PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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Phil. Trans. R. Soc. Lond. A 1971 **268**, 727-729
doi: 10.1098/rsta.1971.0023

Phil. Trans. Roy. Soc. Lond. A. **268**, 727–729 (1971) [727]
Printed in Great Britain

Viscosity control of the composition of ocean floor volcanics

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The fact that volcanic rocks from the ocean floor cover a restricted range in composition does not necessarily imply that only this narrow range of magmas is available in this environment. Instead it is postulated that the viscosity exercises a control by limiting the range of magmas (to those with a sufficiently low viscosity) which is capable of penetrating the upper part of the oceanic crust to emerge on the ocean floor. On land, this control can be over-ridden by the generation of gases.

There is a striking contrast between the uniformity in composition of volcanic rocks collected from submerged parts of mid-oceanic ridges and the variability of those from emerged parts. Thus Iceland, which stands astride the Mid-Atlantic Ridge, has a great abundance of acid and to a lesser extent intermediate volcanic rocks besides a good variety of basalts, and the Azores (which are also astride the Ridge) have an abundance of trachytes besides a wide variety of basaltic types ranging to ankaramites and basanites. Relationships are illustrated diagrammatically by figure 1. Oceanic islands situated far from a ridge normally show a comparable variability.

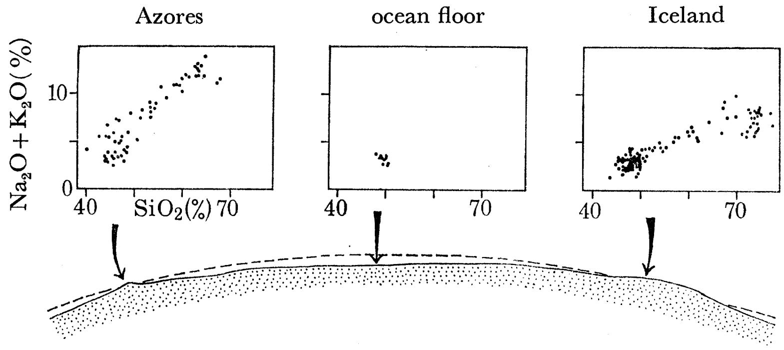

Figure 1. Diagrammatic representation of the composition of rocks from the Mid-Atlantic Ridge, showing the contrast between the variability of rocks collected from subaerial parts, and the uniformity of those from submerged parts.

Current interpretations of this contrast are several and varied, but all have one feature in common: they assume that the spectrum of magmas that is available to emerge on the surface (whether it be the surface of the land or the floor of the ocean) is markedly different below the ocean floor from what it is below the land surface.

The alternative interpretation now proposed avoids making this basic assumption. The restriction in composition of ocean-floor volcanics is postulated to be due to the existence of a barrier which only a narrow range of magmas is capable of traversing.

The barrier in question is the kilometre or more of cold and generally waterlogged rocks lying immediately below the surface. Magmas must traverse this barrier before they can emerge as lava. In general, the lower the viscosity of the magma the more quickly it can move through a narrow fissure and the more likely it is to be capable of traversing the barrier; and the more viscous it is, the more slowly it is capable of moving through a fissure and the greater the likelihood that it will congeal within the barrier and fail to emerge as lava.

The barrier exists, of course, below the surface of the land as well as below the oceans. The fact that a wide range of magmas reaches the surface by volcanism on land is attributed largely to the participation of a gas phase, the gas being in part exsolved from the magma and in part generated from the rocks of the barrier. This gas phase is responsible for explosive volcanic eruption, which can create a path for the rise of magma through the upper part of the barrier.

The reality of this barrier is shown by the great number of roofed granitic intrusions found in the crust (congealed below the surface despite the favourable density contrast by which granitic magma tends to rise); by the frequent occurrence in areas such as Japan of earthquake swarms of the type that normally presage a volcanic eruption, in which no eruption occurs (such occurrences could reasonably be regarded as abortive eruptions); by the well-known fact that in many andesitic-rhyolitic volcanoes characterized by high-viscosity magmas, explosive eruptions dominate the activity, pyroclastics predominate among the volcanic products, and lava extrusions (if they form at all) generally form only towards the end of the eruption after the main explosive phase.

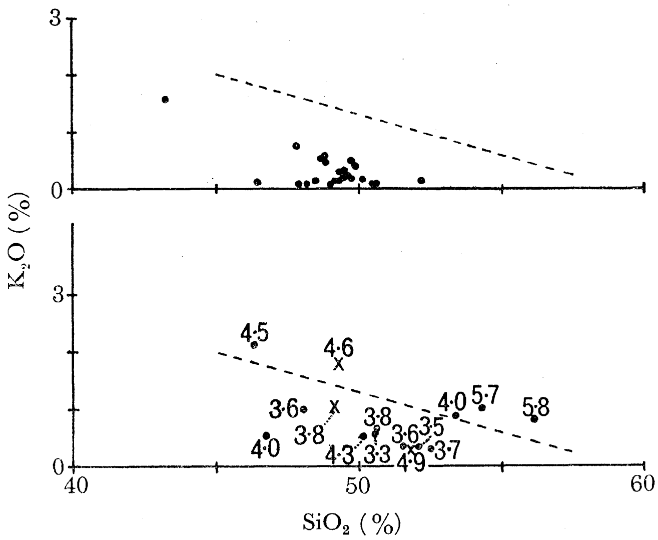

FIGURE 2. (*a*) Plot of fresh basalts collected from the submerged parts of the Mid-Atlantic Ridge, the Carlsberg Ridge and the East Pacific Rise. (*b*) The viscosity of lavas as a function of SiO_2 and K_2O contents. The figure given is lg η, where η is the viscosity in poises. The dashed line is the approximate upper boundary of the low-viscosity field referred to in the text, within which lie all the lavas with a viscosity $< 10^4$ P (< 1 kN s m^{-2}).

The situation is different under the ocean, in places where the water is more than about 1 km deep, for it has been shown (McBirney 1963) that a separate gas phase is unlikely to exist at the confining pressure there. The traverse of the barrier by a magma cannot therefore be aided by the participation of a gas phase.

Figure 2*a* is a plot of available field measurements on the viscosity of lavas as a function of their SiO_2 and K_2O contents. For those volcanic eruptions where more than one figure is available, the lowest viscosity value is plotted. The lowest values have been obtained on tholeiitic basalts of Hawaii. Data are insufficient to draw lines of equal viscosity on figure 2, and it is unlikely in any event that they could be drawn on a two-component diagram such as this where chemical components other than SiO_2 and K_2O also influence the viscosity. Nevertheless, it is possible to delineate a low-viscosity field within which lie the Hawaiian lavas.

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It is noted that analysed fresh ocean-floor basalts (figure 2*b*) plot within this low viscosity field. It is therefore postulated that only the most highly fluid lavas are capable of penetrating the barrier, unaided as they are by gases. The existence is postulated of what might appropriately be called a low-viscosity 'window' which controls the composition of magmas capable of penetrating the barrier to emerge on the ocean floor.

There has recently been much discussion on the status of alkali basalt in the oceanic environment. Alkali basalt of low silica content can have a viscosity comparable to that of Hawaiian tholeiitic basalt, and it is significant that alkali basalt dredged from near St Paul's Rocks (Melson, Jarosewich, Cifelli & Thompson 1967) does have a low silica content (43.15 %), but it should be pointed out that alkali basalts generally have a higher viscosity than tholeiites of the same silica content.

Finally attention is drawn to the geology of the Troodos Massif in Cyprus, which is probably the best-authenticated segment of oceanic crust known on land. In the core of the Troodos are intrusions of gabbro and ultramafic rocks, and associated with them are substantial amounts of granitic rocks. Again, it is noted that volcanic eruptions in Iceland frequently bring up pieces of granitic rocks (Sigurdsson 1967), which suggests the possibility that granitic material may be fairly widespread, though not necessarily in large amount, beneath Iceland. One can speculate that the acid rocks in Troodos, and the inferred acid rocks beneath Iceland represent magmas which, in a deep oceanic environment have failed to penetrate the barrier because of their high viscosity, whereas on land in Iceland they have succeeded in doing so on a large scale.

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