygen have been consumed in oxidation of methane. It seems difficult to accept the idea of all 'juvenile' methane having been oxidized prior to its escaping from vents situated very close to the molten lava lakes, while sulphur, carbon monoxide and hydrogen, on the contrary, are still present in significant proportions.

On the other hand, methane has been found only in those volcanic gases—collected relatively far from the molten lava—on volcanoes situated in a geologically quite different situation, namely, in orogenic belts: Ambrym volcano (New Hebrides)[4], Guadeloupe[5], Santorin[6], Novarupta and the Valley of Ten Thousand Smokes[7], Kliuchevskii[8], Bezymiannyi[9], Asama Yama[10], etc.

The analyses of the occluded gases in the lava (melilite basanite) of Nyiragongo[11] show no methane but 23 per cent carbon monoxide and 13 per cent hydrogen for 60 per cent carbon dioxide and 4 per cent nitrogen. This very high content of unoxidized gases (36 per cent), the low content of nitrogen (4 per cent) and the total absence of methane, all argue against a juvenile origin hypothesis of methane in the waters of the close-by Lake Kivu. On the contrary, methane has been found occluded in the lavas from orogenic belts: Tuscany ignimbrites[12], Mont Pelée (Martinique)[13], Novarupta[14].

All these facts show, I think, that the absence of methane in the volcanic gases of Nyiragongo is original, and is not due to atmospheric oxidation.

Therefore, the high methane content of Lake Kivu should not be attributed to volcanism, and most probably, as Kufferath and Schmitz have supposed, is of biogenic origin; while carbon dioxide, the main constituent of the Nyiragongo 'active gases', would be of a juvenile origin.

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Tazieff's conclusion that the presence of substantial amounts of carbon monoxide and hydrogen in gas from Nyiragongo rules out the possibility of juvenile methane existing at depth is not justified since oxidation of methane by steam according to the reaction: $CH_4 + H_2O = CO + 3H_2$ would yield just the gases that appear in his analyses. This reaction has been investigated at one atmosphere[1,2] at which pressure equilibrium lies well to the right. My library facilities are limited and I have been unable to find an account of variation with pressure, but clearly high pressure will shift the equilibrium towards the left. Oxidation of methane by steam is not, of course, atmospheric oxidation and I regret the omission of a reference to alternative means of oxidation in my original communication.

If methane is a widespread constituent of magmatic gas at depth its occurrence in surface gas from orogenic belt volcanoes may be correlated with their generally explosive character. Slow upwelling of lava, as at Kilauea and Nyiragongo, might permit complete oxidation of methane by steam while rapidly rising gas, characteristic of the orogenic belts, might not be completely oxidized.

I regard the nitrogen content of volcanic gas from a lava lake as of limited value in assessing the extent of atmospheric oxidation because oxygen can be added to the magma without nitrogen through reaction on the lake surface and subsequent reduction of oxidized material carried downward by convection.

A final answer to the question of origin cannot be given until more complete analyses (and especially isotopic analyses) of the Lake Kivu gas are available for comparison with the excellent results obtained for gas from Nyiragongo by Tazieff and his colleagues.

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Primary and Secondary Arcs in the Scandinavian Caledonian Chain

Prof. J. Tuzo Wilson *et al.*[1] have given an outline of the European Caledonian and Hercynian mountains. Regarding the Scandinavian Caledonian chain these authors mention that secondary arcs can readily be made out in Sweden, and that igneous rocks of primary arcs are exposed in the Lofoten Islands off Norway.

I agree that secondary arcs can be made out in Sweden. With regard to the Lofoten Islands, rhenium/osmium determinations of molybdenites from these Islands gave the pre-Caledonian ages 2080 and 2290 million years[2]. According to my investigations other Norwegian coast districts form parts of primary arcs.

The Scandinavian Caledonian chain became inactive tectonically in Devonian time. The chain is now weathered down, and parts of it are beneath the sea. We can, however, still trace a narrow mountain system[3] (Fig. 1). The primary arcs lie through the following Norwegian counties: Møre and Romsdal, Nordland, and Troms. The arcs are now exposed as Caledonian gneisses and schists.

The junctions of these arcs at which secondary arcs formed are in central and in northern Scandinavia. The secondary arcs consist of two parts, an uplifted massif or