

## Natural garnet–pyroxene transformation in Cenozoic alkali basalt from Nigeria?

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**SUMMARY.** Aggregates of clinopyroxene in some doleritic lavas have external outlines strongly reminiscent of garnet crystals. They cannot be satisfactorily identified either as Upper Mantle fragments or as cognate synneusis aggregates, and it is suggested that they may have developed by inversion from original garnets, which crystallized at very high pressures. Neither morphology nor composition can provide conclusive proof of their original nature, but there is circumstantial evidence from the presence of an unusual inclusion suite in basalts nearby. The commonest phases are zircon and corundum, minerals more usually found in kimberlites than in basalts. Corundum in kimberlite inclusions is almost invariably accompanied by calcium-rich garnet, which adds some significance to the suggestion that these clinopyroxene aggregates are pseudomorphing original garnet.

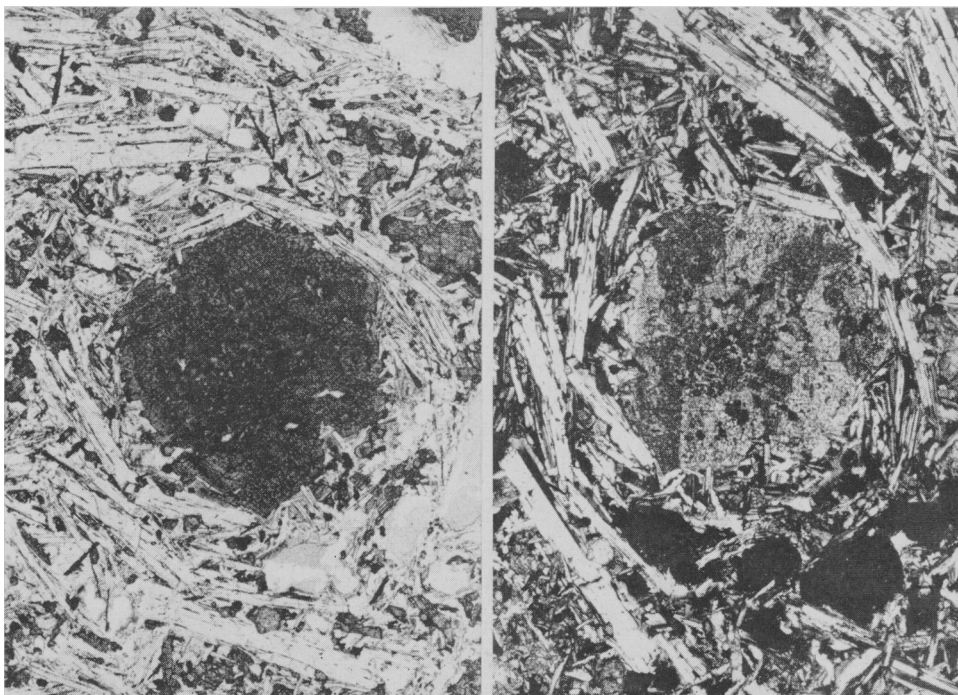
RINGWOOD (1967) demonstrated experimentally that given sufficiently high pressures, aluminous pyroxene compositions can crystallize with garnet structure, which would be expected to invert to pyroxene at lower pressures. Strong evidence of such a transformation has been presented by Ringwood and Lovering (1970), who conclude that pyroxene–ilmenite intergrowths from some kimberlite inclusions have formed by inversion–exsolution from an original garnet structure. This note describes evidence indicating a similar transformation in alkali basalts from the Nigerian part of the Cenozoic Gulf of Guinea volcanic province (Wright, 1968).

*The pyroxene aggregates.* Some of the lavas on the extensive volcanic plain of the Gimi River valley about 60 km south-west of Jos are greyer and more doleritic than the majority of flows. A faint mottling on these rocks is due to aggregates, between 1 and 4 mm in diameter, of pyroxene crystals, sometimes in complex intergrowth, but more commonly as independent grains of irregular shape. Many of these aggregates have partial or complete outlines reminiscent of sections through garnet porphyroblasts in metamorphic rocks (figs. 1 and 2). An especially striking feature of the aggregates is the way in which individual grains have straight boundaries *only* on the outer margins of the aggregates. Moreover, these straight boundaries are collinear between adjacent grains of contrasted orientation, as exemplified in fig. 2.

The pyroxene appears to be a diopsidic variety, with  $\beta$  1.691  $\pm$  0.002, and moderate  $2V_{\gamma}$ . It is somewhat turbid and spongy due to alteration, with development of brownish chlorite (?) and scattered granular oxide (ilmenite?). Further evidence of chemical disequilibrium is the clear rim of titanite, similar to that in the groundmass, round the margins of these aggregates. Such reaction rims are of course common around xenocrysts and high-pressure phases in basalts.

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The rock is otherwise a fresh doleritic alkaline olivine basalt of quite normal aspect, with laths of calcic plagioclase reaching 2 mm in length, subhedral (0.5 mm) olivine, granular titanite and iron-titanium oxides. Scattered small biotite flakes and green terminations to some of the groundmass pyroxene crystals are additional signs of alkaline affinity. No other inclusions have been found in these rocks.



FIGS. 1 and 2: FIG. 1 (left). 2 mm diameter aggregate of clinopyroxene, possibly inverted from original garnet. Groundmass plagioclase laths wrap round the aggregate, in a manner reminiscent of garnet porphyroblasts in metamorphic rocks. FIG. 2 (right). As fig. 1, crossed polars and rotated  $45^\circ$  to the right, to show diverse orientations of irregular pyroxene crystals composing the aggregate.

*Origin of the aggregates.* Two possibilities are considered: the pyroxene may be original, or it may be formed by inversion from original high-pressure garnet.

The evidence of alteration and the reaction rims suggest that the aggregates appeared at an early stage in the history of the magma. They might be pyroxenite fragments of Upper Mantle origin, although their restricted small size range and monomineralic composition makes this unlikely. Another possibility is that the pyroxene crystals are of early high-pressure cognate origin, and that they drifted together into syneusis aggregates. This alternative is totally inconsistent with the nature of the large and compositionally uniform high-pressure clinopyroxene crystals that constitute an abundant megacryst phase in basalts elsewhere in this volcanic province (Frisch and Wright, 1971). In either case, it is very difficult to see how the aggregates could have acquired their regular external morphology.

The alternative explanation is that these aggregates are original garnet crystals, which *either* crystallized direct from the magma at great depth, *or* were incorporated as xenocrysts from the Upper Mantle, and which subsequently inverted to clinopyroxene at lower pressures.

Internal adjustments upon inversion might be expected to develop diversely oriented pyroxene crystals, while retaining the overall outline of original garnet. The spongy, altered, and often disrupted aspect of the aggregates could be due to slight expansion accompanying inversion. A density decrease of about 10 % is involved (Ringwood, 1967), which would result in a 1 cm cube of garnet becoming a 1.04 cm cube of pyroxene, sufficient to weaken the structure and make it susceptible to fracturing and alteration.

As yet there is no way of distinguishing unequivocally between these alternatives. Sections through both garnet and pyroxene crystals can give square, hexagonal, and flattened hexagon outlines, all of which can be found among slides of these aggregates. We can only say that the outlines of the aggregates *could* be those of original garnet.

Chemical analyses may not provide positive proof of original identity either. High-pressure pyroxene megacrysts are known to be characterised by an alumina content greater than normal for basaltic pyroxenes, and Ringwood's experiments were conducted mainly on compositions with 10 %  $\text{Al}_2\text{O}_3$ . If the pyroxene in these aggregates proves to be aluminous, this will only tend to confirm a high-pressure origin, already deduced independently. It will not resolve the question of whether the pyroxene was originally garnet. Nor would a low alumina content be conclusive, for Smith and Mason (1970) have described a garnet with pyroxene composition, containing less than 3 %  $\text{Al}_2\text{O}_3$ , from the Coorara meteorite. The pyroxenes that Ringwood and Lovering (1970) believe to have inverted from garnet contain similar small amounts, and indeed have compositions indistinguishable from many ordinary augites (cf. Deer, Howie, and Zussman, 1965, 2, table 17).

Other compositional characteristics may have a bearing on the problem, however, and for this reason, as well as for the intrinsic interest of these aggregates, analytical work is projected. In the meantime, it is pertinent to review some of the circumstantial evidence, detailed elsewhere (Wright, 1971), supporting the suggestion that the pyroxene aggregates may be inverted garnets.

Not far away, in the same lava field from which the rocks with pyroxene aggregates were collected, there are alluvial concentrations of zircon and blue corundum crystals, with lesser amounts of green spinel. There is good evidence that the provenance of all these phases lies in the otherwise normal alkaline basaltic lavas of the Gimi Valley (Wright, 1971).

Zircons are not uncommon among kimberlite assemblages (Ahrens *et al.*, 1967), and have also been found along with high-pressure megacrysts in alkali basalts (Binns, 1969). More significant is corundum, which occurs in the eclogitic and related inclusions of kimberlites, generally as a blue variety, accompanied almost always by calcium-rich garnet, usually by omphacitic pyroxene, sometimes by kyanite, and occasionally also by green aluminous spinel (Mathias *et al.*, 1970). Assemblages of this kind have been tentatively ascribed to very high-pressure fractionation deep in

the Upper Mantle, leading to Ca-Al enrichment (Mathias *et al.*, 1970). It may thus be significant that possible pseudomorphs of diopsidic pyroxene after calcium-rich garnet occur in the same lava field as the only corundum so far recorded in Nigeria, corundum that appears to be derived, along with zircon and spinel (and olivine nodules, Wright, 1971) from a source in the Upper Mantle. It would seem that in this region, deeper levels of the Upper Mantle have been tapped than elsewhere in the Nigerian province, where megacryst phases in the basalts (sodic feldspar, aluminous pyroxenes, pyropic garnet, amphibole, ilmenite, and spinel) differ in no significant way from those in other parts of the world (Frisch and Wright, 1971).

If these speculations prove ultimately to be valid, some other questions will have to be answered. In particular, how do phases typical of kimberlites come to be in basalts, usually regarded as being generated at depths of less than 100 km (e.g. MacGregor, 1968), especially when the experiments of Ringwood (1967) and Ringwood and Lovering (1970) suggest that pyroxene can only crystallize with garnet structure at pressures in excess of 100 kb, corresponding to depths of 300 km or more?

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*Note added in proof.* From New South Wales Dr. R. A. Binns (priv. comm.) has recently reported 'fairly normal alkaline olivine basalt deficient in normative diopside', carrying megacrysts of blue corundum. This discovery adds considerable weight to the thesis that the Nigerian corundum derives from the Gimi basalt flows.