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The geology of the Goboboseb Mountain volcanics and their relationship to the Messum Complex, Namibia

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The Goboboseb Mountains represent a southern remnant of the Etendeka Formation volcanics. They consist of a 600 m thick sequence of quartz latites .and basalts which almost completely enclose the Messum Complex, a multistage gabbro-granite-rhyolite-syenite ring structure. The volcanic sequence is: Tafelkop basalts (lowest); Quartz Latite (QL) units -I to -III (with intercalated basalts); Messum Mountain basalts; QL unit-IV. These volcanics are intruded by numerous dolerite dykes and sills, less often by plugs, dykes and sills of quartz monzonite (chemically equivalent to the quartz latites) and carbonatite dykes. The Goboboseb volcanics dip gently towards the Messum Complex, steepening in dip adjacent to its margin. North of Messum the volcanics define a north-north-east trending trough-like feature which plunges south towards the complex. The quartz latites are interpreted as high-temperature rheoignimbrites, with well defined vertical lithological changes. The Messum Complex is the inferred source for the quartz latites, and at least some of the basalts, based on various lines of field and chemical data. This implies that the Goboboseb quartz latites are proximal deposits. Based on chemical and mineralogical data, correlations are proposed between the Goboboseb and Springbok quartz latites, the latter exposed in the southern Etendeka: This implies large volumes for these quartz latite units, well in excess of 2000 km^3 for the Upper Springbok unit.

Geological setting and structure

The volcanics of the Goboboseb Mountain region consist of a sequence of basalts and quartz latites which cover an area of approximately 1100 km and partially enclose the Messum Complex. They comprise a southerly remnant of the Etendeka Formation which crops out over *ca.* 78 000 km^2 (Erlank *et al*., 1984) of north-western Namibia (Fig. 1). The Messum Complex is a multistage gabbro-granite-rhyolite-syenite subvolcanic ring structure with an exposed diameter of 18 km. The geology, geochemistry and petrology of Mess urn have been described in some detail by Korn and Martin (1954), Mathias (1956; 1957) and Martin *et al*., (1960), but no work has been carried out on the Goboboseb volcanics prior to this study. The exposed rocks of the complex clearly intrude the surrounding volcanics and are important in defining a minimum age of 132 ± 2 Ma (Rb/Sr isochron) for the lavas (Allsopp *et al*., 1984).

The distribution of the major rock types in the Goboboseb region is presented on Fig. 2. This map was compiled using information from a series of radial traverses through the Goboboseb Mountains aided by photogeological interpretation. The detailed mapping of the boundaries of the volcanic units, taken in relation to topography, enables the broad structure of the volcanic units to be defined. North-south and east-west cross-sections through the Goboboseb Mountains (Fig. 2), show a north-north-east trending, shallow, elongate trough-like structure which plunges south towards Messum, steepening in plunge adjacent to the complex margin. This is interpreted as a collapse (sag) structure. The average dip of the volcanics towards Messum is 1-3°, and a minimum of 300 m of sagging is inferred along the axis of the structure (assuming a simple horizontal extrapolation across the Goboboseb Mountains). Within 500-600 m of the eastern and south-eastern margin of the complex (Fig. 2), the dip of the volcanics steepens to 70-80°, the lavas becoming intensely sheared. Furthermore the margin of this part of the complex cuts across the strike of the volcanics (Fig. 2), suggesting that the final structural development of the eastern side of the complex postdates the sagging of the volcanics.

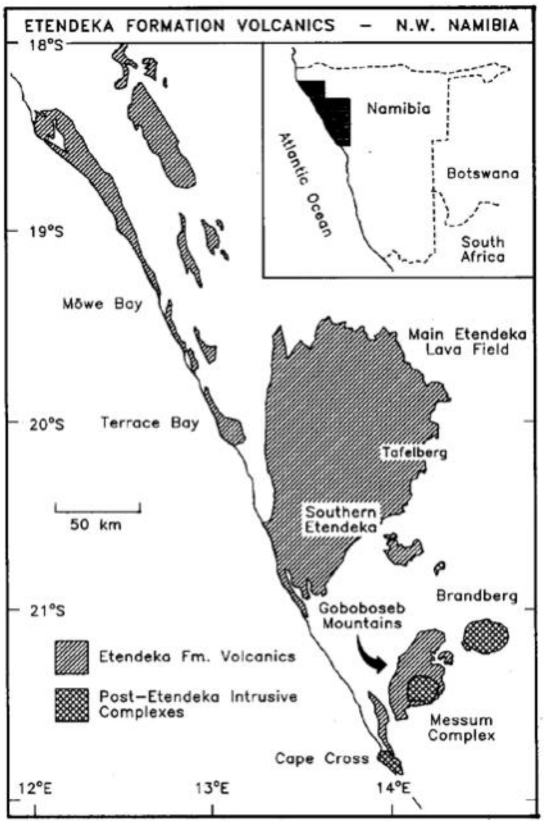


Fig. 1: Geographic locality of the Goboboseb Mountains and the Messum Complex, and the distribution of the Etendeka Formation volcanics in north-western Namibia.

The volcanic succession

Stratigraphy

The volcanics of the Goboboseb region consist of basaltic and minor intermediate lavas interbedded with silicic quartz latite units. The volcanics normally directly overlie Karoo sediments which include coarse arkosic grits, sandstones, siltstones and shales, but occasionally overlie pre-Karoo basement schists and granites of Damaran age.

Our work has enabled us to define the stratigraphy of the Goboboseb succession, a summary of which is illustrated in Fig. 3. The lower part of the succession consists of 250 m of basalt flows (Tafelkop basalts) and is overlain by between 100-150 m of quartz latite. The quartz latites consist of three flow units, referred to as QL units -I, -II and -III; locally these units are separated by relatively thin basalt flows, each generally less than 20 m thick. These quartz latite units are in turn overlain by an additional 130 m of basalts (Messum Mountain basalts), and a fourth quartz latite unit (QL unit-IV), with a maximum observed thickness ono m, forms the uppermost part of the succession. It is important to note, however, that the observed thickness of QL unit-IV represents a minimum thickness estimate for this unit since its upper portion has been removed by erosion.

The maximum observed thickness of volcanics occurs at Tafelkop (Fig. 2) where some 300 m of section is preserved. This section represents the lower half of the overall Goboboseb succession and is selected as a reference section for the Tafelkop basalts. The uppermost unit preserved at this locality is QL unit-II. The upper half of the Goboboseb succession crops out in the hills closer to the Messum Complex. A reference section for the Messum Mountain basalts is at the northern end of the Messum Mountain range, adjacent to the north-eastern margin of the complex (Fig. 2), where the Messum Mountain Basalts are underlain by QL units -I, -II and -III. Remnant outcrops of QL unit-IV are confined to hills adjacent to the northern and north-western margin of Messum. In total, a combined stratigraphic thickness (minimum) of 600 m of volcanics is exposed around the northern quadrant of Messum, within the Goboboseb Mountains. Comparable exposures do not occur around the southern part of Messum.

A prominent feature in the north-eastern part of the Goboboseb region is the Copper Valley basalt flow (Fig. 2), which reaches a maximum thickness of 170 m. The flow is confined to a north-south trending palaeovalley, the precise origin of which is unknown. Normal faulting occurs along the eastern side of the valley, and it is believed that the palaeovalley is a fault controlled graben-like structure. The absence of any over thickened quartz latite deposits along the axis of the valley, particularly north of the Copper Valley prospect (Fig. 2), suggests that this feature was not well developed prior to the eruption of QL unit-I. However, significant deepening of the palaeovalley (up to 200 m) has occurred between the eruption of QL units -I and -II, allowing the Copper Valley basalt flow to fill the valley to the observed thickness.

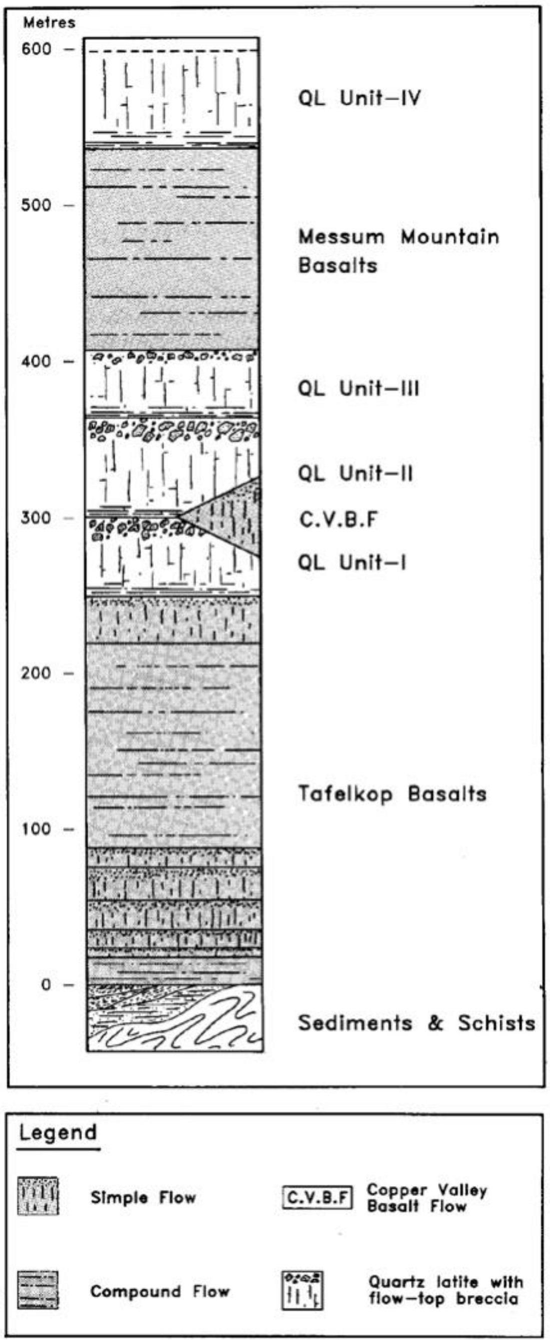


Fig. 3: The stratigraphy of the Goboboseb volcanic succession.

Field characteristics and petrography

Quartz latites

Field characteristics of the different quartz latite units exposed in the Goboboseb Mountains are very similar, thus allowing a general account of the features observed.

A single cooling unit can be conveniently divided into basal, central and upper zones the boundaries of which are gradational, but broadly defined by gross changes in texture (Fig. 4).

The basal zone typically consists of a thin, dark grey to black, devitrified, rather flinty layer which merges upwards into a laminar banded zone which may exhibit highly attenuated fiammé (flattened pumice lapilli), sometimes resembling flow banding (Fig. 5). The banded zone often has a strong centimetre-scale horizontal jointing associated with it and in some instances is completely obscured by a strong fissile fabric. The basal zone is typically 4-5 m thick (12 m maximum), above which the horizontal jointing gives way to the more massive central zone. It is noteworthy that no basal vitrophyres have been found in the Goboboseb Mountains. Moreover, in proximity to the margin of Messum, the basal fiammé zones are notably more recrystallised. Remnant pyroclastic textures are erratically preserved and are commonly obliterated by welding, flow age and devitrification. In some instances eutaxitic texture is only observed on surfaces etched and weathered in the arid desert environment (Fig. 6), while freshly broken rock surfaces appear featureless.

The central zone usually forms the thickest portion of the flow, particularly in units thicker than 60-70 m. It is characteristically massive with crude vertical jointing and consists of grey to reddish brown, thoroughly devitrified and recrystallised quartz latite, with all original pyroclastic structure destroyed. It is this zone which forms the characteristic cliff-forming outcrops. Very rare occurrences of isolated spherulites, up to 6 cm in diameter, have been found, nucleated on xenoliths.

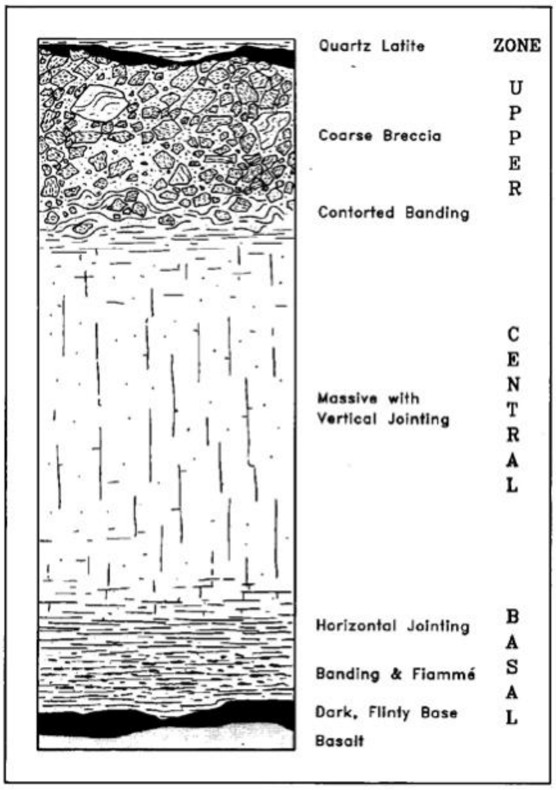


Fig. 4: A schematic section through an idealised Goboboseb quartz latite flow unit. (see Table Ia for range of typical thickness).

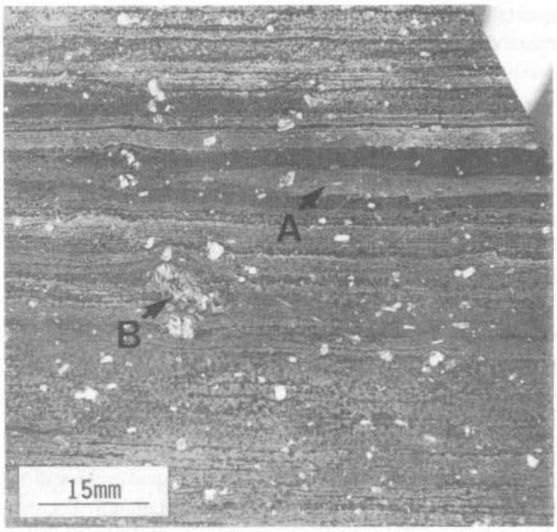


Fig. 5: Laminar-banded quartz latite exhibiting a highly flattened pumice fragment or fiammé (A) and the compaction of matrix material round plagioclase phenocrysts (white) and a large feldspar xenocryst (B). Sampled 1-2 m above the base of QL unit-I, 15 km north of Messum.

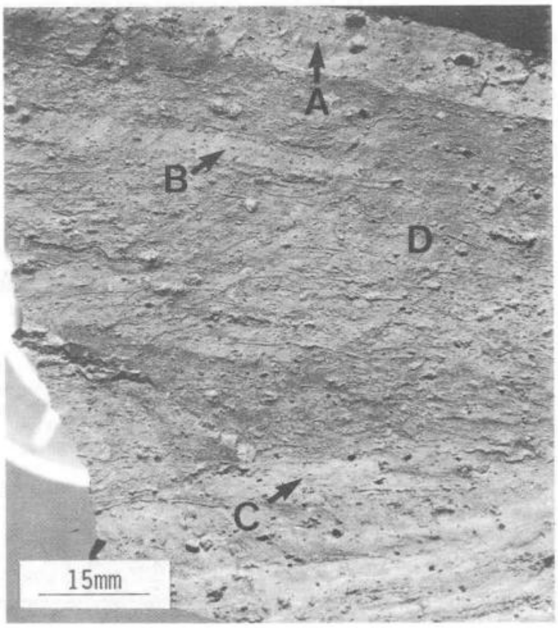


Fig. 6: Pyroclastic textures enhanced by desert weathering and etching. Fiammé (A, B and C) are set in a finer grained matrix of flattened shards (D). Sampled from the base of QL unit-II, 29 km north-east of Messum adjacent to the Brandberg intrusion.

The upper zone is more variable. In the central and north-western Goboboseb, it can vary in thickness between 5 and 25 m. The contact between the central and upper zones is gradational with individual clasts and pockets of breccia closely associated with contorted, flow banded quartz latite which appears contiguous with the underlying, massive central zone. The breccias consist of a chaotic mixture of angular to subrounded blocks of quartz latite set in a friable matrix of smaller fragments. Clast sizes range from sub-centimetre fragments to blocks of up to 3 m in diameter, although, most blocks are within the 5- 30 cm size range. A majority (70-80%) of the blocks are strongly amygdaloidal, although more massive non-amygdaloidal blocks, some of which exhibit flow-banding, also occur. In the northern and north-north-eastern Goboboseb Mountains, such as at Tafelkop, the upper zone of QL unit-I consists of approximately 6 m of highly amygdaloidal, almost pumiceous, quartz latite. Near the base of this zone the amygdales are strongly flattened and stretched, but become more spherical near the top, accompanied by minor brecciation.

Considerable variation in the thickness and preservation of individual quartz latite units has been encountered across the study area. Table 1a illustrates this variability, and in the case of QL unit-I, indicates a general thickening away from Messum. The variability of thickness could be attributed to topographic irregularities on the pre-quartz latite land surface.

The quartz latites of the Goboboseb are petrographically (and geochemically; see later) rather uniform. All contain sparse phenocrysts of labradorite, pigeonite and titanomagnetite, while QL unit-I contains additional augite. Total phenocryst contents range from 4.4 to 10.8% (by vol; QL units -I to -III), to ~11.0% (QL unit-IV). Phenocrysts are euhedral to subhedral, unbroken and range in size from 0.25-3.0 mm; glomeroporphyritic aggregates are relatively frequent. More rarely samples contain lath-shaped microphenocrysts (0.1-0.2 mm) of labradorite, most notably QL unit-IV. Devitrified or lithoidal groundmass textures occur throughout the flow with textures depending on the part of the quartz latite unit sampled (Fig. 4). The upper and lower portions of the flow are characteristically very fine-grained and aphanitic. In the more central parts of the flow a patchy granophyric texture is observed, typically best developed adjacent to joints and fractures. Most samples from the Goboboseb have undergone low grade hydrothermal alteration, resulting in the development of secondary albite, chlorite, sericite, calcite and epidote.

In conformity with the interpretations of Milner (1986, 1988), we interpret the Goboboseb quartz latites as pyroclastic deposits, as evidenced by the fiammé textures and the local preservation of relict shard textures (Figs 5 and 6). The deposits are identified as rheoignimbrites, i.e. emplaced as dense, high-temperature ash flows which underwent rheomorphism and lava-like flow prior to their final cooling. Such deposits appear not to have been widely recognised, but notable examples occur in Idaho (U.S.A) which have very similar lithological and mineralogical characteristics to the Goboboseb quartz latites (e.g. Bonnichsen and Citron, 1982; Ekren *et al*, 1984).

Unusual quartz latite mega-breccia deposits are encountered north of the Copper Valley prospect (Fig. 2) within the northern extension of the previously described graben structure. The deposits are composed

TABLE 1: Estimated thicknesses (in metres) of the quartz latite units within the Goboboseb Mountains (a), and their inferred correlatives in the southern Etendeka (b).

(a) Goboboseb Mountains

Location, Distance and Direction from Margin of Messum Complex	Messum Mts. 2.5-3.5 km NNE	1 km N	10 km NNW	10.2 km NNE	12.7 km N	17.8 km NE	21.7 km NNE	Tafel kop 26 km NNE	Tafel 28.7 km NE
QL unit-IV	-	> 70	-	-	-	-	-	-	-
QL unit-III	20	-	-	-	10	-	-	-	-
QL unit-II	50	-	-	> 70	90	> 90	60	> 65	> 80
QL unit-I	30	-	> 70	30	-	40	30	40	-

(b) Southern Etendeka

Location, Distance and Direction from margin of Messum Complex	S.W. Etendeka approx. 90 km NW	Awahab (Huab Outliers) 78 km N	Krone & Fonteine (farms) 95-105 km NNW to N	Trig. Beacon 26 105 km NW
Upper Springbok unit (≈ QL unit-IV)	-	> 190	> 295	> 270
Lower Springbok units: (QL units -I, -II (& -III))				
Upper unit	10 - 20	35	25-30	-
Lower unit		40-45	40-45	-

entirely of brecciated quartz latite and the term “mega-breccia” is used here to distinguish them from breccias which commonly occur in the basal and upper zones of quartz latite units in the Goboboseb Mountains and the southern Etendeka. The mega-breccias are up to 15 m thick, chaotic in nature, and have clasts ranging in size from sub-centimetre to 10 m in diameter. Outcrops of .the mega-breccia are irregular in nature and overlie a variety of rock types, including basalt, Karoo sediment and Damaran schist, which form a highly irregular pre-breccia surface. The mega-breccias are strongly welded and local flow banding of the matrix is observed between the smaller clasts suggesting that the mega-breccias are of synvolcanic origin. They are interpreted as forming through auto-brecciation accompanying channelling and trapping of material within pre-existing topographic irregularities, but it is not known whether this material was derived from the accumulation- of hot pyroclastic debris or from a lava flow (sensu stricto). Note is also made of two occurrences of within-flow syndepositional breccias in QL units -1 and -II further south along the inferred palaeovalley, closer to Messum. One of these occurrences coincides with a local steepening of the palaeovalley floor.

Basalts

The Tafelkop basalts form a nearly continuous series of outcrops circumferentially around Messum, and extend north-eastwards to the Brandberg intrusion (Fig. 2). The complete sequence is not exposed close to Messum, and thus its thickness adjacent to the complex is unknown. The Tafelkop basalt reference sequence (Fig. 3) contains at least ten flow units consisting of simple and more complex compound flows. The simple flows are 5-30 m thick, and are characterised by massive basal and central zones that give way to amygdaloidal, frequently rubbly flow tops. In contrast the compound flows contain flow-within-flow contacts and are variably amygdaloidal throughout, making the identification of individual flows difficult. Simple flows predominate near the base of the section and are overlain by 130 m of strongly altered compound flows (Fig. 3). Both porphyritic and aphyric basalts occur in the section. Two distinct types of porphyritic basalt occur, one strongly olivine-phyric (near the top of the sequence) and a second type with abundant phenocrystal plagioclase with minor phenocrystal olivine and clinopyroxene. Estimated modal proportions of phenocrysts in these two basalt types are 10-15% and 30-40% respectively. A mineral assemblage containing plagioclase, olivine, clinopyroxene and opaque oxides is common to most of the Tafelkop basalts, although two fine-grained aphyric lavas do not contain olivine. All of the lavas are moderately to severely altered with plagioclase and olivine most strongly affected. Petrographically, the Tafelkop basalts are the most variable suite of basalts encountered in the Etendeka region. Chemically, most are quartz tholeiites, but the olivine-phyric types are *ol*- to *ne*-normative, and are among the few lavas in which abundant modal olivine has been found.

The Messum Mountain basalts occur as a relatively narrow sequence of outcrops around the northern and western rim of Messum, with small remnant outcrops capping the higher peaks of the central to northern Goboboseb Mountains. The outcrop pattern is indicative of an original eruptive centre within Messum. There is no evidence as to the original extent, if any, of these basalts south of Messum. Within the Messum Mountain basalts reference sequence (Fig. 3) individual lava flows are not readily distinguished. This is partly due to the scree-covered nature of the outcrop but also because amygdaloidal portions of the flows, usually indicative of the flow top, are not well developed. Samples collected from a series of bench-forming horizons through the section reveal that the Messum Mountain basalts are predominantly fine-grained, aphyric lavas which contain groundmass plagioclase, clinopyroxene and magnetite. The two lowermost samples contain rare pseudomorphed microphenocrysts of olivine and plagioclase. A sample collected from the central part of the section has a strongly developed ophitic texture with oikocrysts of clinopyroxene up to 2 mm in diameter. All of the Messum Mountain basalts are strongly altered. Chemically, the Messum Mountain basalts are tholeiites, ranging from quartz tholeiites to transitional olivine tholeiites. A systematic decrease of MgO occurs with increasing stratigraphic height in the type sequence, indicative of the eruption of increasingly fractionated lavas with time.

Korn and Martin (1954) suggested that the “lava sheets” which comprise the Goboboseb Mountains were extruded through fissures and not by the “Messum volcano”, which they believed had formed on top of the Goboboseb Mountain volcanics. These authors also indicated that remnants of the Messum volcano extrusives only occurred within the confines of the Messum Complex. We believe that the Goboboseb Mountain volcanics formed an integral part of the Messum “volcano” and we thus interpret the Tafelkop basalt sequence to have originally formed a broad shield volcano centred on the present Messum Complex.

Intrusions

Intrusive rocks which cut the Goboboseb Mountain volcanics include dolerite, gabbro, quartz monzonite, granite, felsite and carbonatite. Numerous dolerite dykes and sills intrude both basalts and quartz latites, as do four plugs of olivine-rich gabbro.

The occurrence of quartz monzonites in the Goboboseb Mountain region is considered most significant, since they are the first intrusive equivalents of quartz latite to be found cutting Etendeka Formation volcanics. The following are details of their occurrence and petrography:

(a) Two plug-like bodies of massive quartz monzonite intrude quartz latite approximately 3 km north of Messum (Fig. 2). The plugs are approximately 200-300 m in diameter and are associated with a group of four distinct, but closely spaced, olivine gabbro plugs and some minor granite apophyses. The quartz monzonite is medium- to coarse-grained and pinkish-grey in colour. In thin section it contains sparse phenocrysts of plagioclase, more abundant microphenocrysts of plagioclase and magnetite, and chlorite pseudomorphs after pyroxene. The groundmass consists of an intergrowth of turbid alkali-feldspar and fine skeletal quartz.

(b) On the eastern margin of the Messum Complex, a north-north-west trending ring dyke segment, approximately 1 km long, consists of a pale grey, medium-grained quartz monzonite. The dyke is approximately 10-15 m wide and intrudes sheared Messum Mountain-type basalts. Shearing also affects the margins of the dyke and an equigranular recrystallisation of the groundmass is observed in the more massive parts of the dyke. Strong alteration obscures the primary mineralogy, although sparse phenocrysts of plagioclase can still be recognised.

(c) South of Messum, an unusual composite sill-like body intrudes the base of the Goboboseb succession between coarse-grained arkosic grits and the overlying basalts. The main body of the sill (25-30 m) consists of a very fine-grained, black, porphyritic quartz monzonite with well developed columnar jointing. The phenocrysts consist of plagioclase, pseudomorphed pigeonite and titanomagnetite, and are set in a fine-grained granophyric groundmass, which also encloses small grains of titanomagnetite and altered pyroxene. The top and bottom zones of the sill consist of a very fine-grained, aphyric rock, 2 and 15 m thick respectively. In thin section this material exhibits an intergranular texture with plagioclase, clinopyroxene and titanomagnetite, and appears to be considerably more mafic in composition than the quartz monzonite. The contacts between the aphyric margins and the quartz monzonite portion of the sill appear to be gradational over a thickness of about 2 m. This feature is indicated by a gradual increase in the abundance of phenocrysts, and an increase in the proportion of quartz and alkali-feldspar in the groundmass, towards the centre of the sill.

Adjacent to the north-western margin of the Messum Complex a radial felsite dyke of rhyolitic composition (our unpublished data) intrudes Messum Mountain-type basalt. The dyke is 500 m long, has a maximum width of 2 m and consists of a pale grey, fine-grained, sparsely porphyritic rock.

Three carbonatite dykes have been encountered in the Goboboseb Mountain region. The largest of these, located about 9 km north-north-east of Messum, is approximately 1-2 m wide and 70-100 m long. It is predominantly brecciated, consisting of angular fragments of Goboboseb type volcanics and rarer quartzite clasts set in a matrix of yellowish-orange carbonate. Although not an integral part of the present study, these dykes are particularly important in terms of the evolution of the Messum Complex as a whole, and the localities of these dykes are recorded as follows: (1) 14°14’52”E 21°15’52”S, (2) 14°06’32”E 21°19’44”S and (3) 14°11’40”E 21°13’I7”S.

TABLE 2: A comparison of the average compositions of quartz latites and quartz monzonites from the Goboboseb region and the Springbok quartz latites of the southern Etendeka.

	[1]		[2]		[3]		[4]		[5]		[6]	[7]	[8]		[9]	
	n=24	s.d.	n=23	n.d.	n=10	s.d.	n=4	s.d.	n=5	s.d.	n=1	n=1	n=8	s.d.	n=27	s.d.
SiO_2	66.72	0.31	66.91	0.30	67.18	0.31	67.56	0.13	66.94	0.03	67.42	67.66	67.35	0.53	67.68	0.58
TiO_2	1.06	0.02	1.02	0.03	1.01	0.03	0.95	0.00	1.02	0.00	0.92	0.95	1.02	0.02	0.95	0.02
Al_2O_3	12.73	0.06	12.75	0.05	12.83	0.05	12.84	0.07	12.73	0.06	12.98	12.90	12.93	0.17	13.10	0.38
Fe_2O_3	7.68	0.12	7.70	0.21	7.49	0.14	7.40	0.11	7.45	0.09	6.91	7.05	7.51	0.10	6.92	0.27
MnO	0.12	0.01	0.12	0.01	0.12	0.02	0.12	0.00	0.12	0.00	0.11	0.11	0.10	0.02	0.10	0.02
MgO	1.11	0.07	1.04	0.12	1.05	0.09	1.00	0.06	1.17	0.05	1.26	1.29	1.00	0.28	1.24	0.25
CaO	3.29	0.40	3.24	0.30	2.92	0.39	3.03	0.06	3.17	0.13	2.88	2.70	2.65	0.57	2.56	0.37
Na_2O	2.78	0.18	2.84	0.23	2.80	0.29	2.78	0.08	3.05	0.11	3.01	2.47	2.59	0.38	2.68	0.41
K_2O	4.21	0.41	4.07	0.14	4.29	0.22	4.03	0.12	4.05	0.18	4.24	4.59	4.53	0.19	4.49	0.35
P_2O_5	0.32	0.00	0.31	0.00	0.30	0.00	0.28	0.00	0.31	0.00	0.27	0.27	0.31	0.00	0.29	0.01
Rb	160	15.8	154	12.6	165	13.1	162	5.1	162	3.1	170	180	174	8.4	176	15.3
Ba	695	63.0	714	93.0	723	26.0	681	4.2	703	14.9	672	632	707	19.0	689	70.0
Sr	137	41.0	142	30.0	142	23.0	150	7.5	154	4.2	155	149	148	9.7	142	19.8
Zr	311	5.0	304	5.3	302	6.4	287	3.6	294	1.6	273	271	296	5.0	276	5.7
Nb	23	0.4	23	0.3	22	0.4	21	0.3	22	0.4	21	22	25	1.6	23	1.0
Sc	21	0.6	20	0.9	20	1.0	19	0.3	19	0.5	18	19	21	0.3	20	0.8
Y	51	0.8	50	0.7	49	1.5	46	1.7	49	1.5	45	42	48	1.3	44	2.8
La	47	1.3	46	1.7	45	2.8	45	2.4	47	0.9	43	47	47	1.2	48	3.7
Ce	97	3.4	94	3.3	94	6.4	93	4.0	94	2.2	89	94	97	1.8	93	4.2
Nd	49	2.0	49	1.6	48	3.5	49	3.3	49	2.9	44	50	55	1.5	50	2.2

[1] QL unit-I
[2] QL unit-II
[3] QL unit-III
[4] QL unit-IV
[5] Quartz Monzonite plugs
[6] Quartz Monzonite ring dyke
[7] Quartz Monzonite sill
[8] Lower Springbok quartz latite
[9] Upper Springbok quartz latite

Data normalised to 100% volatile-free, all Fe as Fe_2O_3.

Quartz latite and quartz monzonite geochemistry

A total of 155 samples from the Goboboseb Mountain region have been analysed for 32 major and trace elements, and included in this total are 62 samples of quartz latite and 7 quartz monzonite samples. Averaged data, including standard deviations, are shown in Table 2 for QL units -I to -IV, the quartz monzonites, together with comparative data for the Springbok quartz latites from the southern Etendeka. Milner and Duncan (1987) have shown certain elements, most notably Ti, Fe, P, Ba, Zr and Y, are unaffected by alteration processes in the southern Etendeka quartz latites. Emphasis is therefore placed on these elements for comparative purposes.

The Goboboseb quartz latites can be divided into several groups by small but significant variations in elements such as Ti, Fe, P, Zr and Y; this is illustrated by plots of TiO_2 *vs*. P_2O_5 and Zr *vs*. Y (Figs. 7 and 8) which

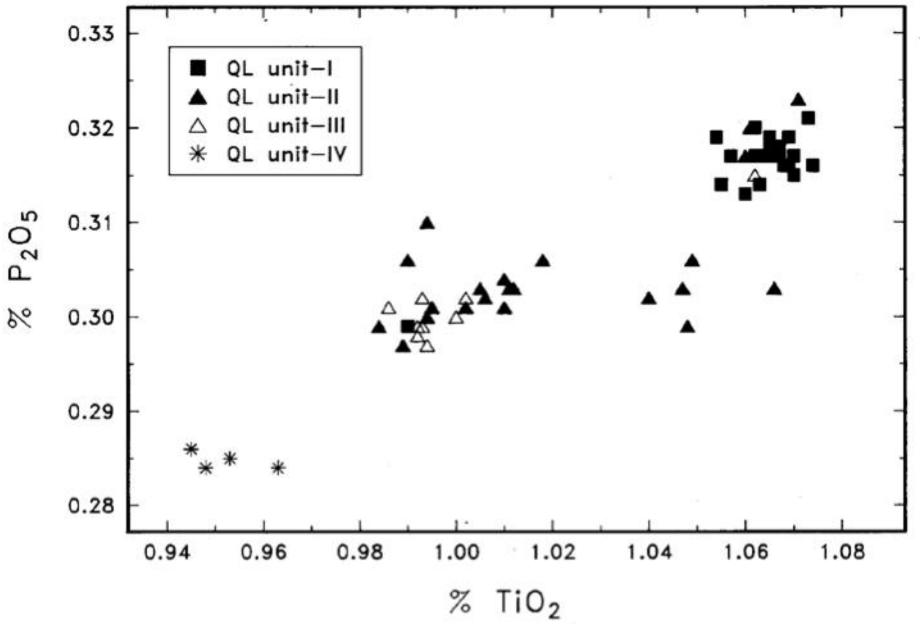


Fig. 7: Plot of P_2O_5 against TiO_2 for the Goboboseb quartz latites. (The data are normalised to 100%, volatile-free).

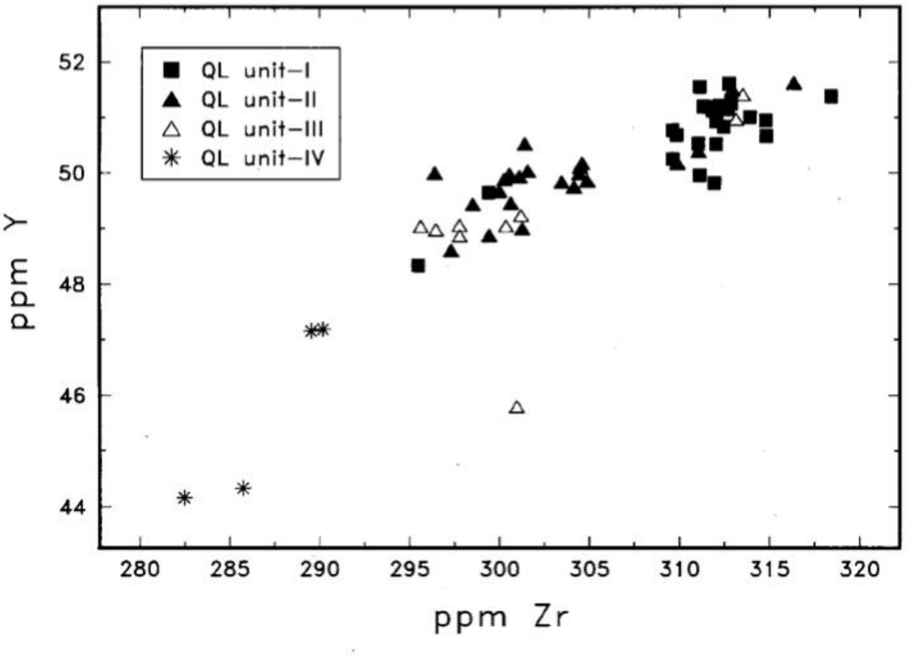


Fig. 8: Plot of Y against Zr for the Goboboseb quartz latites. (The data are normalised to 100%, volatile-free).

demonstrate that groups of data points are dominated by specific quartz latite units. On both diagrams, three principle groups of points emerge and are characterised by the following units: (1) QL unit-I, (2) QL units -II and -III, and (3) QL unit-IV. In Fig. 7 a fourth group of data points, adjacent to the QL unit -II and -III array, consists of samples from the black, flinty flow base of QL unit-II, and might indicate that minor intra-flow zonation is developed in this unit. Several sample mismatches occur between the groups; for example, some samples thought to represent QL units -II or -III in the field plot within the QL unit-I grouping and vice versa.. These anomalies are believed to result from ambiguities in identifying the various quartz latite units in certain field localities. The geochemical data may thus provide the basis for the geochemical characterisation of individual quartz latite units.

Notwithstanding the differences highlighted above between the QL units (see Table 2), there is a remarkable overall uniformity of chemistry between the four QL units, and a very high degree of chemical uniformity when each QL unit is considered individually.

Comparison of the quartz monzonite and quartz latite compositions reveal an almost identical chemistry between the quartz monzonite plugs and QL units -II and -III. The quartz monzonite compositions of the ring dyke and the composite sill both exhibit close similarities to QL unit-IV.

Discussion

Relation of quartz latites to the Messum Complex

We interpret the QL units -I to - IV as each having erupted from the Messum Complex. Lines of evidence supporting this interpretation include:

(a) The concentration of the outcrop pattern of the QL units around much of the Messum Complex.

(b) The occurrence of the relatively thick QL units stratigraphically between two major basaltic sequences, these also interpreted as emanating from Messum (see previous discussion). This is, furthermore, consistent with the presence of major gabbroic ring intrusions within Messum (Korn and Martin, 1954). In this context, it is also relevant to note the occurrence of voluminous and monotonous regional tholeiites erupted throughout the Etendeka area (notably the Tafelberg-type basalts), evidently fed by regional dyke swarms (Erlank *et al*., 1984). The Goboboseb lavas, however, exhibit a greater range of compositions, extending to *ne*-nonnative, olivine-phyric types, although still dominated by tholeiites. This is again consistent with a different source for the basalts.

(c) The occurrence of quartz monzonite intrusives in and adjacent to the Messum Complex, which are chemically and mineralogically equivalent to the quartz latites (Table 2). These are the only intrusive equivalents of quartz latite which have been recognised. Quartz monzonite dykes also cut the Brandberg intrusion, but chemical data (unpublished) show that these cannot be equated with the Goboboseb quartz latites.

(d) Possible indicators of flow direction within QL units -I to -IV have proved very difficult to identify. However, observations of the orientations of rapid dip changes and mega-breccias along, and into, the inferred palaeovalley extending to Copper Valley (Fig. 2) indicate northerly moving eruption clouds for QL units -I and -II.

(e) The Goboboseb volcanics occupy a broad southerly dipping trough-like structure, the plunge of which steepens adjacent to Messum, as described. We interpret this as a collapse (sag) structure, preferentially affecting the northern part of Messum. It is the existence of this sag that has allowed so much of the Goboboseb volcanic succession to be preserved. We attribute this structure to subsidence accompanying voluminous quartz latite eruption from Messum (see next section). A minimum sagging of 300 m was previously suggested, based on a simple linear extrapolation across the Goboboseb Mountains. If, however, the Goboboseb Mountains were initially part of a broad basaltic shield volcano centred on Messum, then by assuming an initial 3° slope from Messum to the present outcrop limits of the Tafelkop basalts, a possible subsidence of the order of 2 km is indicated along the axis of the sag structure adjacent to Messum.

(f) Regional aeromagnetic data (Aeromagnetic Survey, Geological Survey of SWA/Namibia. 1:50 000 map sheets 2114 AC and 2114 AD) clearly define the Messum Complex, but further suggest the existence of a hidden northern margin to the Messum structure. This lies approximately 4-5 km north of the exposed margin, based on the magnetic induction contours. Significantly, the two previously described quartz monzonite plugs occur inside, but close to the margin of, this inferred hidden structure. We interpret the structure as part of an early caldera stage accompanying the eruption of QL units -I, -II and -III, now filled by these and the later volcanic sequences.

Correlations between Goboboseb and southern Etendeka quartz latites

A geochemical study of the southern Etendeka quartz latites (Milner and Duncan, 1987) showed that they could be divided into distinct compositional groupings. The few data then available from the Goboboseb (QL units -I to -III) were shown to correlate closely with the Lower Springbok quartz latites.

The much more extensive chemical data now available for the Goboboseb units (Table 2) reinforces these previous observations. Based on the chemical similarities, together with the very homogeneous chemistry of the individual units in question, we propose that QL units -I to -III correlate with the two Lower Springbok quartz latite units and that Q L unit-IV correlates with the Upper Springbok unit. These chemical correlations are consistent with the stratigraphic position of the respective units in each area. Considering the relative thinness of QL unit-III compared to QL units -I and -II (Table 1a), we believe that this unit did not reach the Etendeka.

Supporting evidence for these correlations is derived from phenocryst mineralogy. Milner (1988) has previously demonstrated that the types and abundances of pyroxene phenocrysts are useful in characterising the different groups of quartz latites in the southern Etendeka. Table 3 summarises the relevant phenocryst compositions and abundances. Pigeonite compositions are averaged, the compositional ranges rarely exceeding 3% of the mean value.

Comparison of the respective mineralogies reveals strikingly close similarities between the two Springbok units and the Goboboseb QL units -I to -IV. Two exceptions are, however, apparent: (1) augite which is present in the Goboboseb QL unit-I has not been observed in the Lower Springbok quartz latite units; (2) the Upper Springbok unit exhibits two phenocryst assemblages, one containing hypersthene (apparently restricted to the lowest and highest levels within the unit; Milner, 1988). Hypersthene has not been found in the Goboboseb QL unit-IV

Additional supporting evidence for a correlation between the Upper Springbok unit and the Goboboseb QL unit-IV is the presence, in both, of quartzite xenoliths and quartz xenocrysts. Such xenolithic material has not been observed in any of the other southern Etendeka quartz latite units nor in the Goboboseb QL units -I to -III.

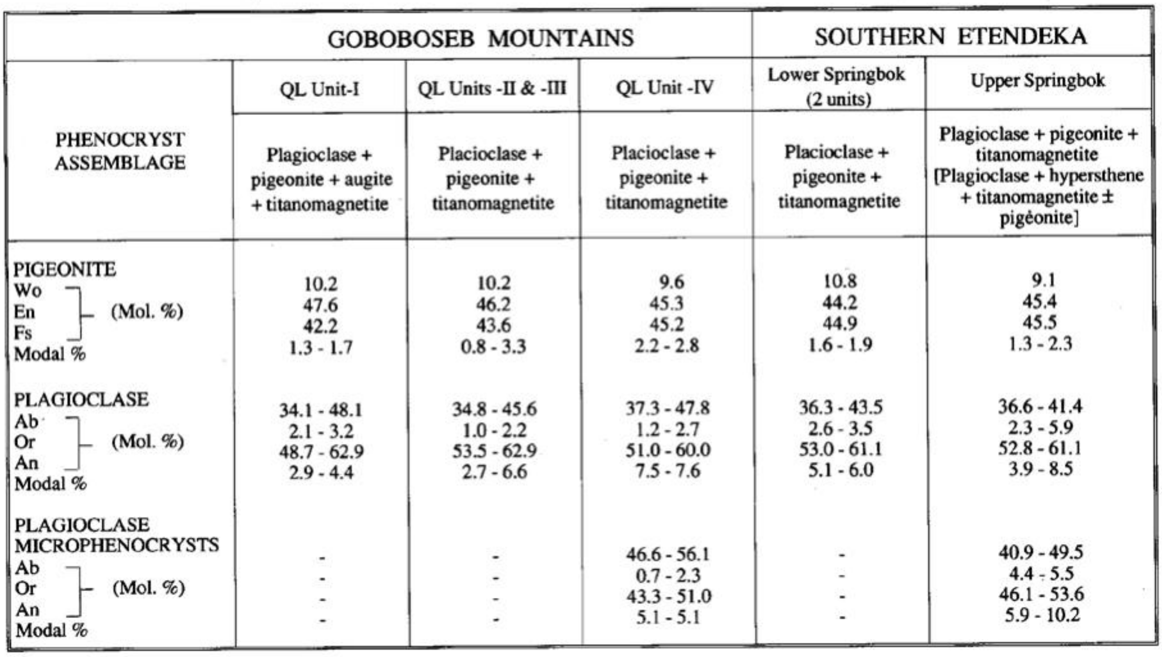
Volcanological implications

Two major implications of these correlations between the Goboboseb and Springbok quartz latites are apparent:

(a) If the Messum Complex was the eruptive centre, then the very large magnitudes of the quartz latite eruptions become evident. Erosional remnants of the Springbok and Goboboseb quartz latites are found up to 130 km from Messum. The minimum area which will encompass all these remnants is approximately 8 800 km^2. Noting the thickness of the Springbok units (Table 1b) and their apparent a real extent implies large erupted volumes. Assuming that the Lower Springbok quartz latites each have an average thickness of 60 m near Messum the estimated volume for each unit is 300-500 km^3. The estimated thickness of the Upper Springbok quartz latite is 250-300 m (note that this is a minimum estimate since the upper portion of the unit has been removed by erosion) implying a volume of 2200-2600 km^3 for this unit. Clearly, if our interpretations are correct, the Springbok quartz latites represent the products of some of the largest pyroclastic eruptions recorded anywhere.

(b) Comparison of equivalent quartz latite units of the southern Etendeka and Goboboseb not only allows evaluation of vertical lithological changes to be documented, but also the lateral changes in the form and structure of these rheoignimbritic units. Of particular potential relevance is the inference that the Goboboseb quartz latites represent proximal facies of the eruptive units. Although the literature on conventional ash-flow deposits is extensive, the documentation of high-temperature rheoignimbrites is very limited and available

TABLE 3: Comparison of phenocrystal mineralogies of Goboboseb and southern Etendeka quartz latites.



	GOBOBOSEB MOUNTAINS			SOUTHERN ETENDEKA	
	QL Unit-I	QL Units -II & -III	QL Unit -IV	Lower Springbok (2 units)	Upper Springbok
PHENOCRYST ASSEMBLAGE	Plagioclase + pigeonite + augite + titanomagnetite	Placioclase + pigeonite + titanomagnetite	Placioclase + pigeonite + titanomagnetite	Placioclase + pigeonite + titanomagnetite	Plagioclase + pigeonite + titanomagnetite [Plagioclase + hypersthene + titanomagnetite ± pigeonite]
PIGEONITE					
Wo (Mol. %)	10.2	10.2	9.6	10.8	9.1
En (Mol. %)	47.6	46.2	45.3	44.2	45.4
Fs (Mol. %)	42.2	43.6	45.2	44.9	45.5
Modal %	1.3 - 1.7	0.8 - 3.3	2.2 - 2.8	1.6 - 1.9	1.3 - 2.3
PLAGIOCLASE					
Ab (Mol. %)	34.1 - 48.1	34.8 - 45.6	37.3 - 47.8	36.3 - 43.5	36.6 - 41.4
Or (Mol. %)	2.1 - 3.2	1.0 - 2.2	1.2 - 2.7	2.6 - 3.5	2.3 - 5.9
An (Mol. %)	48.7 - 62.9	53.5 - 62.9	51.0 - 60.0	53.0 - 61.1	52.8 - 61.1
Modal %	2.9 - 4.4	2.7 - 6.6	7.5 - 7.6	5.1 - 6.0	3.9 - 8.5
PLAGIOCLASE MICROPHENOCRYSTS					
Ab (Mol. %)	-	-	46.6 - 56.1	-	40.9 - 49.5
Or (Mol. %)	-	-	0.7 - 2.3	-	4.4 - 5.5
An (Mol. %)	-	-	43.3 - 51.0	-	46.1 - 53.6
Modal %	-	-	5.1 - 5.1	-	5.9 - 10.2

TABLE 4: A comparison of the flow unit structure of quartz latites from the Goboboseb and the southern Etendeka.

	GOBOBOSEB MOUNTAINS	**SOUTHERN ETENDEKA**
UPPER ZONE	Coarse Breccias (amygdaloidal & massive quartz latite blocks) Contorted banding & Breccia	Pumiceous Blocks Pitchstone lenses Contorted banding Amygdaloidal
CENTRAL ZONE	Massive Devitrified quartz latite Columnar jointing	Massive devitrified quartz latite Columnar jointing
BASAL ZONE	Horizontal jointing Laminar flow-banding & Fiammé Black, flinty base	Horizontal jointing Laminar flow-banding & Fiammé Contorted flow-banding & Breccia Pitchstone base

descriptions have concentrated on general characteristics and vertical lithological changes. The most relevant examples are described by Byers *et al*., (1976), Bonnichsen and Citron (1982), Ekren *et al*., (1984) and Bonnichsen and Kauffman (1987). Thus, in Table 4, a comparative summary is presented of the major lithological features of the Springbok units of the southern Etendeka, and the Goboboseb quartz latites. The major differences seem to be the occurrence of upper zone breccias and the absence of vitrophyres in the Goboboseb Mountains. Significantly, these also seem to be the major differences with respect to the descriptions of the Idaho deposits (Bonnichsen and Citron, 1982; Ekren *et al*., 1984.)

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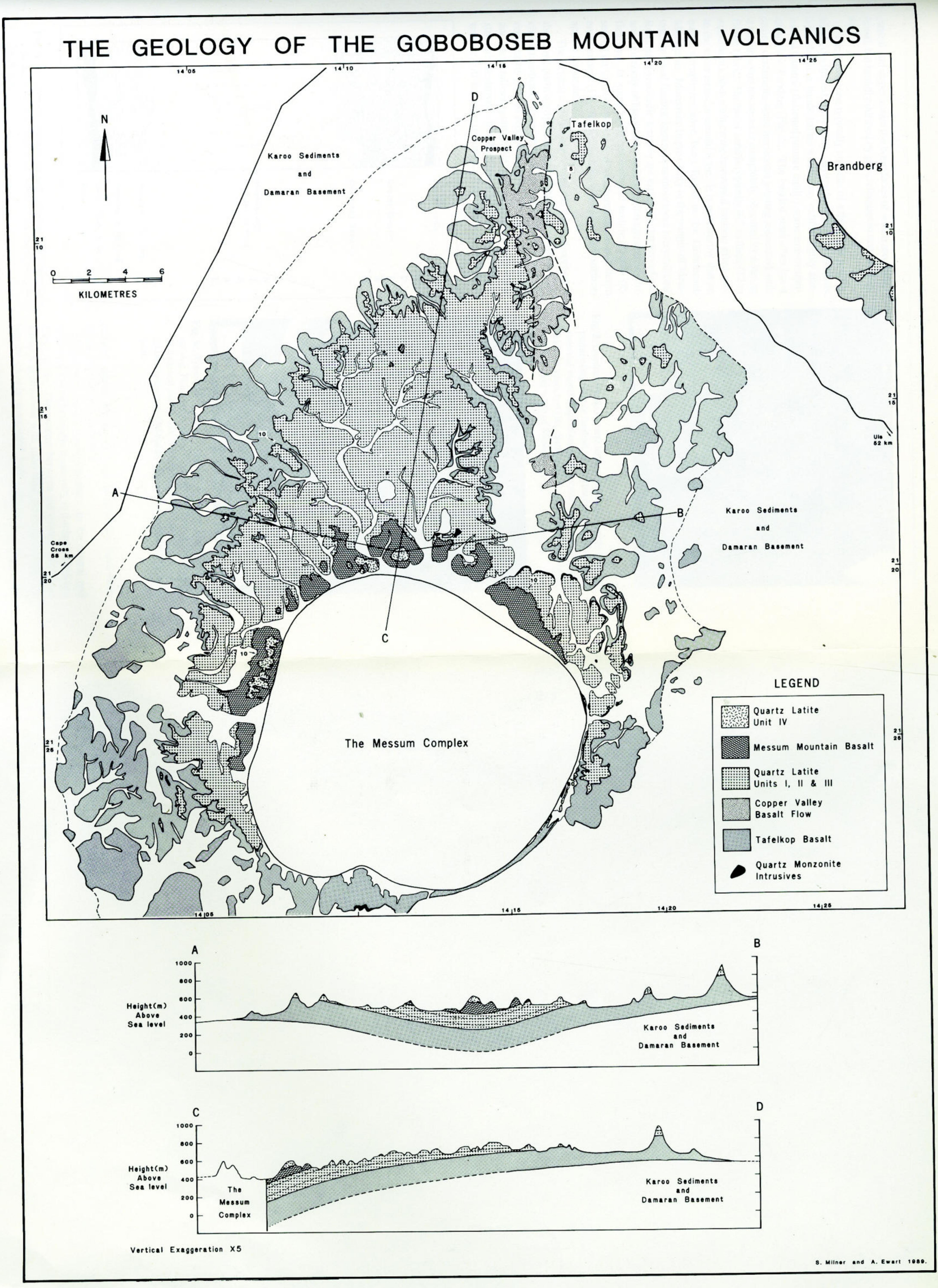

Fig. 2: Geological map of the Goboboseb Mountain volcanics.