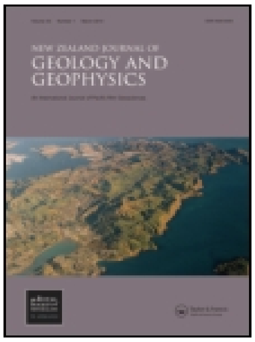

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QUARTZOSE XENOLITHS AND PYROXENE AGGREGATES IN THE AUCKLAND BASALTS

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ABSTRACT

Quartz xenoliths in the Auckland basalts are surrounded by envelopes of glass and reaction rims of pyroxene. Evidence is presented that the reaction rim may develop ultimately to replace the quartz completely and form a pyroxene aggregate. The miscibility of the xenolithic glass with magmatic glass is discussed.

INTRODUCTION

During an examination of a large number of thin sections of basalt from the Auckland volcanic field, several examples of segregations of pyroxene crystals were noted. In most of these segregations the pyroxene, while exhibiting optical properties similar to the phenocrystic and granular pyroxene of the basalt, differed markedly from it in the habit adopted. In the segregations the individual crystals were notably prismatic, of fairly even size, and arranged in a more or less radiating pattern. The outlines of the segregations were fairly distinctly defined against the host basalt (Fig. 1).

Quartzose xenoliths, ranging in size from small grains to sugary aggregates several inches across, are common both in the basalt of lava flows and in the scoriaceous basalt of pyroclastic deposits. In the latter they are not infrequently found in the cores of bomb fragments or as accidental bombs with thin skins of adherent basalt from which liquid has apparently been stripped off during flight through the air. The presence of these xenoliths was noted by Hochstetter (1864, p. 186), who explained their sugary texture as due to roasting in the lava. Shrewsbury (1892) rejected the underlying Waitemata Sandstones (mid-Tertiary) and the greywacke of the basement rock of the area as possible sources of the quartz, and tentatively suggested petrified wood as the original material. Wong (1946) regarded the xenoliths as formed by fusion of the more arenaceous members of the Waitemata Formation. This latter view is unlikely to be correct for the Waitemata Formation contains no known purely quartzose members. On the other hand, the basement greywacke formation, where exposed in neighbouring areas, does contain siliceous members and thick quartz veins. If these rocks are the source of the quartzose xenoliths, as would seem most probable, one might reasonably expect also to find normal greywacke fragments as abundant xenoliths in the basalt. In fact, such xenoliths are

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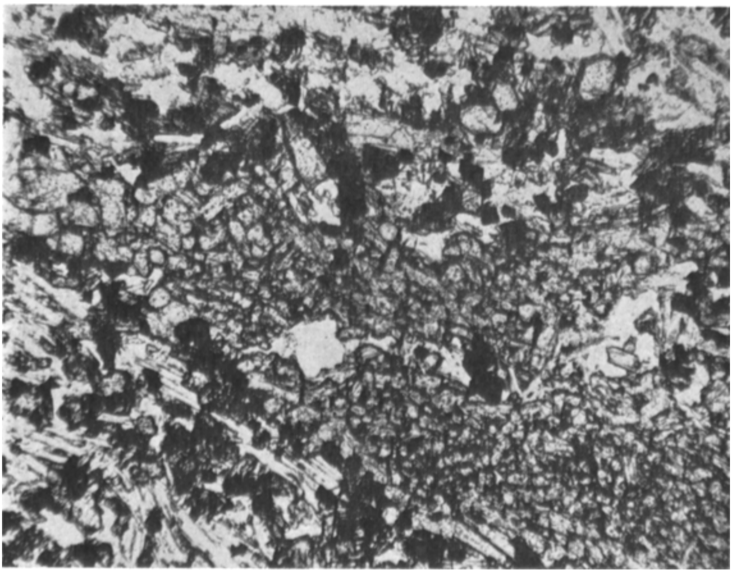

FIG. 1—Segregation of pyroxene in Auckland basalt. (4911 from Mt Eden flow, Almorah Rd., Newmarket). × 100

exceedingly rare, for apart from a few accidental blocks in tuff accumulations about two magmatophreatic volcanoes in the district (Taylors Hill and the St Heliers volcano), and one or two rather dubious greywacke xenoliths in the basalts, intensive search failed to reveal greywacke in the volcanic accumulations of the field. It seems not unlikely that the explanation of the absence of greywacke fragments lies in the high susceptibility of this rock to fuse when heated. Searle (1949) pointed out that greywacke pebbles 15 ft above a coal seam at Kopuku had been vesiculated and fused by heat from burning of the coal. It is presumed that the liquid produced by such melting of greywacke xenoliths could readily be assimilated by the magma. The more refractory siliceous material would tend to survive and would thus form the predominant type of xenolith, although it may have represented only a small proportion of the sedimentary material originally engulfed by the magma.

The quartzose xenoliths from the Auckland basalts range from almost unaltered quartzites to those in which, as a result of magmatic reaction, very little quartz remains. In the majority of examples, the relict quartz is surrounded by an envelope of colourless glass, which in turn is surrounded by a layer of pyroxene grains. This reaction texture developed about xenolithic quartz is in conformity with numerous records from all parts of the world, contained in a very large literature. The sections described below may be regarded as typical of the various xenoliths examined in this survey, and the examples are intended to illustrate progressively more advanced states of fusion of the quartzose material.

DESCRIPTION OF SPECIMENS

(1) *Section 1522* (petrological collection, Geology Department, University of Auckland) (Fig. 2) shows a typical sugary quartz xenolith from pyroclastic deposits of the Mt Wellington scoria cone. It consists of a mosaic of interlocking quartz clouded with inclusions, surrounded by an outer zone of clear quartz deposited in optical continuity with the core. The grains are fitted together along sharply defined suture lines. The rock appears originally to have been a quartzite; its present friable and granular texture in the hand specimen may be attributed to the effects of sustained heating.

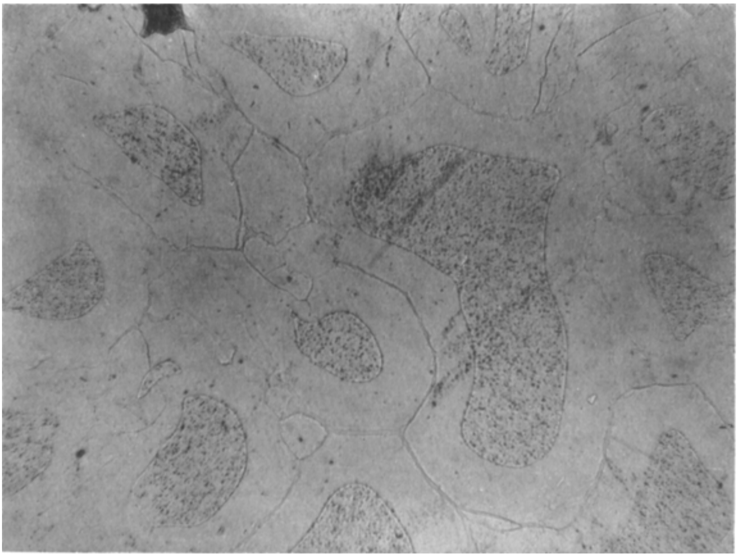

FIG. 2—Granulose quartz xenolith in which detrital cores packed with inclusions are surrounded by optically continuous, clear quartz forming a mosaic (1522). × 40.

(2) *Section 1540* (Fig. 3), cut from a specimen collected from similar pyroclastic deposits at Mangere Mountain, also has a granoblastic texture, but the grains of quartz have become fritted along the edges and widened by fusion of the quartz. The suture lines between the majority of the grains are filled with colourless glass. In some parts of the section only small relics of the quartz grains remain, and the whole area has become invaded by veins of brownish glass, with refractive index greater than that of Canada balsam. A few of the veinlets contain very small euhedral grains of augite, but no other crystalline phase was noted. The larger veins seem to be due, in part, to direct infiltration of the glassy mesotasis from the contiguous basalt, but elsewhere the glass appears to have resulted primarily from fusion of the quartz. In *section 5153,* from Mt Wellington, the

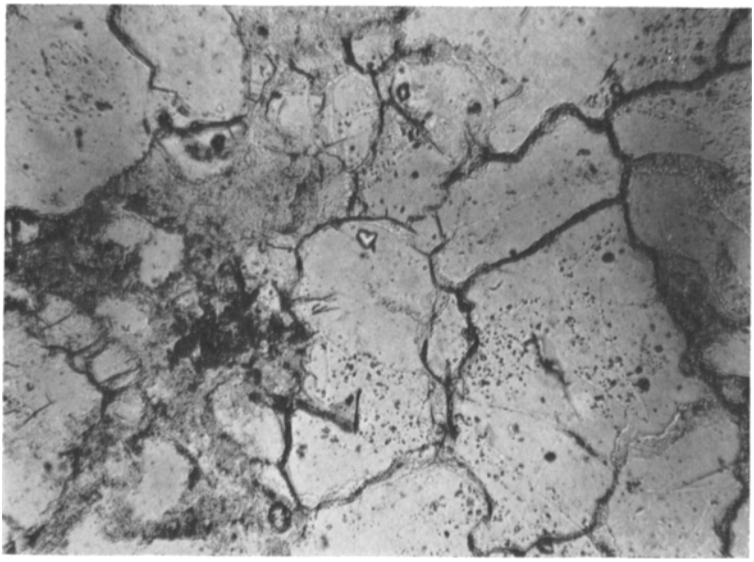

FIG. 3—Granulose quartz with sutures somewhat fritted and infilled with glass (1540). Some pockets of glass (on right) surround relict grains of quartz. × 100.

grains are markedly fritted along the edges and the glass-filled suture lines are 0·02 mm wide. The "glass" is semi-isotropic, possibly cryptocrystalline, and slightly fibrous, with refractive index distinctly lower than that of quartz. Against the basalt is a thin film of brownish glass, 0·2 mm thick, in which augite ($2V_Z = 68°$; $Z\Lambda c = 53°$) occurs in moderately large prisms parallel with the interface or in smaller radiating crystals growing from the interface into the glass.

(3) *Section 5325* (Figs. 4 and 5) is cut from scoriaceous basalt from one of the Three Kings scoria cones. The basalt is highly vesicular and was collected from close to an irregular dyke cutting the scoria mound. The basalt appears to have been roasted by gases escaping from the dyke, as suggested by the presence of hematised pseudomorphs after olivine, a golden-brown variety of pyroxene, and needles of rutile. The quartz grains of the xenolith are extensively corroded near the basalt interface, the relict grains being surrounded by a colourless siliceous glass. In some areas the glass appears to have invaded the basalt and has in some places devitrified to form a feldspathic phase. Along the interface between basalt and xenolith, prisms of brownish, non-pleochroic augite form a palisade of subparallel crystals more or less normal to the interface and growing into the glass from the interface. Augite crystals remote from the interface are much lighter in colour than are those close to it. Pockets of glass separating the relict quartz grains contain radiating aggregates of pyroxene crystals commonly 0·1 mm long by 0·01 mm wide; rarer individual pyroxenes are scattered through areas of glass, as are occasional plates of red-brown biotite with a maximum diameter of 0·01 mm.

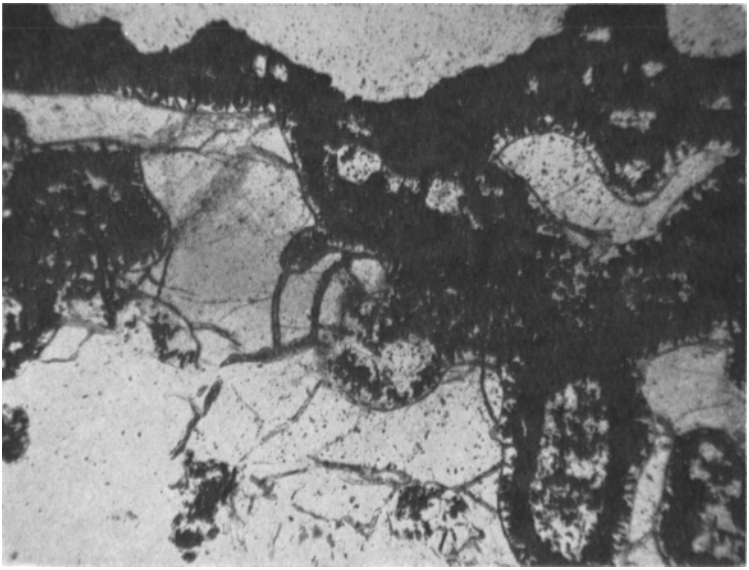

FIG. 4—Border of much corroded quartz xenolith with thin fringe of pyroxene margining the quartz (5325). × 33.

FIG. 5—Detail of corroded quartz from same section as Fig. 4, showing glass with prisms of diopsidic augite enveloping relict quartz. × 100.

(4) Smaller xenoliths often demonstrate the more advanced stages of fusion. *Section 5072B* (Figs. 6 and 7), from a Mt Wellington flow, Panorama Rd, Penrose, shows a small xenolith, approximately 1·0 mm in length, within which there is a rounded grain of quartz containing rows of minute inclusions and with distinctly fritted edges. The quartz is surrounded by a wide envelope of colourless glass. Outside this glass envelope, stumpy pyroxene prisms form another entire mantle from which individual needles of diopsidic pyroxene have grown into the zone of glass. Fewer and generally smaller needles have grown into the glass from the surface of the relict quartz kernel.

(5) In *section 4449* (Fig. 8), from a One Tree Hill flow, Selwyn Street, Onehunga, a sliver of a greatly reduced quartz grain is surrounded by an envelope of colourless glass, much wider than in the previous example. The individual crystals in the outer reaction rim are also larger and stouter than those forming coronas about the xenoliths described earlier, and the corona itself is much thicker. Here, again, growth of the pyroxene of the corona appears to have been more active towards the xenocryst than it has been on the outside of the pyroxene mantle, although it is apparent that individuals on the outside have increased somewhat in size during development of the mantle. The purely glassy area is much reduced with respect to the size of the xenolithic system as a whole.

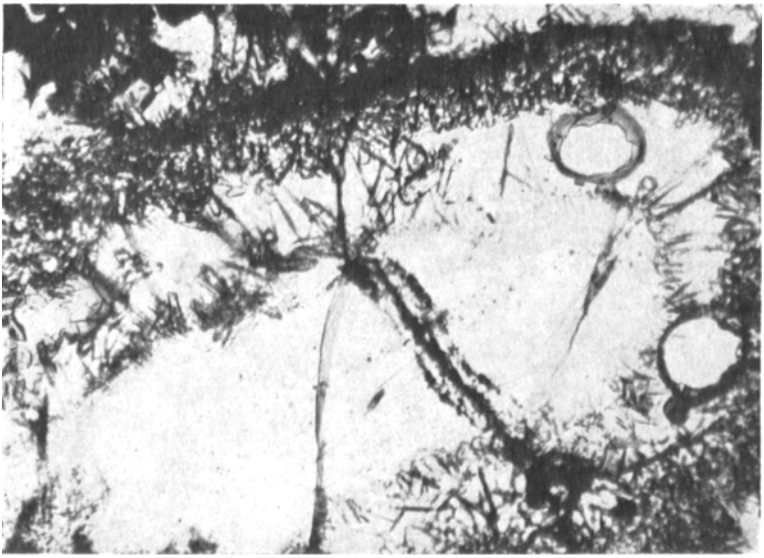

FIG. 6—Relict quartz inclusion in basalt (5072B). The quartz is surrounded with an investment of glass. Pyroxene crystals have grown both from the quartz kernel and from the basalt interface. × 100.

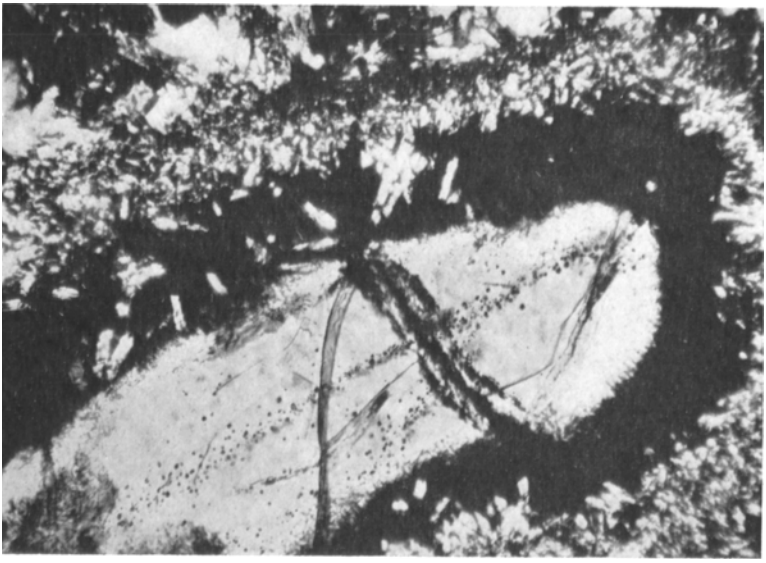

FIG. 7—Same field as Fig. 6; crossed nicols. × 100.

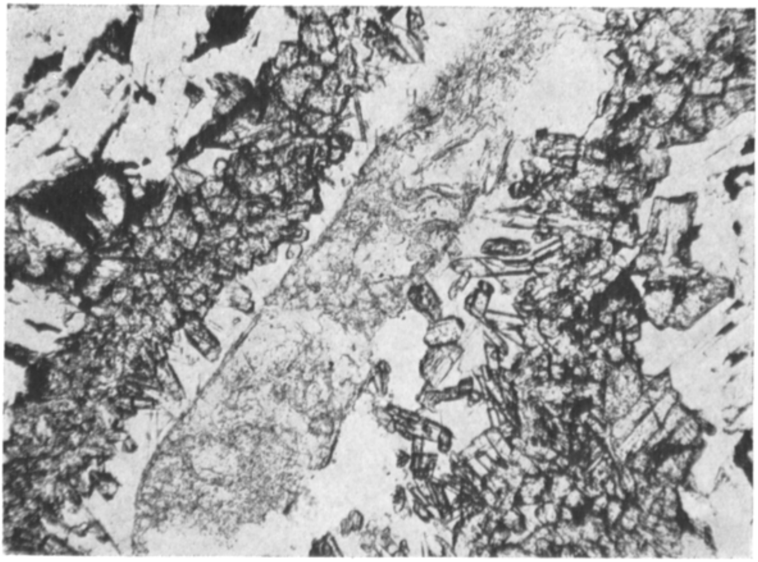

FIG. 8—Sliver of quartz in glass investment with wide and dense border of pyroxene crystals (4449). Euhedral pyroxene isolated in glass. × 100.

DISCUSSION

The basalts of Auckland, in which the xenoliths occur, are of the olivine-rich alkaline type in which the composition ranges as follows (Searle, 1960):

	Weight %			Weight %	
	(Min.)	(Max.)		(Min.)	(Max.)
SiO_2	41·9	48·2	CaO	9·6	10·7
TiO_2	1·42	2·33	Na_2O	2·7	3·5
Al_2O_3	12·7	15·1	K_2O	0·65	1·4
Fe_2O_3	1·6	4·1	H_2O+	0·15	0·95
FeO	8·4	10·3	H_2O-	0·05	0·35
MnO	0·12	0·2	P_2O_5	0·34	0·62
MgO	9·5	12·6			

The obvious sequential forms exhibited by the xenoliths in different stages of digestion in the basalt leave little room for doubt that original quartz inclusions may be entirely replaced by pyroxene close in composition to that normal to the host rock. Where not dispersed or drawn out into strings or bands by flowage of the rock, the pyroxene forms distinct segregations. These observations confirm those of Thomas (1924, p. 154), who described assimilation of quartz fragments in the Loch Uisg granophyre, Mull, Scotland, and noted that where assimilation was complete "the place of the quartz is taken by clots and strings of pyroxene, which . . . might be taken for cognate pyroxenic nodules".

Small pockets of feldspar found occasionally in association with xenoliths may represent drops of glass squeezed out of the xenolithic system, and this process may play a part in the formation of the pyroxene segregation, although no section so far examined has shown such bodies close to pyroxene segregations. Alternatively, the feldspathic inclusions may represent devitrified glass formed from the digestion of quartz in which pyroxene has failed to develop before the whole of the quartz has been fused.

Xenoliths similar to those described are a common feature of basic igneous rocks in all parts of the world and have often been recorded in the literature [*see,* for example, Thomas (1924), Benson (1945), Richarz (1924), Holgate (1954), Stevens (1955)]. The nature of the interaction between quartz xenolith and basic host and its petrogenetic implication have been discussed at length by many authors, notably, in recent years, by Holgate (1954) and Roedder (1956).

Holgate suggests that the petrographic evidence shows that each xenolith tends to become separated from the host by an investment of dominantly quartzo-feldspathic character and that this investment is glassy where the host has a glassy mesostasis; where the host is holocrystalline the investment is crystalline. The investment is typically bounded externally by a layer of ferromagnesian material, originally a pyroxene, precipitated from the host magma. This mafic layer is normally entire but may be breached so that the quartzo-feldspathic zone appears to invade the host rock. He believes that the phenomena displayed are due to a condition of immiscibility between the glass investment of the xenolith and the glassy mesostasis of the host, the immiscibility being effective at, and through some interval below, the temperature of onset of crystallisation in the host magma.

In Holgate's opinion, marginal transfusion of fused xenocrystic quartzose material in contact with the basic host tends to form a product which is enriched in alumina, soda, and potash when compared with the host material and, at the same time, impoverished in the major oxides of the cafemic group. Selective transfer through the pyroxene "armour" occurs as through a semipermeable boundary between immiscible liquids, which preserves the integrity of the xenolithic system. Alkaluminous oxides and water or hydroxyl ions diffuse into the xenolithic system, but, so long as the immiscible relationship remains, cafemic constituents are unlikely to do so in any significant amount. It is only when crystallisation changes the composition of magma so that the residua become miscible, that any significant incursion of cafemic ions occurs. Immiscibility, permanently effective at higher magmatic temperatures, ceases to be so when by the process of crystallisation, the basaltic residuum comes to a composition dominated by its alkali-feldspar content.

Roedder (1956) sees no need to invoke immiscibility as a factor. He imagines that on first contact with the xenolith, reaction with the undersaturated magma results in the precipitation of pyroxene. Further transport of cafemic material could lead to growth of the rim, for the host is saturated with respect to pyroxene or olivine or both.

Petrological observations cannot, perhaps, fully resolve the discrepancies between these two explanations. The following observations and deductions with respect to the Auckland xenoliths may, however, be pertinent to the problems of petrogenesis.

No xenoliths were observed in which an outer pyroxene mantle was developed without an intervening glass investment. Nor, for that matter, were any examples noted where a glass investment existed about a quartz kernel in the absence of an enveloping rim of pyroxene. Fusion of the quartz, presumably assisted by alkaluminous ions from the surrounding magma, appears to be a necessary preliminary stage to reaction with cafemic ions in forming pyroxene.

In some examples (e.g., 5154, from a scoria cone, Three Kings), the glass zone is very thin and is of the same brown colour as the mesostasis of the basalt. In others, the investment in colourless and forms the bulk of the inclusion. In section 1451 (from Mt Eden), a siliceous xenolith (not a quartz xenocryst), there is no capsular structure, and the xenolith is invaded by veinlets of glass merging into the mesostasis. The glass has a pronounced violet colour that becomes paler in tint and finally almost colourless the further the vein penetrates the xenolith; comparable examples were noted by Richarz (1924). Such examples favour the supposition that conditions of miscibility exist between the glass of the mesostasis and the glass formed by fusion of the quartz, at least at some stage in the cooling history of the rock.

In many xenoliths the pyroxene envelope is very thick in proportion to the investment of glass; this fact, together with the occurrence of isolated aggregates of pyroxene in the glass, suggests the ultimate growth of pyroxene to fill completely the space occupied by both quartz and glass at an earlier stage. This would support the contention of Thomas (1924) that precipitation of pyroxene could take place on the inside of the envelope at a time when pyroxene (but not alkali feldspar) was separating from the magma. The ultimate result would seem to demand miscibility of the residual glass of the xenolithic system with that of the mesostasis of the host during the final stages.

On the other hand, it cannot be denied that the integrity of the xenolithic system is preserved over a broad range of changing conditions during the solidification of the enclosing rock. This clearly indicates a reluctance of the liquid formed about the quartz to mix with the liquid phase of the host. It is not apparent to what extent this is due to inherent immiscibility between the two liquids or to the physical restriction of the barrier of pyroxene enclosing the xenolithic system. Whatever restraint there may be to mixing, there can be little restriction on the diffusion of cations into the inclusion. The continued fusion of the quartz kernels demands ready ingress of alkaluminous ions. There is textural evidence that cafemic ions also migrate into the system and are not prevented from doing so by a semipermeable boundary as suggested by Holgate (1954). Growth of the pyroxene rim may arise in part by accretion on the outside, where the continued growth of individuals sometimes results in the outer crystals being larger and stouter. Nevertheless, most examples give the impression that the important factor in the build-up of the pyroxene envelope is inward growth towards the xenocrystic quartz and fresh precipitation on the inner margin. In several xenoliths, as noted earlier, there is a distinct development of individual crystals and aggregates within the glass investment and in veins from the investment that penetrate the quartz. Attention has also been drawn to the formation of radiating prisms of pyroxene at the quartz-glass interface. These instances provide clear evidence of the presence of cafemic ions in the liquid phase of the investment.

It seems likely therefore that both alkaluminous and cafemic ions enter into the glassy investments about quartz xenocrysts. As cooling proceeds, pyroxene will continue to form in the xenolithic system as well as in the host magma. At least during the later stages of crystallisation, if not throughout the cooling history, the compositions of the two residua are likely to be such that the liquids are miscible; liquid may then be expressed from the xenolithic system, either by external pressures or by pressure due to the growth of pyroxene in the closed space, and entirely assimilated by the host. The observed segregations may be explained as forming in this way. The picritic nature of the majority of Auckland basalts provides an abundance of cafemic ions over a long part of the cooling history, so that pyroxene, which forms a large proportion of the phenocrysts, also makes up the bulk of crystalline material in the groundmass; in many rocks, rapid cooling during the final stage has resulted in residual liquids forming a glassy mesostasis rather than crystalline feldspathic material. For similar reasons the residual liquid of the observed xenocrystic systems has failed to crystallise before solidification was complete.

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