# Neogene–Recent rifting and volcanism in northern Tanzania: relevance for comparisons between the Gardar province and the East African Rift valley

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**Abstract**

The tectonic position of the intraplate, alkaline volcanic province of N. Tanzania in a broad rift-controlled area astride the boundary between the Tanzania Craton and the circum-cratonic Mozambique Fold Belt, strongly resembles that of the Gardar province of S. Greenland. Earlier-identified petrological analogies between Gardar magmatism and that in the Kenya sector of the East African Rift Valley can be extended to volcanism in N. Tanzania, and analogies specifically with the Gardar agpaitic suite are strengthened by the occurrence of eudialyte and aenigmatite in some Tanzanian peralkaline, silicic volcanics.

KEYWORDS: N. Tanzania volcanics, tectonic setting, magma types, eudialyte, aenigmatite, comparisons with the Gardar province.

## Introduction

SINCE the seminal studies of Ussing nearly 100 years ago (Ussing, 1898, 1912), the Gardar Igneous Province of South Greenland has been recognized as a classic example of continental alkaline and peralkaline magmatism. Subsequent mapping of the area, mainly by the Greenland Geological Survey, has established that the magmatism took place over a protracted period during the Mid-Proterozoic and that it was associated with repeated rifting (reviewed by Upton and Emeleus, 1987). A comparison between the Gardar province and the Tertiary–Recent igneous activity along the Kenya sector of the East African Rift Valley (EAR) (Macdonald and Upton, 1993), concluded that most magmatic types and the repeated rifting are broadly similar in the two areas, but a more recent review of the EAR (Macdonald *et al.*, 1994), drawing on local studies of different parts of the rift (Dawson, 1992; Morley *et al.*, 1992; Smith and Moseley, 1992), has emphasized the difficulties in presenting a cohesive picture of the EAR due to variations both in the basement structure controlling the rifting and the timing of the magmatism. The present paper seeks to highlight the tectonic setting of the alkaline–peralkaline magmatism and repeated rifting in the northern Tanzanian sector of the Rift valley, which serve to strengthen the overall similarities between Gardar and the East African Rift Valley.

## Tectonic setting

The magmatic rocks of the Gardar province were emplaced mainly in the Ketilidian circum-cratonic orogen close to its contact with the Greenland segment of the North Atlantic Craton (Winchester, 1988). The dykes, lavas and central complexes, with an areal extent of approximately 80 km from north to south and180 km from east to west (though it is is not known whether there are further intrusives or lavas under the inland ice to the north east of the province), were emplaced in three major episodes over a period of 200 m.y. beginning at around 1320 Ma. The magmatism was associated with repeated ENE rifting that has preserved, in downfaulted troughs, the relics of the early Gardar (approximately 1320 Ma) Eriksfjord lava field; the rifting also controlled the ascent and orientation of some mid-Gardar (1219–1299 Ma) and most late-Gardar (around 1150 Ma) dyke swarms, though other mid-Gardar dykes have a WNW strike (Upton and Emeleus, 1987). The three late Gardar centres of Tugtutôq, Ilimaussaq and Nunataq, form an ENE-trending chain following the

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orientation of the dyke swarm, but there is no convincing alignment of the older central complexes relative to their coeval dyke swarms.

In Kenya, the modern Rift Valley is a linear structure, around 60–70 km wide, that largely follows the N–S trend of the Mozambique Fold Belt. There is abundant evidence for extrusion since the mid-Tertiary of both basaltic and more salic lavas from fissures that both precede and accompany the development of the Rift Valley, and late central volcanoes and calderas occur along the N-S axis of the rift. Early Miocene nephelinite volcanoes along the Kenya-Uganda border outside the rift are also aligned N–S. Departures from the general N–S linearity are the E–W striking Kavirondo Rift; the NE–SW-trending Nyambeni fissure eruption zone on the north-east side of the isolated centre of Mt Kenya; and the NW–SE trending fissure eruption zone of the Chyulu Hills. The last two are relatively minor features and are outside and to the east of the main rift system. Looking well into the future, and assuming a long period of erosion and uplift, it is not difficult to envisage that the Kenya sector of the rift valley would be mainly an elongate N–S zone demarcated by numerous dykes and intruded by a chain of N–S aligned plutonic centres.

In the EAR the onset of Tertiary magmatism has varied from around 35 Ma in Ethiopia in the north, with the onset in the youngest province in N. Tanzania at the southern end of the southerly propagating rift at around 8 Ma (Baker *et al.*, 1972). The exact timing of the rifting in N. Tanzania relative to the onset of the magmatism is not known. In N. Tanzania, the N–S trending rift structures found in Kenya converge upon the surface contact between the Mozambique Belt and the Archaean Tanzania Craton (Dawson, 1992). Compared with the relatively narrow zone in northern and central Kenya, Mid- to Late-Tertiary faulting in N.Tanzania and southernmost Kenya has given rise to a wider zone of tectonic disturbance, the major boundaries of which diverge from the N–S linearity found further to the north (Fig. 1). This divergence is most probably controlled by the buried easterly extension of the Tanzania Craton that underlies the Mozambique Belt in northern Tanzania. This easterly extension, similar to that proposed for southern Kenya (Smith and Mosley, 1992), exists to at least the Monduli area where xenoliths of Archaean granulite occur at the Lashaine volcano (Jones *et al.*, 1983; Cohen *et al.*, 1984); this is some 140 kms to the east of the surface outcrop of the contact between the craton and the Mozambique Belt near Lake Eyasi. The broad divergence zone in northern Tanzania bifurcates to the SE to form the Pangani graben, where the Tertiary structures were controlled by Precambrian shear zones (McConnell, 1972). To the SW, the rift structures leave the Mozambique Belt and cut across into the Tanzania Craton, following NE–SW zones of crustal weakness that have been repeatedly reactivated and injected by older dolerite dyke swarms, the oldest of which may be Archaean (Vail, 1970).

Rifting in N.Tanzania began with the formation of the broad tectonic depression (Fig.1) in the Mid–Late Tertiary, though the timing is not well constrained. Later dated faulting was at around 2.1 to 2.2 Ma, 1.2 Ma and 0.4 Ma (MacIntyre *et al.*, 1974). Hence, the case for repeated rifting is clear. The faulting at 1.2 Ma, manifested by the major E-facing escarpment bounding the present-day, asymmetric rift valley, was superimposed on the earlier Tertiary depression.

Within this relatively wide tectonic depression, volcanicity has taken place in two major episodes (i) a phase dominated by alkali basalt-trachyte/phonolite extrusions from major central volcanoes from ~ 8 Ma to ~.2 Ma and (ii) a post-1.2 Ma phase dominated by evolved phonolite - olivine-free nephelinite - carbonatite activity (which continues to the present at the active carbonatite volcano Oldoinyo Lengai), but which also includes minor extrusions of primitive potassic olivine nephelinite and melilitite (Dawson, 1992; Dawson *et al.*, in press); extrusions of primitive magmas are absent in the Kenya rift. (Macdonald, 1994). Following protracted uplift and erosion in the future, as in the Kenya analogy above, the Tanzania tectonic depression would be the site of numerous plutonic centres (Fig. 1), with a wider and more scattered distribution than the chain of complexes inferred for Kenya.

In its position across the craton/fold belt boundary, with its broader zone of tectonic disturbance and wide scatter of igneous centres due to the basement influence, the Tanzania sector of the EAR shows even stronger analogies with Gardar than does Kenya.

## Comparison of magma types

The Gardar province shows a compositional continuum from alkali-basaltic to alkali-salic compositions, and the central complexes show a trend towards either silica saturation (syenite-quartz syenite granite)or towards silica undersaturation (syenite-pulaskite-foyaite), and strongly peralkaline (agpaitic) rocks are associated with each association. Despite the dominance of more salic rocks in the central complexes, Upton and Emeleus (1987) emphasize the abundance of basic magmas that can be inferred from the presence of 'giant' dykes and the relics of formerly extensive lava fields.

Compared with Gardar, the overall magma chemistry of the N. Tanzania magmatism is still poorly known, with only a few centres (Kilimanjaro,

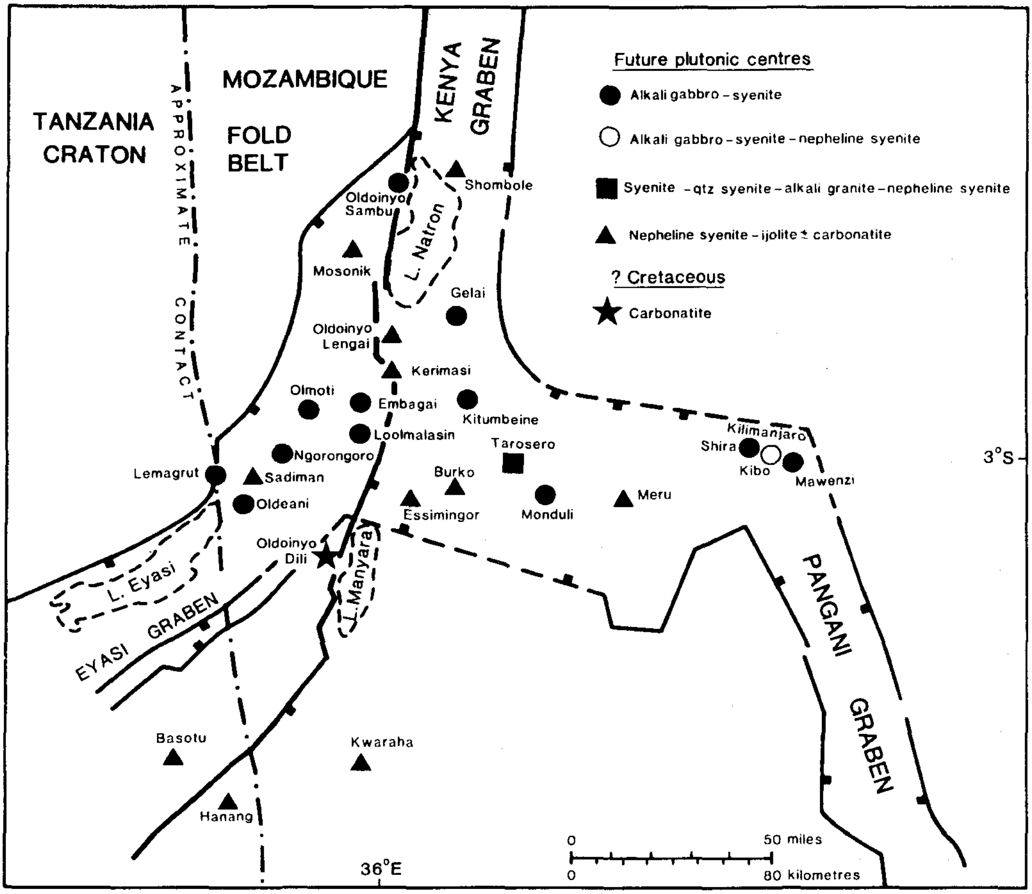


FIG. 1. Map showing the broad, fault-bounded, late-Tertiary rift depression in northern Tanzania, relative to the surface contact between the Tanzania Craton and the Mozambique Fold Belt, and the distribution of future plutonic complexes. Plutonic complex labelling assumes equivalence of plutonic rock types with present-day volcanics. Boundaries of the rift depression and distribution of igneous centres from Dawson (1992).The western boundary fault of the present-day Rift valley, cutting across the Tertiary depression, is depicted by the heavier line running approximately N–S from Oldoinyo Sambu to the Basotu-Hanang area.

Oldoinyo Lengai and Tarosero) studied in any detail. However, even these few suffice to show strong analogies with the Gardar Province, as shown in Fig. 2, a total alkalies *vs* silica plot on which data from some of these Tanzanian centres are superimposed on data from Gardar (modified from Upton, 1974). The general overlap of the rocks from the two provinces on this type of plot is immediately apparent. There are, to be sure, some differences. For example, there are, to date, few volcanics in N. Tanzania with $SiO_2$ concentrations as high as some of the Gardar granites, and conversely there are few Gardar rocks that match some of the low-$SiO_2$/high alkali rocks from Oldoinyo Lengai. Furthermore, the low $SiO_2$/low alkali rocks in Gardar are monchiquites, whereas such rocks in Tanzania are olivine nephelinites and olivine melilitites. However, such differences are relatively minor compared with the good chemical match between the rock types forming the greater part of the two provinces. Furthermore, despite the relative proximity of the the Gardar and N.Tanzania provinces to their respective cratons, strontium isotope studies on rocks from both provinces (Blaxland *et al.*, 1978; Paslick *et al.*, 1995) show no evidence for significant magma modification by radiogenic granitic crust, although

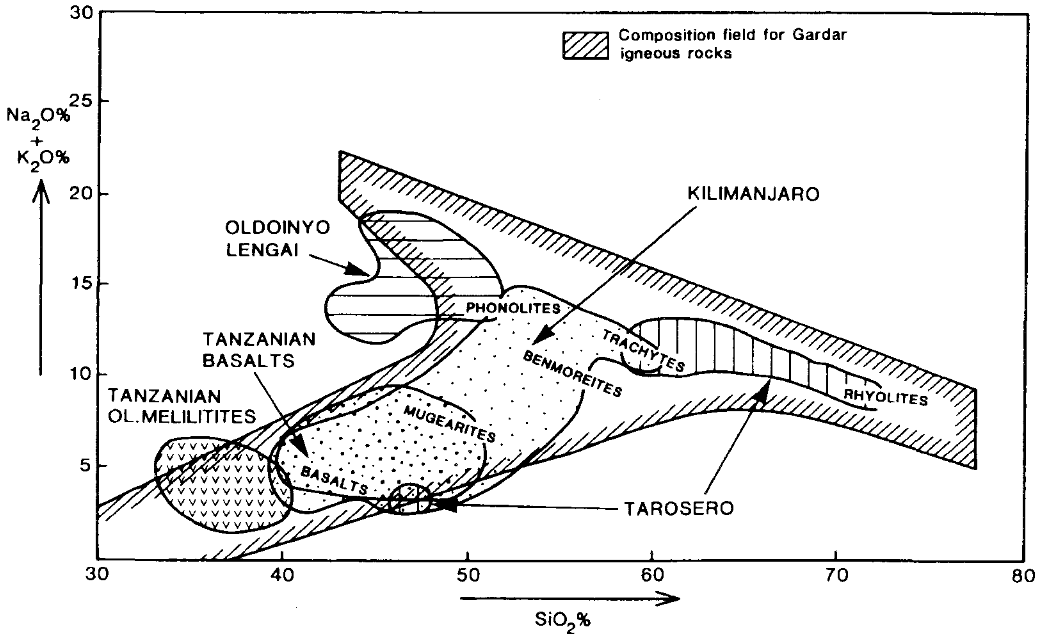


FIG. 2 Total alkalies/silica plot comparing the compositional field for Gardar rocks (Upton 1974) with selected rocks suites from northern Tanzania. Tanzanian data sources: Tarosero – Cooper (1972); olivine melilitites - Dawson *et al.* (1985; in press), Oldoinyo Lengai – Donaldson *et al.* (1987); Kilimanjaro – Downie and Wilkinson (1972); Tanzanian basalts – Paslick *et al.* (1995).

in central Kenya some basalts show strong evidence of having assimilated sialic crustal material (Davies and Macdonald, 1987). However, another difference between the volcanics in N. Tanzania and current data for others in Kenya, Ethiopia and the Red Sea is the presence of more radiogenic lead in the Tanzanian rocks (Paslick *et al.*, 1995); whether this is related to the on-craton siting of the N. Tanzania province, is far from clear in our current state of knowledge.

One of the distinctive features of the Gardar province is the agpaitic rocks, peralkaline rocks defined by Sørensen (1974) as containing alkali-rich phases such as arfvedsonite, aenigmatite and eudialyte, and any comparison between the Gardar and N. Tanzania provinces must address whether similar rock types exist in Tanzania, and also should consider the question of the proportions of the various rock types in the two provinces. In N. Tanzania, alkali basalts are the dominant extrusive type, and trachytes and phonolites are relatively small in volume. Both the latter are major rock types, in their plutonic form, in Gardar, although the agpaitic rock types are volumetrically quite minor (despite the mass of petrological and mineralogical literature devoted to them). In N. Tanzania agpaitic rocks are similarly rare but they occur at Oldoinyo Lengai both as lavas (Donaldson *et al.*, 1987) and syenite blocks (Dawson *et al.*, 1995), and also at the Tarosero volcano (3°12'S, 36°22'E) (Dawson, 1964). A geochemical study of the Tarosero lavas, aged between 1.9 and 2.4 Ma (Macintyre *et al.*, 1974), has distinguished two groups: Group 1 – a series ranging from benmoreite through quartz trachyte, trachyte and phonolite to pantellerite, with the more siliceous being peralkaline; and Group 2 – comprizing peralkaline phonolites, trachytes and quartz trachytes, that are enriched in Cl, Ba, Sr, Rb, *REE*, Nb, Zr and P relative to Group 1 rocks with the same major element concentrations (Cooper, 1972). The Group 2 rocks are agpaitic and the affinities between these rocks and some of the more agpaitic members of the Gardar suite are strengthened by the occurrence in Tarosero phonolite (new data, reported here, Table 1) of eudialyte and aenigmatite, which are regarded as characteristic of the agpaites (Sørensen, 1974). Trachytes and phonolites are also major rock types in Kenya occurring, not only in the late caldera-type volcanoes within the rift, such as Menegai, but also as the major outpourings of plateau trachyte and plateau phonolite (Williams, 1972). Unfortunately, despite the occasional reference to the

TABLE 1. Analyses of eudialyte and aenigmatite from Tarosero, N. Tanzania

| | 1 | 2 |
|---|---|---|
| $Nb_2O_5$ | 0.55 | 0.43 |
| $SiO_2$ | 50.1 | 38.5 |
| $TiO_2$ | 0.18 | 6.08 |
| $ZrO_2$ | 11.3 | 0.19 |
| $Al_2O_3$ | 0.20 | 1.19 |
| $La_2O_3$ | 0.57 | na |
| $Ce_2O_3$ | 0.94 | 0.08 |
| $Nd_2O_3$ | 0.58 | na |
| FeO* | 7.50 | 41.9 |
| MnO | 1.24 | 1.55 |
| MgO | na | 0.80 |
| CaO | 8.70 | 0.62 |
| $Na_2O$ | 12.9 | 7.72 |
| $K_2O$ | 0.33 | 0.04 |
| Cl | 2.13 | na |
| Total | 96.74 | 99.10 |

na, not analysed; * total iron as FeO
1. Eudialyte, in sodalite phonolite BD 295. Total includes −0.48 wt.% O≡Cl.
2. Aenigmatite in sodalite trachyte BD512.
Analyst: J.B. Dawson

presence of aenigmatite in some phonolites (Lippard, 1973) comparisons with the Gardar agpaites are hampered by an absence of modern geochemical and mineralogical data.

## Repeated episodes of alkaline magmatism

A specific aspect of Gardar magmatism noted by Upton and Emeleus (1987) is that it took place sporadically in three major episodes over a period of some 200 Ma . In Kenya, although there is as yet no evidence for rift-related magmatism older than around 25 Ma, there has been repeated magmatism since that time. In northern Tanzania, although the most recent igneous activity spans less than 10 Ma there have been two major episodes of magmatism, each following a major phase of rifting. Further, there is some limited evidence for older magmatism. Oldoinyo Dili, lying just to the west of Lake Manyara (Fig. 1), is a deeply eroded complex consisting of pyrochlore sövite surrounded by a fenite aureole, and its depth of erosion clearly marks it as considerably older than the Neogene–Recent activity (McKie, 1966). If the emplacement of Oldoinyo Dili is linked to the phase of magmatism at around 100–120 Ma when other carbonatite complexes were intruded around the southern and western margins of the Tanzania craton (van Straaten, 1989), then continental alkaline magmatism has taken place in northern Tanzania spasmodically for at least 100 Ma. In a broader context, van Straaten (1989) has pointed out that carbonatite magmatism has taken place repeatedly since the mid-Proterozoic in the fold belts surrounding the Tanzania Craton.

## Conclusions

1. In its tectonic position astride a craton/fold-belt boundary, the N. Tanzania volcanic province has closer analogies to Gardar than does Kenya. Like Gardar, the N. Tanzania igneous centres are scattered across a broad area of tectonic disturbance, unlike the relatively-narrow linear zone of rifting and intrusion in Kenya.

2. Most rock types found in Gardar can be matched by their volcanic equivalents in N. Tanzania, and the recent discovery of eudialyte and aenigmatite has strengthened analogies with the Gradar agpaitic suite. However, the proportions of basic to salic rock types are different and, in this respect, the magmatism in Kenya is possibly a closer match to Gardar.

3. Like the magmatism in the Kenyan sector of the EAR, the alkaline continental magmatism in N. Tanzania is still young compared with Gardar, and it is still evolving. However, even in the geologically-brief period since magmatism begun in East Africa, there is good evidence that it, and the associated rifting, are repetitive.

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## References

Baker, B.H., Mohr, P.A. and Williams, L.A.J. (1972) *Geology of the Eastern Rift System of Africa.* Geol. Soc. Amer. Spec. Paper **136**.

Blaxland, A.B., Van Breemen, O., Emeleleus, C.H. and Anderson, J.G. (1978) Age and origin of the major syenite centers in the Gardar province of South Greenland:Rb-Sr studies. *Bull. Geol. Soc. Amer.*, **89**, 231–44.

Cohen, R.S, O'Nions, R.K. and Dawson, J.B. (1984) Isotope chemistry of xenoliths from East Africa: implications for the devlopment of mantle reservoirs and their interaction. *Earth Planet. Sci. Lett.*, **68**, 209–20.

Cooper, J.R. (1972). *Geochemistry of Tarosero volcano, northern Tanzania*. Unpubl. M.Sc. thesis, University of Manchester.

Davies, G.R. and Macdonald R. (1987) Crustal influences in the petrogenesis of the Naivasha basalt-rhyolite complex: combined trace element and Sr-Nd-Pb isotope constraints. *J. Petrol.*, **28**, 1009–31.

Dawson, J.B. (1964) *Monduli*. Tanzania Geol. Surv. Quarter Degree Sheet 54,with explanation.

Dawson, J.B. (1992) Neogene tectonics and volcanicity in the North Tanzania sector of the Gregory Rift Valley: contrasts with the Kenya sector. *Tectonophysics*, **204,** 81–92.

Dawson, J.B. Smith, J.V. and Jones, A. P. (1985) A comparative study of bulk rock and mineral chemistry of olivine melilitites and associated rocks from East and South Africa. *Neues Jahrb. Mineral. Abh.*, **152**, 143–75.

Dawson, J.B., Smith, J.V. and Steele, I.M. (1995) Petrology and mineral chemistry of plutonic igneous xenoliths from the carbonatite volcano, Oldoinyo Lengai, Tanzania. *J. Petrol.*, **36**, 797–826.

Dawson, J.B., James, D., Paslick, C. and Halliday, A.M. (in press) Ultrabasic potassic low-volume magmatism and continental rifting in north-central Tanzania: association with enhanced heat flow. *Proc Volume Sixth Internat. Kimberlite Conf., Novosibirsk 1995.*

Donaldson, C.H, Dawson, J.B., Kanaris-Sotiriou, R., Batchelor, R.A. and Walsh, J.N. (1987) The silicate lavas of Oldoinyo Lengai, Tanzania. *Neues Jahrb. Mineral. Abh.*, **156**, 247–79.

Downie, C. and Wilkinson, P. (1972) *The Geology of Kilimanjaro*. University of Sheffield, 253 pp.

Jones, A.P., Smith, J.V., Dawson, J.B. and Hansen, E.C. (1983) Metamorphism, partial melting and K-metasomatism of garnet-scapolite-kyanite granulite xenoliths from Lashaine, Tanzania. *J. Geol.*, **91**, 143–65.

Lippard, S.J. (1973) The petrology of phonolites from the Kenya Rift. *Lithos*, **6**, 217–34.

Macdonald, R. (1994) Petrological evidence regarding the evolution of the Kenya Rift Valley. *Tectonophysics*, **236**, 373–90.

Macdonald, R. and Upton B.J.G. (1993) The Proterozoic Gardar rift zone, south Greenland: comparisons with the East African Rift System. In *Magmatic Processes and Plate Tectonics* (H.M. Prichard, T. Alabaster, N.B.W. Harris and C.R. Neary, eds). Geol. Soc. London, Spec. Publ. **76**, 427–42

Macdonald, R., Williams, L.A.J. and Gass, I.G. (1994) Tectonomagmatic evolution of the Kenya rift valley: some geological perspectives. *J. Geol. Soc. London*, **151**, 879–88.

Macintyre, R.M., Dawson, J.B. and Mitchell, J.G. (1974) Age of fault movements in the Tanzania sector of the East African Rift system. *Nature*, **247,** 354–6.

McConnell, R.B. (1972) Geological development of the rift system of eastern Africa. *Geol. Soc. Amer. Bull.*, **83**, 2549–72.

McKie, D. (1966) Fenitisation. In *Carbonatites* (O.F. Tuttle and J. Gittins, eds), 261–94, Interscience, New York.

Morley, C.K., Wescott, W.A., Stone, D.M., Harper, R.M., Wigger, S.T. and Karanja, F.M. (1992) Tectonic evolution of the northern Kenya Rift. *J. Geol. Soc. London*, **149,** 333–48.

Paslick, C., Halliday, A., James, D. and Dawson, J.B. (1995) Enrichment of the continental lithosphere by OIB melts: isotopic evidence from the volcanic province of northern Tanzania. *Earth Planet. Sci. Lett.*, **130**, 109–26.

Smith, M. and Mosley, P. (1992) Crustal heterogeneity and basement influence on the development of the Kenya Rift, East Africa. *Tectonics*, **12**, 591–606.

Sørensen, H. (1974) Alkali syenites, feldspathoidal syenites and related lavas. In *The Alkaline Rocks* (H. Sørensen, ed.) 22–52, Wiley, Chichester.

Upton, B.G.J. (1974) The alkaline province of south-west Greenland. In *The Alkaline Rocks* (H. Sørensen, ed.) 221–38, Wiley, Chichester.

Upton, B.G.J., Emeleus, C.H. (1987). Mid-Proterozoic alkaline magmatism in southern Greenland. In *Alkaline Igneous Rocks* (J.G. Fitton and B.G.J. Upton, eds), Geol Soc. London Spec. Publ. **30**, 449–72.

Ussing, N.V. (1898) Mineralogisk-petrografisk undersøgelse af grønlandske Nefelinsyeniteer og beslægtede Bjergarter. *Meddr. Grønland*, **14**, 1–220.

Ussing, N.V. (1912) Geology of the country around Julianehaab, Greenland. *Meddr. Grønland*, **38**, 1–376.

Vail, J.R. (1970) Tectonic control of dykes and related irruptive rocks in eastern Africa. In *African Magmatism and Tectonics*, (T.N. Clifford and I.G. Gass, eds), 337–54, Oliver and Boyd, Edinburgh.

Van Straaten, P (1989) Nature and structural relationships of carbonatites from southwest and west Tanzania. In *Carbonatites: Genesis and Evolution* (K. Bell, ed.) 177–99, Unwin Hyman, London.

Williams, L.A.J.(1972) The Kenya Rift volcanics; a note on volumes and chemical composition. *Tectonophysics*, **15**, 83–96.

Winchester, J.A. (1988) Later Proterozoic environments and tectonic evolution in the northern Atlantic lands. In *Later Proterozoic Stratigraphy of the Northern Atlantic Regions* (J.A. Winchester, ed.). 253–70, Blackie, Glasgow.

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