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THE PETROLOGY AND GEOCHEMISTRY OF THE BARBY FORMATION, SINCLAIR SEQUENCE

by

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ABSTRACT

Preliminary results concerning the stratigraphy and geochemistry of the Barby Formation volcanics from the type locality of the Sinclair Sequence are briefly presented. The Barby volcanics have, on petrological and geochemical grounds, been subdivided into two geographically distinct successions. The southern succession is considered to represent typical Barby Formation, whereas that in the north is inferred to overlie the southern succession. The southern region has a well-defined base where the Basal Volcaniclastic Member forms a widespread marker horizon directly overlying the Kunjas Formation. Above this Member the succession is characterized by 'porphyritic lavas which show a complete compositional range from basaltic andesite to rhyolite. Together with thin intercalated pyroclastic deposits, these volcanics appear to have been deposited in elongate basins separated by syndepositional faults. The northern succession consists of bimodal sequences of aphyric basalt and thick pyroclastic rhyolite within which sedimentary units are intercalated. Major and trace element data for these successions reveal two discrete chemical trends which support this subdivision of the volcanics. The southern volcanic sequence has potassium-rich calc-alkaline affinities, whereas the northern succession is tholeiitic. Trace element data suggest stratigraphic correlation between the northern succession rhyolites and the Guperas Formation rhyolites, which in the south directly overlie the southern volcanic succession.

1. INTRODUCTION

The Barby Formation investigated in this study lies within the type area of the Sinclair Sequence (Watters, 1977) in southern South West Africa/Namibia, between 24°45'S and 25°45'S and east of 16°E. The Sinclair Sequence, which is late Precambrian, comprises a wide variety of high level comagmatic intrusive and volcanic rocks with intercalated clastic sediments. The volcanics and clastic sediments were subaerially deposited in elongated fault-bounded basins. Tholeiitic and calc-alkaline lavas are present and Watters (1974) has suggested that they were generated at an active plate margin.

Von Brunn (1967) and Watters (1974) investigated the Sinclair Sequence in two major regional studies and have recognized five volcanic and sedimentary formations. The basal Nagatis Formation, consisting predominantly of felsic lavas and pyroclastics with minor basic lavas and intercalated arkose and shale bands, rests unconformably on granitic basement rocks which have been incorporated in the Namaqualand Metamorphic Complex by Miller (1980). The Nagatis Formation is overlain by the Kunjas Formation consisting of basal conglomerates, arkoses and siltstones. This is followed by a major volcanic sequence, the Barby Formation, which consists of porphyritic basaltic andesite, andesite, trachyandesite and rhyolite with associated pyroclastic units and minor intercalated clastic sediments which have been intruded by gabbroic, dioritic and monzonitic bodies. The Barby Formation is unconformably overlain by the Guperas Formation, which consists of rhyolitic lavas and tuffs overlain by coarse conglomerates and sandstones. The Guperas Formation is intruded by quartz porphyry dykes and sills and is succeeded by the thick, but localised development of red feldspathic sandstones, conglomerates and shales of the Aubures Formation. Several major granitic intrusive events occurred before and after the deposition of the volcano-sedimentary Sinclair Sequence. The Sinclair Sequence exhibits local effects of low grade contact metamorphism.

Watters (1974) suggested that the Sinclair Sequence, together with less well preserved "correlates" to the north, forms a prominent and extensive curvilinear feature or arc that was situated at the edge of a highly stable continental platform (Fig. 1). This distribution, together with the presence of thick piles of calc-alkaline and shoshonite lavas in the Sinclair Sequence, persuaded Watters (1976) to propose that the succession was the result of subduction of oceanic crust beneath the Kalahari Craton. However, other workers (e.g. Mason, 1981) believe there is insufficient evidence to support Watters' hypothesis, despite the calc-alkaline affinities of the Sinclair volcanics. Mason (1981) suggests that the evidence points towards a rifted intracontinental environment, and that the problems of correlation are a manifestation of localised yoked basins.

A detailed petrological and geochemical study has, therefore, been initiated in an attempt to resolve this problem. The current project is specifically concerned with the Barby Formation, the major volcanic episode of the Sinclair Sequence. The objectives of this investigation are to document the wide variety of volcanic and sedimentary rock-types and to ascertain the styles of eruption, volcanic types and depositional environments of the Barby Formation. The study is limited to an area north of Sinclair Mine and bounded by the Schwarzrand escarpment to the east and the fringes of the Namib Desert to the west (Figs. 1 and 2).

2. FIELD CHARACTERISTICS AND PETROLOGY

2.1 Stratigraphic Subdivisions

The Barby Formation, as defined by Watters (1974), comprises both extrusive and intrusive phases, the former being dominant. To date, the project has concentrated specifically on the volcanics with only minor geochemical sampling of the intrusions.

In the study area the Barby volcanics crop out extensively over an area of 820 km^2. Correlation along strike is complicated by block-faulting, multiple intrusion by

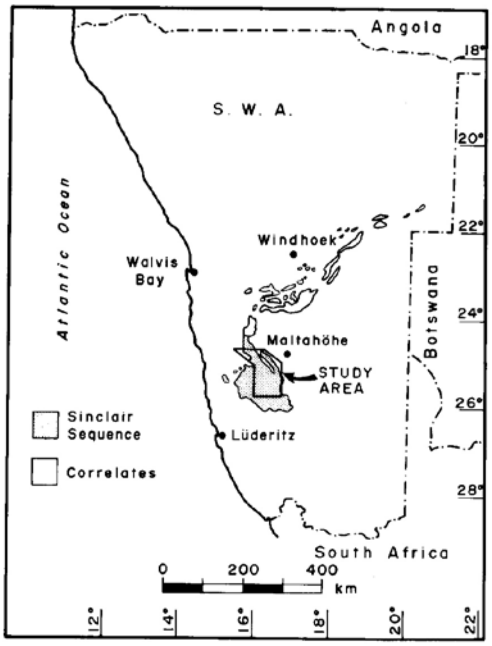

Fig. 1: Location of the study area and the distribution of the Sinclair Sequence and correlates (from SACS, 1980).

SACS, 1980).

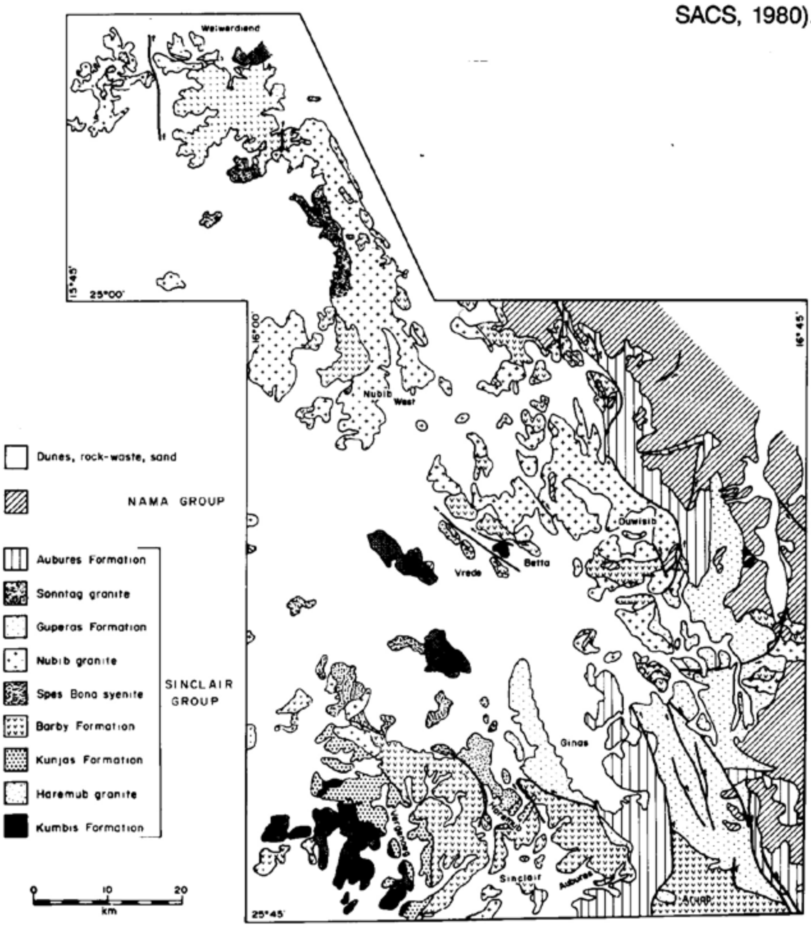

Fig. 2: Generalized geological map of the study area showing farm localities (modified from Watters, 1974, and Schalk, 1972, unpublished map).

the Nubib Granite and subsequent erosion. The resulting disconnected exposures, together with the lack of suitable marker beds and the limited lateral distribution of volcanic beds noted by Watters (1974), have prompted subdivision of the study area into four adjacent geographical regions. Stratigraphic relationships within these subareas are unequivocal, thereby eliminating ambiguous correlations.

The present data suggest that the southern area contains typical Barby volcanics (von Brunn, 1967), the succession being most extensively developed on the farms Klein Haremub 1, Aubures 22 and Vergenoeg 56 (Fig. 2), but thinning northwards towards the farm Vrede 80. The volcanics in the northern areas which crop out on the farms Nubib West 109 and Welverdiend 140 may overlie those in the southern areas. It is questionable whether the latter should be included in the Barby Formation.

2.2 Southern Region

The stratigraphic sequences on the farms Vrede 80, Vergenoeg 56, Klein Haremub 1 and Aubures 22 are shown in Fig. 3. These sequences represent individual volcanic basins, separated by syndepositional faults. The relationship between the individual basins has not been fully resolved, but lithostratigraphic correlations of some flow units suggest the simultaneous deposition of these various successions. Therefore, it is proposed that the successions of various basins do not overlie one another as Watters (1974) envisaged, but represent a lateral variation of volcanic activity in response to regional magmatic and tectonic activity. Thus the 'Member' status which Watters (1974) assigned to various volcanic units is considered to be invalid with the exception of the basal volcaniclastic unit.

2.2.1 Basal Volcaniclastic Member

This member forms a distinctive set of stratigraphic units which, because of its unique character, persistence and widespread nature, constitutes an important and easily identifiable stratigraphic base to the Barby Formation. The contact of this member with the Kunjas Formation is invariably well defined and is recognized by: (a) a distinct change in the style of the Kunjas sedimentation in the extreme upper portion of the formation; and (b) the first outpouring of rhyolitic, crystal-rich, ignimbritic sheets of the Barby Formation. This contact is best described as disconformable, although in places an angular unconformity does exist. The overall thickness of this member is between 140 and 400 m. The greater part is made up of pyroclastic flow deposits, with lesser proportions of air-fall tuffs, tuffaceous sediments and minor dacitic or andesitic lava flows (Fig. 4).

The pyroclastic flow deposits are poorly sorted and massive, but may show subtle grading and imbrication or alignment of clasts. Grading, where recognized, may be both inverse and normal. Crude stratification has been noted in the poorly welded varieties, particularly in several of the basal flows on the farm Vrede 80. Pyroclastic flow deposits exhibit a wide variation in the proportion of their components, although they are typically crystal-rich with lesser, yet significant amounts of pumice and lithic fragments. Lithic fragments rarely exceed 20 per cent of the total volume, and commonly have a composition similar to that of the enclosing matrix. Fragments of Kunjas sandstone (Fig. 5) and of amphibolite have been recognized. Maximum proportions of lithic fragments are generally associated with the basal, block and ash flows which possibly represent colder avalanche type deposits rather than 'nuee ardente; type deposits. The original pumice fragments have collapsed with welding, compaction and lithification and their original internal pumice structure has been destroyed. They now occur as dark, dense fragments commonly with frayed or shredded margins. These are comparable with the 'fiamme' or 'flame' structures described by Ross and Smith (1961). Pumice fragments are generally most abundant at the top of individual flows and are commonly sufficiently concentrated to give the rock a foliated appearance or eutaxitic texture (Fig. 6). Phenocrysts are more abundant in the matrix than in the pumice fragments and constitute from 10 to 35 per cent of the total rock volume. The phenocrysts, consisting dominantly of quartz and sanidine, are commonly broken, angular and chip-like, in contrast to the euhedral or embayed phenocrysts found in pumice fragments and rhyolite lavas. Devitrification products consisting essentially of granular or fibrous quartzofeldspathic aggregates have, in most cases, replaced the original groundmass and destroyed the vitroclastic texture. Crystal shards are locally preserved, some portraying plastic deformation typically associated with welding and compaction. A globular texture characteristically occurs within the top of some thicker flow sheets (Fig. 7). This texture consists of tightly-packed clusters of siliceous spherical to sub-spherical forms that range in diameter from 2 to 40 mm. The matrix is identical to the underlying pyroclastic flow deposit and consists of angular plagioclase and sanidine crystals and welded glass shards. The pyroclastic flow is gradational upwards into the globular portions, which are thus considered to have resulted from extensive vesiculation during the final stages of the outpouring of the pyroclastic tuff.

Air-fall tuff deposits are lacking in the basal pyroclastic unit. Only thin (less than 0,5 m thick) impersistent layers have been recognized. However, the stratified tuffite deposits described by Von Brunn (1967) and Watters (1974) form several distinctive horizons. The thickest of these has been correlated from Vrede 80 in the north to Vergenoeg 56 in the south, thus forming an extensive marker horizon. In the southern outcrops, six different stratified tuffite units, with thicknesses between 5 and 60 m, have been recognized. They are composed predominantly of angular crystals of quartz, plagioclase, K-feldspar, opaques, and lithic fragments set in an extremely fine-grained, quartzofeldspathic groundmass. These tuffs are characterized by conspicuous thin bedding or lamination (15 mm or less in thickness) defined by subtle variations in grain size, but mantle bedding, commonly a diagnostic structure of air-fall tuffs, has not been observed. Low angle planar cross-bedding with graded foresets indicates some degree of

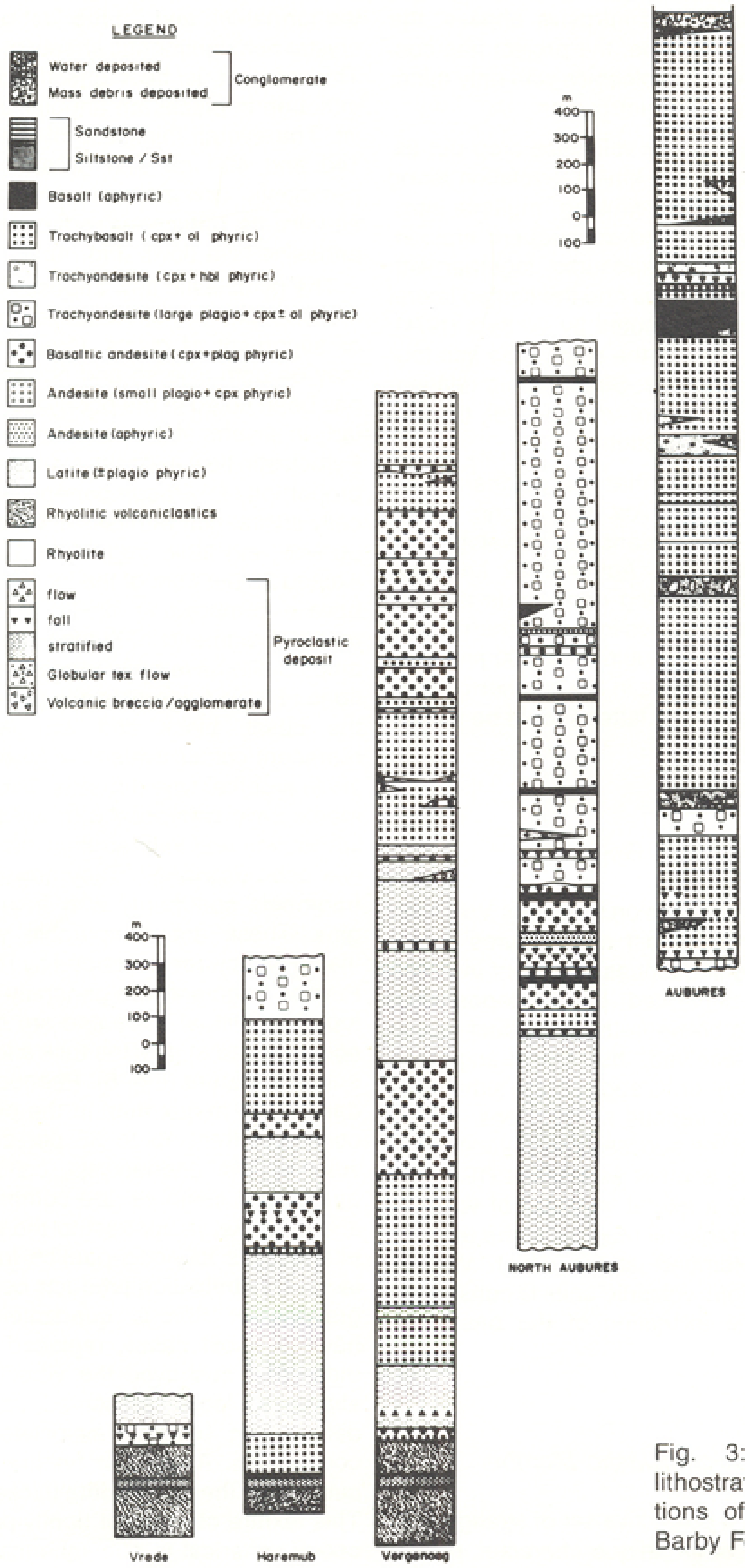

Fig. 3: Generalized lithostratigraphic sections of the southern Barby Formation.

reworking. The origin of this rock-type remains ambiguous, but it exhibits a strong resemblance to coarse- and fine-stratified deposits of recent eruptions of the Fossa cone, Vulcano (Frazetta *et al.*, 1983).

The intercalated sediments of fluvial origin in the Basal Volcaniclastic Member are typically lenticular and impersistent. Clast-supported conglomerates and coarse-grained sandstones form normal graded beds, 1 to 2 m in thickness. Clasts are subrounded and may be derived from a local felsic volcanic source. Matrix-sup-

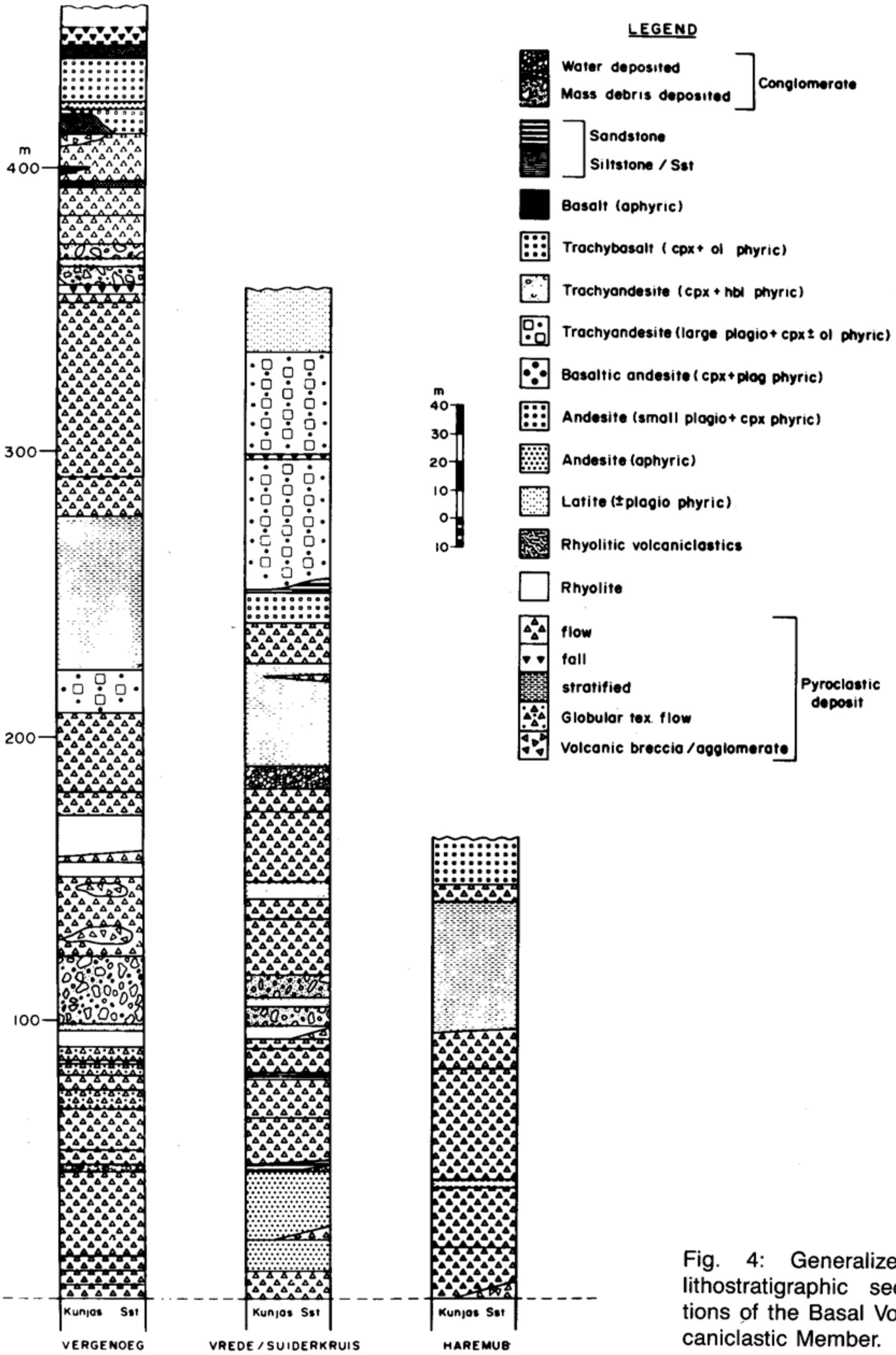

Fig. 4: Generalized lithostratigraphic sections of the Basal Volcaniclastic Member.

ported conglomerates form thick, massive, unsorted, poorly graded units, 30 to 40 m thick. Clasts in this assemblage are angular and are dominantly volcanic but include a wide variety of rock-types. The matrix is also highly variable in composition, but is dominantly a tuffaceous ash. These conglomerates probably represent mass flow or lahar type deposits.

2.2.2 Felsic Volcanic Units

Several thick, porphyritic latite flows are developed near the base of the volcanic sequence overlying the

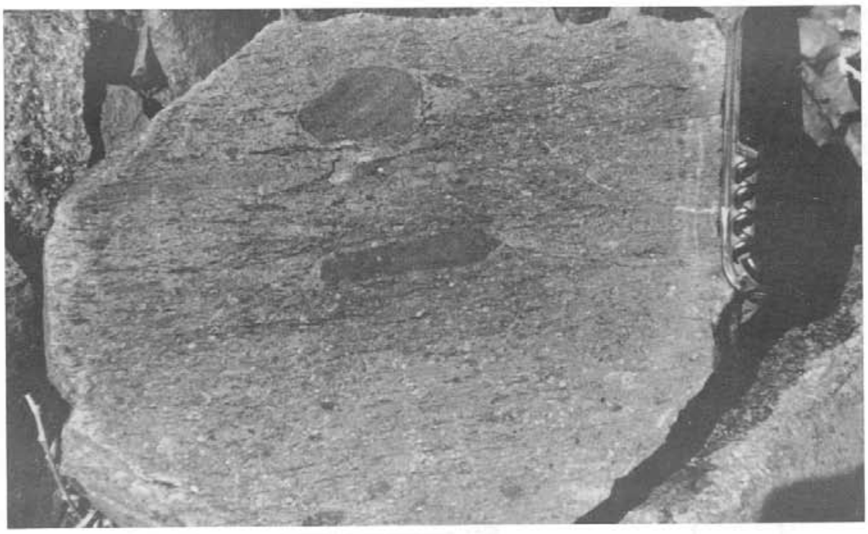

Fig. 5: Kunjas sandstone fragments in basal ignimbrite of the Barby Formation.

Fig. 6: An ignimbrite illustrating 'fiamme' and rock fragments which impart to the rock a crude foliation or eutaxitic texture.

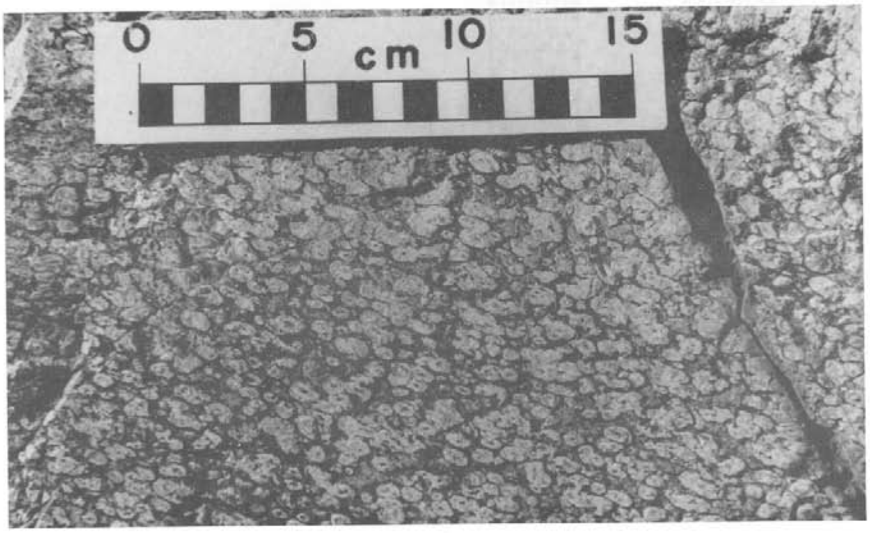

Fig. 7: Globular texture occurring at the top of a thick pyroclastic flow of the Basal Volcaniclastic Member.

Basal Volcaniclastic Member, which is otherwise dominantly mafic in character. These latite lavas, which are equivalent to Watters' (1974) high-Ca rhyolites (a term which is obsolete in the light of current geochemical and petrological data; Hughes, 1982) are intercalated with minor layers of porphyritic andesite or basaltic andesite. The total thickness of these units ranges from 600 to 1 300 m. The latite is pink to dark grey in colour and is plagioclase phyric, being characterized by glomeroporphyritic clusters of plagioclase laths set in a flow-banded aphanitic groundmass. Planar flow banding is common, but rare large-scale contortions of the banding are typically trough-shaped and may represent lava tubes. Autoclastic breccias are also developed, consisting of angular blocks or fragments of strongly flow-banded latite.

2.2.3 Mafic Volcanic Units

The major portion of the Barby Formation in the southern region comprises mafic lava flows (which include a complete compositional range from basalt to andesite). These lavas are characteristically highly porphyritic, with only minor aphyric and vesicular varieties. Watters' (1974) subdivision of the 'mafic portion' into various members is considered to be incorrect as these do not form distinctive stratigraphic units.

(i) Plagioclase and Clinopyroxene Phyric Andesite

The phyric andesite of our classification may be correlated with Watters' (1974) 'small feldspar trachyandesite' unit which is best developed on Vergenoeg 56 and western Klein Haremub 1, but which is absent east of the Haremub/Aubures fault. Minor andesitic flows have also been recognized on the farm Vrede 80. Phyric andesite is usually developed near the base of the 'mafic' portion of the sequence occurring between the lower latite unit and an overlying clinopyroxene basaltic andesite. It is characterized by an abundance of plagioclase phenocrysts with subordinate, yet ubiquitous clinopyroxene phenocrysts.

(ii) Clinopyroxene Phyric Basaltic Andesite

This rock-type is principally developed on the farms Vergenoeg 56 and Klein Haremub 1 and is directly correlated with Watters' (1974) basaltic andesite unit. The basaltic andesite is a dark green colour with conspicuous ferromagnesium phenocrysts and subordinate plagioclase. The clinopyroxene phenocrysts are typically zoned (Fig. 8) and commonly form glomeroporphyritic aggregates. The groundmass exhibits a pilotaxitic texture.

(iii) Coarse Feldspar Phyric Trachyandesite

This distinctive, red-brown, feldspar phyric lava is well documented by Watters (1974), but has a wider distribution than previously recognized. Thin flows have been recorded within the basal portion of the Vrede and Vergenoeg outcrops. Although these flows appear to form massive and thick successions, they are typically interlayered with rhyolitic and dacitic tuffaceous beds and minor sedimentary lenses.

(iv) Clinopyroxene and Olivine Phyric Trachybasalt.

This well-defined assemblage dominates the Aubures succession and can be correlated with Watters' (1974) pyroxene trachybasalt. It is pinkish-grey in colour with small mafic phenocrysts and comprises relatively thin flow units which are commonly interlayered with tuff horizons of rhyolitic and basaltic composition. The clinopyroxene phenocrysts form glomeroporphyritic aggregates that enclose olivine. The groundmass consists of randomly orientated plagioclase laths with interstitial pyroxene grains.

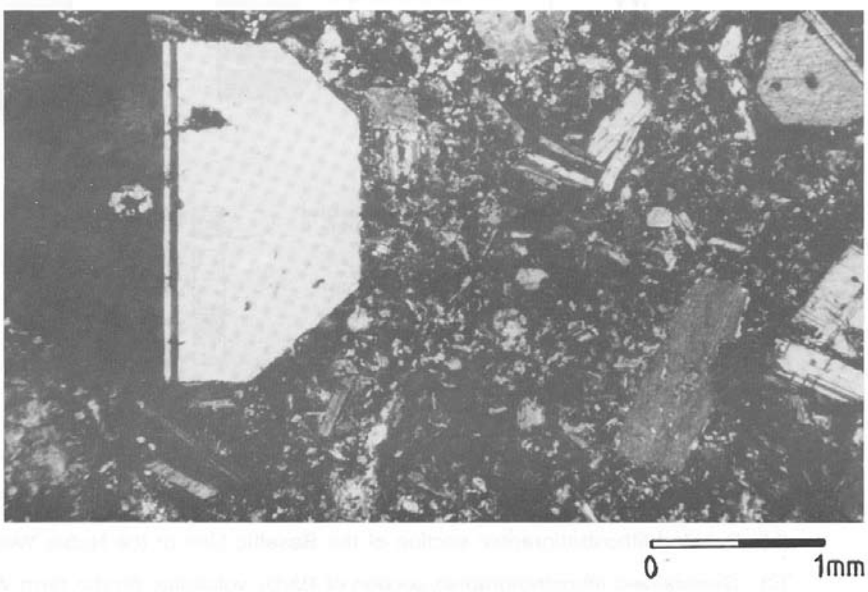

Fig. 8: Photomicrograph showing zoned euhedral clinopyroxene phenocrysts in basaltic andesite lava. (Crossed nicols).

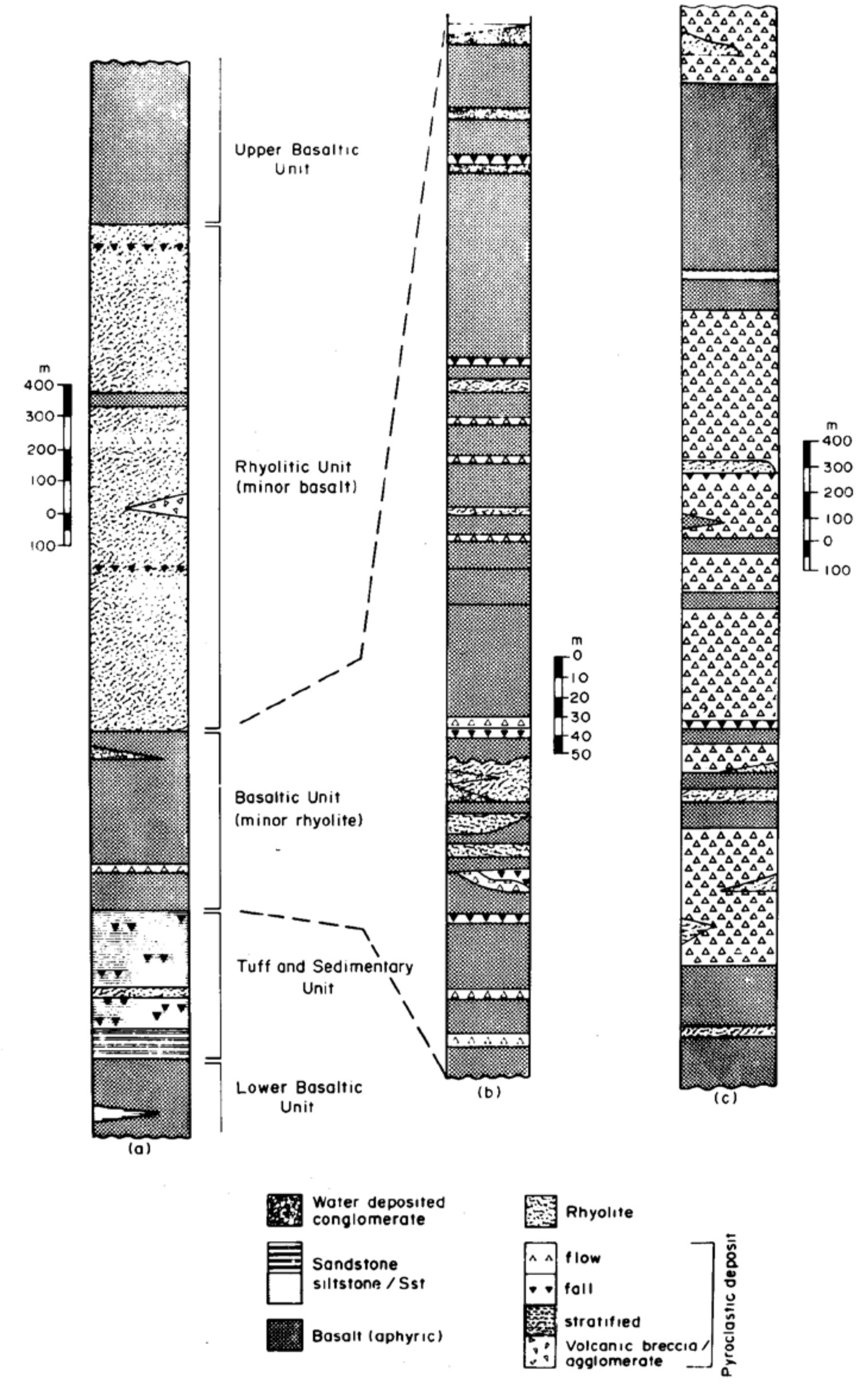

Fig. 9: (a) Generalized lithostratigraphic section of the Barby Formation in the Nubib West vicinity.

(b) Detailed lithostratigraphic section of the Basaltic Unit of the Nubib West Section.

(c) Generalized lithostratigraphic section of Barby volcanics on the farm Welverdiend.

(v) Hornblende Phyric Trachyandesite

This lava is similar to the trachybasalt, but is distinguished by the presence of slender needle-like hornblende phenocrysts. Trachyandesites crop out mainly in the Aubures succession, but flows of this composition have also been recognized in the Haremub and Vergenoeg successions. Brown oxyhornblende and clinopyroxene are present as phenocrysts in a groundmass comprising random- to flow-orientated laths of plagioclase.

2.3 Northern Region

The volcanic rocks that occur in the northern region are distinctly bimodal in composition with a general lack of porphyritic varieties, which contrasts markedly with the southern localities. Included in the northern region are the volcanic units cropping out on the farms Duwisib 84, northern Vrede 80, Betta 87, Nubib West 109, and Welverdiend 140, but the sequence is only well-preserved on the farms Nubib West 109 and Welverdiend 140. Consequently, this study has concentrated on these two areas (Figs. 9a and c). The correlation between the Nubib and Welverdiend sequences has not been fully resolved, but it is evident that the lava types in both these localities are very similar.

2.3.1 Nubib West

The stratigraphic succession on Nubib West 109 (Figs. 9a and b), which illustrates a strong compositional bimodality, has been subdivided into five broad stratigraphic units.

(i) Basal Basaltic Unit

This predominantly basaltic unit comprises dark-green, aphyric, fine-grained basaltic lavas with minor sediments and two thin rhyolite intercalations. The base of the unit is obscured by the intrusion of the Nubib Granite which has caused extensive alteration of the country rocks. Several gabbroic intrusions have also invaded the lower portion of the unit. The basaltic lavas appear to be massive, but individual flows of 2 m thickness and less have been observed.

(ii) Tuffaceous and Sedimentary Unit

This unit has an overall thickness of 450 m and is dominantly sedimentary with minor intercalations of air-fall tuffs and thin rhyolite lavas. The sedimentary portion comprises alternating beds of feldspathic siltstone and quartz-rich sandstone. Cross-lamination, planar laminated bedding and graded beds are common sedimentary features. Bedding units are commonly between 2 and 3 m thick within sedimentary layers which range from 15 to 40 m in thickness.

(iii) Basaltic Unit with Minor Rhyolitic Bands

This unit forms a 550 m thick succession of predominantly aphyric basaltic lava with many intercalated, thin bands of rhyolite and several prominent conglomerate horizons (Figs. 9 and 10). The aphyric basalt is typically fine-grained with groundmass textures ranging from pilotaxitic to intergranular. Highly vesiculated and amygdaloidal flow tops are common features, whereas hyaloclastic breccias and pillow lavas have also been noted. A laterally persistent conglomeratic bed overlies this unit. The intercalated rhyolite beds consist of a complex association of ignimbritic sheets and air-fall tuffs. Thin, clast-supported conglomeratic horizons are interspersed throughout this unit, individual beds being up to 10 m thick. Clasts consist of banded rhyolite, rhyolitic tuffs, basalts and granite. Their size is highly variable, but some beds exhibit large boulders averaging 45 cm in diameter.

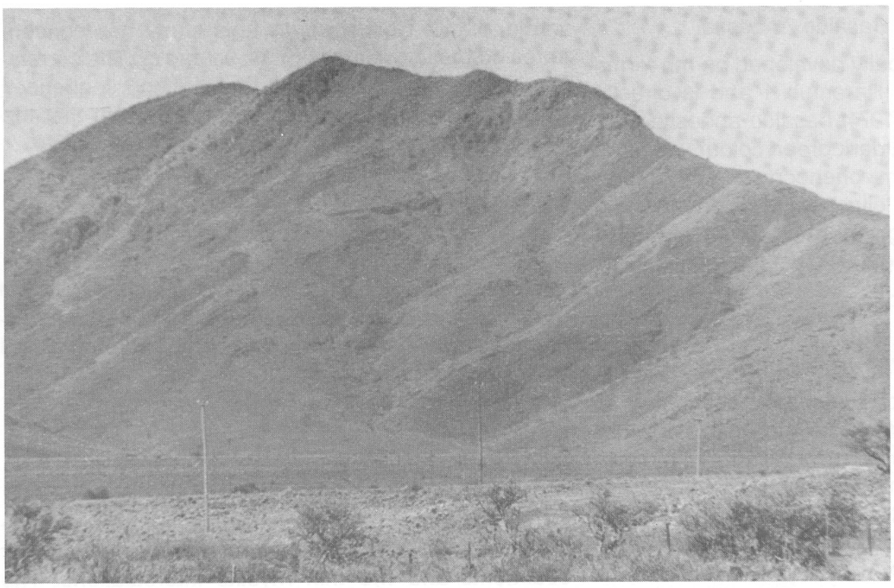

Fig. 10: A succession of aphyric basaltic lavas with numerous intercalated thin bands of rhyolite from the northern sequence. Some quartz porphyry dykes within this section can be recognized by their cross-cutting nature.

(iv) Rhyolitic Unit With Minor Basaltic Beds

This unit is approximately 1 500 m thick and consists of composite rhyolite lava flows with intercalations of thick ignimbrite sheets, ash-fall tuffs and associated epiclastics. Thin, minor basaltic lava flows are interspersed throughout the unit. The typical Pelean volcanic pattern of air-fall tuff and ignimbrite followed by lava has been recognized in some units.

(v) Upper Basaltic Unit

The rhyolites grade into the upper basaltic unit (500 m thick) which caps the Nubib West sequence. This unit is extensively altered and is typically aphyric, fine-grained and amygdaloidal. The intrusion of the Nubib Granite terminates the sequence.

2.3.2 Welverdiend

The Sinclair Sequence that crops out to the north of 25°00'S has been mapped by Schalk (1972). These volcanics occur in many small outcrops covering a large area, but form a thick, well-preserved open synclinal structure on the farm Welverdiend 140. This syncline plunges 20° to the NW with dips of 30 to 40° on the limbs. The volcanics attain a maximum thickness of 4300 m, yet neither the base nor the top of the succession is exposed (Fig. 9c). This succession is subdivided into two major rock-types.

(i) Rhyolites

The rhyolites are similar to those on Nubib West 109 and comprise minor rhyolitic domes and lava flows, thick massive pyroclastic flow sheets and thin air-fall tuff beds. The rhyolite flows have a limited lateral extent. Flow-banding is a prominent and characteristic feature and ranges in thickness form 2 to 100 mm. Pyroclastic flow deposits form thick, crystal-rich sheets, which comprise the major portion of the rhyolites. Individual units are often characterized by their high crystal content, with feldspar phyric, feldspar and quartz phyric, and quartz phyric varieties. Pumice fragments, now collapsed to form typical fiamme (Ross and Smith, 1961) exhibit a wide variation in size, concentration and compaction. Lithic inclusions form a relatively minor proportion of the total volume, but are always present. The upper 5 to 25 m of several of the thicker flows are characterized by the development of a globular texture, which is overlain by a thin air-fall tuff. The globular texture is identical to that recognized in the Basal Volcaniclastic Member described above.

(ii) Basalts

The basaltic lavas in this area have suffered considerable alteration and deformation and only major textural features are recognized. Basalts are subordinate to the rhyolites, but are intercalated throughout the succession to give a cumulative thickness of 1 500 m. The basalts are uniform dark-green to green in colour, generally aphyric and massive with some amygdaloidal development. Highly vesiculated horizons have been recognized and are associated with breccias and fumarole vents.

3. GEOCHEMISTRY

Von Brunn (1967) and Watters (1974) recognized the lack of intermediate rock-types in the Sinclair Sequence and proposed that the 'bimodal' compositional character resulted from the extrusion of unrelated magmas. Furthermore, Watters (1974) reported tholeiitic and calc-alkaline magmatic affinities within the Barby volcanics and suggested that part of the calc-alkaline rock series had a shoshonitic fractionation trend. The new geochemical data are presented primarily to define more precisely the magmatic affinities, and thus the genesis, of the volcanics. A total of 250 samples (231 Barby volcanics and 19 Guperas volcanics) have been analysed for major and trace elements using X-ray fluorescence techniques. Major elements were analysed using the lithium tetraborate fusion method of Norrish and Hutton (1969) and trace elements were analysed using pressed powder briquettes. Although all the major element data are presented, only 180 trace element analyses are available at present.

3.1 Major Elements

The AFM diagram (Fig. 11) illustrates two distinct chemical trends. The majority of samples from the northern area plot in the tholeiitic field, whereas the samples from the southern localities fall in the calc-alkaline field. A distinct bimodality is observed for the tholeiitic

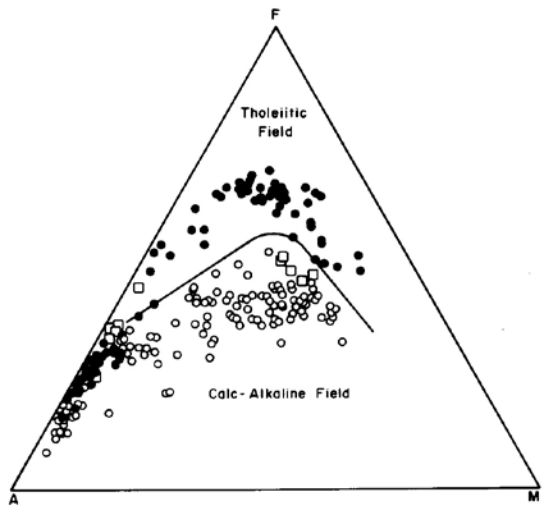

Fig. 11: A (Na_2O + K_2O) — F (Total Fe as FeO) — M (MgO) (tholeiitic and calc-alkaline field boundary after Irvine and Baragar, 1971) plot for Barby lavas. ○ southern localities; ● northern localities; □ Guperas volcanics.

samples, but a more continuous compositional range characterizes the calc-alkaline series. These trends are shown in Fig. 12. Data for the northern localities clearly illustrate iron enrichment from basalt to basaltic andesite compositions, which corresponds very closely to that displayed by the Thingmuli volcano (Carmichael, 1964). On the other hand, data for the southern localities illustrate the lack of iron enrichment and closely match the trend displayed by the calc-alkaline Cascade volcanics (Carmichael, 1964). Hence, on the basis of iron enrichment, the Barby volcanics show both tholeiitic and calc-alkaline magmatic trends pertaining to the northern and southern sequences, respectively.

Variation of K_2O with SiO_2 for the southern Barby lavas (calc-alkaline) is illustrated by two separate trends in Fig. 13a, the first arising from the basalts and basaltic andesites (steep trend), the second emanating from the andesites, dacites and rhyolites (flat trend). Fig. 13b compares these average trends with those of various Cenozoic circum-Pacific and other selected volcanic provinces. The steep trend for the basalts and basaltic andesites is distinctly steeper than that displayed by many typical calc-alkaline provinces and can be compared to the shoshonitic suite of Fiji (trend 19, Gill, 1970; Fig. 13b). The average trend of the andesite-dacite-rhyolite compositional range is unusual in having a slope similar to the typical calc-alkaline trend of the circum-Pacific provinces, but being considerably richer in K_2O. It is suggested that the southern localities be subdivided on this basis into shoshonitic and calc-alkaline series. Although not presented here, other geochemical data support the presence of a shoshonitic suite.

In Fig. 14, major element oxides are plotted against the Differentiation Index (DI) of Thornton and Tuttle

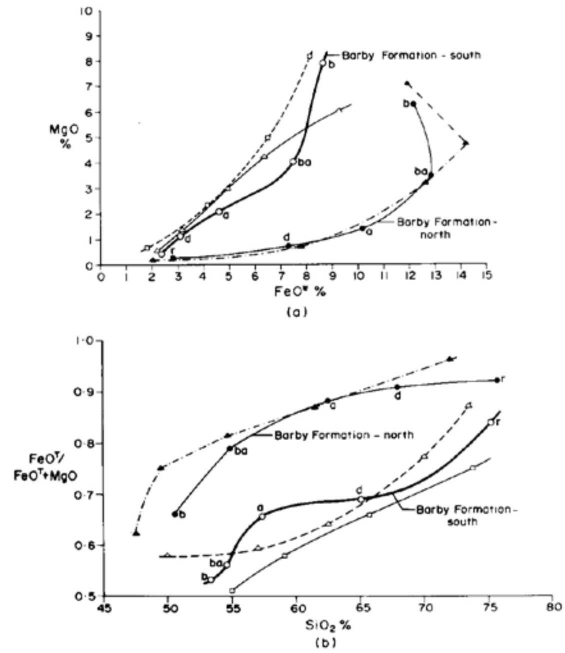

Fig. 12: Plots of (a) MgO against FeO*; where FeO* = 0.9038 x (FeO + Fe_2O_3) and (b) $FeO^T/(FeO^T + MgO)$ against SiO_2; where $FeO^T = (FeO + Fe_2O_3)$.

Data points for figures (a) and (b) represent the arithmetic means of samples of the northern and the southern volcanics that fall in each of the classes defined in the scheme of Peccerillo and Taylor (1976). These have been labelled b for basalt; ba for basaltic andesite; a for andesite; d for dacite; and r for rhyolite. Average trends for some other volcanic suites are included for comparison.

Calc-alkaline: Haib (Reid, 1977); Cascades (Carmichael, 1964). Tholeiitic: Thingmuli (Carmichael, 1964).

△ = Cascade trend;
▲ = Thingmuli trend;
□ = Haib trend;
○ = southern localities Barby trend;
● = northern localities Barby trend.

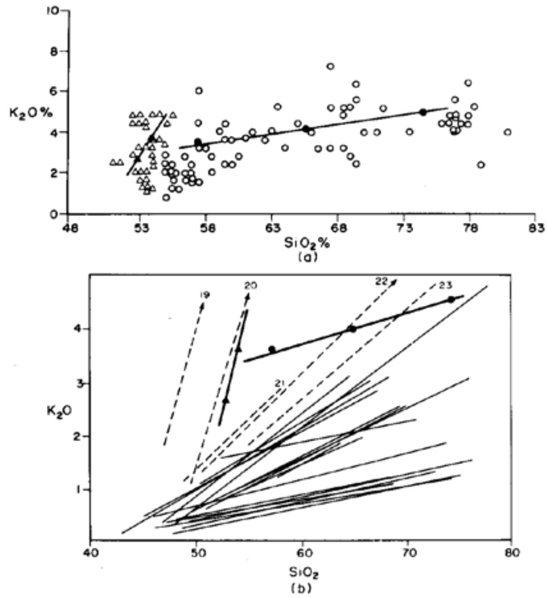

Fig. 13: Plot of K_2O against SiO_2 for the southern area.

(a) Data points and average composition with increasing silica content for basalts, basaltic andesites, andesites, dacites, rhyolites.
△ = shoshonitic suite
○ = calc-alkaline suite
▲ = average compositions for shoshonitic suite
● = average compositions for calc-alkaline suite

(b) Bold lines and symbols as for (a). Thin solid lines are for Cenozoic suites in the circum-Pacific region (Gill, 1970).
19 = Shoshonitic suite of Fiji (Gill, 1970).
20 = Barby Shoshonitic lavas (Watters, 1974).
21 = Salvia (Reid, 1977).
22 = Borrowdale (Reid, 1977).
23 = Haib lavas (Reid, 1977).

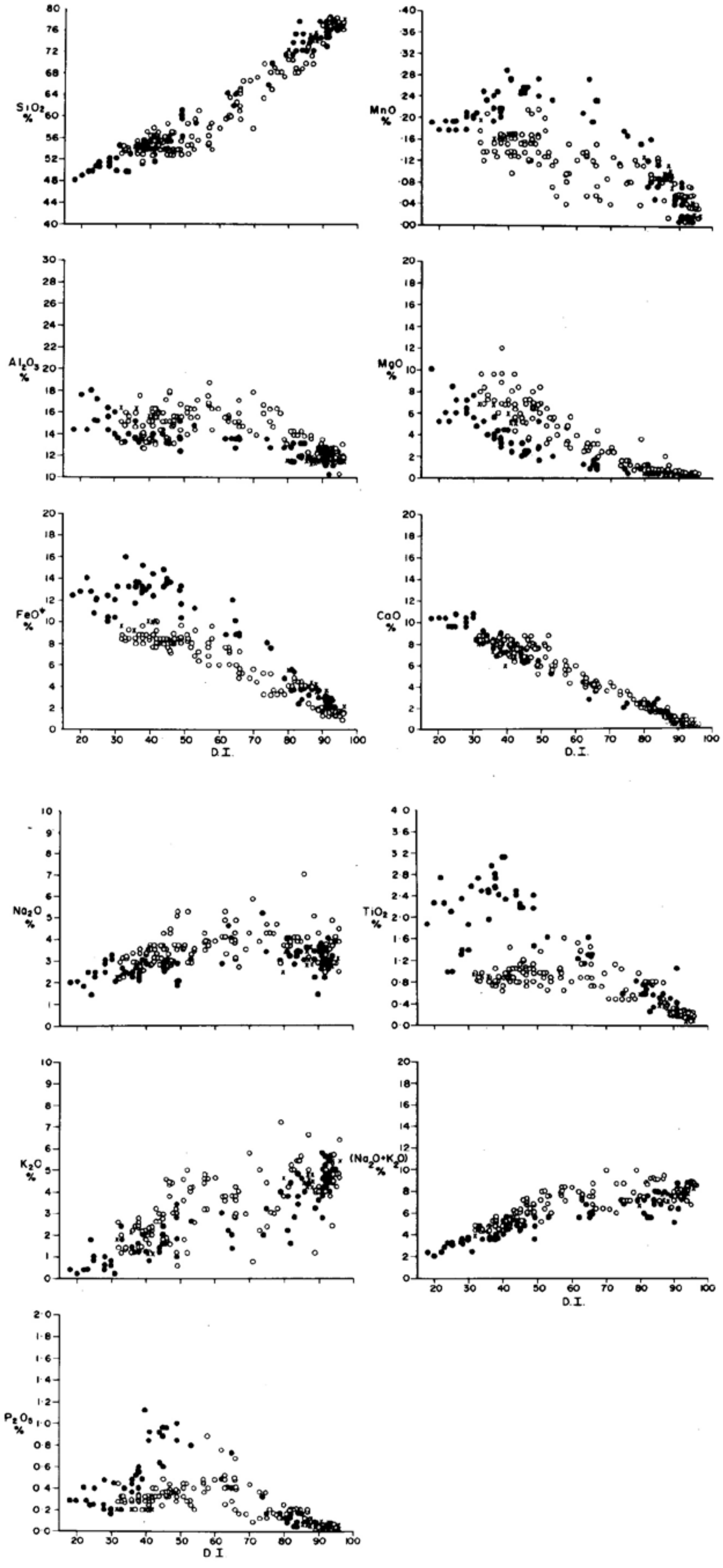

Fig. 14: Plot of major oxides against DI for the Barby lavas.
○ = southern localities;
● = northern localities;
x = Guperas volcanics.

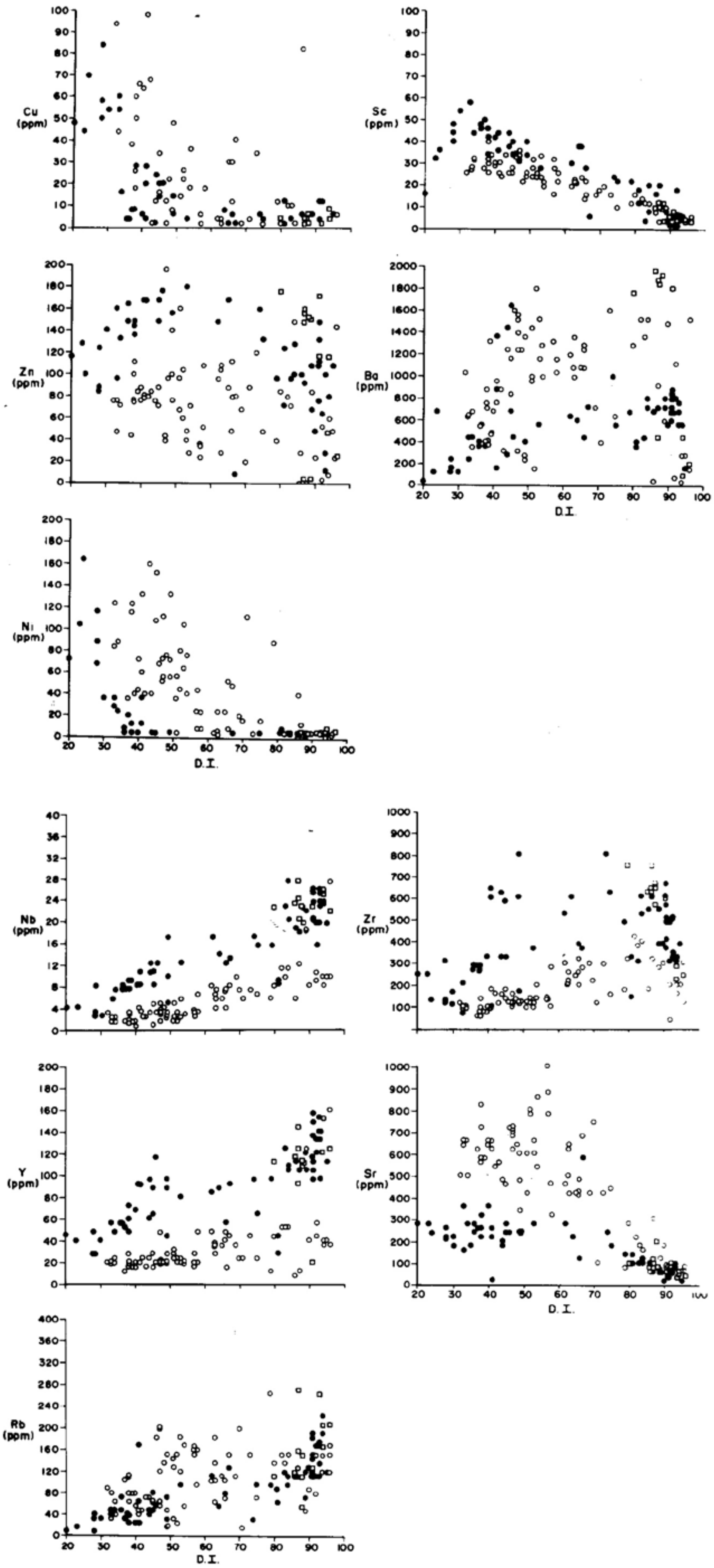

Fig. 15: Plots of selected trace elements against DI for Barby lavas. Symbols as in Fig. 11.

(1960), which can be expressed as the sum of the felsic normative minerals Q + Or + Ab + Ne + Kp + Lc. The alumina plot discriminates between the tholeiitic and calc-alkaline suites, but samples of the shoshonitic series are depleted in Al_2O_3 relative to the calc-alkaline trend. The mafics (less than 50 DI) from the two suites are distinguished by the diagrams showing total iron (expressed as FeO*), MgO, MnO, alkalies, P_2O_5 and TiO_2. Whereas Guperas basaltic andesites appear to lie on the calc-alkaline trend with respect to total iron and TiO_2, they occupy an intermediate position on the MgO diagram. TiO_2 contents have been used to distinguish tholeiitic and calc-alkaline series (Chayes, 1964; Miyashiro and Shido, 1975). Tholeiitic series show enrichment in TiO_2 in basaltic members, a feature which is clearly apparent in the basalts and basaltic andesites from the northern study area.

The plot of CaO exhibits a colinear trend for both the tholeiitic and calc-alkaline suites. Those samples that show a slight deviation from the general trend belong to the shoshonitic suite. Total alkalies show a scattered linear trend, with the calc-alkaline suite having higher alkali contents in comparison to the tholeiitic suite. This plot does, however, reduce the wide scatter seen in the K_2O and Na_2O plots.

3.2 Trace elements

In Fig. 15 selected trace elements are plotted against DI. Niobium allows clear distinction to be made between the two volcanic suites, with the samples from the northern localities having higher Nb contents than those of the southern localities. The Guperas rhyolites group with the tholeiitic northern suite. Yttrium shows a similar, but more scattered, trend. Overall the tholeiitic series has higher Y contents with a distinct enrichment in the rhyolites. Again the Guperas rhyolites group with the tholeiitic suite rather than with the calc-alkaline suite. The plot of Rb exhibits a scatter of data points, but there is an overall increase with DI. A considerable enrichment is apparent within the rhyolites of the tholeiitic suite. The mafic calc-alkaline lavas show a marked Rb enrichment, and can be correlated with a similar enrichment shown in the K_2O diagram (Fig. 13b). Zirconium contents discriminate between the calc-alkaline suite (characterized by low Zr contents with small scatter) and the tholeiitic suite (high Zr content and considerable scatter). The rhyolites of the northern localities show a marked scatter, a feature also displayed by the Guperas rhyolites. The Sr plots show a high degree of scatter but also discriminate between the northern and southern localities. There is, however, a systematic decrease in Sr with differentiation which results in a common grouping for all the rhyolites.

The Cu, Ni, Zn plots have a wide scatter of data points, but show some separation of the two magmatic trends (Fig. 15). Of these, the Ni plot discriminates most clearly between the two suites and illustrates the rapid depletion of Ni during the early stages of differentiation in the basalts. Scandium discriminates well between the two trends with basalts of the tholeiitic suite showing an initial enrichment trend, but decreasing with further differentiation. The calc-alkaline suite has low Sc contents and is negatively correlated with DI. The barium plot shows considerable scatter, with the calc-alkaline lavas exhibiting higher Ba contents than the tholeiitic suite. Six samples of the Guperas volcanics atypically group with the calc-alkaline suite.

The Y-Zr plot (Fig. 16) shows a very close coherence of the data for the calc-alkaline suite. Samples from the tholeiitic suite which contain less than 80 ppm Y define a straight line, but samples with more than 80 ppm Y exhibit a wide scatter. Both suites are either poorer in Y or richer in Zr with respect to chondritic Zr/Y values. The calc-alkaline suite has an exceptionally high Zr/Y ratio of 6.4 compared to the average chondritic value of 2.5, and it is suggested that Y may have been removed as a result of early amphibole fractionation. It is also significant that the observed Zr/Y ratios are more akin to those reported for continental rift basalts than for island arc basalts.

4. SUMMARY AND CONCLUSIONS

The typical Barby Formation is apparently restricted to the differentiated suite of porphyritic lavas developed in the southern portion of the study area and the ‘Barby’ Formation cropping out in the northern portion has distinctly different chemical and petrological characteristics.

The southern sequence shows a calc-alkaline trend and ranges in composition from basalt to basaltic andesite, through andesite and dacite to rhyolite. Associated with this suite is a highly fractionated shoshonitic suite which dominates the basalt to basaltic andesite compositions. The southern sequences appear to have been deposited into yoked basins, but there is still insufficient evidence to relate the depositional controls to a particular geotectonic environment. Copper mineralization, the most notable economic prospect of the Sinclair Sequence, is developed only in the southern region.

The northern volcanic sequences illustrate a bimodal distribution of basalt and rhyolite, which may be related by a tholeiitic trend. The rhyolites of this sequence have petrological and chemical similarities to those in the Guperas Formation, the latter formation overlying the Barby volcanics in the south. However, the basaltic andesites of the Guperas Formation cannot be related to similar rock-types in either the southern or the northern areas.

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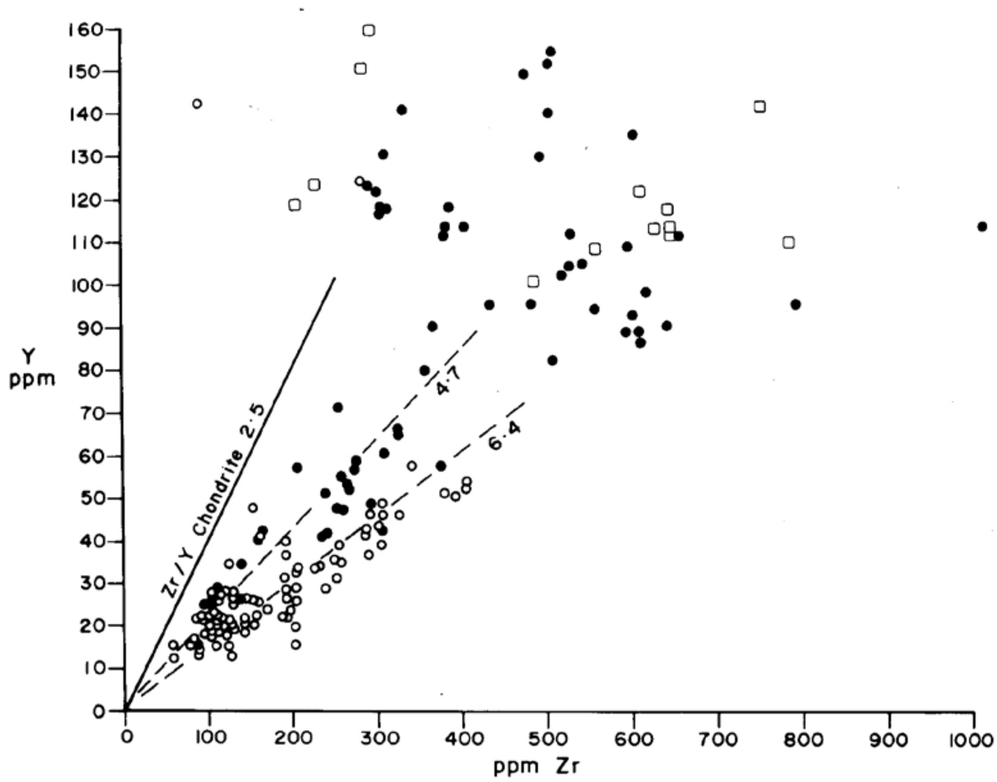

Fig. 16: Plot of Yttrium against Zirconium. Symbols as in Fig. 11.

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