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Promotion of the Etendeka Formation to Group status: A new integrated stratigraphy

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The Etendeka volcanic rocks of northwestern Namibia are currently defined as the upper part of the Karoo Sequence in Namibia and have thus been represented as stratigraphically equivalent to the volcanic rocks of the Karoo Sequence in South Africa, Botswana, Lesotho, Swaziland and Zimbabwe. However, the Etendeka volcanic rocks (130-135 Ma) are considerably younger than those of the Karoo Sequence (180-190 Ma) in the areas mentioned above. They are compositionally distinct from Karoo volcanic rocks, and constitute an eastern portion of the Paraná Igneous Province of Brazil. Stratigraphic studies have shown the Etendeka Formation to be made up of several definable volcanic successions and it is suggested that these successions now be formally recognised as Formations within an Etendeka Group which itself should *no longer* be part of the Karoo Sequence. Prominent quartz latite units and sequences of basalt flows are defined as Members within the new Formations.

Introduction

During the past decade the Etendeka Formation volcanic rocks have been the subject of detailed studies by the Karoo volcanics working group at the University of Cape Town in collaboration with colleagues from Rhodes University and the University of Queensland (Erlank *et al.*, 1984; Milner 1986; Milner and Duncan, 1987; Milner, 1988; Milner and Ewart, 1989; Milner *et al.*, 1992 and Milner *et al.*, in press). With the new information available we believe that it is now necessary to present a formal scheme for the lithostratigraphic subdivision and nomenclature of the Etendeka volcanic rocks. We propose that the existing Etendeka Formation be promoted to Group status, that it be separated from the Karoo Sequence in Namibia and that recognisable successions within this Group be defined as Formations.

Remnants of the Etendeka Formation volcanic rocks crop out within an area of approximately 78 000 km^2 of northwestern Namibia (Fig. 1), and consist of a bimodal association of mafic to intermediate (51-59% SiO_2) tholeiitic lavas interbedded with more felsic (66-69% SiO_2) quartz latite rheoignimbrites (Milner *et al.*, 1992). The Etendeka Formation overlies, and in some cases is interbedded with, the aeolian Etjo Sandstone Formation of the Karoo sedimentary succession and has thus been considered to form the uppermost part of the Karoo Sequence in Namibia (SACS, 1980). The volcanic units frequently overstep the Karoo sedimentary rocks to lie directly on pre-Karoo basement of both Pan-African (Damara) and Palaeoproterzoic to Mesoproterozoic age. Due to its stratigraphic position the Etendeka Formation has been traditionally thought to be part of the Karoo Igneous Province of southern Africa (SACS, 1980; Eales *et al.*, 1984). However, the age of the Etendeka Formation (~130-135 Ma) is 50-60 My younger than most of the Karoo volcanic rocks, including the basalts of the Kalkrand Formation of central-southern Namibia (Fitch and Miller, 1984; Milner *et al.*, 1995). The age and geochemical characteristics of the

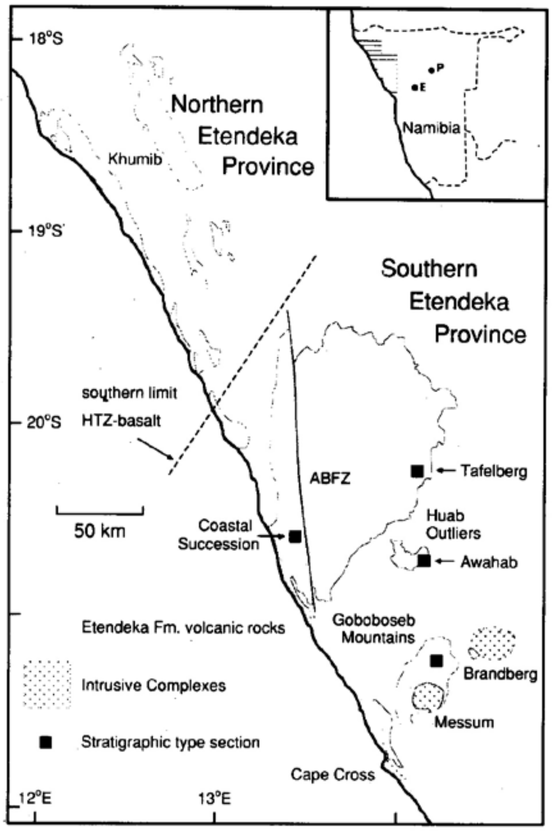

Figure 1: Map showing the distribution of Etendeka volcanic rocks, and the location of intrusive complexes in northwestern Namibia. Stratigraphic type sections are located with arrows, and the ABFZ marks the trace of the Ambrosius Berg Fault Zone. The boundary between northern and southern Etendeka provinces is indicated by the dashed line, which represents the southern outcrop limit of HTZ (high Ti and Zr) basalt. Inset map shows the location of the main map area within Namibia and the location of the Erongo (E) and Paresis (P) complexes.

Milner & Duncan (1987) Milner et. al. (1992)		Milner & Ewart (1989) Milner et. al. (1992)	Current Proposal	
Main Etendeka lava field		Goboboseb Mountains	Southern Etendeka Province	
Succession	**Quartz latite unit(s)**	**Quartz latite unit(s) & basalt sequences**	**Member**	**Formation**
(Interbedded) Coastal	Upper Middle Lower		*Upper*: *Middle*: *Lower*: Gemini Quartz Latite (KTbGi) Wêreldsend Quartz Latite (KTbWe)	Tafelberg (KTb) (*western area*)
Tafelberg	Beacon Upper Middle Lower		Beacon Quartz Latite (KTbBc) Grootberg Quartz Latite (KTbGb) Bergsig Quartz Latite (KTbBs) Wêreldsend Quartz Latite (KTbWe)	(*eastern area*)
Springbok	Upper Lower: unit B Lower: unit A	QL unit-IV Messum Mountain basalt QL unit-III QL unit-II QL unit-I Tafelkop basalt	Springbok Quartz Latite (KAwSp) Messum Mountain Basalt (KAwMm) Goboboseb Quartz Latite (KAwGb) (*Goboboseb-I, -II, & -III quartz latites*) Tafelkop Basalt (KAwTk)	Awahab (KAw)
	Pirajno (1990)		Erongo Berg Volcanics	
Erongo Volcanic Complex	Ekuta Event Ombu Event Erongorus Event Erongo basalts		Ekuta Rhyolite (KEbEk) Ombu Rhyodacite (KEbOb) Erongorus Rhyodacite (KEbEg) (KET_b)	Erongo Berg (KEb)

Table 1: The subdivisions and nomenclature of the proposed Etendeka Group, and a comparison with the informal subdivisions currently in use. Codes in parentheses are the suggested lithological codes which would be used to identify these units on 1:250 000 scale maps produced by the Geological Survey of Namibia. Italics in parentheses is informal terminology.

Etendeka volcanic rocks are identical to those of the Serra Geral Formation of the Paraná basin (Erlank *et al.*, 1984; Bellieni *et al.*, 1984), which occupies much of southern Brazil and extends into the neighbouring countries of Paraguay, Argentina and Uruguay. Plate reconstruction models of western Gondwana (de Wit *et al.*, 1988) locate the Etendeka region adjacent to the southeastern corner of the Paraná basin and it is clear that the Etendeka Formation represents the most easterly remnants of a once continuous Paraná-Etendeka Igneous Province.

The Etendeka Formation

The Etendeka region can be divided into northern and southern provinces, a division which is based mainly on the geochemical characteristics of the mafic rocks. Mafic rocks in the north are generally characterised by higher abundances of Ti, Zr, P and high field strength elements, and are referred to as the HTZ- (high Ti and Zr) basalts, relative to the LTZ- (low Ti and Zr) basalts in the south (Duncan, 1987). These geochemical provinces are referred to as the northern Etendeka and the southern Etendeka provinces respectively and the boundary between them is taken as the southernmost outcrop of the HTZ-basalt type (Fig. 1). Remnants of the Etendeka Formation which lie outside the Etendeka region itself include the volcanic rocks associated with the Erongo Complex and probably also those associated with the Paresis Complex. Outcrops of volcanic rocks in the Omatako Mountains and two small outliers south of Karibib are also probably remnants of the Etendeka Formation.

Southern Etendeka province

The most detailed studies have been carried out in the southern Etendeka province. Mapping and geochemical characterisation of extensive (with outcrop remnants enclosing areas up to 8 800 km^2) quartz latite sheets in this province have revealed that the Etendeka Formation, as currently defined, consists of several recognisable lava successions. Informal stratigraphic terms currently used to describe these successions include the

Springbok, Tafelberg, Interbedded Coastal or Coastal, and Goboboseb Mountain successions. These individual successions can be summarised as follows (after Milner *et al.*, 1992):

(1) The Springbok succession with a maximum observed thickness of 560 m, comprises basalts interbedded with three porphyritic quartz latite units. Two lower units separated by 5-10 m of basalt are collectively referred to as the Lower Springbok quartz latites, subdivided into units -A (lowermost) and -B. A single upper unit is referred to as the Upper Springbok quartz latite.

(2) The Tafelberg succession with a maximum observed thickness of 880 m. The principal quartz latite units of this succession consist of one lower and two upper units, referred to as the Lower Tafelberg, Upper Tafelberg and Beacon Tafelberg quartzlatites respectively. In some sections a fourth quartz latite unit, the Middle Tafelberg, crops out 15-20 m below the Upper Tafelberg unit. The Tafelberg succession also contains a minor latite unit which crops out approximately 200 m below the Lower Tafelberg quartz latite.

(3) The (Interbedded) Coastal succession is the thickest single accumulation of quartz latites encountered in the Etendeka (800-1000 m) and crops out in tilted fault blocks in the coastal region, west of the Ambrosius Berg Fault Zone (ABFZ) (Fig. 1). Twelve different quartz latite units have been recognised in this succession and the uppermost units are interbedded with several thin basaltic lava flows. On the basis of geochemical and petrographical criteria the succession can be divided into lower, middle and upper portions.

(4) The Goboboseb Mountains succession consists of interbedded basalts and quartz latites having an overall estimated thickness of 600 m. The lower part of the succession consists of 250 m of basalt flows, the Tafelkop sequence, which is overlain by 100-150 m of quartz latite. These quartz latites consist of three flow units, referred to as QL units -I, -II, -III; locally these units are separated by relatively thin basalt flows, each generally less than 20 m thick. A prominent basalt flow fills a N-S trending palaeovalley extending northwards from Messum and is referred to as the Copper Valley basalt. This flow has a maximum observed thickness of 170 m and lies stratigraphically between QL units -I and -II. The QL units -I to -III are in turn overlain by an additional 130 m of basalt flows, referred to as the Messum Mountain basalts. A fourth quartz latite unit (QL unit-IV), with a maximum observed thickness ono m (its top is always eroded), forms the uppermost part of the succession.

Of these four successions only the Springbok and Tafelberg successions are in direct, unfaulted contact with one another, with the Springbok succession underlying the Tafelberg. Although units within both successions are essentially flat-lying, the contact between them shows onlap of units near the base of the Tafelberg succession over an erosional surface cut into the Upper Springbok quartz latite. It is important to note that although maximum observed thicknesses have been given for these successions all four of them have eroded tops and the maximum observed thickness must therefore be less than the original total stratigraphic thickness.

It is not possible to correlate directly the Coastal and Goboboseb successions with either the Springbok and/or Tafelberg successions because of discontinuous outcrop and faulting along the ABFZ and within the Coastal succession. There are also differences in the total stratigraphic package within each succession and it is difficult to correlate individual basaltic or quartz latite units between different successions on petrographic character alone. However, individual quartz latite units and groups of these units are geochemically distinctive and it is possible to use composition as a primary criterion for the correlation of major quartz latite units throughout the Etendeka (Milner and Duncan, 1987; Milner and Ewart, 1989; Milner *et al.*, 1992). The geochemical correlation of quartz latite units between the different successions has allowed us to reconstruct the overall stratigraphy of the Etendeka Formation in the southern Etendeka province (Fig.2).

Northern Etendeka province

Our present state of knowledge on the stratigraphy of the northern Etendeka province is insufficient to define specific stratigraphic successions comparable to those discussed above for the southern Etendeka province. Work currently in progress has revealed that sections through lava remnants east of the faulted coastal region are composed entirely of interbedded HTZ- and LTZ-basalt flows. Sections most comprehensively sampled have been in the so-called Khumib remnant (Fig. 1) between Orupembe and Purros. In the coastal areas of the northern Etendeka province the volcanic section can be divided into a lower basaltic sequence and an upper latitic and quartz latitic sequence. This northern coastal region is clearly down faulted relative to the Khumib remnant and it is possible that an upper felsic portion of the inland remnants has been removed by erosion.

Erongo Berg Volcanic rocks

Although we have not worked on the Etendeka Formation rocks associated with the Erongo Complex we include information from recent studies in an effort to present as complete a picture as possible. Information on the Erongo Complex and associated volcanic rocks comes from Pirajno (1990), and from an unpublished map by F. Pirajno made available to SCM by Gold Fields of Namibia (Pty) Ltd.

Two major sequences are recognised within the Eron-

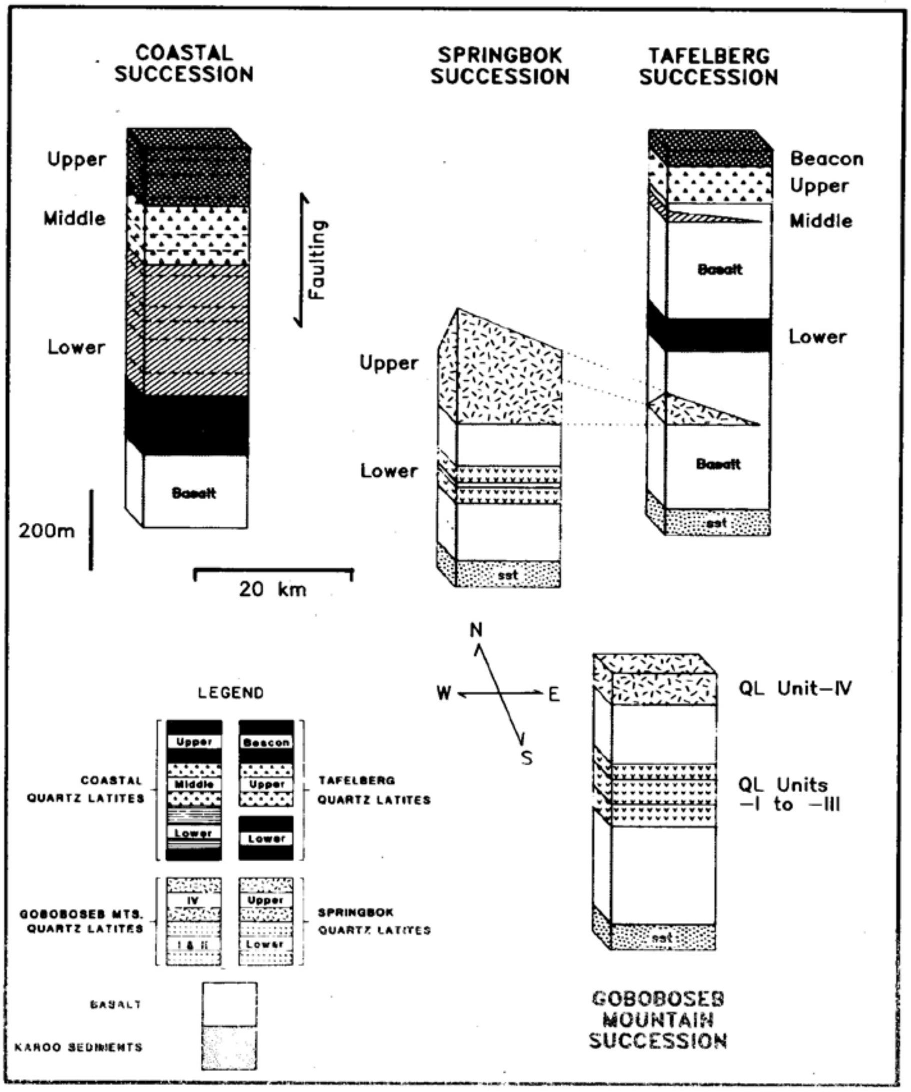

Figure 2: Reconstruction of the stratigraphy of the southern Etendeka-Goboboseb Mountain volcanic rocks (adapted from Milner *et al.*, 1992).

go volcanic succession. A lower basaltic sequence which attains a maximum thickness of 300 m, and an upper felsic sequence which is inferred to have erupted from the Erongo Complex (Pirajno, 1990). Three distinct eruptive events are recognised in the felsic sequence. The earliest of these, the Erongorus event, is characterised by a 200-300 m thick sequence of ash-flow tuffs of intermediate to felsic composition, interbedded with basaltic lavas at the base. This was followed by the Ombu event, characterised by the emplacement of a series of rhyodacitic *sensu lato* ash-flow tuffs, with a maximum observed thickness of 500 m. The third and uppermost sequence, the Ekuta event, consists of sparse outcrops of rheomorphic rhyolitic rocks with a maximum thickness of 100m (Pirajno, 1990).

Stratigraphic Proposal

We propose that the existing Etendeka Formation be promoted to Group status and separated from the Karoo Sequence of Namibia. Within the new Etendeka Group some of the successions described above will be given Formation status, and prominent quartz latite units, or groups of units and certain basalt sequences within these formations will be given Member status. Details of the proposal are outlined below and are summarised in Table 1, which also illustrates the informal subdivisions currently in use and the suggested lithological codes to be used for units on 1:250 000 scale maps produced by the Geological Survey of Namibia (K.-H. Hoffmann, pers. comm. 1993).

Southern Etendeka province

In the southern Etendeka province the Etendeka Group consists of the Awahab and Tafelberg Formations. The Awahab Formation replaces the current informal terms Springbok and Goboboseb Mountains successions, and

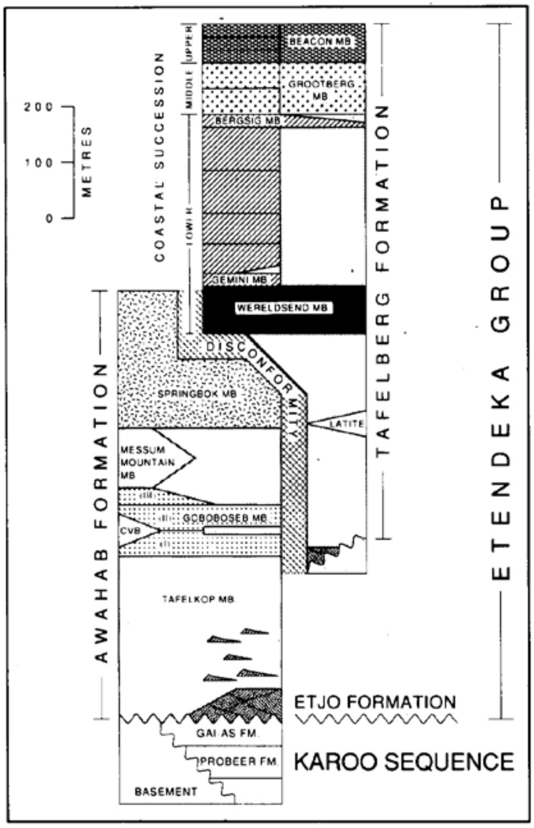

Figure 3. Lithostratigraphic subdivision and nomenclature of the Etendeka Group in the southern Etendeka province. The ornament used for the quartz latites is the same as that used in Fig. 2. MB = Member. CVB = Copper Valley basalt flow.

contains within it the Tafelkop Basalt Member, the Goboboseb Quartz Latite Member, the Messum Mountain Basalt Member, and the Springbok Quartz Latite Member. The type section of the Awahab Formation is Awahab Mountain (14°09'23"E 20°38'13"S) in the Huab outliers (Fig. 1), where all of the Members outlined above are present, with the exception of the Messum Mountain Basalt Member (which is confined strictly to the periphery of the Messum Complex). It is important to emphasise that the Goboboseb Quartz Latite Member consists of at least three quartz latite units but that these units are virtually indistin-guishable from one another in the field. Individual quartz latite units within the Goboboseb Quartz Latite Member are referred to informally as Goboboseb-I, (-II, -III) quartz latites. At the Awahab type locality the Goboboseb Quartz Latite Member is represented by what is currently termed (see Table 1) the Lower Springbok units -A and -B, which can be geochemically correlated with the Goboboseb-I and -II quartz latites respectively (Milner *et al.*, 1992). The quartz latite units of the Awahab Formation are interpreted as having erupted from the Messum Complex (Milner and Ewart, 1989; Ewart *et al.*, in prep) and the third unit (Goboboseb-III quartz latite), which is relatively thin in the Goboboseb Mountain region, apparently did not reach the Huab Outliers. Reference to the Copper Valley basalt flow will remain unchanged and informal.

The Tafelberg Formation replaces the Tafelberg succession, and also includes the (Interbedded) Coastal succession as a lateral facies variant. In the eastern part of the main Etendeka lava field (Fig. 1) the Tafelberg Formation contains the Wêreldsend, Bergsig, Grootberg and Beacon Quartz Latite Members, which correspond to what are currently termed the Lower, Middle, Upper and Beacon Tafelberg units, respectively (see Table 1). The type locality of this eastern facies of the Tafelberg Formation is the mountain Tafelberg (14°09'03"E 20°10'15"S) on the farm Nil Desperandum 713. The latite unit in this succession is not given member status and will continue to be referred to informally as the Tafelberg (Formation) latite. The western facies of the Tafelberg Formation (west of the ABFZ, Fig. 1), is represented by the Coastal succession, the type section for which is a transect extending from a location 13°23'59"E 20°34'59"S at the base of the section to 13°25'36"E 20°35'28"S at the top. It is not possible to give member status to all of the quartz latite units in this part of the Tafelberg Formation. Firstly, because low relief and superficial cover make it difficult to map individual units along strike; and secondly, because it is not known whether the multiple Units of any particular compositional type represent multiple flow units within a single cooling unit. An informal, geochemical, subdivision of the coastal succession into lower, middle, and upper portions will still remain. Only the Wêreldsend and Gemini Quartz Latite Members can be recognised in the field. They constitute the two lowermost quartz latite units of the coastal succession and geochemically form part of the lower coastal succession, which contains at least five quartz latite units. The Wêreldsend Member is the only quartz latite unit which can be correlated directly between the eastern and western parts of the Tafelberg Formation across the ABFZ (Fig. 1), although a general geochemical correlation exists between the quartz latite units of the middle and upper coastal succession with the Grootberg and Beacon Quartz Latite Members respectively.

A summary of our proposed stratigraphic subdivision and nomenclature of the Etendeka Group in the southern Etendeka region (Fig. 1) is illustrated in Fig. 3. In this diagram the previously termed Goboboseb and Springbok successions are represented on the left and right hand sides of the Awahab Formation column, respectively, and the former (Interbedded) Coastal and Tafelberg successions are represented on the left and right hand sides of the Tafelberg Formation column respectively. It is important to emphasise that the Awahab and Tafelberg Formations are essentially juxtaposed, and that nowhere does the observed thickness of the volcanic succession exceed 900 m.

Northern Etendeka province

Although we can demonstrate that the basalt and quartz latite magma types of this province are clearly distinct from those of the proposed Awahab and Tafelberg Formations, we are not yet able to define the overall stratigraphy of this area. Until such time as detailed mapping can be completed in this remote part of Namibia, these volcanics will remain unclassified in terms of Formations within the Etendeka Group.

Discussion

Our attempt to formalise the stratigraphic nomenclature of the Etendeka region has raised several other issues which need to be discussed. The most important of these is the relationship between the Etendeka Group and a series of high-level, subvolcanic intrusions known as the Damaraland Complexes (e.g. Messum, Brandberg and Erongo; Fig. 1), and in particular whether or not volcanic rocks associated with these complexes form part of the Etendeka Group. A study of the timing of Mesozoic igneous activity in northwestern Namibia (Milner *et al.*, 1995) has revealed that Etendeka volcanism (~130-135 Ma) and activity among the Damaraland Complexes (~124-137 Ma) was broadly contemporaneous and related to the same thermal event. It should be possible, therefore, to include all the volcanic rocks erupted at this time within the Etendeka Group. For example, the widespread Awahab Formation quartz latite units which are inferred to have erupted from the Messum Complex (Milner and Ewart, 1989) form well defined members in the Etendeka Group. However, there are numerous smaller outcrops of compositionally diverse volcanic rocks associated with the complexes for which there is no relative age information. Examples of rocks that fall into this category include basalts and rhyolites which crop out entirely within the Messum ring structure. It is not possible to give them a relative stratigraphic position because they are isolated by ring faults from the surrounding Goboboseb Mountain succession. In such instances, or in instances where the volcanic rocks associated with a particular complex are separated by major discontinuities of outcrop from the main Etendeka region (e.g. Paresis), it is better to refer to such rocks as belonging to a particular complex. We suggest an exception to this recommendation in regard to the Erongo Complex. Drawing on the work of Pirajno (1990), we propose that the volcanic rocks associated with the Erongo Complex should constitute an Erongo Berg Formation, as distinct from the Erongo Complex which encompasses a variety of plutonic rocks. Within the Erongo Berg Formation we redefine the felsic Erongorus, Ombu and Ekuta “events” (Pirajno; 1990) as Members. We believe this is justified because of the large area covered by these volcanic rocks.

Finally, with regard to the Etjo Formation we propose that it be included in the Etendeka Group. Recent studies of the Karoo Sequence sediments in the Huab Basin (Horsthemke *et al.*, 1990) have revealed that the aeolianites of the Etjo Formation are separated from the underlying Gai As Formation by a pronounced unconformity, which represents a hiatus in sedimentation of 50-100 My. The Etjo Formation sandstones are conformable with, and in some cases interbedded with, basalts at the base of the volcanic succession and it is clear that they have a much closer temporal relationship with the Etendeka volcanic rocks than they do with rest of the underlying Karoo Sequence.

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