

Rhyodacite glass in Réunion basalt

B. G. J. UPTON

Grant Institute of Geology, University of Edinburgh

AND

W. J. WADSWORTH

Department of Geology, University of Manchester

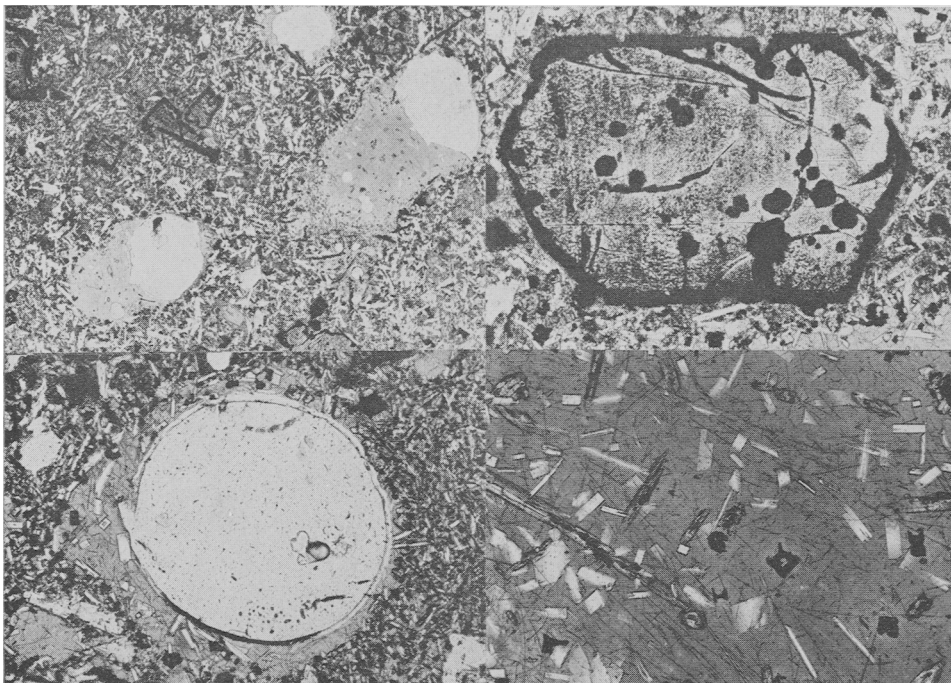
SUMMARY. The local development of strongly oxidizing conditions during crystallization of a recent basalt lava lake on Piton de la Fournaise, Réunion, led to the production of approximately 15 % residual rhyodacite liquid. This was segregated into the vesicle cavities as the lava solidified, and congealed as a glass containing microlites of feldspar, clinopyroxene, and hematite. The rhyodacite is compared chemically with the residual glasses recorded from other basaltic and doleritic occurrences, and with the Mauna Kuwale rhyodacite of Oahu.

THE summit area of Piton de la Fournaise, the active basalt shield volcano forming the south-eastern half of Réunion, comprises a large caldera structure, the Enclos Fouqué, from which rises the summit cone. This reaches a height of approximately 400 m above the lavas ponded in the Enclos Fouqué, and the highest point is 2631 m above sea level. At the top of the cone are three intersecting craters, aligned from east to west and referred to as Cratère Dolomieu, Enclos Velain, and Cratère Bory respectively. Cratère Bory is the highest and smallest of the three, being situated immediately to the east of the highest point on the volcano, and measuring approximately 350 m (N-S) by 300 m (E-W).

The general morphology of Piton de la Fournaise and the detailed volcanic history of the summit region have been described by Lacroix (1936, 1938), Bussière (1958), Ducrôt (1958), Neumann van Padang (1963), and Aubert de la Rue (1965). Cratère Bory seems to have been the principal site of eruptions in the period immediately prior to 1766, but between 1766 and 1937 most of the summit activity was centred on the more easterly craters. However, since 1937 Cratère Bory has again been active; it was occupied by a lava lake fed from a nearby fissure in 1937, and again in 1942 lava flowed from fissures near the rim into the crater itself. Further minor activity occurred in the vicinity of Cratère Bory in 1953, 1956, 1957, 1959, and 1960.

During a reconnaissance of the volcano in July 1964, Cratère Bory was seen to be floored by deeply crevassed pahoehoe lava, and a sample of this material (Re 490), showing prominent glass-lined vesicles, was collected. After sectioning, Re 490 was crushed (through 120-mesh), and the glass extracted by heavy liquid separation with tetrabromoethane. On analysis it was shown to be of acid composition. Unfortunately it was necessary to use the whole specimen in order to obtain enough glass for chemical

It did not prove practicable to separate these microlites from their glassy matrix, and therefore the analysed material of Re 490 represents the bulk composition of the material segregated into the vesicles rather than the extreme liquid fraction that congealed as pure glass.



FIGS. 1-4: Fig. 1 (top left). Photomicrograph of Re 490, showing vesicles partly filled with glass, as well as oxidized olivine phenocrysts and general groundmass appearance ($\times 7$). Fig. 2 (top right). Photomicrograph of olivine phenocryst in Re 490, densely charged with magnetite particles, and with a distinct rim of magnetite grains ($\times 30$). Fig. 3 (bottom left). Photomicrograph of single vesicle in Re 490, coated with rhyodacite glass ($\times 40$). Fig. 4 (bottom right). Photomicrograph of rhyodacite glass in vesicle of Re 490, showing pyroxene, feldspar, and iron oxide microlites ($\times 40$).

Chemically, the Re 490 glass (table I) is similar to the Mauna Kuwale rhyodacite lava dome (or thick flow) of the Waianae volcanic series, Oahu, which was shown by Macdonald and Katsura (1964) to be close in composition to the average rhyodacite of Nockolds (1954). Mineralogically, however, the Mauna Kuwale rock is characterized by brown hornblende and biotite phenocrysts, together with plagioclase phenocrysts, in a finely crystalline groundmass.

The Réunion glass also displays similarities to the residual glasses associated with other basalt or dolerite occurrences (table I). This applies particularly to the interstitial glass recorded from certain tholeiitic dykes, notably the Kap Daussy dyke of east Greenland (Vincent, 1950), the Kinkell dyke in Stirlingshire (Walker, Vincent, and Mitchell, 1952), and the Eskdalemuir dyke in the Southern Uplands (Elliott, 1956).

TABLE I. *Chemical analysis of some residual glasses*

	1	2	3	4	5	6	7	8
SiO ₂	49.15	44.6	64.94	66.78	64.03	66.80	70.58	52.84
Al ₂ O ₃	14.79	15.1	13.92	15.69	11.27	12.10	11.62	20.63
Fe ₂ O ₃	1.59	1.2	2.92	1.45	2.98	0.97	1.52	1.24
FeO	9.96	12.5	0.84	1.40	2.81	1.50	1.35	2.74
MgO	6.03	7.2	1.88	1.28	1.18	0.50	0.72	0.51
CaO	10.99	13.1	3.76	2.61	5.57	2.62	1.36	2.56
Na ₂ O	2.87	2.6	3.87	4.49	1.82	2.40	3.10	5.08
K ₂ O	0.81	0.0	3.66	3.60	1.56	4.20	3.44	5.07
TiO ₂	2.99	3.5	1.12	0.59	0.79	0.18	0.65	1.05
P ₂ O ₅	0.31	0.1	1.04	0.58	0.98	0.39	0.18	0.89
MnO	0.18	0.3	0.12	0.05	0.05	—	0.02	0.04
H ₂ O ⁺	0.14	—	0.38	0.59	6.23	5.75	4.98	6.99
H ₂ O ⁻	—	—	—	0.66	0.73	3.00	—	0.21
CO ₂	—	—	1.26*	—	—	—	—	—
Total	99.81	100.2	99.71	99.77	100.00	100.41	99.52	99.85
<i>C.I.P.W. norms</i>								
Q	—	—	20.94	20.76	36.3	30.7	35.04	—
Or	4.80	—	21.70	21.13	9.2	25.0	18.30	30.02
Ab	24.36	13.85	32.73	38.25	15.4	20.4	28.80	42.44
An	25.16	29.55	9.79	9.17	17.9	10.0	5.84	7.78
Ne	—	4.40	—	—	—	—	—	0.28
C	—	—	—	1.02	—	—	0.51	3.88
Di	22.61	28.73	1.62	—	2.7	0.3	—	—
Hy	8.74	—	3.93	3.60	3.1	2.5	2.33	—
Ol	5.57	15.06	—	—	—	—	—	2.61
Mt	2.31	1.74	—	2.09	4.3	1.4	2.09	1.86
Hm	—	—	2.92	—	—	—	—	—
Il	5.70	6.65	2.03	1.22	1.5	0.5	1.22	2.13
Rt	—	—	0.05	—	—	—	—	—
Ap	0.74	0.02	2.26	1.34	2.3	1.0	0.34	2.02
D.I.†	29.2	18.3	75.4	80.1	60.9	76.1	82.1	72.7

1. Basalt (Re 634), Cratère Bory, Réunion. Also Ba 210 ppm, Rb 15, Sr 340, Zr 205, V 295, Yt 42, Zn 105, Cu 135, Ni 75, Cr 5 (X-ray fluorescence determinations).

2. Calculated composition of crystal extract (K₂O content nil) from analysis 1 to produce rhyodacite glass (analysis 3).

3. Rhyodacite glass (from Re 490), Cratère Bory, Réunion. Also Ba 1000 ppm, Rb 160, Sr 260, Zr 585, V 600, Yt 80, Zn 100, Cu 550, Ni 10.

4. Mauna Kuwale rhyodacite, Waianae Range, Oahu (Macdonald and Katsura, 1964; table 2, analysis 12.)

5. Residual glass from Kap Daussy tholeiite dyke, east Greenland (Vincent 1950; table 1, analysis II).

6. Residual glass from Kinkell tholeiite dyke, Stirlingshire (Walker, Vincent and Mitchell, 1952, table III, analysis 4).

7. Residual glass from Eskdalemuir tholeiite dyke, Southern Uplands (Elliott, 1956, table I, analysis B).

8. Residual glass from alkali olivine basalt, New England Highway, New South Wales (Wilkinson, 1966, table II, analysis 1).

* Regarded as a volatile constituent trapped in the glass, and hence not calculated as calcite in the norm.

† Differentiation Index.

Of these, the Kinkell and Eskdalemuir glasses show a similar degree of alkali enrichment to the Re 490 glass, but have rather higher silica contents, whereas the Kap Daussy glass has an exceptionally low alkali content considering the degree of silica enrichment (see fig. 5). All these glasses are strongly oversaturated, with normative quartz contents $> 20\%$. For comparison, an analysis of a residual glass in an alkali basalt lava from New South Wales (Wilkinson, 1966) is also shown in table I. This material is relatively poor in silica but the alkali content is high and the bulk composition is that of an alkali-trachyte, just undersaturated in terms of its normative nepheline content. This contrast in the composition of the residual fractions stemming from tholeiitic and alkali basalts respectively is precisely what would be expected from experimental data on low-pressure fractionation, and is matched by the composition variation occurring in lava sequences and intrusive bodies involving differentiation in high-level magma chambers.

However, the Réunion results do not exactly fit this pattern. On an alkali-silica diagram (fig. 5) the Re 490 glass plots in a position intermediate between the residua of tholeiitic and alkali basalt ancestry respectively, and while this might be interpreted as reflecting the transitional or mildly alkaline nature of the parent Réunion basalt (Upton and Wadsworth, 1965), the most significant feature is the divergence of the Re 490 glass composition from the normal Réunion fractionation trend, as shown by the lavas of the Differentiated Series and their related minor intrusions (fig. 5).

It is suggested that unusually oxidizing conditions were developed locally in the Cratère Bory lava lake (see below), and that early precipitation of iron and titanium oxides led to abnormal silica enrichment of the residual liquid (cf. Osborn, 1962). Calculation of the crystal extract (K_2O content nil) required to produce the rhyodacite from basalt is also shown in table I.

A relatively high pO_2 is also thought to have been responsible for the development of the Mauna Kuwale rhyodacite of Oahu (Macdonald and Katsura, 1964), but in this case the parent magma is inferred to have been more distinctly tholeiitic (probably similar to the basalts of the lower Waianae volcanic series, fig. 5), and the corresponding low pO_2 trend is believed to have led to the production of iron-enriched tholeiitic residua such as the Palolo granophyre (Kuno *et al.*, 1957).

Other distinctive chemical features of the Cratère Bory glass (table I) are the low water content (compared with the other interstitial glass occurrences) and the significant quantity of CO_2 . Among the minor constituents, P, Cu, and V are considerably more abundant than in the lavas and minor intrusions representing an equivalent degree of fractionation in the Réunion Differentiated Series (Upton and Wadsworth, *in press*).

Discussion. Evidence of small-scale fractionation in basalt lava flows is rather uncommon, although segregation of residual liquid fractions into distinct veinlets has been recorded in a number of cases (Kuno, 1965). The possibility that such residual material was able to find its way into vesicle cavities, although suggested by Harker (1904, p. 400) to account for certain textural features in Skye lavas and minor intrusions, and discussed briefly by Nicholls (1959) in describing amygdaloidal spilites of

the Builth Volcanic Series, has only recently received detailed attention in a paper by Smith (1967), who refers to such occurrences as 'segregation vesicles'. However, the examples cited have generally suffered considerable late-magmatic and post-magmatic modification, and it has not been possible to investigate the primary chemical variation involved in the segregation process. The Cratère Bory lava provides indisputable evidence of the operation of this type of fractionation mechanism, and chemical data on the composition of the final residue as well as the parent magma.

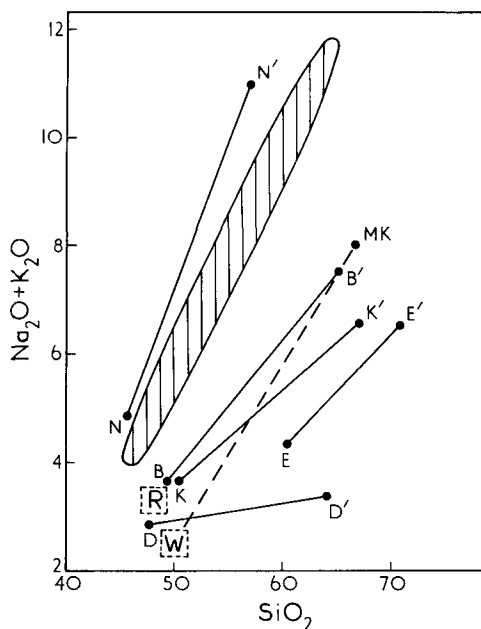


FIG. 5. Plot of alkalis ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) against SiO_2 showing the lines (firm lines) between parent basalt and residual glasses (B-B', Cratère Bory; K-K', Kinkell; E-E', Eskdalemuir; D-D', Kap Daussy; N-N', New South Wales) MK is Mauna Kuwale rhyodacite, linked by dashed line to approximate field of the tholeiitic basalt of the lower Waianae volcanic series (W). R indicates the approximate field of the Piton de la Fournaise basalts, Réunion. The shaded area is the field of the Réunion Differentiated Series (approximately equivalent to the Hawaiian alkalic series).

Smith (1967) concluded that the residual magma migrates into the vesicles as the result of a reduction in the volume of the gas phase after the final shape and size of the cavity has been defined by the development of a continuous rigid framework of interlocking plagioclase and pyroxene crystals. He listed four possible explanations of this reduction in the volume of the vesicle gas phase: cooling of the gas at constant pressure; escape of the gas; solution of the gas in the surrounding melt; and increase in the external pressure. In discussing the amygdales of Ordovician basalts from New South Wales, Smith preferred the last of these alternatives, since there was evidence that the lavas had been erupted into a shelving marine environment, where the down-slope increase in confining pressure would have provided an obvious mechanism for

progressively reducing the volume of gas in the vesicles. However, the Réunion occurrence clearly demands a different explanation.

The production of the Cratère Bory rhyodacite has been related to the development of unusually oxidizing conditions during the crystallization of the host basalt. It also seems a reasonable assumption that the occurrence of a high partial pressure of oxygen was in some way connected with the gas phase present in the vesicles, but since the majority of Réunion basalts are vesicular, in part at least, yet do not show this type of oxidation effect, the inference is that the gas phase of Re 490 was abnormal in composition.

One of the more likely causes of oxidation in lavas is groundwater, since this will have equilibrated with the atmosphere (Hamilton, Burnham, and Osborn, 1964). It is suggested that groundwater became locally involved with the Cratère Bory lava lake, was vaporized and formed bubbles in the molten basalt. However, this water vapour is unlikely to have influenced the course of crystallization unless it was to some extent dissolved by the melt, and such solution would imply that the basalt was initially undersaturated with respect to water. This in turn implies that the normal vesiculation of Réunion lavas was not caused by water coming out of solution, but by the exsolution of some other fluid, perhaps CO_2 , as suggested by Moore (1965) in discussion of submarine basalts from the east rift zone of Kilauea.

Solution of water vapour from the vesicles not only accounts for the oxidation and hence the development of the rhyodacite trend, but also helps to explain the necessary reduction in the volume of the vapour phase (after the size of the vesicles was fixed by incipient crystallization) to accommodate the residual magma. As shown by Smith (1967) there would be some volume reduction simply as the result of cooling, but this is unlikely to have been sufficient to account for the observed degree of segregation. Actual solution of water vapour in a relatively dry basalt melt provides a more effective mechanism, and this would presumably be enhanced by the ability of hydrogen to diffuse out of the system following dissociation of the water molecules.

Thus it is envisaged that as the basalt crystallized under the influence of a high partial pressure of oxygen, the residual rhyodacite liquid was segregated into the partly vacated vesicle cavities by a process of suction towards low-pressure sites, and there congealed as a glass.

It might be argued that there would be insufficient time for a process of this complexity, involving contamination with groundwater, fractional crystallization, and migration of residual fluids, to take place under sub-aerial conditions. However, it is clear that effective fractionation, although on a very small scale, did in fact occur, and was presumably facilitated by a relatively favourable location (in terms of heat loss) in the upper part of the lava lake, and by the effect of the dissolved water in reducing the temperature at which crystallization was completed.

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