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JOHANNESBURG

CONTEMPORANEOUS SEDIMENTATION AND VOLCANISM AT THE BASE OF THE EARLY PRECAMBRIAN NSUZE GROUP, SOUTH AFRICA

by

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ECONOMIC GEOLOGY RESEARCH UNIT
INFORMATION CIRCULAR No. 142
February, 1980

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ABSTRACT

Arenaceous sediments, with intercalated lenses of volcaniclastites and lavas, comprise an 800 m thick sequence at the base of the circa 3 000 Ma Nsuze Group. The volcanics range in composition from basaltic andesite to rhyolite and the sandstones are characterized by trough and planar cross-stratification displaying a unimodal palaeocurrent distribution. The sandstones are predominantly quartz wackes which contain lenticular matrix-supported conglomerates. Deposition is thought to have taken place in a distal braided stream environment which derived sediment from a granitic source terrane located towards the west. Rapid lateral migration of the facies tract suppressed the development of vertical accretionary deposits. Away from the major channels, sheet flood sequences accumulated in response to high precipitation. The presence of volcanogenic sediments and volcanic bombs, lapilli, and chert stringers in the sedimentary rocks, provides evidence of coeval sedimentation and extrusion.

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Published by the Economic Geology Research Unit,
University of the Witwatersrand,
1 Jan Smuts Avenue,
Johannesburg.

ISBN 0 85494 618 7

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I. INTRODUCTION

The early Precambrian Pongola Supergroup, which straddles parts of the eastern Transvaal, Swaziland and northern Natal (Figure 1), consists of a lower, predominantly volcanic Nsuze Group overlain by the Mozaan Group, the latter being composed mainly of sedimentary rocks. The Nsuze Group comprises a basal sedimentary-volcanic unit (this study) overlain by a thick sequence of basalts, andesites, dacites and rhyolites which together attain a maximum thickness of 7 000 m (Armstrong, in preparation). The Mozaan Group contains fluvial, marginal marine and shelf sediments with minor volcanic intercalations (Watchorn, 1979).

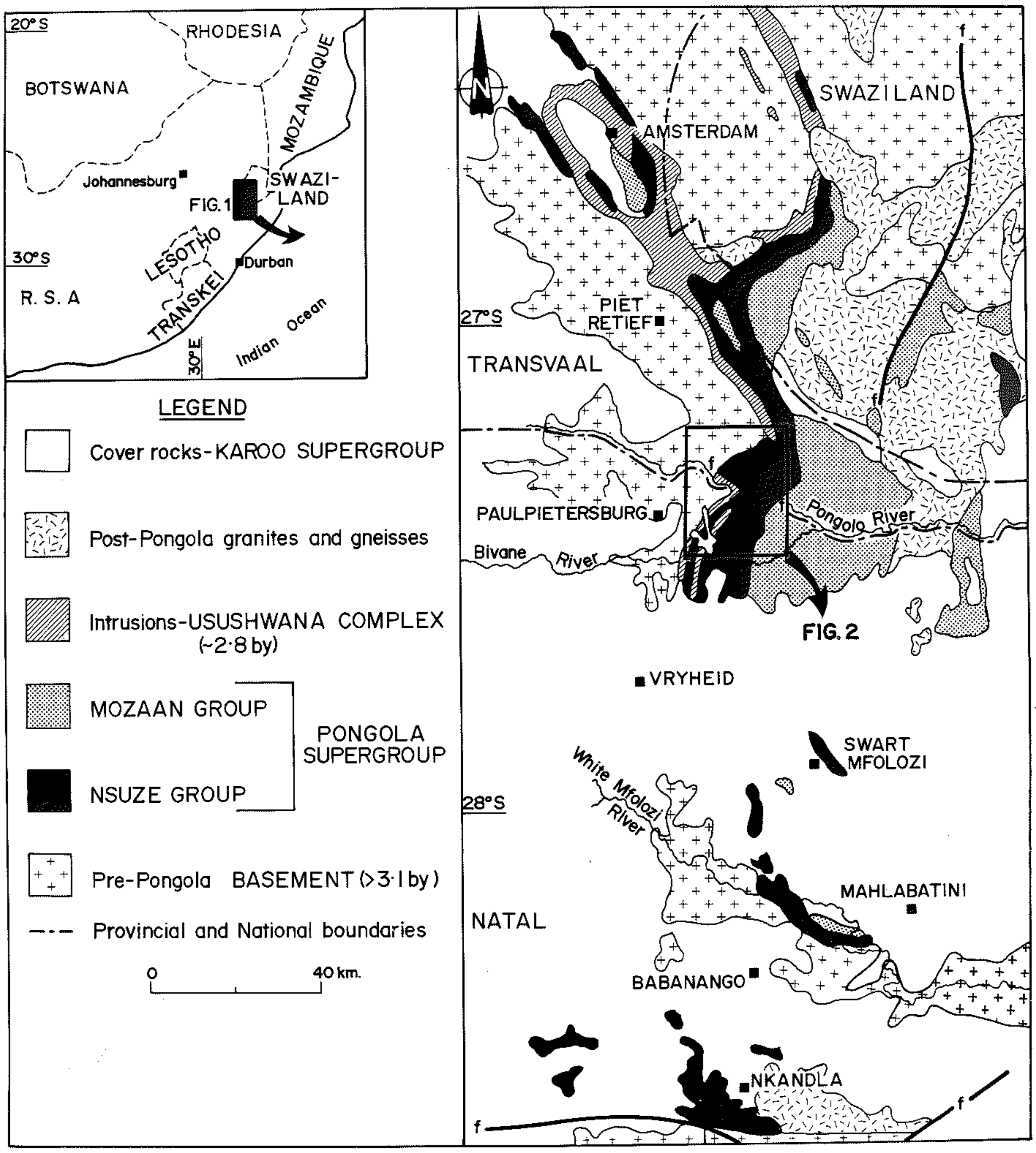

Figure 1 : *Map showing the location of the area described in this study and the distribution of the Early Precambrian Pongola Supergroup and associated intrusive rocks.*

Prior to this study there had been no previous sedimentological analysis of the clastic rocks of the Nsuze Group which rest on a palaeoregolith derived from the underlying granitoid basement (Matthews and Scharrer, 1968).

Geochronological studies carried out on a pre-Nsuze granite yielded an U-Pb age of 3 230 ± 80 Ma (Burger and Coertze, 1973), which is a maximum age limit for the Pongola Supergroup. Zircons from Nsuze lava gave an U-Pb age of 3 090 ± 90 Ma (Burger and Coertze, 1973). The Usushwana Complex, which intrudes the Pongola Supergroup, has been dated at 2 870 ± 30 Ma (Davies et al., 1970), and it appears reasonable to assume that the latter succession has an age of between 2 900 and 3 100 Ma.

In the study area the Nsuze Group is exposed on the gently dipping, western limb of a major southeasterly plunging synform (Figure 2). In most of the region Nsuze rocks are underlain by non-intrusive granitoids, but in the northern part of the map-area (Figure 2A), a thin sequence of basic volcanics intervenes between the granitic basement and the basal sedimentary-volcanic unit. On the basis of their lithological and chemical similarities to the Nsuze Group volcanic rocks, it is thought that these lavas reflect an early, but limited, extrusive episode related to Nsuze volcanism. These basic lavas are, in turn, intruded and deformed by the Usushwana Complex.

The lower sedimentary-volcanic unit of the Nsuze Group is best exposed over a 15 km strike length north of the Pongola River (Figure 2A). In other areas the continuity of outcrop is masked by a cover of Karoo rocks or is disrupted by the widespread intrusion of rocks related to the Usushwana Complex. Previous studies documented the sequence as comprising 800 m of epiclastic sediments (Humphrey and Krige, 1931; Matthews and Scharrer, 1968). This investigation has revealed, however, the presence of contemporary volcanicity during the deposition of the basal sediments.

Lenticular volcanic and volcaniclastic beds are developed in the basal succession which attains a maximum thickness of 800 m in the White River area (Figure 2). The sandstones are generally quartz wackes and, more rarely, quartz and arkosic arenites. Thin conglomerate horizons are present and argillaceous deposits are infrequently developed. Most of the volcanic rocks are basaltic andesites but range in composition to rhyolites (Armstrong, in preparation).

The preservation of undeformed pebbles, amygdales and vesicles indicates that the Nsuze Group has been subjected to only low intensity strain. However, a pervasive southeasterly axial cleavage is related to the major synformal development. In some of the tuffaceous units a flat-lying crenulation cleavage is apparent. This is considered to have formed in response to gravitationally-induced vertical shortening during burial.

The major volcanics in the Nsuze Group are characterized by the mineral paragenesis; tremolite/actinolite-albite-chlorite-zoisite/clinozoisite-quartz±epidote±calcite±sphene±biotite± leucoxene. The felsic volcanics contain the assemblage quartz-albite-sericite-biotite±calcite± zoisite/clinozoisite±K-feldspar. These mineral assemblages indicate the metamorphic grade to be in the low temperature part of low-grade regional metamorphism (Winkler, 1974). The added presence of chloritoid in the basal clastic sediments is consistent with this grade of metamorphism.

II. SEDIMENTOLOGY

Sedimentary structures are generally poorly preserved in the rocks of the basal Nsuze Group. This is attributed to the inherent instability of the wackes (due to differences in physical properties between quartz grains and the surrounding matrix), rather than being a primary depositional feature. Recrystallization and the growth of new minerals during low grade metamorphism are thought to have also been contributing factors. Nevertheless, sufficient directional and textural data are available to make at least a tentative environmental interpretation.

The basal sandstones form a thick tabular unit, which thickens slightly towards the north (Figure 3). The majority of these sandstones are immature and medium- to very coarse-grained with thin intercalated grits and conglomerates. Occasionally the conglomerates overlie an irregular erosion surface at the base of a 1-2 m upward-fining cycle. Isolated pebbles are scattered throughout the sequence. These features, in association with the prevalence of unimodal palaeocurrents (Figure 3) and the underlying palaeosoil, all point to deposition in a fluvial regime (Long, 1978). Furthermore, the paucity of fine-grained clastics suggests that the system was braided (Miall, 1977).

A. Cross-Stratification

Trough cross-beds are the most commonly encountered sedimentary structures. They generally occur as superimposed sets, having an average set thickness of 20 cm (Plate 1A). Similar structures have been identified in the South Saskatchewan River, where they were deposited in the deeper channels during the downstream migration of sinuous-crested dunes (Cant, 1978; Walker and Cant, 1979). Cosets of trough cross-beds resulted from aggradation during high water. Isolated subrounded pebbles, up to 20 cm in diameter, and consisting predominantly of vein quartz and chert, are associated with the trough cross-bedded sandstones. The rarity of these pebbles is thought to be a function of clast availability in the source terrain.

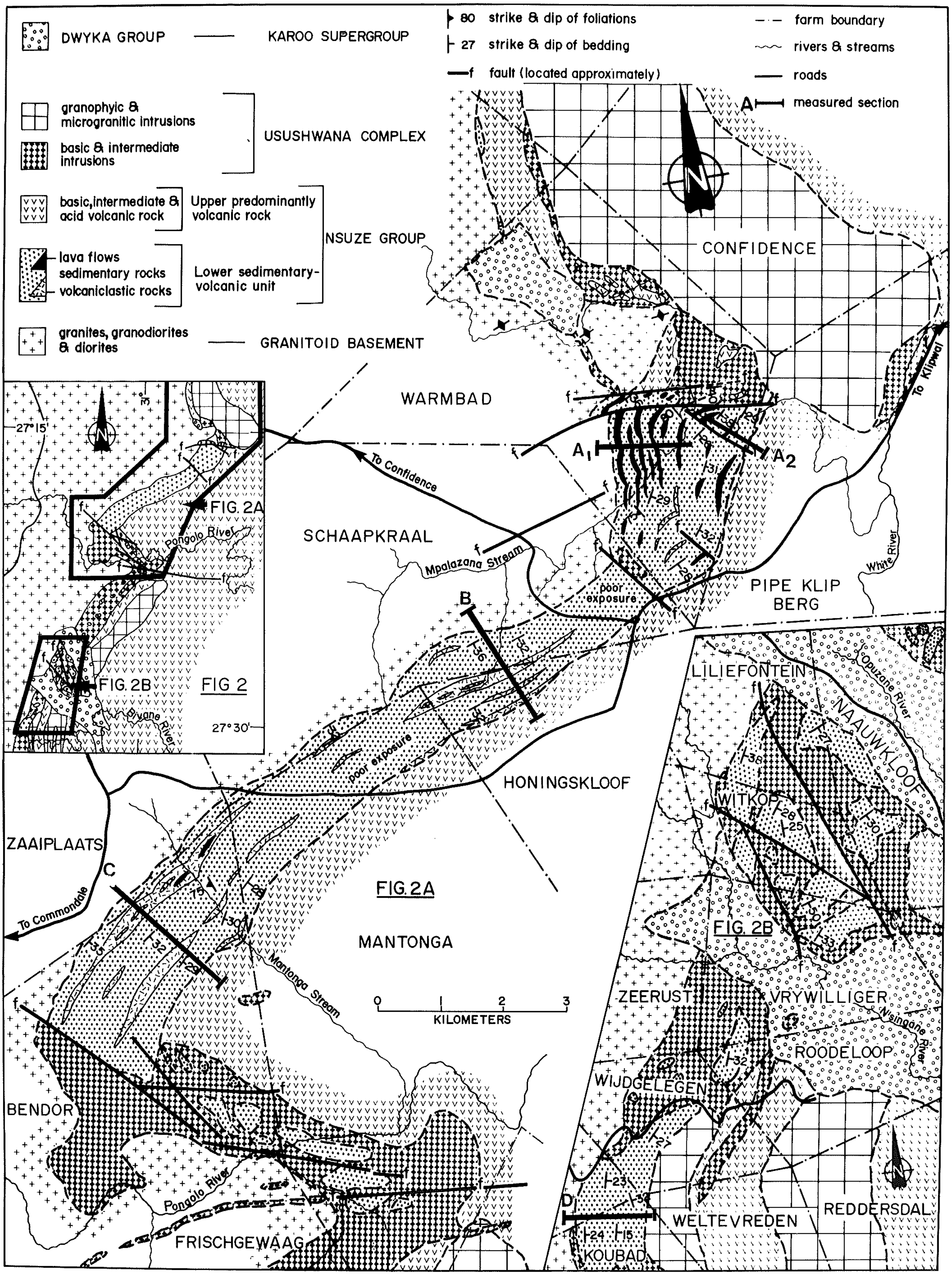

Figure 2 : *The geology of the basal Nsuze Group in the southeastern Transvaal and northern Natal.*

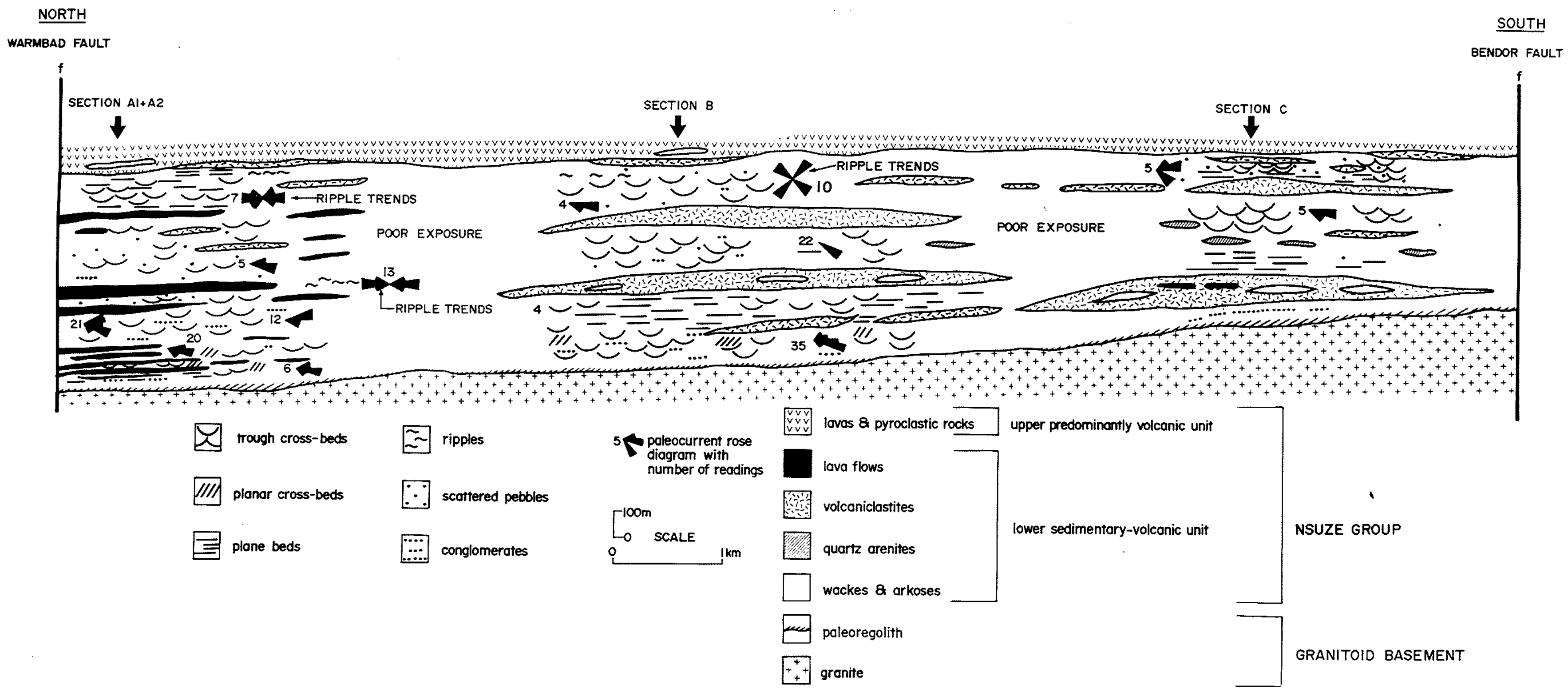

Figure 3 : Sedimentology of the lower sedimentary-volcanic unit of the Nsuze Group between the Warmbad and Bendor faults.

Solitary sets of planar cross-stratification are intercalated within trough cross-bedded units. The sets are up to 40 cm thick and have an angular relationship with the underlying strata. In braided streams, planar foresets are indicative of the formation of transverse bars (Smith, 1970; Miall, 1977), which build laterally into active channels (Cant and Walker, 1976). Some of the planar foresets comprise normally graded couplets (Plate 1B). Similar features, described in the Platte River, Nebraska, developed during transverse bar accretion in response to dunes migrating over the bar-top (Smith, 1972).

On a regional scale, palaeocurrent rose diagrams and calculated vector means (Figure 3; Table 1) indicate a palaeoflow direction varying between northeast to southeast. However, at individual outcrops, palaeocurrent data display a high consistency ratio and a low variance (Table 1). This suggests that the fluvial system drained an undulating terrain (Turner, 1977), whereas individual channels were persistent linear features. The angular discordance in directional data from trough foresets, with that from planar cross-beds, has previously been ascribed to the lateral growth of transverse bars (Cant and Walker, 1976; 1977).

B. Plane Bedding

Thick sequences of plane beds frequently occur stratigraphically above trough cross-bedded units (Plate 1C). The sandstones containing these structures are generally finer-grained than the cross-bedded variety and are devoid of pebbles. Similar sediments have been described from ephemeral streams where deposition occurs in shallow water under upper flow regime conditions (McKee et al., 1967; Picard and High, 1973; Boothroyd and Ashley, 1975). The absence of primary current lineation is attributed to the degree of recrystallization undergone by the Nsuze Group.

C. Ripples

Current ripples are confined to the medium-grained sandstones, since they are not generated in coarser sediment (Harms et al., 1975). Both straight and sinuous crested varieties are present (Plate 1D). Picard and High (1973) recognized these bedforms in ephemeral streams, the sinuous types being developed within channels, whereas the linear ripples were found restricted to the tops of cross-channel bars. Some sinuous ripples display flattening of the crests (Plate 1D), which is attributed to a planing effect by subsequent laminar flow or wind deflation. Occasional adhesion ripples are exposed (Plate 1E) which are believed to indicate subaerial emergence (Reineck and Singh, 1973). Therefore, these structures probably formed on bars during falling water stage. The fact that current ripples in the Nsuze Group are poor indicators of flow direction (Figure 3) may be due partly to their formation during falling water when the flow direction is not parallel to the channel axis, due to the emergence of bars.

TABLE 1

PALAEOCURRENT DATA FOR THE LOWER UNIT OF THE NSUZE GROUP

Station	Section	No. of Readings	Vector Mean (Degrees)	Consistency Ratio (%)	Standard Deviation (Degrees)	Variance
4	A2	5	101	90	12,70	161,24
3	D	22	127	90	25,96	673,92
5	D	12	125	90	29,38	863,18
6	A1	20	89	87	29,22	853,81
2	A1	3	113	95	17,59	309,41
4	A1	3	89	99	9,43	88,92
8	A1	6	78	91	35,66	1 271,64
9	A1	15	84	81	36,77	1 352,03
11	A1	4	63	96	15,99	255,68
12	A1	8	72	87	28,01	784,56
5	C	5	91	86	30,23	913,85
3/2	C	5	110	94	15,23	231,95
4/6	B	6	125	97	13,62	185,50
2	B	4	117	96	15,53	241,18
1	B	35	119	96	27,33	746,93

Sections A1, A2, B, C, see Figure 2A and Figure 3.
Section D, see Figure 2B.

D. Conglomerates

A large proportion of the conglomerates are matrix-supported within which clast-supported phases are developed (Plate 1F). The conglomerates have a maximum thickness of 50 cm and are best developed in the lower portion of the basal sediments (Figure 3). Subrounded to subangular vein quartz and chert pebbles are the most frequent, whereas occasional granite and lava clasts are also present. The matrix is generally a very-coarse to gritty quartz wacke, indicating rapid deposition with little reworking.

The recurrence of these lenticular conglomerates suggest that they were deposited as lags within a hydrodynamically fluctuating system. Within individual channels, vertical accretion resulted in the construction of longitudinal bars and occasional thin upward-fining sequences (Cant and Walker, 1976).

The higher proportion of conglomerates at the base of the sequence suggests a gradual denudation of the provenance area through time. Clast composition of the conglomerates and the geology of the region (Figure 2) indicate that the source area was a granite-greenstone terrane, although some of the detritus may have been locally derived from volcanic centres.

E. Mudstones

Significant thicknesses of argillaceous sediments are notably absent. This is probably due to rapid channel migration with subsequent erosion of overbank deposits (Walker and Cant, 1979). It is also attributed to the lack of bank stability in pre-vegetation times (Schumm, 1968).

The only mudstones observed were drapes over ripple cross-laminated sandstones (Plate 2A). These sediments have a maximum development of about 2 m and are thought to represent lower flow regime conditions at the edge of an active fluvial tract. Similar deposits have been recognized in the Battery Point Sandstone, Canada, where they were interpreted as an overbank accumulation (Cant and Walker, 1976).

III. VOLCANIC AND VOLCANICLASTIC ROCKS

Rocks of volcanic origin, intercalated with the arenaceous sediments at the base of the Nsuze Group, include both flow and fragmental varieties. The lava flows are mainly restricted to exposures in the northern part of the map-area (Figures 2 and 3). Volcaniclastites include both pyroclastic rocks and volcanogenic sediments. The pyroclastics comprise air-fall tuffs, welded ash-flows and agglomerates. Volcanogenic sediments are composed of reworked pyroclastic deposits mixed with sedimentary material during deposition. The influence of volcanic activity decreases towards the south as no evidence of volcanogenic deposits could be found in the southernmost exposures of the lower Nsuze Group unit (Figure 2B).

The predominance of lava flows in the north of the area, with an increase of volcaniclastites southwards, indicates a northerly disposition of extrusive centres. Pyroclastic accumulations in the south are mainly finely tuffaceous and probably reflect deposition considerably removed from the source. The fine-grained character of the deposits possibly results from winnowing by wind action during transportation.

A. Lava Flows

The classification of the lava flows is based on the reconstituted metamorphic mineralogy, combined with chemical criteria (Streckeisen, 1979). They range in composition from basaltic andesite through andesite and dacite to rhyolite and are quartz normative. The flows are generally laterally impersistent and vary from 2-30 m in thickness. Amygdaloidal, vescicular, and porphyritic textural types are common within the basic and intermediate varieties. The rhyodacitic and rhyolitic flows are characterized by spherulitic textures believed to be devitrification products derived from an originally glassy, felsic component. Devitrification growths vary in morphology and include dendritic strands and quartz-feldspar intergrowths resembling bowties. Spherical clusters of radiating intergrowths represent advanced stages of devitrification (Lofgren, 1971).

B. Pyroclastic Rock Types

The pyroclastic rocks are mainly represented by air-fall tuffs but include some minor agglomeratic phases and a welded ash-flow unit.

1. *Air-fall Tuffs*

These tuffs are compacted rocks with fine- and coarse-grained varieties, in places showing a well-defined stratification. Tuffaceous horizons are up to 120 m thick and contain agglomeratic zones and intercalated lava flows and sedimentary units. They are composed predominantly of lithic and crystal fragments (< 4 mm in diameter) embedded in a fine-textured matrix composed of volcanic ash and dust. The original nature of the finely divided tuffaceous material is often obscured by secondary alteration. Tuffs containing a high proportion of crystal fragments probably reflect an advanced stage of crystallization of the magma at the time of the explosive outburst.

2. *Agglomerates*

Agglomerates occur in localized zones sporadically developed within the tuffaceous horizons. They are composed of heterolithic rounded-to-ellipsoidal clasts representing stream-lined magma clots ejected during explosive eruptions. Variations in clast composition and texture reflect derivation from a diverse source. Angular, accidental sedimentary fragments within some zones represent country rock ripped up in the region of a vent.

3. *Welded Ash-flows*

A 10 m thick acid volcanic unit, exposed in Section A1 (Figure 2A), shows some features indicative of a welded ash-flow origin. This rock is interpreted as having been deposited by flowage of a turbulent mixture of gas and pyroclastic material (Ross and Smith, 1961).

Discontinuity of outcrop limits the study of the unit. Devitrification, metamorphism and recrystallization have obliterated most of the originally vitroclastic nature of the rock and have destroyed many of the features diagnostic of welded tuffs. The pyroclastic material includes plagioclase and quartz crystals, some lithic fragments, as well as collapsed and flattened pumice inclusions. The crystals may be arranged with their long axes perpendicular to the bedding. Devitrification products, forming thin bands and layers of granular crystals, appear to outline a primary foliation, possibly representing originally welded, stretched out and flattened glass fragments. The wrapping of these bands around crystal inclusions indicates a degree of compaction. Coarse, polyhedral crystal aggregates have either crystallized from a vapour phase prior to consolidation or result from subsequent devitrification. Deformation of devitrified glass and pumice fragments is considered to be an indication of welding (Ross and Smith, 1961). Crystals oriented perpendicular to the bedding, lithic and pumice fragments showing signs of welding, and compaction, together serve to distinguish these welded tuffs from the normal lava flows.

4. *Volcanogenic Sedimentary Rocks*

Volcanogenic sediments include two types: (i) coarse lithic wackes derived from semi-consolidated pyroclastic accumulations that are identified by coherent fragments composed of tuffaceous material within a matrix of sedimentary origin (Plate 2B, C and D). (ii) wackes formed either by the contribution of pyroclastic material directly from the air into the sub-aqueous environment, or by reworking of unconsolidated tuffaceous deposits. These volcanogenic sediments are deficient in quartz and are made up largely of finer-grained pyroclastic material with occasional lithic fragments. In places they can be seen to grade into unequivocal air-fall tuffs. In both cases pyroclastic material has been reworked and mixed together with detrital fluvial sediment during deposition.

IV. SEDIMENTARY-VOLCANIC INTERRELATIONSHIP

The geometric relationship between the fluvial sandstones and intercalated lenses of extrusive rocks (Figure 3) indicates contemporaneous sedimentary deposition and volcanicity. This is borne out by the presence of occasional pyroclastic bombs and lapilli explosively ejected into the adjacent clastics. Towards the top of section A1 (Figure 2A), discrete, elongated lenses of amorphous chert, up to 15 cm in length, are concentrated over a 3 m stratigraphic thickness within the sediments. These lenses are always concordant with the bedding, suggesting that they are not pebbles, but may represent colloidal precipitates related to nearby volcanicity. They occur within sediments interpreted as overbank accumulations and hence have a low preservation potential.

The contact between sedimentary beds and lava flows is generally sharp, with the fluvial sediments erosional into the underlying volcanic rock (Plate 2E). The observed contacts of lavas resting on sedimentary rock are chilled and slightly autobrecciated against the sediment. Very little mixing takes place along these boundaries. The contact between the volcaniclastites and the fluvial sediments is generally gradational with the development of volcanogenic sediments in the transitional phases.

V. PALAEOENVIRONMENTAL RECONSTRUCTION

The nature of the clastic rocks at the base of the Nsuze Group indicate deposition in a distal braided stream environment, similar to the South Saskatchewan model constructed by Miall (1978) and Walker and Cant (1979). The high proportion of trough cross-stratification suggests that individual channels had low sinuosity (Eriksson, 1978), although overall sedimentation was influenced by undulating topography. The generation of a tabular sandstone, with minimal associated mudstones, attests to the rapid lateral migration of channels in what was probably a tectonically active environment. A modern analogue is the Kosi River, in the foothills of the Himalayas, which may shift up to 30 km annually (Reineck and Singh, 1973).

The major river channels were dominated by migrating dunes with transverse bars developed in the shallower reaches. Gravel lags were deposited within the channels, which occasionally aggraded into low longitudinal bars. Away from the channels, thin overbank deposits accumulated but these apparently had a low preservation potential. Sheet wash in response to high precipitation was uninhibited, due to the lack of vegetation, and was probably not confined to the major channels. This resulted in the development of sequences similar to the Bijou Creek deposits (McKee et al., 1967). The vertical relationship between channel and flood sediments is attributed to changes in the locus of deposition. Lenticular quartz arenites (Figure 3) possibly represent major channels which were occupied for extended periods with subsequent reworking.

The volcanic rocks were extruded from vents located to the north of the map-area. The lava flows are thin and impersistent and probably extruded from crater cones or small fissures. The limited volume of the ash-flow unit indicates an immediate origin within a volcanic cone or dome. Pyroclastic material was erupted high into the air from vents situated on land or in shallow water. During wind transportation, these fragmental ejections were winnowed prior to deposition on the braided alluvial plain. Volcanogenic sediments resulted from the reworking and mixing of pyroclastic debris with fluvial detritus.

Hence, the concomitance between sedimentary deposition and volcanicity (Figure 4) resulted in the volcanics providing some of the detritus. However, the volume of volcanic rock is insufficient to have supplied all the sediment, the bulk of which must have been derived from a granite-greenstone terrane.

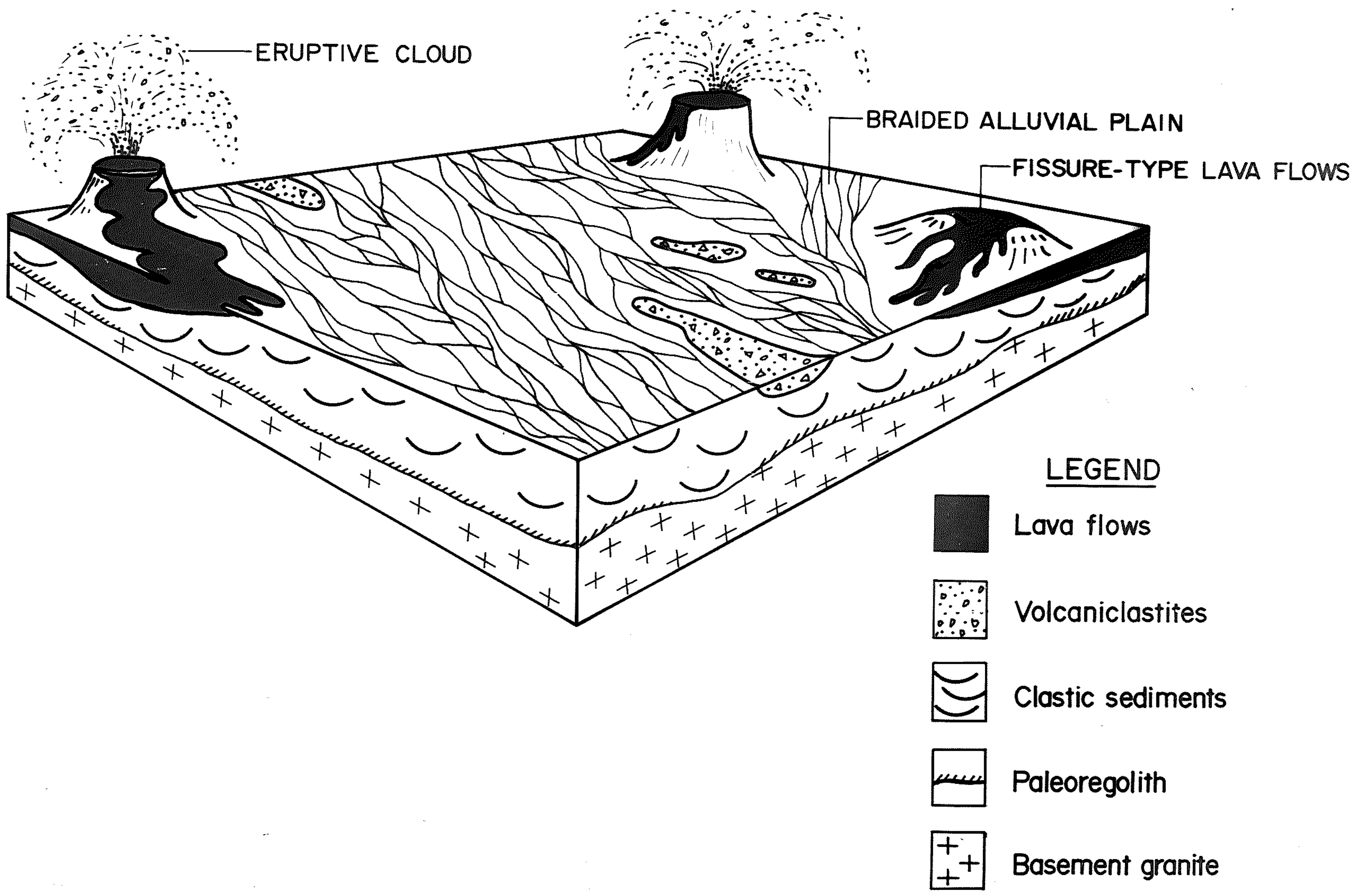

Figure 4 : *Diagrammatic palaeoenvironmental reconstruction of the lower sedimentary-volcanic unit of the Nsuze Group.*

VI. CONCLUSIONS

The development of a palaeosoil, overlain by a thick sequence of fluvial sediments, indicates the emergence of a stable crust in the eastern part of southern Africa, prior to the formation of the Nsuze Group. Downwarping of this predominantly granitic crust, with the simultaneous uplift of adjacent areas, led to the initiation of the Nsuze depository. The resultant gradient differential caused physical weathering of the elevated terrane, which was drained by a braided alluvial system. The tectonic adjustments brought about fracturing of the rigid granitic basement with the subsequent extrusion of lavas and associated pyroclastics. Repeated uplift in the source region resulted in renewed influxes of immature clastic sediments accompanied by continued volcanism. Denudation of the provenance area probably contributed to the termination of fluvial activity. The extrusion of large volumes of volcanic material and a slow rate of subsidence in the depository, probably also resulted in conditions unfavourable for the development of extensive sedimentary deposits at higher stratigraphic levels in the Nsuze Group.

ACKNOWLEDGEMENTS

One of us (N.V.A.) is grateful to the University of Natal and the C.S.I.R. for financial assistance. In addition thanks are due to Mrs. L. Le Roux and Mr. P. Seyambu for technical aid.

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KEY TO PLATE 1

A. Transverse view of superimposed sets of trough cross-stratification.
Locality, Section D, Figure 2B.

B. Longitudinal section of graded planar cross-stratification.
Locality, Section A1, Figure 2A.

C. Upper flow regime plane bedded sandstone.
Locality, Section C, Figure 2A.

D. Sinuous current ripples displaying flattened crests.
Locality, Section A2, Figure 2A.

E. Adhesion ripples.
Locality, Section A1, Figure 2A.

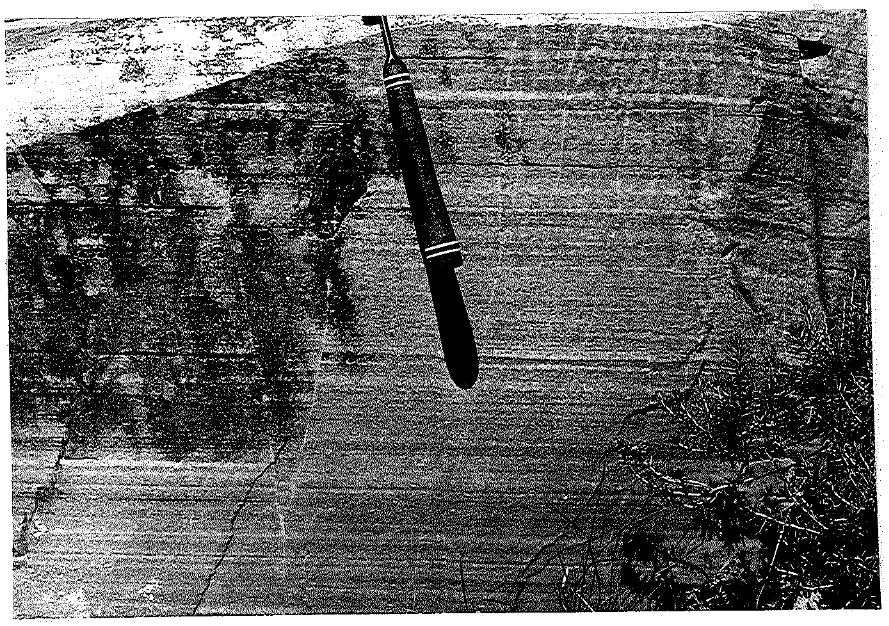
F. Poorly sorted matrix supported conglomerate.
Locality, Section A2, Figure 2A.

PLATE 1

A

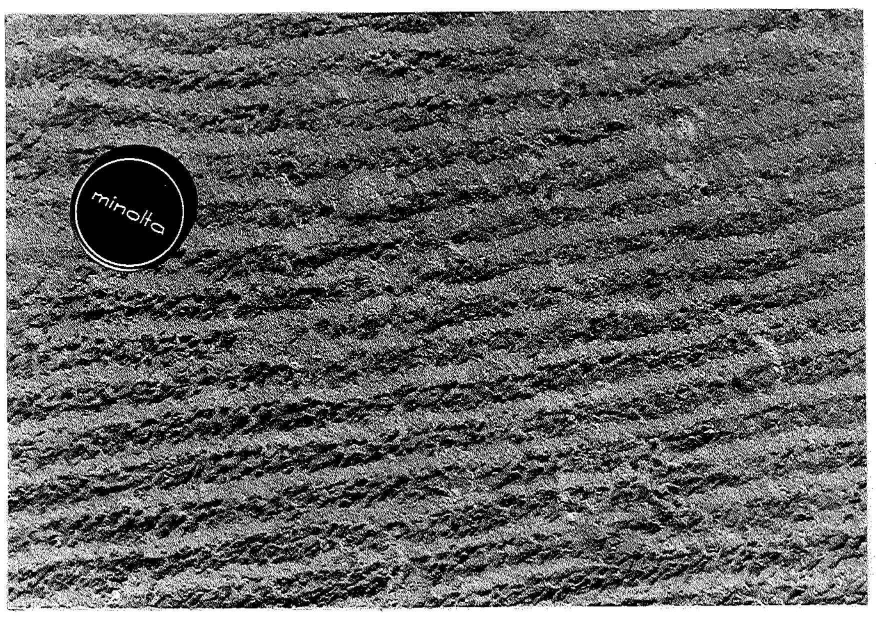
B

C



D

E



F

KEY TO PLATE 2

A. Ripple cross-laminated sandstone with mudstone drapes.
Locality, Section A1, Figure 2A.

B. Lithic wacke containing tuffaceous fragments in a clastic sedimentary matrix.
Locality, Section B, Figure 2A.

C. Heterolithologic tuffaceous clasts within a clastic matrix.
Locality, Section B, Figure 2A.

D. Volcanic bombs and lapilli within a clastic sedimentary matrix.
Locality, Section A2, Figure 2A.

E. Fluvial sediments erosively overlying an earlier lava flow.
Locality, Section A1, Figure 2A.

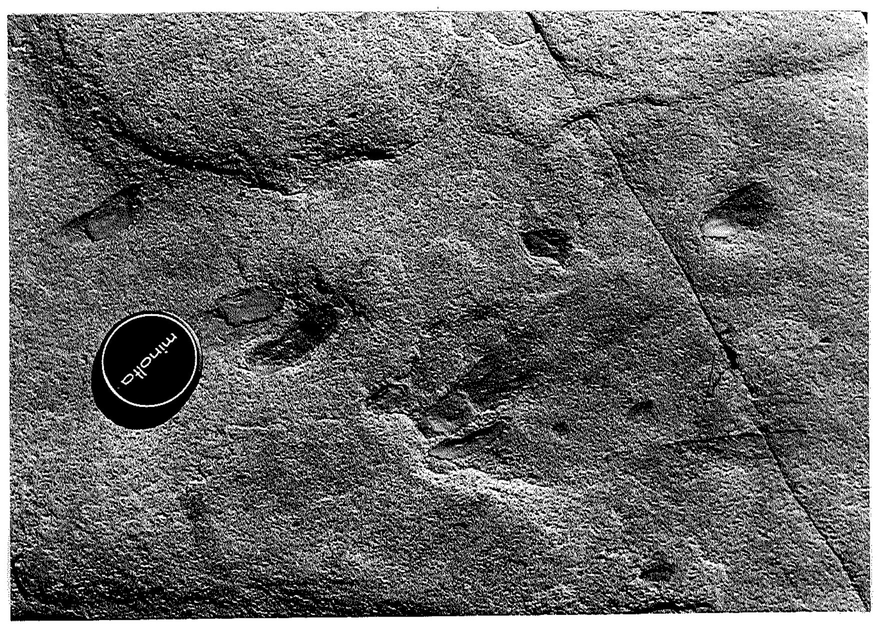
PLATE 2

A

B

C

D



E