Primary Basalts and Magma Genesis

I. Skye, North-West Scotland

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Abstract. Three Eocene lavas from Skye, NW Scotland, have been subjected to anhydrous experimental studies within their melting ranges at pressures up to 30 kb. Two of these, an olivine-phyric magnesian alkali basalt and a near-aphyric Mg-poor transitional basalt, appear to show four-phase points on their liquidi at high pressures which are thought to have genetic significance. From experimental and mineralogical evidence, the magnesian basalt is postulated to be a primary magma, erupted without significant compositional change from its genesis by slight partial melting of a relatively Fe-rich spinel lherzolite upper mantle at about 60 km depth. The liquid seems to have had a reaction relationship with Ca-poor pyroxene (pigeonite) in the residual lherzolite. Partial crystallization of batches of this magma, delayed during its ascent at depths of about 40 km, is thought to have given rise to the Mg-poor basaltic liquids. The third lava studied experimentally, a sparsely olivine-phyric hawaiite, does not have olivine on the liquidus in any part of its anhydrous P-T diagram and therefore cannot have been derived under anhydrous conditions from olivine-saturated sources. The mineralogy and chemistry of the lavas are used to support an hypothesis that the hawaiites are products of partial crystallization of pockets of basalt magma at depths approximating to the crust/mantle boundary beneath Skye, with $P_{H_2O}$ rising to sufficient values to make the residual liquids comparatively rich in normative feldspar. Finally, the genesis of all other Skye Eocene lavas is reviewed in the light of the new experimental data.

Introduction

This paper is concerned with the use of high pressure melting studies of terrestrial lavas in attempts to understand their genesis and evolution. The development of suitable apparatus by Boyd and England (1960) has led to a spate of experimental work on both natural and synthetic systems, designed to elucidate the processes of formation of basaltic and allied magmas, at pressures corresponding to depths thought to be relevant from geophysical evidence, and their evolution between such depths and the surface. The results of such studies have almost all been published in the form of general discussions, often of monumental length, of magma genesis on a world-wide scale (e.g. Yoder and Tilley, 1962; Cohen, Ito and Kennedy, 1967; D. H. Green and Ringwood, 1967; O'Hara and Yoder, 1967; Kushiro, 1968; T. H. Green and Ringwood, 1968; O'Hara, 1968; Green, 1970; Bultitude and Green, 1971).

One of the most important themes throughout these papers has been discussion of the primary magma concept. A primary magma is generally defined as one which has formed by partial melting of the earth’s upper mantle and has moved to the surface without further modification. O’Hara (1965) took the view that the rate of ascent of mafic magmas from source depths was so slow that primary magmas never reached the surface as such but instead precipitated substantial amounts
of various phases, notably olivine, as they progressed upwards, so that their compositions were close to low pressure cotectics when erupted. Other workers, such as Bultitude and Green (1971) and Kushiro (1973), have placed less emphasis on the modification of magmas between source and surface, implying that considerable quantities of primary magma are erupted in their pristine state. The debate of this theme has been given added impetus by recent experimental studies of lunar lavas, where, because of obvious sampling restrictions, several teams of investigators have been forced to study the same specimens with access to the same body of field, mineralogical and chemical data. This focussing of attention on specific problems has led to substantial collaborative cooperation (e.g. Green et al., 1971; Biggar et al., 1971; Ringwood and Green, 1972; O’Hara and Biggar, 1972; Biggar et al., 1972).

Relatively few high pressure experimental studies of mafic terrestrial lavas have been made with the intention of trying to solve specific petrological problems related to a particular specimen or rock suite, rather than establishing general relationships. Examples are work by Green and Hiberson (1970) on a megacryst-bearing New Zealand lava, Cawthorn, Curran and Arculus (1973) on the basalts and andesites of Granada, Lesser Antilles and Cox and Jamieson (1974) on the Nuanetsi basalts of Rhodesia. The present study uses the specific problem approach and is intended to enter into generalized petrogenetic discussion only as a subsidiary activity. Finely ground rock powders were used for starting materials in all the experiments reported here. In this respect the approach contrasts with that of D. H. Green and co-workers, who generally use glasses derived from rock powders, often with addition of “a pinch of what you fancy” (to misquote Biggar et al., 1972, p. 137), or composed as synthetic mixes representing average compositions of rock groups. In the present work the lava chemistry was preserved, apart from driving off volatiles, in order to conform with the rather trite presupposition that rocks have the compositions they possess for very good reasons, which may perhaps be revealed if they are tampered with as little as possible before being subjected to experiments.

The large majority of the lavas in the igneous provinces that will be considered in this report are basalts, as are half of the specimens chosen for high pressure experiments. Much of the discussion will centre around the balance between high, medium and low pressure processes in controlling their erupted compositions; i.e. the extent to which they are, or are not, primary magmas. In addition, similar consideration will be given to the magma genesis of other rock types, such as hawaiites and tholeiitic andesites, associated with the basalts; also to a representative of the strongly potassic lavas, an augite leucitite. The results will be presented in several parts. The first concerns Skye, N.W. Scotland.

Skye Lavas

The lavas of northern and central Skye outcrop over an area of approximately 1500 km². They lie in a shallow faulted oval basin, attaining a maximum preserved thickness of about 700 m. Their minimum age is probably Lower Eocene, as one of the high-level granites in the central intrusive complex, which they predate, has a radiometric age of 56 (±1.5) m.y. (Beckinsale, Thompson and Durham,