LIGHT ELEMENT METASOMATISM OF THE CONTINENTAL MANTLE: THE EVIDENCE AND THE CONSEQUENCES

By

F.E. Lloyd and D.K. Bailey
(Dept. of Geology, University of Reading, England)

The highly potassic volcanics of S.W. Uganda and the sodi-potassic volcanics of the West Eifel, Germany, represent two distinctive aspects of the highly alkaline volcanism characteristic of uplifted and rifted continental cratons. The sparse lavas are feldspathoidal clinopyroxenites and the associated explosive volcanism provides highly typical ultramafic nodules composed of dark mica + clinopyroxene ± amphibole with titanomagnetite, sphene and apatite. These are, generally, alkali clinopyroxenites. The Eifel suite also includes lherzolites, harzburgites, wehrlites and dunites. Olivine-bearing nodules are scarce in the highly potassic fields of Bunyaraguru and Katwe Kikorongo, but more abundant in the less potassic Bufumbira province. No eclogite, garnet lherzolite or gabbro nodules have been found in West Eifel or S.W. Uganda.

Carbonatitic nodules are found, and carbonates are abundant among the pyroclastics, the soluble extracts showing characteristic carbonatite trace-element enrichment (Rb, Sr, Y, Nb, Ba and La). The volcanic gases are CO_2-rich.

Evidence of metasomatism. All stages of transition from anhydrous nodules to alkali clinopyroxenite can be found - the olivine, orthopyroxene and chrome diopside being replaced by diopside-salite, dark mica, amphibole and iron ores. The early stages of replacement are localized along cracks and fissures, traversing the crystalline anhydrous assemblages, and cross-cutting phase boundaries. The nature and manner of replacement are analogous to the process of fenitization (alkali metasomatism) in crustal rocks. The final stages of the process are preserved in an alkali clinopyroxenite which contains scattered relicts of spinel lherzolite. Small amounts of glass are found within the veins of hydrous minerals in some cases. There are no signs of reaction with the adjacent minerals. The glass is commonly vesiculated, presumably due to the pressure drop on eruption. Where nodules are in contact with lava the hydrous minerals are dehydrated, so that the formation of hydrous minerals and glass within the nodules must relate to higher vapour (and total) pressures or lower temperatures, or both. (See Tables, page 4).

The transitions between anhydrous and hydrous ultramafic nodules eliminate the possibility that the latter are of crustal origin. There is no evidence to show that the hydrous nodules are xenoliths from a deep igneous intrusion, although some could have such an origin. All the internal evidence suggests that the ultramafic nodule suite is a sample of the local mantle, which has been partly metasomatised (by the addition especially of alkalis, iron, H_2O and CO_2).

Supporting evidence. (a) Recent experimental studies of the stabilities of phlogopite and amphiboles, indicate that these phases would be stable in the upper mantle, and therefore alkali clinopyroxenite is a permissible mantle composition.

(b) Geophysical studies of the Rhine and East African rifts have indicated the existence of low density (3.2) mantle below the crust. Alkali clinopyroxenite with about 25% mica (which is average for the W. Eifel and Uganda) has the appropriate density.

(c) These regions are characterized by geologically long-persistent uplifts. Most explanations relate the uplift to thermal disturbances in the underlying mantle, but these are inadequate in terms of amount of uplift and its geological persistence (Bailey, 1972). Conversion of the top 15 km of anhydrous mantle to alkali clinopyroxenite, however, could produce uplift of the right order (~1 km), and this uplift would be geologically persistent.

(d) The associated magmatism is characterized by extreme richness in alkalis and volatile emission. Plutonic equivalents, in other provinces, display widespread crustal fenitization, and the feldspathic magmas in many of these cases appear to be rheomorphic fenites.

(e) The overall chemical compositions of the lavas resemble those of the alkali clinopyroxenite nodules, and their Mg, Cr and Ni contents suggest mantle derivation.

Proposed Model. All the above evidence is consistent with a model in which long-sustained degassing of the underlying mantle leads to progressive metasomatism at the top, where the alkalis (and H_2O) are fixed within the stability range of phlogopite and amphibole. The increased volume causes uplift of the overlying crust. Continued passage of volatiles ultimately induces melting (Bailey, 1970) producing volatile-rich magmas and the characteristic explosive alkaline magmatism. The experimentally-determined stabilities of amphibole and phlogopite are such that in regions of low-geothermal gradient (30° C/kb) amphibole could be stable to depths around 80 km, whilst phlogopite would be stable to 120 km: along steep geothermal gradients (100° C/kb) these depth limits converge around 30 km and the separate existence of phlogopite-enriched mantle seems out of the question. Time is an essential term in the metasomatic argument, allowing for the long and gradual development of light-element minerals in the top layers of the mantle. We propose that the alkali-rich magmas are rheomorphic mantle fenites. Highly potassic lavas are generated where the initial continental geothermal gradient was low, from phlogopite-rich mantle below the level of amphibole stability: sodi-potassic lavas are formed at higher levels, when amphibole-bearing mantle becomes involved in melting (see Figure). In the oceans highly potassic lavas are not recorded, (Lloyd, in press). This accords with the present hypothesis because under conditions of steep oceanic geotherms phlogopite stability is only slightly greater than that of amphibole: thus there will be very little opportunity for a layer of potassium-enriched mantle to develop, except possibly in the older and cooler parts of the oceanic lithosphere, near the margins.

References.

Bailey, D.K., 1970. - Geol. J. (Special Issue) No. 2, pp. 177-86.

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FIG. Schematic cratonic crust-mantle sections, showing the generation of different alkaline magmas by melting of metasomatized upper mantle. Phlogopite-rich mantle underlies the zone of amphibole stability.

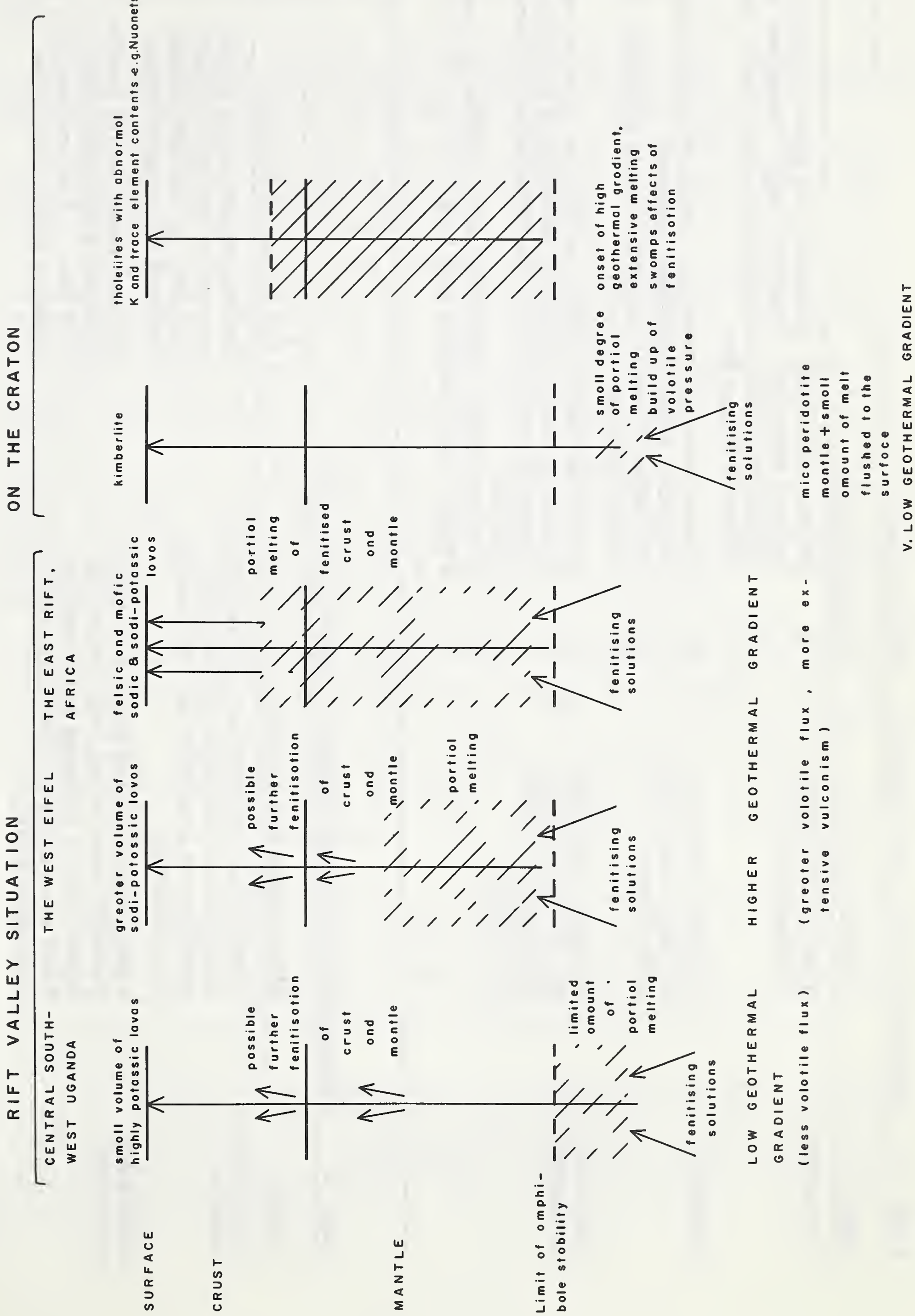

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Table 1. Paragenesis of the nodule phases 1 - clinopyroxene

Nodule	Primary cpx.	Secondary cpx.	
Lherzolite	Pale green chromiferous diopside	(i)	Darker brown cpx. associated with glass, spinel and hydrous minerals. Found in "vugs" throughout nodule.
		(ii)	Alteration of pale green diopside to pale brown cpx. by contact with host lava.
Wehrlite	Diopside with more Fe and Ti than lherzolite diopside	(i)	Darker greenish brown cpx. associated with opaque iron minerals, glass and hydrous minerals.
		(ii)	Alteration of primary diopside to pale brown cpx. by contact with host lava.
Alkali clinopyroxenite	Diopside with more Fe, Ti and Ca than lherzolite or wehrlite diopside	(i)	Dark green salite forming patchy edge or centre zones. Zoning often follows lines of weakness in nodule and is frequently associated with the introduction of hydrous minerals.
		(ii)	Purplish brown, titaniferous outer oscillation zones. Product of interactions with lava.

Table 2. Paragenesis of the nodule phases 2 - hydrous minerals

Nodule	Mineral type and occurrence	Low pressure alteration
Lherzolite and Wehrlite	Pale yellow amphibole and pale red mica occupy lenses and bands of alteration together with secondary cpx. and opaque iron minerals.	Hydrous minerals are notably corroded where they contact host lava - they are usually replaced by cpx and olivine.
Alkali clinopyroxenite	Alkali hornblende and dark mica occupy corroded areas of cpx. and olivine and follow lines of weakness in the nodules. Their occurrence is often associated with salite zoning.	Hydrous minerals are notably corroded where they contact host lava - they are usually replaced by cpx and olivine.