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THE GEOLOGICAL AND VOLCANOLOGICAL FEATURES OF THE QUARTZ LATITES OF THE ETENDEKA FORMATION

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ABSTRACT

The volcanic Etendeka Formation of S.W.A./Namibia consists predominantly of interbedded basalt and quartz latite units with an approximate age of 121 m.y. The quartz latites, which represent a significant proportion of the succession, exhibit characteristics common to both ignimbrites and lava flows. The local preservation of pyroclastic textures and broad areal extent of the units have led to the conclusion that these quartz latites are the products of high-temperature ash flows, which underwent en masse lava-like flowage following their deposition but prior to final cooling.

1. INTRODUCTION

The study area, situated in the Skeleton Coast Park and western Damaraland, is bounded by latitudes 21°00'S and 20°00'S and longitudes 13°15'E and 14°15'E (Fig. 1). Investigations have been confined to the volcanics of the Etendeka region, more specifically the acid rocks which crop out over a wide area within the southern Etendeka. The volcanic Etendeka Formation is the uppermost unit of the Karoo Sequence in S.W.A./Namibia and overlies discontinuous Karoo sediments and pre-Karoo basement. The basaltic rocks have yielded a K-Ar isochron age of 121 ± 2 m.y. (Siedner and Mitchell, 1976) and similar ages of approximately 125 m.y. were recently obtained by $^{39}Ar/^{40}Ar$ step heating analysis of three dolerites intruding Karoo sediments and the basaltic lavas near Cape Cross (Erlank *et al.*, in press).

The Etendeka Formation consists of a series of interbedded basalt (including both primitive and more evolved varieties) and quartz latite units, with some minor latite, which reach an observed maximum thickness of 900 m at Tafelberg (Erlank *et al.*, 1984). Although earlier workers have mentioned the presence of acidic rocks in the lava sequence, described as orthoclase porphyry (Reuning, 1929) or rhyolites (Korn and Martin, 1954; Martin *et al.*, 1960), they were ascribed only to the upper part of, or as a capping to the sequence. The widespread interbedded nature of the quartz latites has only recently become apparent (Erlank *et al.*, in press). The original maximum stratigraphic thickness of volcanics is unknown, although it is thought to have exceeded 2 km (Reuning and Martin, 1957).

The use of the term "quartz latite" to describe the acid volcanics of the Etendeka was first introduced by Erlank *et al.* (in press) to avoid the genetic implications of the term "dacite". Despite the absence of modal quartz, whole-rock chemical data fall within the field of quartz latites originally defined by Iddings (1913), and more recently by Ekren *et al.* (1984).

The descriptive information presented below shows that the quartz latites exhibit features common to both ignimbrites and lava flows and are similar in many respects to the rhyolites of the Lebombo (Bristow and Cleverly, 1979; Cleverly *et al.*, in press). Despite conflicting evidence, many workers on Karoo rhyolites in southern Africa have favoured an ignimbritic origin, although convincing macro- and micro-textural information has often not been available or apparent.

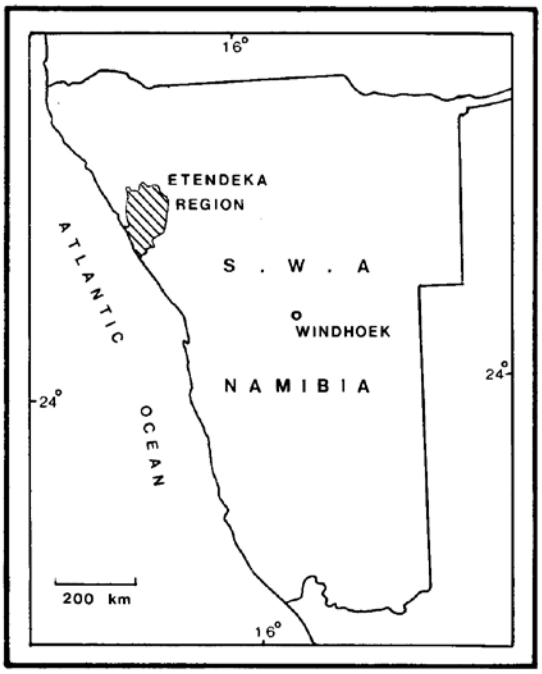

Fig. 1: Geographic locality of the Etendeka region in S.W.A./Namibia.

2. DETAILED GEOLOGY

The geology of the southern Etendeka volcanics is presented in Fig. 2. This illustrates the most detailed mapping of the Etendeka lava field currently available and covers approximately one third of the area of the main lava field.

2.1 Structure

The area mapped is divided into two structural regions by the Ambrosius Berg fault zone. This fault zone can be traced for a distance of 60 km north of Ambrosius Berg and constitutes a major structural break (Fig. 2).

West of the Ambrosius Berg fault zone the volcanics dip between 5° and 30° east and form a series of blocks which are bounded by faults parallel to the coast. Within single fault blocks the dip is normally constant and there is a general westward increase in the easterly dip. However, within certain fault blocks there are local unconformities which may have resulted from synvolcanic fault movements. Unfortunately, these faults are often obscured by superficial material in areas of low relief and are thus rarely detected.

To the east of the Ambrosius Berg fault zone the succession is characterised by predominantly flatlying units with a slight westerly dip in the order of 1° or less. A fault with a trend parallel to the road north and south of Bergsig has lowered the volcanic sequence approximately 100 m to the west.

The difficulty in correlating stratigraphic units across the Ambrosius Berg fault zone, and the faulted nature of the coastal succession, imply that no overall stratigraphic column for the Etendeka volcanic succession can be readily compiled, although in local areas this has been possible as discussed below.

2.2 Quartz Latite Lithostratigraphy

The quartz latites are here divided into three main groups, the Springbok, Tafelberg and Interbedded Coastal varieties, which may be recognised in the field by differences in outcrop pattern and petrographic characteristics.

The Springbok group is composed of upper and lower members which are separated by approximately 90 m of basaltic lavas. The base of the lower member is situated between 150 and 180 m above the base of the Etendeka Formation, and appears to consist of a single unit between 10 and 20 m thick which crops out discontinuously over a wide area. The contact relationship of this unit with the underlying basalts is clearly transgressive and provides evidence, supported by a variation in unit thickness and stratigraphic height, for the existence of palaeorelief prior to its eruption. The upper Springbok member exhibits a maximum observable thickness of 270 m which thins out rapidly towards its northern contact, where it is overlain transgressively by flows of the Tafelberg group. Certain stratigraphic sections have allowed the recognition of three units within the upper member using criteria established for an idealised quartz latite unit. However, where this member thins beneath the Tafelberg lavas there is no evidence to support the presence of three units. It is tentatively suggested that the upper member was truncated by an erosional feature prior to the eruption of the Tafelberg group.

Outcrops of the more massive upper Springbok member are characterised by large, rounded, boulderstrewn hills which are in contrast to the trap-like outcrops of the Tafelberg volcanics. Both upper and lower members are characteristically feldspar phyric and range in colour from a rusty brown, devitrified rock to a black pitchstone.

Fig. 2 illustrates the large area over which the Springbok quartz latites occur. The upper member covers a present day area of some 1250 km^2 and it is evident from outliers to the south of the Huab River valley that this represents only a portion of the original area covered.

Upper and lower quartz latite members of the Tafelberg group are 85 m and 100 m thick, respectively, and are separated by approximately 320 m of basaltic material. At Tafelberg, the base of the lower member is about 340 m above the base of the Etendeka Formation. However, where the Tafelberg group overlies the upper Springbok member the intervening basalt wedge varies in thickness from 230-250 m in the west to zero near Driefontein. In the Driefontein area the lower Tafelberg member is truncated against the upper Springbok member.

The Tafelberg quartz latites are typically aphyric, devitrified and pink to grey in hand specimen with only occasional basal vitrophyre horizons. They tend to form significant topographic steps, or cliffs, which commonly exhibit a rough columnar joint pattern. Many of these features have been recognised in the quartz latite immediately west of the Ambrosius Berg fault zone, in particular where it is cut by the Koigab River. These features, together with similarities in chemistry, suggest that this outcrop should be correlated with the lower Tafelberg quartz latite. South of the Koigab River this unit is overlain by two sparsely feldspar-phyric quartz latite units which are separated by approximately 60 m of basalt. This represents a considerable departure from the normal Tafelberg stratigraphy.

The quartz latites and basalts of the Tafelberg group exhibit a classic trap morphology. Individual flows, showing a constant thickness, can be traced for many kilometres and hill-top remnants of the lower Tafelberg quartz latite member have been mapped 70 km west of Tafelberg itself. Although the observed outcrop area of this lower member is not as great as that for the Springbok units, an area of 2500 km^2 may have been covered within the limits of the outcrop remnants observed. In the northern Etendeka region the preserved extent of the upper Tafelberg quartz latite approaches 2000 km^2,

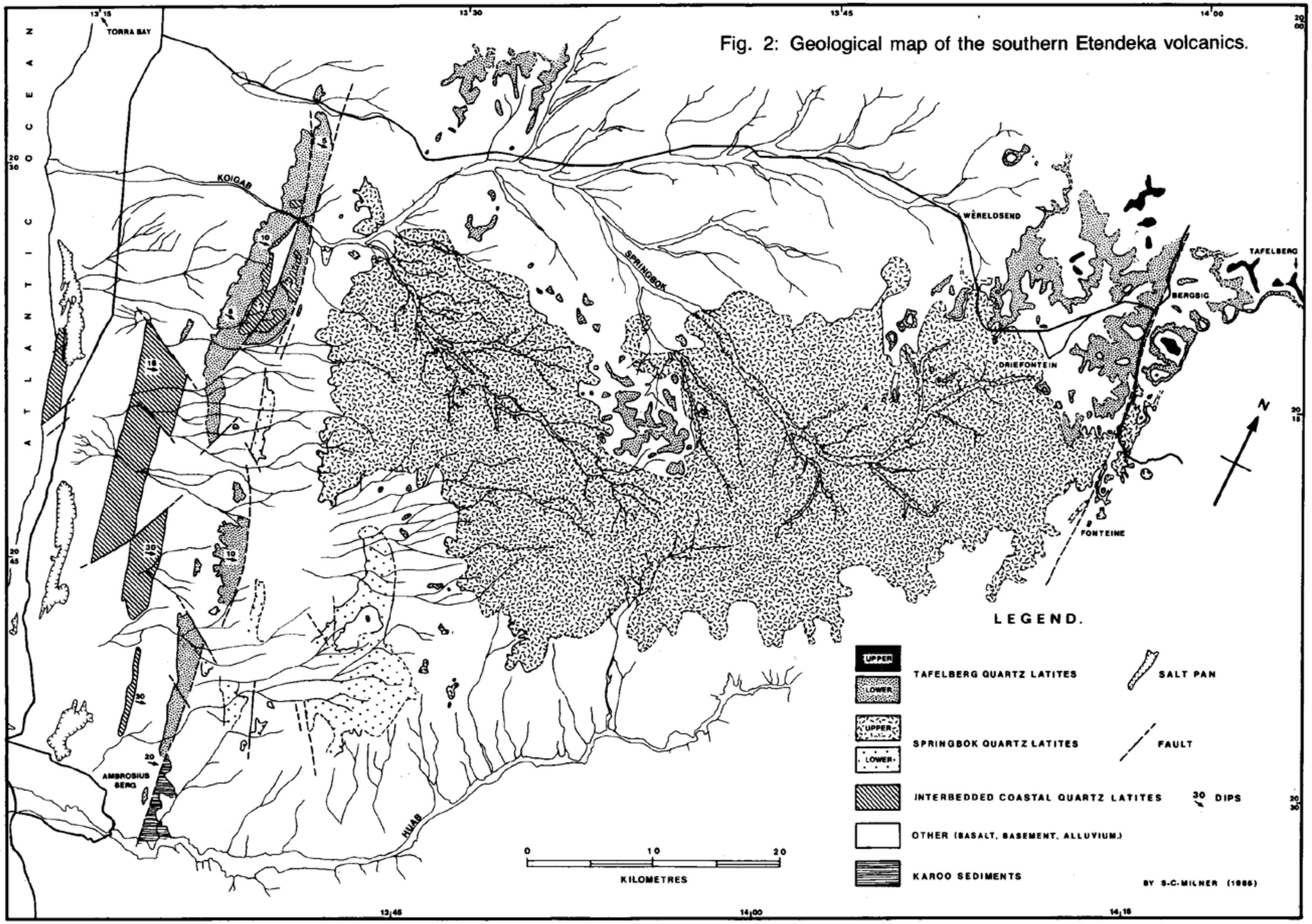

Fig. 2: Geological map of the southern Etendeka volcanics.

(R.McG. Miller, 1980, pers. comm.) and there is little doubt that these units form very extensive horizons.

The thickest individual accumulation of quartz latite units in the Etendeka area occurs in the coastal region west of the Ambrosius Berg fault zone. In this area a pile of quartz latite units, here termed the Interbedded Coastal group, have a maximum thickness of approximately 800 m and overlie an unknown thickness of basalt. The number of units observed varies from seven, encountered in a traverse across the southern end of the fault block, to eleven or more at the northern end, where the uppermost units are intercalated with basaltic material. The tilted and faulted nature of the coastal succession make it impossible to estimate the areal extent of these quartz latites. However, the lower units can be traced for up to 25 km along strike suggesting that these units covered a considerable area.

In outcrop both feldspar-phyric and aphyric varieties are observed and are predominantly devitrified and pink to grey in colour, although basal pitchstone zones are commonly encountered.

The overall position of the Interbedded Coastal quartz latites within the stratigraphic column is uncertain, as no equivalent formation has been recognised to the east of the Ambrosius Berg fault zone. The overall outcrop pattern for these units and the Koigab equivalent of the lower Tafelberg member suggest deposition within a fault-controlled depression or basin. In Fig. 2 the additional quartz latites in the region south of the Koigab are tentatively assigned to the Interbedded Coastal quartz latite group and may represent the interfingering of quartz latites from different volcanic centres.

The eruptive centres of the quartz latite volcanism are unknown. As yet no caldera related structures have been identified in the Etendeka region and no vent or acid dykes, which may have acted as feeders to the eruptions, have been observed. It is also interesting to note that no air-fall ash horizons, commonly associated with acid volcanism, have been seen.

3. THE QUARTZ LATITE UNIT

The terms flow unit, cooling unit and compound cooling unit are described by Fisher and Schmincke (1984). Briefly, the term flow unit is usually reserved for the product of a single pyroclastic eruption; this is in contrast to the cooling unit which occurs when several flows are erupted in rapid succession and cool as a single unit. The overall massive nature of the quartz latites in outcrop often precludes this distinction, hence the term "unit" has been used in preference to flow unit in this text.

A composite section of an idealised quartz latite flow unit is presented in Fig. 3 and brings together many important features common to the Etendeka quartz latites as a whole. It is important to note, however, that the development of many of the basal features are in most cases localised and not common to all sections, although one or more of these features are usually present.

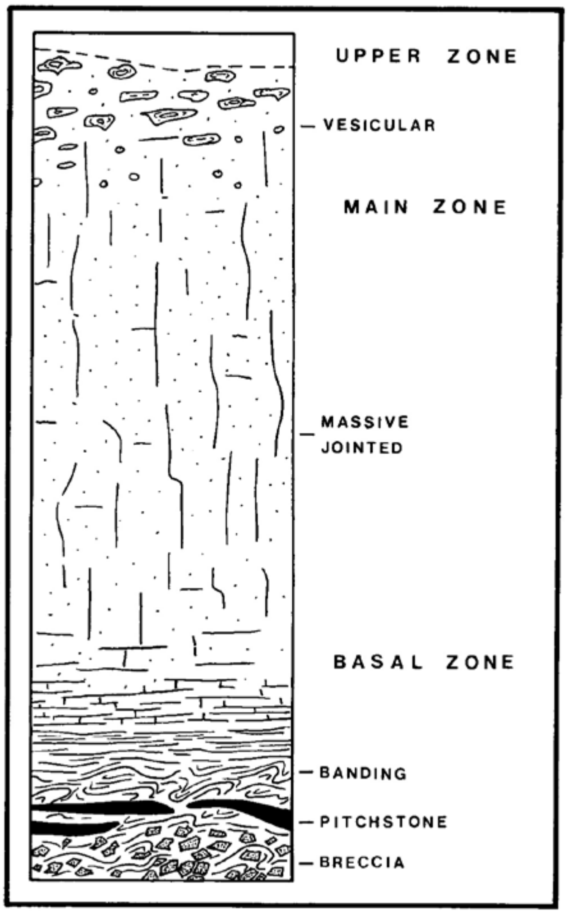

Fig. 3: Schematic section through an idealised Etendeka quartz latite flow unit.

3.1 Basal Zone

The most informative portion of the unit is the base, where many features are preserved by rapid contact chilling with the ground surface. Banding, which is frequently contorted, a basal pitchstone, and a basal breccia are among the more important features observed.

3.1.1 Banding and Fiamme

In most cases the form of the observed banding has been enhanced by alteration which has differentially coloured the bands in shades of red, orange and grey. The alteration may have taken place shortly after deposition by late-stage phreatic or degassing events which may also have produced the breccia-filled pipes observed in some units. The banding typically occurs on a millimetre to decimetre scale. Near the base of the unit, normally within 2 or 3 m, the banding may be highly contorted both vertically" and laterally. Towards the main body of the unit these contortions frequently give way to more laminar banding which often becomes associated with a strong centimetre-scale jointing in the same plane. There would appear to be a correlation between the presence of strongly contorted banding and an undulating topography prior to deposition. Quartz latites of the Tafelberg group rarely show contorted banding to any great degree, a feature attributed to their near planar contacts.

Thin sections from laminar banded regions near the base of flow units occasionally contain fiamme-like structures (see Fig. 5). These show textures consistent with pore space elimination and have frayed ends, a description not unlike that given for fiamme by Ross and Smith (1961).

3.1.2 Basal Pitchstone

Pitchstone occurs in irregular pods and bands, normally within 2 m of the base, and may show either sharp or gradational contacts with the devitrified portions of the unit. The exceptions to this are the very thick pitchstone horizons in the upper Springbok member which may be as much as 10 m thick. These particular pitchstones exhibit a lenticular fabric near the base similar to that observed in the brecciated material.

In thin section these pitchstones are for the most part homogeneous glass with varying amounts of phenocrysts. A typical example is shown in Fig. 4. In other examples from glassy, friable perlitic horizons, a texture composed of plastically moulded clasts of dark brown hydrated glass has been observed (Fig. 6). An almost identical photomicrograph is presented by Ross and Smith (1961, Fig. 39) which they describe as "a thoroughly welded glassy tuff with large pumice fragments that have collapsed and all the pore space eliminated. ....." This explanation is consistent with observations made of relict pores which occur as thin lines surrounded by slightly different coloured glass.

3.1.3 Basal Breccia

The breccia is composed of clasts of quartz latite, fragments of pumice and glass, and occasional fragmented feldspars. Figs. 7 and 8 depict a breccia with ignimbritic textures, where individual glassy fragments can be clearly seen filling interstitial areas between lithic and pumice-like clasts. Fig. 9 illustrates a similar texture although in this case the shards are more stretched out and the lithic fragments show some welding. The quartz latite clasts often have a lenticular nature resulting from the flattening and stretching of vesicles which have subsequently been filled with silica and zeolite.

3.2 Main Zone

The main body of a unit, in excess of 95 per cent of the whole, is characteristically massive and devitrified with little or no internal structure, although occasional horizontal laminations have been observed. The homogeneous nature of this central portion is borne out by petrographic studies, which normally reveal monotonous devitrification textures common to both phyric and aphyric varities alike. It is this type of quartz latite which is most commonly encountered in the field and although the exposure is good, little useful information may be gained as to the eruptive origin of the rock. In this respect, the main zone of the quartz latites resembles the central part of the rhyolite units of the Lebombo (Bristow and Cleverly, 1979).

3.3 Upper Zone

Flow tops, where they are still preserved, tend to be highly vesicular. Individual geodes with diameters of up to 40-50 cm have been observed and the cavities are filled with quartz, agate, zeolite and calcite and show a diversity of shapes from ovoid to complex flattened structures. The quartz latite in this portion of the flow tends to be highly altered and discoloured, a feature attributed to the passage of silica-, zeolite- and calcite-depositing solutions.

4. DISCUSSION

The existence of the Etendeka quartz latites and other Karoo-age acid volcanics in southern Africa have long posed problems as to their volcanological history and emplacement mechanisms. For those unacquainted with the problems at hand, a brief summary of the main distinguishing features of lavas and ignimbrites is presented in Table 1 (after Bristow and Cleverly, 1979). Comparison with the Etendeka quartz latite reveals that they exhibit many features common to both ignimbrites and acid lavas.

TABLE 1. Comparative features of ignimbrites and acid lavas.

IGNIMBRITES	**ACID LAVAS**
** Extensive sheet form	Limited extent
** Planar flow contacts	Irregular contacts
** Pyroclastic character	** Autobrecciated
** Welded/Non-welded	** Contorted banding
** Glassy/Devitrified	** Glassy/Devitrified

** Characteristics exhibited by the Etendeka quartz latites.

Despite the contorted banding and brecciation, more commonly associated with rhyolite lavas, it is considered that the extensive sheet-like form and the pyroclastic features provide evidence that the quartz latites are ignimbritic in origin. Even if one invokes a lava with a low viscosity (e.g. Twist, 1984) to account for the extensive outcrop, rhyolite lavas do not usually exhibit features that can be confused with the pyroclastic textures reported here. Twist (1984) attributes low viscosity rheologies to high eruptive temperatures (900-1 100°C) and water contents of between 6 and 9 weight per cent. Such high water contents are unlikely in the Etendeka quartz latites as hydrous phases are rare.

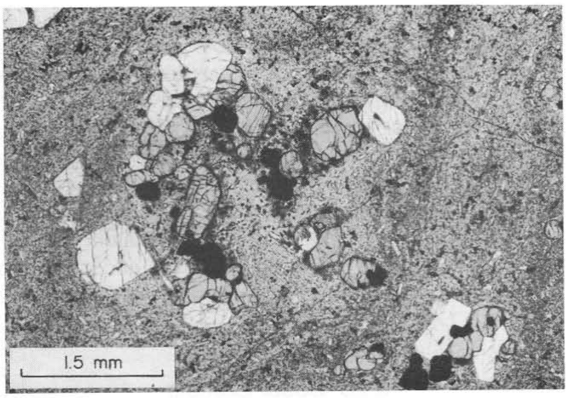

Fig. 4: Photomicrograph of a typical quartz latite pitchstone, showing a crystalline aggregate of plagiocalse, pigeonite and magnetite set in a microlitic glass (plane polarised light).

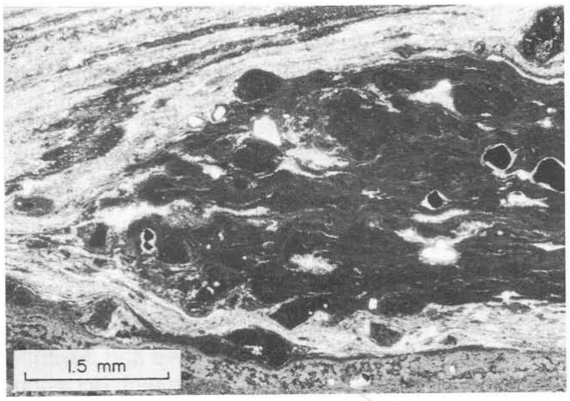

Fig. 5: Photomicrograph of a fiamme-like structure consisting of a flattened pumice with phenocrysts of plagioclase and magnetite (plane polarised light).

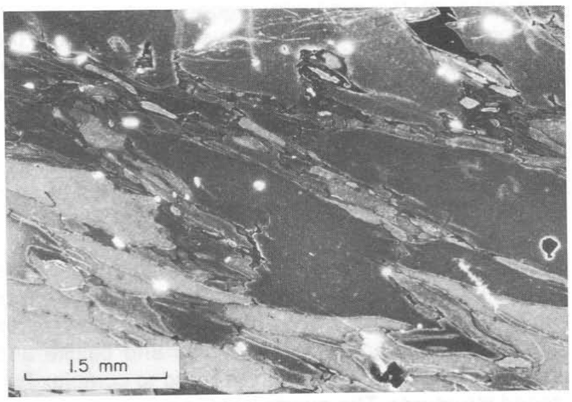

Fig. 6: Photomicrograph of a glassy perlitic pitchstone consisting of clasts of glass welded together (plane polarised light).

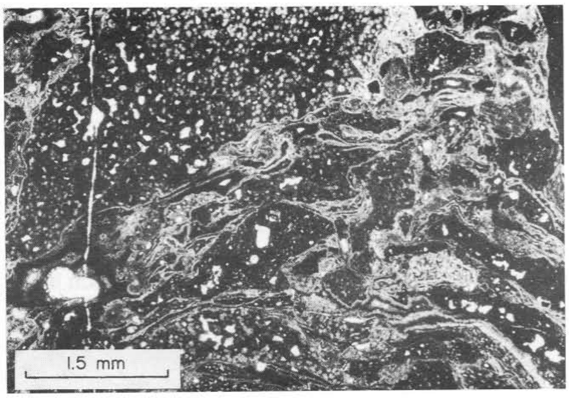

Fig. 7: Photomicrograph showing shards and pumice clasts infilling areas between lithic quartz latite fragments (plane polarised light).

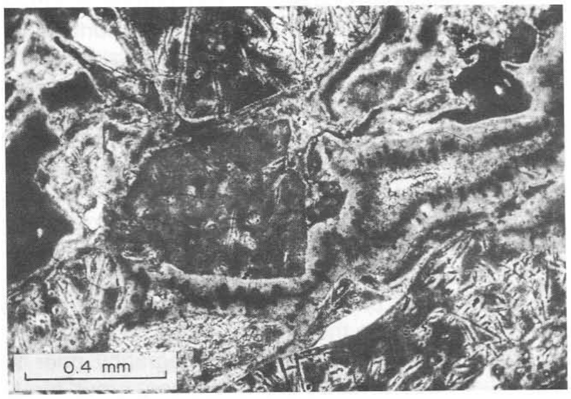

Fig. 8: A higher magnification photomicrograph of the textures illustrated in Fig. 7 shows the shards to be glassy with incipient microlites (plane polarised light).

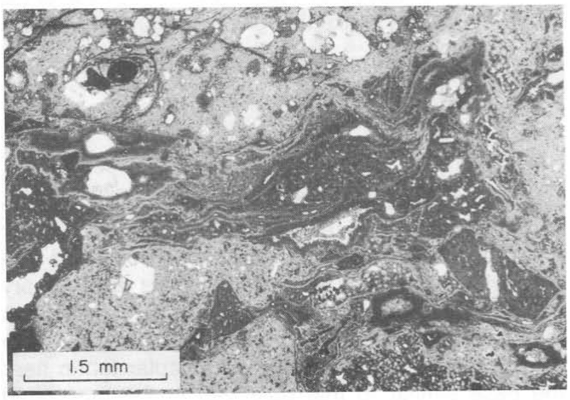

Fig. 9: Photomicrograph illustrating a more strongly welded and flattened fabric than that seen in Fig. 7 (plane polarised light).

It is therefore considered that the Etendeka quartz latites are the result of dense, high-temperature ash flows composed of a near molten suspension of material. In the final stages of emplacement, such flows still maintained sufficient heat and momentum to induce viscous lava-like flowage resulting in the observed banding. Ekren *et al.* (1984) described 10-16 m.y. old rhyolites from south-western Idaho, USA and suggested that they are principally high-temperature welded ash-flows which have characteristics indicative of viscous lava-like flowage. Many of the features they describe, such as the local preservation of pyroclastic textures, basal vitrophyres, brecciation and contorted banding, bear a strong resemblance to features seen in the Etendeka. The lava-like features, breccia and flow banding are explained by Ekren *et al.* (1984) in the following manner. The high-temperature, 'atypical' ash-flow tuff units are densely welded from bottom to top and have marked vitrophyre horizons at the base. The rapidly chilled lowermost portions of the flow could be easily disrupted by en masse movements of the still mobile overlying sheet causing a breccia to form. This explanation can be readily applied to previously described brecciated clasts with a lenticular fabric and the frequent occurrence of lenticular pitchstone at the base of some Etendeka quartz latite units.

Furthermore, Ekren *et al.* (1984) stated that mass-flow movements often occur when hot ash-flow material is deposited over irregular relief. More importantly, such movements occur over any terrain when the ash-flow is extremely hot and starts to coalesce to a viscous liquid while still moving away from the eruption column.

Eruption columns giving rise to pyroclastic deposits, as described by Sparks and Wilson (1976), consist of gas thrust and convective thrust regimes which give rise to ash-flow and air-fall tuffs respectively. Magma gas content, vent radius and the entrainment of atmospheric air are all said to have an effect on the products of such eruptions (Sparks and Wilson, 1976). Furthermore, these authors state that a hot dry magma will give rise to a dense eruptive column with minimal atmospheric interaction. This would result in a poorly developed convective thrust component and little air-fall ash associated with the resulting deposit. Ekren *et al.* (1984) appealed to this mechanism as a method of producing the Idaho rhyolites and suggested that large vent diameters would also minimise atmospheric mixing, ensuring that the ash-flow maintained a temperature high enough to produce the textures observed.

The apparent lack of calderas and the high temperature of the Idaho rhyolites has been attributed by Ekren *et al.* (1984) to deep, possibly lower crustal, magma chambers which precluded caldera collapse. Similar deep-seated eruptions could possibly have given rise to the Etendeka quartz latites and may explain the difficulty in identifying their eruption centres.

The above discussion has been used to strengthen the contention that the Etendeka quartz latites are ignimbritic in origin. In conclusion the areal extent of the Etendeka quartz latites is emphasised, particularly in the context of what appear to be large amounts of Karoo age quartz latite near Porto Alegre, in the southern Parana basin of South America (Bellieni *et al.*, 1984), as pre-drift Gondwanaland reconstructions show the juxtaposition of the Etendeka and Parana volcanics. A major input of thermal energy is required to generate extensive volumes of quartz latite over such large areas, accordingly future studies will consider the relationship between this thermal event and intercontinental rifting.

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