Melting of Acid Xenoliths into a Basanite: An Approach to the Possible Mechanisms of Crustal Contamination

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Abstract. Biotite gneiss xenoliths included in a basanitic flow in the Causses region (France) show several kinds of partial melting. Rhyolitic glasses appear at the expense of the quartz + feldspar assemblage; initially undersaturated latitic glasses at the expense of biotite + feldspar (+ quartz); lastly hyperaluminous products derivating from large phenoblasts of alkali feldspar.

The microprobe study of these glasses, of their contacts with the host lava, as well as that of the neogenic mineral phases, show that contamination occurs through, at least, four possible processes:

1. Diffusion at the interface between two liquids of contrasted composition (rhyolitic and basanitic).

2. Mechanical mixing of two liquids of less contrasted chemistry (latitic and basanitic).

3. Progressive solution of a solid phase (quartz) into the magma.

4. Vapour phase transfers.

Qualitative magmatic contamination in alkalies (mainly K) and silica results from all these processes; quantitatively, the most important of them seems to be 4.

The incidence of crustal contamination on the evolution of continental magmatic series is frequently put forwards on the basis of geochemical data (Sr isotopic ratios). But(as far as we know)only a few studies (i.e. Doe *et al.*, 1969) have been based on its usual petrographic criterion: the occurrence of xenocrysts and xenoliths, commonly surrounded by reactional rims.

The problem of the influence of crustal contamination is particularly striking in some alkalic volcanic series of the French Massif Central (Cantal and Mont Dore stratovolcanoes), where progressive transition from silica-undersaturated trachyandesites to saturated ones occurs. Two explanations have been put forwards in order to explain this transition: fractional crystallization of amphibole under high water pressure (Mervoyer *et al.*, 1973) and contamination accompanying the differentiation process (Brousse, 1971; Girod and Lefèvre, 1972). The volcanic rocks of Massif Central usually contain granitic or gneissic xenoliths from the Paleozoic basement.

In order to test possible mechanisms of magmatic contamination, we have studied, mainly by microprobe analyses, partially melted biotite gneiss xenoliths in a basanitic flow from the Causses region, France.

Occurrence of the Xenoliths

The ten meters thick Azinières flow (north of Millau, Auvergne) lies on the Lias
of the Causse Rouge, and is 5.7 ± 0.2 m.y. old (Gillot, 1974). This relatively
potassic basanite (Table 1, a) contains some alkali feldspars in the matrix. Xeno-
liths are numerous and either of deep-seated origin (peridotites, pyroxenites,
clinopyroxenes or potassic oligoclase megacrysts) or of more superficial one. These
latter are centimetric to decimetric xenoliths of biotitic gneisses, of "granitic"
composition, which have, in all cases, undergone partial melting. They contain
20 to 50% of glasses, which prove to be of various kinds under the microscope (two
or even three types of glasses coexisting in the same xenolith) and numerous high-
temperature mineral phases. Residual minerals of the gneissic paragenesis are
quartz, potassic feldspar inverted to high-temperature sanidine, oligoclase An21.
Biotite can only be recognized by its breakdown products (groups of octahedrons
of magnetite and hercynite). Muscovite and primary aluminous silicates have
never been found; however muscovite may have been destroyed at the very be-
ginning of the melting process (Leyreloup, 1973). Among xenoliths, important
variations in mineralogy or chemical composition (some xenoliths being mostly
quartzo-feldspathic, others mostly biotitic) and in grain size (some alkali feldspar
phenoblasts being larger than 10 mm) can be observed. The melting processes
are controlled by these variations.

Melting Processes

Three types of glassy products have been found:
— an uncoloured glass, of rhyolitic composition, formed at the expense of quartz
and feldspars,
— a brown latitic glass, derivating from the biotite + feldspar (+ quartz) as-
semblage,
— a vacuolar grey glass containing much crystallites of corundum, formed at the
expense of the former alkali feldspar phenoblasts.

   The most common types are uncoloured and brown glasses, which altern reg-
ularly in the xenoliths, reflecting the previous foliation of the gneiss. The
transition between these two types is very smooth, in contrast with the very
steep and well-defined limit (about $5 \mu m$ wide) between uncoloured and grey
glasses. The contact between brown and grey glasses has not been found.

A. Melting of Quartzofeldspathic Material

It has been frequently described (Butler, 1961; Al-Rawi and Carmichael, 1967;
Bogoyavlenskaia, 1972; Leyreloup, 1973) and occurs in mostly quartzofeldspathic
xenoliths as well as in the quartzofeldspathic beds of common gneissic xenoliths.
It gives an uncoloured glass firstly located at the quartz-feldspar boundaries,
such as in experimental melting studies (Mehnert *et al.*, 1973), but sometimes
extending to more than a half of the xenolith. Oligoclase and alkali feldspar melt
simultaneously and partly melted crystals show a typical fingerprint structure;
quartz crystals are corroded. High temperature phases are high sanidine (product
of recrystallization of potassic feldspar; a clear rim at the margins of the crystals

Table 1. Analysis and C.I.P.W. norm of the Azinières basanite and of glasses from its melted xenoliths

Oxides	a	b	c	d	e	f	g	h	i	j
SiO_2	45.2	52.4	70.4	70.4	72.0	72.0	63.0	65.5	68.5	50.4
TiO_2	3.0	2.5								
Al_2O_3	14.4	21.8	13.6	14.1	13.0	13.0	16.7	15.1	13.8	41.3
FeO^*	11.6	5.2	2.3	2.7	2.8	2.8	5.3	3.3	2.7	1.3
MgO	8.0	1.5					1.3	0.7	0.5	0.8
CaO	7.4	1.8	0.5	0.5	0.6	0.5	1.3	0.6	0.6	0.5
Na_2O	4.5	8.2	4.0	3.4	3.2	3.1	3.7	3.3	3.2	3.2
K_2O	2.3	6.1	4.6	4.6	4.4	4.6	4.9	5.6	5.2	4.2
P_2O_5	0.2									
H_2O^+	1.9									
H_2O^-	0.4									
Total	98.9	99.5	95.4	95.4	96.0	96.0	96.2	94.1	94.5	101.7
Q			27.83	31.04	34.31	34.34	13.56	19.68	25.68	12.17
or	14.07	36.22	28.49	28.40	27.08	28.31	28.91	33.36	30.58	24.40
ab	11.76	16.29	35.46	30.05	28.19	27.31	31.44	27.77	27.25	26.61
an	12.74	4.70	2.60	2.59	3.10	2.58	6.39	3.06	3.06	2.44
ne	14.97	28.94								
co			1.19	2.74	1.96	2.10	2.96	1.33	1.73	30.07
di { wo	9.98	1.78								
di { en	5.31	0.73								
di { fs	4.36	1.06								
hy { en							3.20	1.70	1.20	1.96
hy { fs			4.43	5.18	5.36	5.36	9.77	6.07	5.02	2.35
ol { fo	10.73	2.12								
ol { fr	9.70	3.39								
il	5.90	4.77								
ap	0.49									

FeO^*: Total Fe as FeO.
a = basanite; b = basanitic glass; c, d, e, f = uncoloured glasses; g, h, i = transition from typical brown glass (g) to pale brown glass (i) near a quartz; j = product of breakdown of an alkali feldspar phenoblast. The deficit of the analysis of glasses from xenoliths is mainly due to their important water content (up to 5%); this content probably reflects relatively high local water pressures developped in the still fluid xenoliths during cooling of the host magma (Hamilton and Anderson, 1968).

is probably derivating from the liquid), tridymite, and very small needles (5×0.1 μm) with the optical properties of mullite.

The composition of this glass (Table 1, analyses c, d, e, f) is typically rhyolitic, and close to the thermal minimum of Tuttle and Bowen (1958) under low water pressures, and to the piercing point of James and Hamilton (1969) for 3% Anorthite and $P_{H_2O} = 1$ Kb. The temperature of basaltic magma was clearly sufficient to melt granitic compositions even under very low water pressure. Melting was never important enough to completely remove quartz or feldspars, and so the composition of rhyolitic glass is approximately constant (Weill and Kudo, 1968). Although, the quartz/feldspars ratio in the residual crystals varies accordingly to the initial composition of the gneiss.
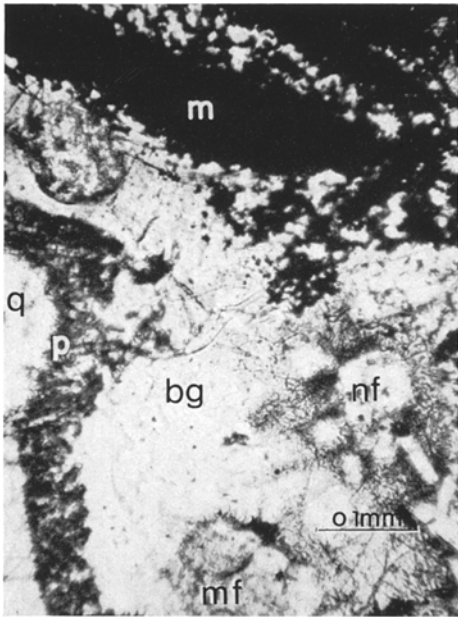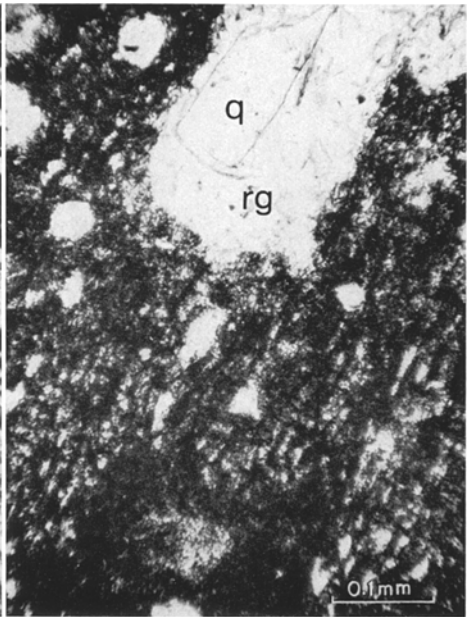
Fig. 1   Fig. 2

Fig. 1. Brown dacitic glass (*bg*) and residual phases: magnetite (*m*) formed at the expense of biotite; partly melted oligoclase (*mf*); quartz (*q*) rimmed by orthopyroxenes (*p*). Some neogenic plagioclases (*nf*) at the right

Fig. 2. Products of breakdown of alkali feldspars: vacuolar glass containing much crystallites of corumdum (*dark*). Lineaments correspond to previous cleavages. At the top, a small quartz crystal (*q*) is rimmed by rhyolitic glass (*rg*)

The important percentage of iron in the glasses can be related to three processes:
— breakdown of possible primary oxides in the gneiss
— contribution of a minor quantity of biotite to the melt
— contamination by the surrounding basanitic magma, Fe being able to migrate in vapour phase (Martin and Piwinskii, 1969).

Lastly, all the analyzed glasses possess normative corundum. This seems to be constant in all glasses developped in similar conditions (Frankel, 1950; Wyllie, 1961; Leyreloup, 1973); morever whole xenoliths presented the same characteristics too. Possibility of selective departure of alkalies from the xenoliths, leaving an excess of alumina in the glasses or as aluminous phases can be inferred.

B. Melting of Biotite + Feldspar (+ Quartz)

1. Description. In biotite-rich gneisses, or in the micaceous beds of common gneisses, a different type of melting occurs. A brown glass appears at the vicinity of spinel aggregates (products of biotite breakdown) and partially melted feldspars (mainly oligoclase) (Fig. 1). The colour of this glass fades progressively towards residual quartz crystals, as well as towards uncoloured glass of the quartzofeldspathic beds. The brown glass contains many high-temperature phases:

— small square sections of cordierite, often containing opaque granulations;
— oligoclase An20 either as euhedral crystals or as a rim around former feldspar crystals;
— small needles with the optical properties of mullite;
— orthopyroxenes, about 10 μm long, forming a radial corona around quartz crystals. These orthopyroxenes are exclusively located at the contacts between quartz and brown glass; when the glass becomes clearer, they disappear;
— rare crystals of magnesian olivine, sometimes mantled by orthopyroxene.

2. Composition. Three analyses ranging from typical brown glass to very pale glass at the vicinity of quartz are given in Table 1 (analyses g, h, i). This colour gradient obviously corresponds to a progressive enrichment in silica of brown glass, the percentage of all other oxides (except K_2O) decreasing towards quartz. Comparatively to rhyolitic uncoloured glass, this brown glass (analysis g) is depleted in silica, enriched in alumina, iron, magnesium, calcium and potassium; its composition falls in the latite field of Streckeisen's classification.

In fact, brown glass is difficult to analyse at the vicinity of feldspar and biotite, owing to the abundance of residual phases: in this area, a partial analysis has given relatively low values for silica (60.2 %).

3. Interpretation. The observed gradient in colour and composition can be considered as the result of progressive diffusion of silica in brown glass at the quartz-glass interface. The original chemical character of brown glass is somewhat problematical. Although all the compositions obtained are silica-saturated, the occurrence of magnesian olivine and of a corona of orthopyroxene around quartz shows the possibility of an initially undersaturated composition. A possible explanation can be advanced by assuming that the excess of alumina (normative corundum) is due to the removing of alkalies. In fact, by recalculation of the excess of alumina to normative alkali feldspars, we obtain about 3 % normative quartz in brown glass, and the partial analysis giving $SiO_2 = 60.2$ probably corresponds to a glass without normative quartz.

4. Melting Process. If all FeO in the glass comes from biotite, it is necessary to postulate a participation of about 25 % stoechiometric biotite to the melted phases; moreover, the initial liquid can have been undersaturated in silica.

Rutherford (1969) has shown experimentally that, in undersaturated systems, partial melting of the feldspar + iron biotite assemblage occurs at 700–750°C at $P_{total} = 2$ Kb by the reaction:

$$\text{Feldspar} + \text{biotite} \rightarrow \text{feldspar} + \text{fayalite} + \text{liquid} + \text{vapour}$$
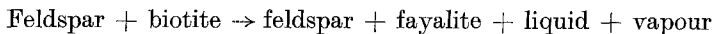
which never occurs in saturated systems.

We suggest that the genesis of brown glass can be related to a similar reaction, silica-poor liquids first appearing at the biotite-feldspar contacts; these liquids are then enriched in silica by diffusion near quartz crystals and removing of alkalies.

C. Breakdown of Alkali Feldspars

This phenomenon is comparatively rare (four out the fourty xenoliths analysed) and limited to large phenoblasts of alkali feldspars. These crystals are transformed into a grey and vacuolar product (Fig. 2) which is a glass with a great number of
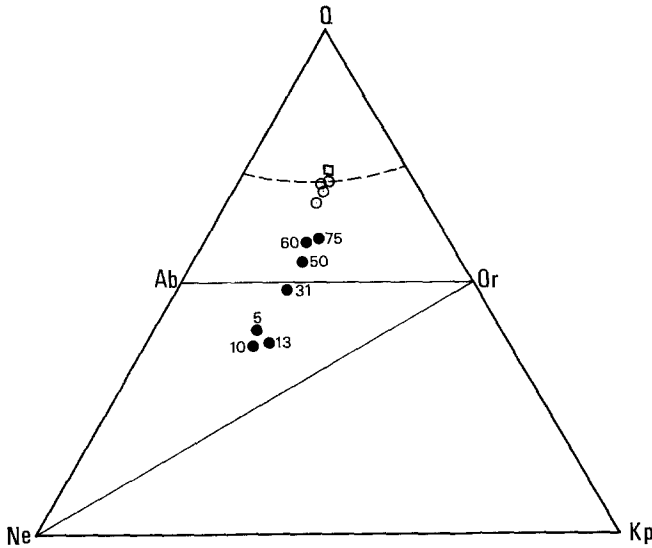
Fig. 3. Q-Ne-Kp diagram showing the transition from undersaturated to oversaturated glasses at the basanite-gneiss contact. White square: composition of the xenolith; white circles: rhyolitic glasses; black circles: "hybrid" glasses. Numbers correspond to the position of glasses expressed in percentages of the total width of the hybrid band, starting from the basanite. Dashed line from Tuttle and Bowen (1958) for $P_{H_2O} = 500$ bars

crystallites of corundum. The original shape of the crystal is still visible, and outlined by surrounding products: the previous cleavages are marked by darker lineaments. Sometimes residual feldspar remains at the center of the grains: its contact with the glass is sharp. When the surrounding material is quartz, a thin rim of uncoloured glass of rhyolitic composition develops at the contact. Microscopically similar products of the breakdown of feldspars have been described by Steiner (1958) in New Zealand andesites.

The global analysis of the breakdown products (corundum + glass) is given in Table 1 (analysis j). Its hyperaluminous character (30% normative corundum) is obvious; moreover, it is anhydrous glass unlike the two other types.

To explain this very particular composition, it must be noted that:

— the shape of previous feldspar crystals is well-preserved, its breakdown products having remained *in situ*;

— there is no evidence for mixing or diffusion with surrounding materials, with the exception of the very thin rhyolite rim near quartz;

— important decrease in volume is shown by vacuolar texture.

We consider that the most satisfying explanation for the genesis of such products is to postulate that, during the breakdown process, an important removing of silica and alkalies occurred, probably by transfer in vapour phase.

Loss of silica and alkalies is indeed a well-known phenomenon during experimental heating of alkali feldspars under water pressures (W. S. Mackenzie, personal communication, 1974). In the case of our samples, assuming that all the alumina
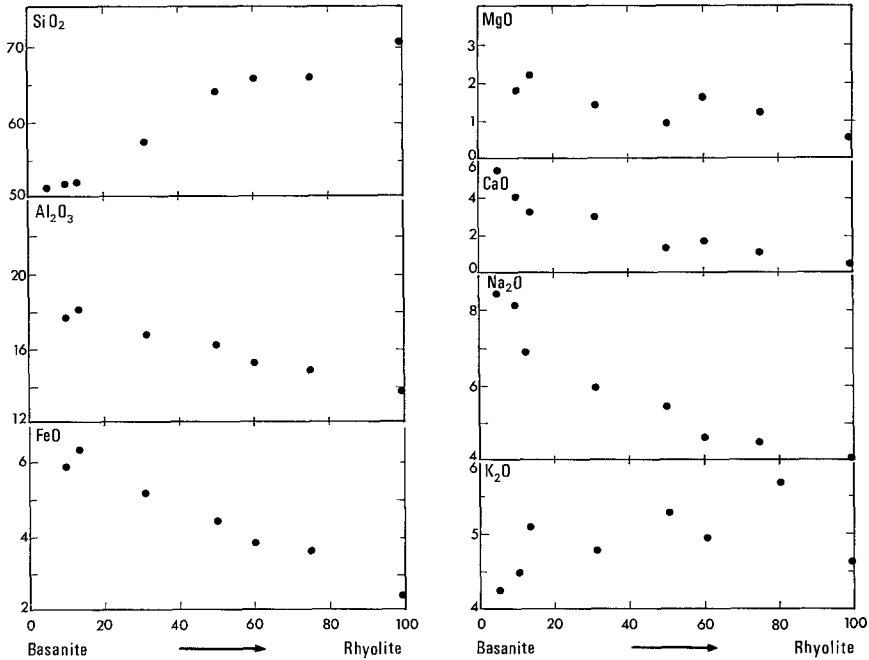
Fig. 4. Oxide variation diagrams showing the composition of hybrid glasses at the basanite-gneiss contact. Numbers in abscissa correspond to percentages of the total width of the hybrid band. FeO* = total Fe as FeO

comes from the initial alkali feldspar, we have calculated a differential loss of 63% silica, 77% Na_2O and K_2O.

Xenoliths-Magma Relations

Three types of contacts between magma and xenoliths have been observed.

A. Rhyolitic Glass-Basanite Contact

Frequently described (Lacroix, 1893; Steiner, 1958) this type of contact involves the development of an hybrid band, 1 to 5 mm wide, marked by a progressive increase of brown colour, and in which have crystallized two minerals:
— clinopyroxenes in radially orientated microlites;
— near the basanite, crystallites of plagioclase connected, at their basis, with the plagioclasic microlites of the host rock.

In this hybrid band, a progressive transition from basanitic to rhyolitic chemistry, well illustrated on the Q-Ne-Kp diagram (Fig. 3) occurs. Fig. 4 shows the progressive variations of major oxides in the hybrid band. The regular variations obtained characterize well chemical diffusion gradients. Possible indications of immiscibility have never been found. The similarity with the experimental diffusions gradients described by Yoder (1973) between rhyolite and basalt is obvious.
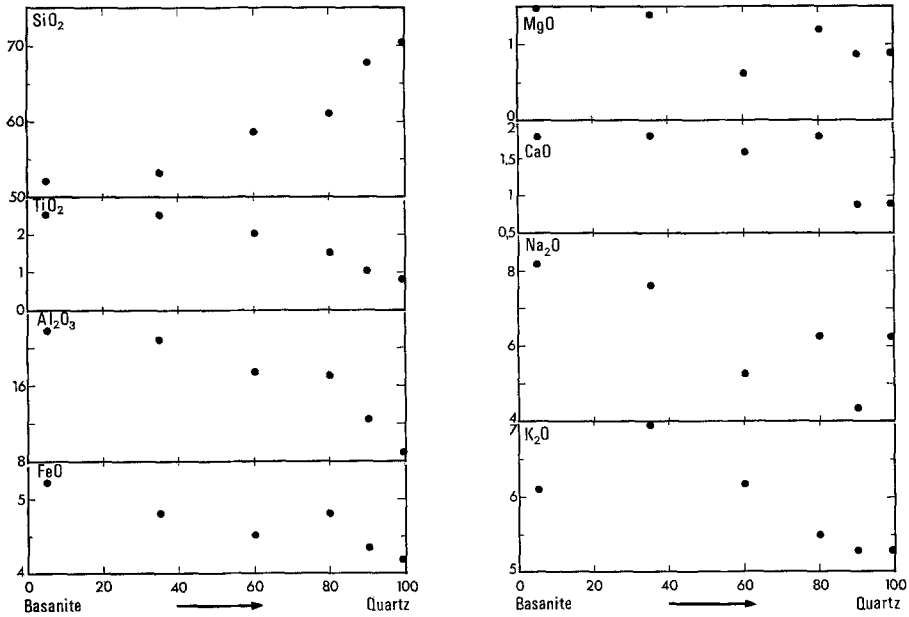
Fig. 5. Oxide variation diagrams showing the composition of glasses at the basanite-quartz contact. Same conventions as in Fig. 2

The detailed interpretation of oxide variations in Fig. 4 is in fact complex owing to the occurrence of clinopyroxenes and plagioclases in the glasses. These mineral phases have crystallized after the major part of the diffusion occurred, as seen from the regular changes in clinopyroxene chemistry, with progressive increase of $CaAl_2SiO_6$ and $Ca\,Ti\,Al_2O_6$ contents towards the basanite (Maury and Bizouard, 1974). So many local modifications of the chemistry of glasses have resulted from the quick and tardive crystallization of mineral phases. For instance, the decrease in MgO and CaO at 50% from the basanite largely results from the vicinity of clinopyroxenes having depleted their surrounding glass in Mg and Ca (Albarède and Bottinga, 1972).

Although variations of diffusion rates from one element to another are very difficult to prove, the smooth gradient of K_2O contrasts with the relatively steep gradients of other oxides; Yoder's (1973) experimental diffusion gradients also show anomalies in the repartition of potassium, the maximal contents being located in the hybrid glasses. These apparently "anomalous" behaviour of K can be attributed either to a very different diffusion rate or to the intervention of another migration process, perhaps vapour phase transfer.

B. Quartz-Basanite Contact

If the microscopic features of these contacts are very constant and well-described (Lacroix, 1893; Searle, 1962), contrasting petrological interpretations have been proposed (Holmes, 1937; Holgate, 1954; Roedder, 1956). In fact, in the Azinières

basanite, quartz xenocrysts are surrounded by an uncoloured glassy area, separated from brown "basanitic" glass by a corona of contiguous radial clinopyroxenic microlites. We have frequently found phillipsite filling the cracks in quartz xenocrysts, or at the quartz-uncoloured glass interface.

Chemically, many similarities with the previous case are noticed:
— all progressive transitions from undersaturated to oversaturated compositions from normal basanitic glass to the quartz-glass interface can be observed.
— clinopyroxene chemistry well reflects this evolution (Maury and Bizouard, 1974).

The major difference is that all oxide variations diagrams (Fig. 5) (with the exception of SiO_2 and K_2O) show a progressive decrease towards quartz: this evolution is compensated by a corresponding increase in SiO_2. So, all the chemical gradients—again with the exception of K_2O—can be satisfactorily explained by progressive enrichment in SiO_2 towards quartz: undoubtedly, this enrichment results from diffusion of silica at the glass-quartz interface.

C. Brown Glass-Basanite Contact

By contrast with the two previous cases, this contact is always diffuse, ill-defined, and difficult to study owing to the similar colour of the two glasses; so no microprobe systematic profile has been undertaken. The most characteristic feature of this type of contact is a progressive disaggregation of the xenoliths. Many basanitic apophyses are penetrating in it, and the residual mineral phases are progressively disseminated into the basanite. Quartz is largely the most abundant of them as the genesis of the brown glass leaves much residual quartz crystals; certainly a great number of the quartz xenocrysts in the Azinières basanite results from the disaggregation of xenoliths partly melted to a latitic liquid.

Interpretation of this contact is difficult in absence of quantitative data; nevertheless, one can stress that the apparently easy "mixing" occurring in this case between basanite and xenoliths results from the relatively few contrast between the chemical composition of the two liquids. The comparizon of analyses g and b (Table 1) shows that the only important differences concern the Si, K (more abundant in the xenolith) and Na (more abundant in the basanite) contents.

Possible Contamination Mechanisms

A. The intervention, *at the elementary scale*, of contamination of the basanitic magma by acid xenoliths cannot be denied. This fact is largely admitted by authors of detailed studies of acid xenoliths (Steiner, 1958; Searle, 1962a, b; Sigurdsson, 1968).

B. At least, *four elementary processes* can be operating:

1. diffusion at the interface between two liquids of contrasted chemistry i.e. rhyolitic and basanitic, the basanitic magma being thus enriched in silica and potassium;

2. diffusion at the interface between a solid phase (quartz) and the basanitic liquid, which is thus enriched in silica;

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3. mixing of two liquids, (basanitic and latitic) and subsequent disagregation of xenoliths, leaving residual xenocrysts (mainly quartz) into the basanite. The balance of assimilation of latitic liquid by the basanite may be an increase of SiO_2 and K_2O contents;

4. transfer in vapour phase of Si, Na, K in the case of breakdown of alkali feldspars to hyperaluminous products. Other arguments for the occurrence of such transfers can be based on the observation of:
— important variation of the H_2O content between xenoliths and magma;
— deficit of alkalies in glasses, which are always corundum normative;
— anomalous repartition of K in hybrid glasses.

Qualitatively, the balance of all of these processes results in a contamination of the basanite in *silica, sodium* and *potassium*. Similar conclusions have been reached by Leake and Skirrow (1960) and Evans (1964) from the study of contamination of basic plutonic rocks by pelitic xenoliths and surrounding rocks. C. *Quantitatively*, the importance of the four processes described is much variable.

1. Contamination due to diffusion at a two-liquids interface is limited by the slowness of these diffusions. Very rough calculations based on Yoder's (1973) results (obtention in one hour at 950°C under $P_{H_2O} = 1$ Kb of an hybrid band 0,3 mm wide) show that the observed width of hybrid bands (1 to 5 mm) corresponds to times of the order of some dozen of hours. A 4 cm wide diffusion band (digestion of a small xenolith) necessits a time of about one year at 950°C. Assimilation of a xenolith of metric size, independently from the problem of supply of heat of fusion, takes very long times of the order of one thousand years, only conceivable at the level of intracrustal magmatic bodies.

2. In spite of the inexistence of experimental results on diffusion of silica in basic magmas near quartz xenocrysts, the same objection can probably be put forwards against magmatic enrichment in silica by assimilation of xenoliths.

3. Disagregation of xenoliths due to easy mixing of liquids seems to be a rapid phenomenon, mixed areas several centimeters thick having frequently been observed into the Azinières flow; by elsewhere the residual mineral phases (quartz, partly melted feldspar, cordierite) are common in rocks the origin of which is attribuated to crustal contamination. But, until this process induces an enrichment both in silica and potassium of the magma, Doe *et al.* (1969) have shown that no significant differences in silica content between contaminated and non-contaminated basalts can be statistically observed; by contrast, they found systematic enrichment in potassium of contaminated basalts.

4. The most satisfying process explaining Doe *et al.* (1969) results is certainly vapour phase transfer, specially of potassium; in the present study, several arguments favorizing the intervention of such transfers have been presented. Mobility of potassium is a well-known phenomenon, and the homogeneity of K contents in composite dykes, contrasting with the important variations of all other major elements between the two components of these dykes, has been demonstrated by Wiebe (1973). Furthermore, transfers in vapour phase do not necessarily imply a melting of xenoliths; so resulting contamination would not be quantitatively limited by heat balance problems stressed by Bowen (1928).

It arises from the present study that contamination by the sialic crust may have an incidence on the observed chemical differences (mainly in K content) between continental and oceanic basalts.

References

Albarède, F., Bottinga, Y.: Kinetic disequilibrium in trace elements partitioning between phenocrysts and host lava. Geochim. Cosmochim. Acta **36**, 141–157 (1972)

Al-Rawi, Y., Carmichael, I. S. E.: A note on the natural fusion of granite. Am. Mineralogist **52**, 1806–1814 (1967)

Bogoyavlenskaya, G. E.: Melted xenoliths of intrusive rocks in the pyroclastic deposits of the Uzon and Semyatchinskaya ring structures (Kamtchatka). Bull. Volcanol. **36**, 443–445 (1972)

Bowen, N. L.: The evolution of the igneous rocks, 334 pp. Princeton, New Jersey: Princeton University Press 1928

Brousse, R.: Magmatologie du volcanisme néogène et quaternaire du Massif Central. Symposium J. Jung, Clermont-Fd, p. 377–478 (1971)

Butler, B. C. M.: Metamorphism and metasomatism of rocks of the Moine series by a dolerite plug in Glenmore, Ardnamurchan. Mineral. Mag. **32**, 866–897 (1961)

Doe, B. R., Lipman, P. W., Hedge, C. H., Kurasawa, H.: Primitive and contaminated basalts from the Southern Rocky Mountains, U.S.A. Contrib. Mineral. Petrol. **21**, 142–156 (1969)

Evans, B. W.: Fractionation of elements in the pelitic hornfelses of the Cashel-Lough Wheelaun intrusion, Connemara, Eire. Geochim. Cosmochim. Acta **28**, 127–156 (1964)

Frankel, J. J.: A note on the vitrification of Karroo sediments by dolerite intrusions. Trans. Roy. Soc. S. Africa **32**, 287–293 (1950)

Gillot, P. Y.: Chronométrie par la méthode potassium-argon des laves des Causses et du Bas-Languedoc. Interprétations. Thèse 3ème cycle, Orsay, 87 pp. (1974)

Girod, M., Lefèvre, C.: Nature et origine des «andésites» et «trachyandésites» du Massif Central français. Contrib. Mineral. Petrol. **36**, 315–328 (1972)

Hamilton, D. L., Anderson, G. M.: Effects of water and oxygen pressures on the crystallization of basaltic magmas. In: Basalts. The Poldervaart treatise on rocks of basaltic composition, Hess. H. H., Poldervaart. A. (eds) I, 445–482. New York: Wiley 1968

Holgate, N.: The role of liquid immiscibility in igneous petrogenesis. J. Geol. **62**, 439–480 (1964)

Holmes, A.: Transfusion of quartz xenoliths in alkali, basic and ultrabasic lavas, south-west Uganda. Mineral. Mag. **24**, 408–421 (1936)

James, R. S., Hamilton, D. L.: Phase relations in the system $NaAlSi_3O_8$—$KAlSi_3O_8$—$CaAl_2Si_2O_8$—SiO_2 at 1 Kb water vapour pressure. Contrib. Mineral. Petrol. **21**, 111–141 (1969)

Lacroix, A.: Les enclaves des roches volcaniques. Protat, Mâcon, 710 pp. (1893)

Leake, B. E., Skirrow, G.: The pelitic hornfelses of the Cashel-Lough Wheelaun intrusion, Co. Galway, Eire. J. Geol. **68**, 23–40 (1960)

Leyreloup, A.: Le socle profond en Velay d'après les enclaves remontées par les volcans néogènes; son thermométamorphisme et sa lithologie: granites et série charnockitique (Massif Central français). Travaux Lab. Petrol. Minéralogie, Nantes, 356 pp. (1973)

Martin, R. F., Piwinskii, J.: Experimental data bearing on the movement of iron in an aqueous vapour. Econ. Geol. **64**, 798–803 (1969)

Maury, R. C., Bizouard, H.: Clinopyroxenes des contacts acides—basiques. Bull. Soc. Franç. Mineral. Crist. (in press) (1974)

Mehnert, K. R., Büsch, W., Schneider, G.: Initial melting at grain boundaries of quartz and feldspar in gneisses and granulites. Neues Jahrb. Mineral. Monatsh. **1973**, 165–183

Mervoyer, B., Maury, R. C., Varet, J.: Un mécanisme possible d'évolution des trachyandésites du Massif Central par cristallisation fractionnées sous pression d'eau. Compt. Rend. **277**, 9–12 (1973)

Roedder, E.: The role of liquid immiscibility in igneous petrology: a discussion. J. Geol. **64**, 84–88 (1956)

Rutherford, M. J.: An experimental determination of iron biotite-alkali feldspar equilibria. J. Petrol. **10**, 381–408 (1969)

Searle, E. J.: Quartzose xenoliths and pyroxene aggregates in the Auckland basalts. New Zealand J. Geol. Geophys. **5**, 130–140 (1962a)

Searle, E. J.: Xenoliths and metamorphosed rocks associated with the Auckland basalts. New Zealand J. Geol. Geophys., **5**, 384–403 (1962b)

Sigurdsson, H.: Petrology of acid xenoliths from Surtsey. Geol. Mag. **105**, 440–453 (1968)

Steiner, A.: Petrogenetic implications of the 1954 Ngauruhoe (New Zealand) lava and its xenoliths. New Zealand J. Geol. Geophys. **1**, 325–363 (1958)

Tuttle, O. F., Bowen, N. L.: Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$—$KAlSi_3O_8$—SiO_2—H_2O. Geol. Soc. Am. Mem. **74**, 153 pp. (1958)

Weill, D. F., Kudo, A. H.: Initial melting in alkali feldspar-plagioclase-quartz system. Geol. Mag. **105**, 325–337 (1968)

Wiebe, R. A.: Relations between coexisting basaltic and granitic magmas in a composite dyke. Am. J. Sci. **273**, 130–151 (1973)

Wyllie, P. J.: Fusion of Torridonian sandstone by a picrite sill in Soay (Hebrides). J. Petrol. **2**, 1–39 (1961)

Yoder, H. S.: Contemporaneous basaltic and rhyolitic magmas. Am. Mineralogist **58**, 153–171 (1973)

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