4 Magmatic Evolution and Petrogenesis in the East African Rift System

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1 Introduction

The East African rift system provides the best example of youthful, profuse and varied volcanism in intimate association with the splitting apart of a continental cratonic regime. The alkaline-ultraalkaline character of a significant volume of these volcanics, previously adverted to by Prior (1903), Finckh (1906, 1912), Lacroix (1906, 1930), Kirschstein (1920), Holmes and Harwood (1932), leading up to Bowen (1938), has tended to become the hallmark of the province. This character has been endorsed through the 2 decades following the first modern syntheses on continental rift volcanism (e.g. Harris 1969; Gass 1970; King 1970; Bailey 1974). Thus alkaline volcanism associated with other rifts and paleorifts of the world is taken to be consistent with the East African type-example, and has become an important factor in formulating geodynamic hypotheses of continental rifting.

Two contrasting overviews of African-rift alkaline magmatism have been proposed:

1. That magma alkalinity has tended to diminish as the rift system has developed, from ultraalkaline magmas associated with a purportedly prerift regional uplift, through alkaline magmatism associated with graben development, to tholeiitic magmatism once seafloor spreading has been initiated (Gass 1970, 1972).
2. That magma alkalinity has, overall, not significantly evolved with time. Continental and oceanic rifts, and their respective associated magmatism, are not correlatable (LeBas 1971; Bailey 1974).

Neither of these proposals has been confirmed in outline by the large volume of recent work. Although broad chemical trends with time have occurred (see e.g. Belousov et al. 1974; Zanettin et al. 1978a), yet some of the earliest erupted lavas were of tholeiitic composition (Holmes 1950; Brotzu et al. 1974; Zanettin et al. 1974).

The proposal of a category of basalt, mildly alkalic and transitional between alkaline and tholeiitic basalt (Barberi et al. 1972a, b, 1975a, b) has led to a widespread recognition of lavas of transitional alkalinity in many parts of the African rift system (e.g. Mohr 1975; Baker et al. 1977; Lippard and Truckle 1978; Bellieni et al. 1981; Kampunzu et al. 1983a, 1984a). Transitional basalts, and some associated tholeiites, are of diverse ages, both pre- and syn-rift. They can predate, be synchronous with, or postdate alkaline lavas of the same region. It has become evident that it is structural setting that exerts a vital, though not always predictable, control on magma composition (Gass 1970; Mohr 1963, 1971a).

Most recently, trace-element and radiogenic isotope analysis of African rift lavas has refined discrimination among the different magma types, and has given insight
into the compositions of mantle sources for the primary magmas (e.g. Piccirillo et al. 1979; Norry et al. 1980; Betton and Civetta 1984; Auchapt et al. 1987). A diversity of mantle compositions, both vertically and laterally, is now indicated. Furthermore, in several instances, the daughter isotopic composition of the rift lavas does not support the high abundance of parent isotopes, indicating a geologically recent episode of upper mantle metasomatism beneath the rift system (Bailey 1982; Dawson 1987; Menzies and Hawkesworth 1987).

Petrographic, geochemical and radiometric data on African rift igneous rocks, published during the last decade, together with a realization that the Eastern and Western Rifts have evolved, despite prominent differences, with many broad features in common, lead to the proposal of a common geodynamic basis for the structural and magmatic evolution of the East African rift system.

2 Regional Setting of Volcanism in the East African Rift System

Volcanism has been much more profuse in association with the Eastern than the Western Rift (Fig. 1). The Ethiopia-Yemen region, centred on the Afar triple junction, has been the site of at least 400000 km$^3$ of volcanics, of which in Ethiopia about 90% comprises flood basalt flows (Mohr 1963). The pile reaches known thicknesses of 3000 m in central Ethiopia, but 1500 m is a more typical, pre-erosion value. Silicic ignimbrites and lavas become more common towards and at the top of the basalt pile. They are more thickly developed within and surrounding the Ethiopian rift valley, and extend to younger ages than on the northern sector of the plateau. Afar forms a separate domain where the Ethiopian rift meets the Red Sea and Gulf of Aden spreading zones (Barberi and Varet 1977; Mohr 1978). The loci of major volcanism moved from the plateau margins to internal Afar and the drift valley in Late-Miocene. In central Afar, Pliocene-Pleistocene flood basalts exceed 800 m thickness, and here, too, salic lavas are more profuse in the upper part of the pile. In western Yemen, the volcanic pile commonly exceeds 1000 m thickness, of which half or locally even more comprises silicic ignimbrites and lavas.

In Kenya, a volcanic succession, separate and in several respects different from that of Ethiopia, has built up to thicknesses of more than 3000 m within the rift valley. The total volume is estimated at 220000 km$^3$ (Williams 1982), and the proportion of basalts to silicic lavas and ignimbrites is 68% : 32% (King 1978). In both Ethiopia and Kenya, the lateral extent of the two volcanic piles, prior to Pleistocene uplift and ensuing erosion, coincided roughly with the perimeters of the regionally uplifted plateaux (Fig. 1). Volcanism has been most intense where rift subsidence has been greatest, near the respective centres of these two areas of recent uplift.

In the Western Rift, the several volcanic subprovinces add to no more than 100000 km$^3$ total volume. However, the smaller volume and thicknesses, compared with the Eastern Rift province, favour exposure of the intimate relations between structural deformation and volcanism. Thus the Toro-Ankole subprovince, SE of Ruwenzori, comprises mainly pyroclastic and phreatomagmatic craters (Holmes and Harwood 1932; Lloyd et al., this Vol.), aligned mostly along NE or ENE fractures on the eastern floor and shoulder of the Mwutan Nzige (Mobutu) rift. The Quaternary