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Abstracts

Distribution and Petrogenesis of the Basic Rocks of the Etendeka Formation of northwestern Namibia

A R Duncan[1], J S Marsh[2], S C Milner[1] and A J Erlank[1]

[1] Department of Geochemistry, University of Cape Town, Rondebosch, S Africa
[2] Department of Geology, Rhodes University, Grahamstown, S Africa

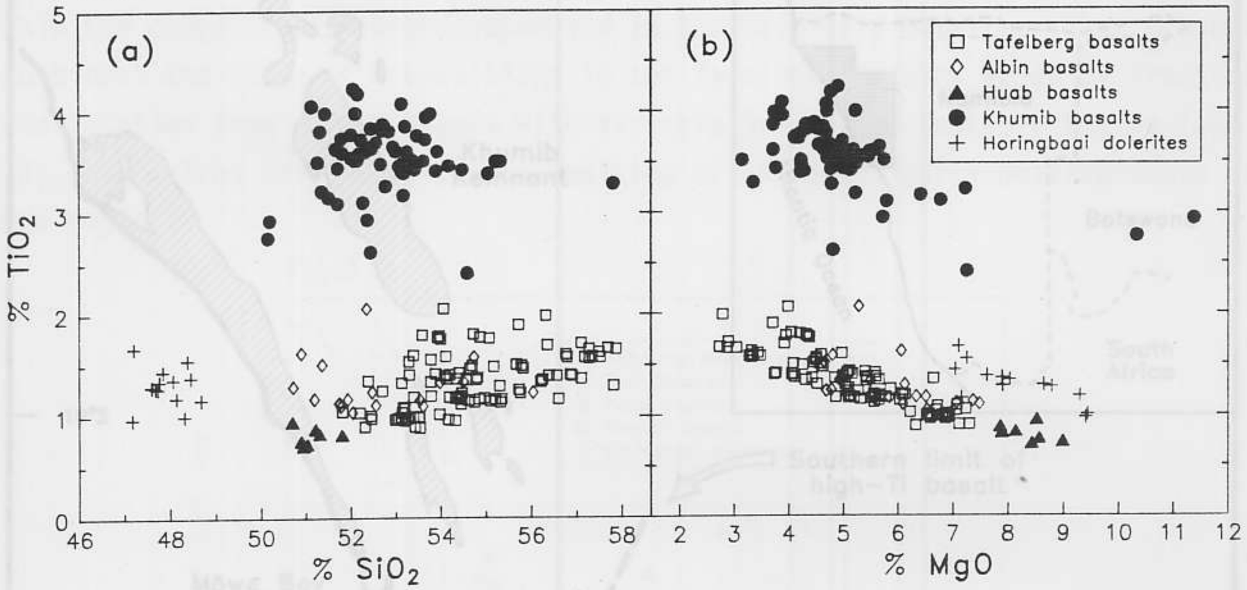
Introduction

The igneous rocks which comprise the Etendeka Formation in northwestern Namibia cover an area of 78 000 km^2 and consist dominantly of interbedded basalts and quartz latites, with minor latites. They are spatially associated with, and intruded by, two suites of dolerites. The rocks of the Etendeka Formation are included in the Karoo Igneous Province but differ from most other Karoo volcanics with respect to their younger age (Cretaceous) and aspects of their mineralogy and geochemistry. In pre-drift reconstructions of Gondwanaland the Etendeka Formation appears as an eastern extension to the volcanics of the Serra Geral Formation in the southern portion of the Paraná Basin of Brazil. There are striking similarities in the geochemistry of the Etendeka and Serra Geral Formation volcanics which, together with their geographic location and coincidence in age, argue strongly for their correlation (Erlank *et al*., 1984; Bellieni *et al*., 1984).

Basic Rock Types and their Distribution

We have defined four basaltic lava types which are distinguished from each other on the basis of geochemistry and/or petrography. It must be noted that we are using the term "basaltic" to include rocks with up to 58% SiO_2 (see Fig.1a). The *Tafelberg* and *Albin* basalt types (Erlank *et al*., 1984) are low-Ti basalts which show complete compositional overlap (Fig.1). The Albin basalts are markedly plagioclase-phyric, are found at or near the base of the volcanic section, not more than 30 km from the coast, and only to the south of Möwe Bay (see Fig.2). The Tafelberg basalts are essentially aphyric and are by far the most abundant basalt type in the main Etendeka lava field (Fig.2). They are interbedded with high-Ti *Khumib* basalts north of Terrace Bay (north of the dashed line in Fig.2) and become progressively rarer further north. They constitute less than 5% of the stratigraphic section north of latitude 19°S. The *Huab* basalts are a low-Ti variety which could be considered a more basic variant of the Tafelberg-type but for their distinctly higher ε_{Nd} values (Fig.3). They are a very minor variety in terms of abundance and are found in the main Etendeka Lava field and in lava remnants south of latitude 18°30′S.

Fig.1



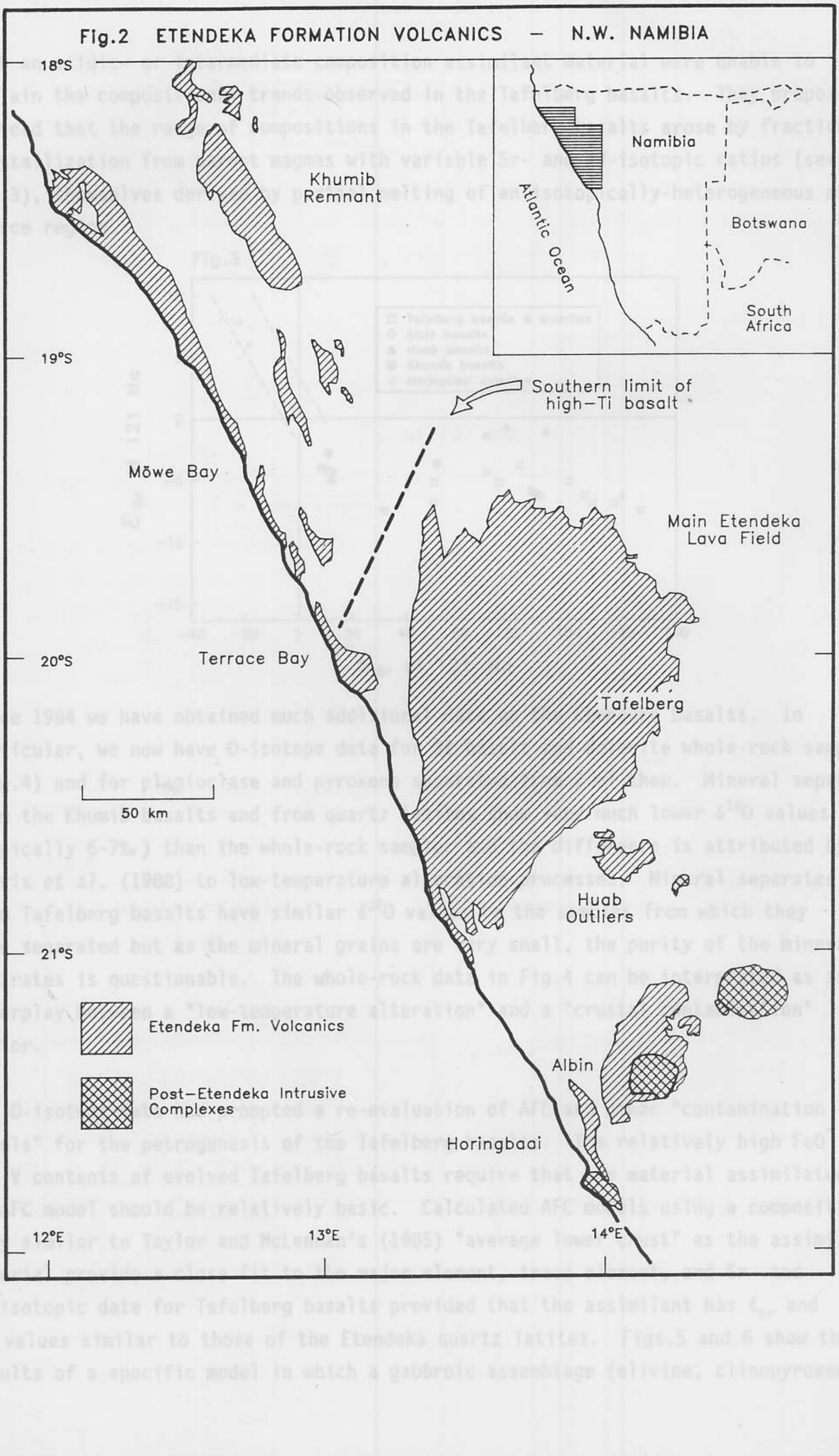
The Khumib basalts are a high-Ti variety (Fig.1) whose type area is in the Khumib lava remnant (Fig.2). Their southernmost occurrence is some 10 km north of Terrace Bay and they have not yet been found in the main Etendeka lava field (Fig.2). They are interbedded with Tafelberg basalts in the lava remnants NE of Möwe Bay and with Tafelberg and Albin basalts SE of Möwe Bay. They are sparsely pyroxene- and plagioclase-phyric and occasionally olivine-phyric as well.

The *Horingbaai* and *Tafelberg* groups of dolerites are spatially associated with the Etendeka lavas and are intrusive into the lava pile. The Horingbaai dolerites are very distinctive in composition (Figs.1 and 3) and have been shown to have strong chemical and isotopic similarities to MORB (Erlank *et al.*, 1984). They form thin dykes and sills intruding the base of the Etendeka lava succession in coastal outcrops south of latitude 20°45'S and form a large sill intruding the Etjo sandstones beneath the Huab Outliers (Fig.2). The Tafelberg dolerites are compositionally very similar to Tafelberg basalts and crop out in the same geographic areas. There are also a few dolerites which cut the Etendeka basalts and which have TiO_2 contents intermediate between those of the Tafelberg and Khumib basalts. No dolerites collected in the area shown in Fig.2 have $TiO_2 > 2.65\%$. This implies that no dolerites have so far been found with compositions such that they could have acted as feeders to the majority of Khumib basalts which contain 2.7-4.3% TiO_2.

Petrogenesis of the Low-Ti Basalts

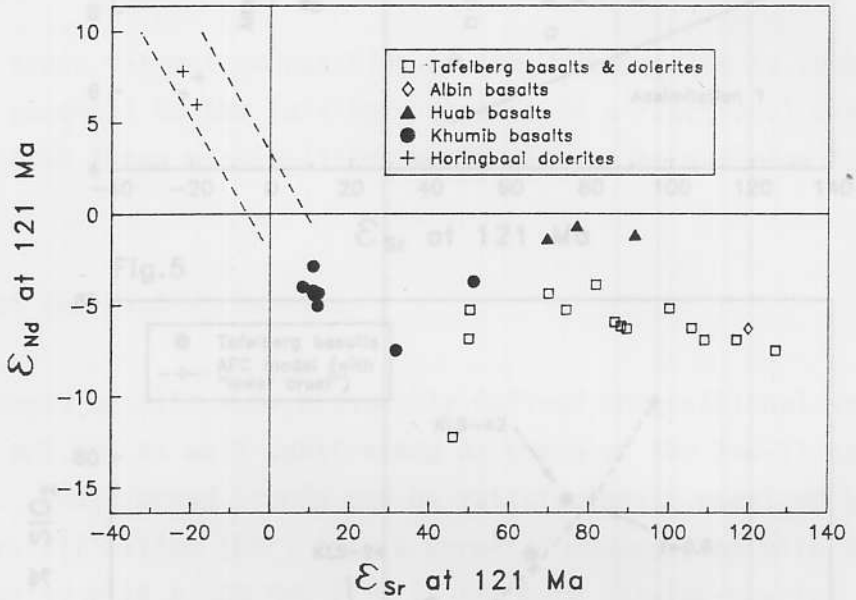
Erlank *et al.* (1984) demonstrated that it was not possible to derive the evolved (low-MgO, high-SiO_2) Tafelberg, and Albin, basalts by magma mixing processes between a primitive Tafelberg basalt and either latite or quartz latite magmas. They also showed that coupled assimilation and fractional crystallization (AFC) models

Fig.2 ETENDEKA FORMATION VOLCANICS — N.W. NAMIBIA



with an acidic- or intermediate-composition assimilant material were unable to explain the compositional trends observed in the Tafelberg basalts. They proposed instead that the range of compositions in the Tafelberg basalts arose by fractional crystallization from parent magmas with variable Sr- and Nd-isotopic ratios (see Fig.3), themselves derived by partial melting of an isotopically-heterogeneous mantle source region.

Fig.3



Since 1984 we have obtained much additional data on the Etendeka basalts. In particular, we now have O-isotope data for 32 basalt and dolerite whole-rock samples (Fig.4) and for plagioclase and pyroxene separated from 7 of them. Mineral separates from the Khumib basalts and from quartz latites show very much lower $\delta^{18}O$ values (typically 6-7‰) than the whole-rock samples and the difference is attributed by Harris *et al.* (1988) to low-temperature alteration processes. Mineral separates from Tafelberg basalts have similar $\delta^{18}O$ values to the samples from which they were separated but as the mineral grains are very small, the purity of the mineral separates is questionable. The whole-rock data in Fig.4 can be interpreted as an interplay between a "low-temperature alteration" and a "crustal contamination" vector.

The O-isotope data has prompted a re-evaluation of AFC and other "contamination models" for the petrogenesis of the Tafelberg basalts. The relatively high FeO^* and V contents of evolved Tafelberg basalts require that the material assimilated in an AFC model should be relatively basic. Calculated AFC models using a composition very similar to Taylor and McLennan's (1985) "average lower crust" as the assimilated material provide a close fit to the major element, trace element, and Sr- and Nd-isotopic data for Tafelberg basalts provided that the assimilant has ε_{Sr} and ε_{Nd} values similar to those of the Etendeka quartz latites. Figs.5 and 6 show the results of a specific model in which a gabbroic assemblage (olivine, clinopyroxene,

Fig.4

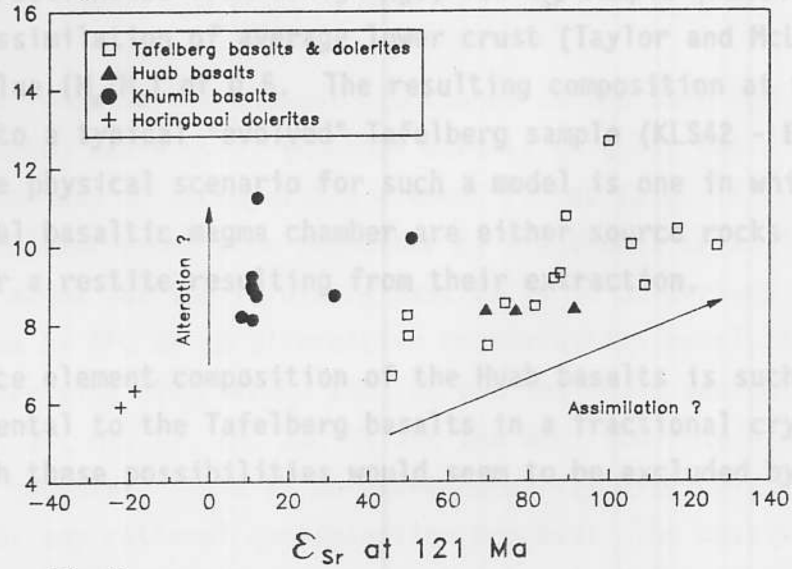


Fig.5

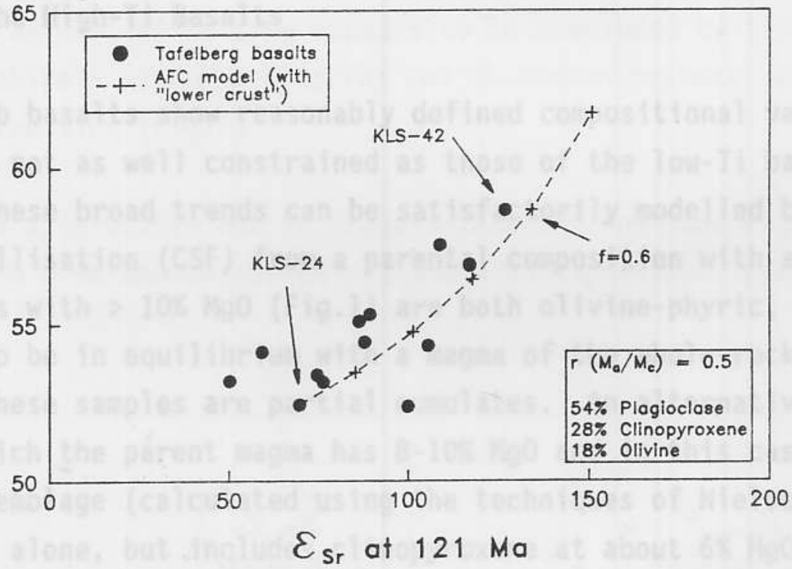
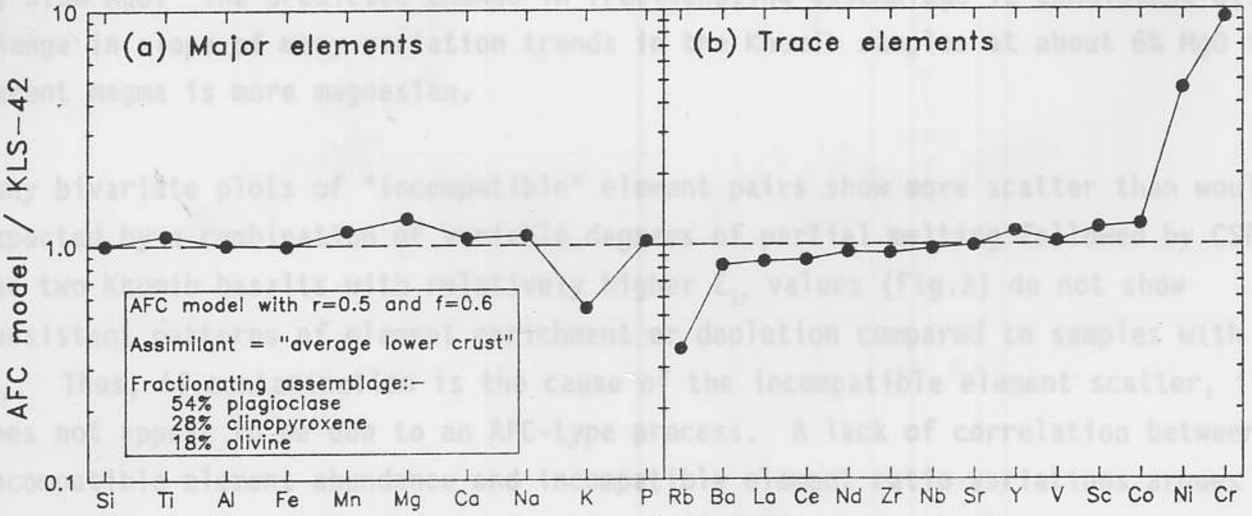


Fig.6



plagioclase) is fractionated from a high-MgO, low-ε_{Sr} sample (KLS24 - Erlank *et al.*, 1984) with assimilation of average lower crust (Taylor and McLennan, 1984) with a model r-value (M_a/M_c) of 0.5. The resulting composition at f=0.6 is compared (Fig.6) to a typical "evolved" Tafelberg sample (KLS42 - Erlank *et al.*, 1984). A possible physical scenario for such a model is one in which the wall rocks for a lower-crustal basaltic magma chamber are either source rocks for the Etendeka quartz latites, or a restite resulting from their extraction.

The major and trace element composition of the Huab basalts is such that they could be considered parental to the Tafelberg basalts in a fractional crystallization or AFC process. Both these possibilities would seem to be excluded by their isotopic data (Fig.3).

Petrogenesis of the High-Ti Basalts

The high-Ti Khumib basalts show reasonably defined compositional variation trends, although they are not as well constrained as those of the low-Ti basalts (e.g. Fig.1b). These broad trends can be satisfactorily modelled by closed-system fractional crystallisation (CSF) from a parental composition with about 6% MgO. The two Khumib samples with > 10% MgO (Fig.1) are both olivine-phyric, but the olivines are too Fe-rich to be in equilibrium with a magma of the whole-rock composition, suggesting that these samples are partial cumulates. An alternative CSF model can be constructed in which the parent magma has 8-10% MgO and in this case the fractionating assemblage (calculated using the techniques of Nielsen, 1985), is initially olivine alone, but includes clinopyroxene at about 6% MgO and plagioclase by 5.5% MgO. The predicted change in fractionating assemblage is consistent with a change in slope of many variation trends in the Khumib samples at about 6% MgO if the parent magma is more magnesian.

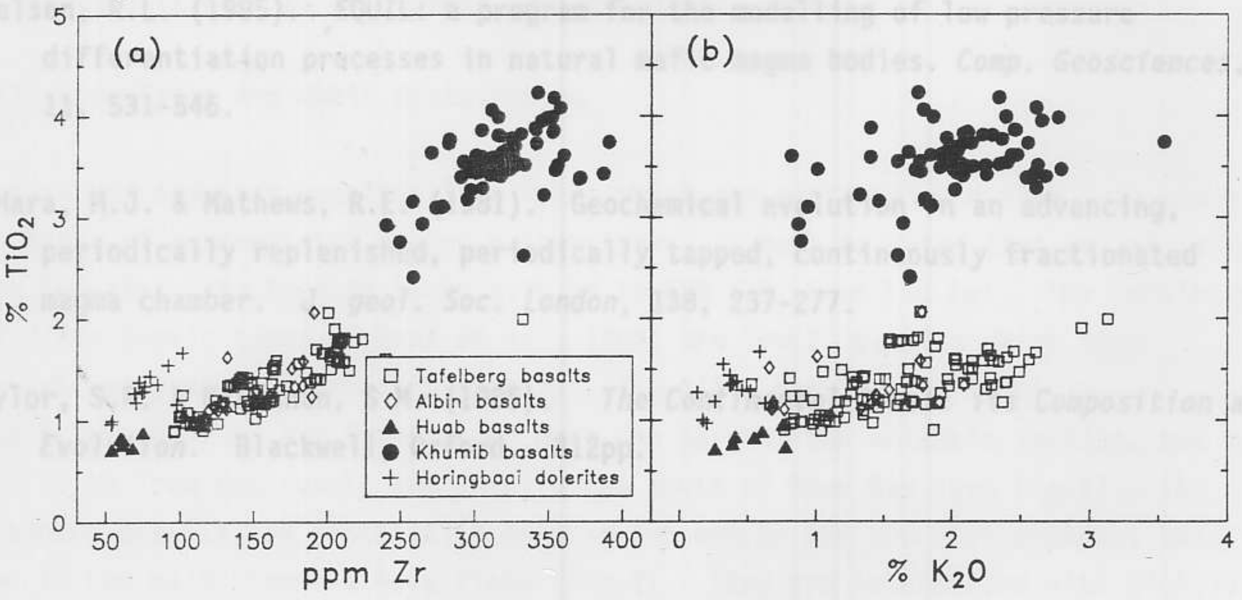
Many bivariate plots of "incompatible" element pairs show more scatter than would be expected by a combination of variable degrees of partial melting followed by CSF. The two Khumib basalts with relatively higher ε_{Sr} values (Fig.3) do not show consistent patterns of element enrichment or depletion compared to samples with lower ε_{Sr}. Thus, if contamination is the cause of the incompatible element scatter, it does not appear to be due to an AFC-type process. A lack of correlation between incompatible element abundance and incompatible element ratio variations argues against "replenished, tapped and fractionated" (RTF) magma chamber processes as proposed by O'Hara and Mathews (1981). Alternative contamination processes such as "conduit contamination" during magma ascent as proposed by Huppert and Sparks (1985) may provide an alternative explanation for the incompatible element variability in a few samples.

Relationship between Low-Ti and High-Ti basalts

The differences in incompatible element abundances at the same MgO content between the low-Ti (Tafelberg) and high-Ti (Khumib) basalts (Fig.1), the difference in ε_{Sr} (Fig.3), and differences in incompatible element ratios (e.g. K/Zr - Fig.7) preclude the derivation of either group from the other by fractional crystallisation. If a suitable parental magma for the Tafelberg basalts is to be derived from a primitive Khumib basalt magma by AFC or an alternative contamination model, then this process must result in increasing SiO_2, Al_2O_3, CaO, Sc and Co; while decreasing TiO_2, FeO^*, P_2O_5, Ba, Sr, Zr, Nb, Cr, Ni, Zn, Y, and the REE; and retaining K_2O, Rb and V essentially constant. This is an extraordinarily difficult set of elemental changes to model by any rational contamination process! The possibility of deriving parental magmas for the Tafelberg and Khumib basalts from the same mantle source by different degrees of partial melting appears to be precluded by their essentially identical and relatively high K_2O (Fig.7b) and Rb concentrations, and by differing Sr-Nd isotope systematics (Fig.3).

There seems little alternative but to suggest that the low- and high-Ti Etendeka basalts are derived from mantle source regions with significant compositional differences.

Fig.7



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