ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

CORRELATION, STRATIGRAPHIC RELATIONS, AND GEOCHEMISTRY OF THE VENTERSDORP SUPERGROUP IN THE DERDEPOORT AREA, WEST-CENTRAL TRANSVAAL

N. TYLER

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by

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ABSTRACT

Exposed to the east of the Botswana border, in the vicinity of Gaborone, is a sequence of sediments, basalts, and rhyolites, which has been correlated with the Ventersdorp Supergroup. The 70 km-long succession has been divided into three belts - the Tshwene-Tshwene, Soekangwana, and Derdepoort belts - all of which are unconformably overlain by the Black Reef Quartzite. The Derdepoort belt is preserved in a post-Black Reef graben. Almost the full Ventersdorp succession is preserved in the west-central Transvaal. It is represented by a basal, basaltic zone, over 2 000 m thick (correlated with the Klipriviersberg Group) an 1 100 m thick chaotic, alluvial-fan deposit (correlated with the Kameeldoorns Formation), a zone of acid volcanics (correlated with the Makwassie Quartz Porphyry Formation), and an upper, meandering-stream-flood-plain sedimentary zone (correlated with the Bothaville Formation).

The basal volcanics of the Ventersdorp Supergroup in the west-central Transvaal (the lower volcanic zones of the Derdepoort and Tshwene-Tshwene belts) have a major-element geochemistry that compares favourably with continental tholeiitic basalts, although the Ventersdorp basic lavas are relatively enriched in K_2O but deficient in Al_2O_3. The acid lavas of the Derdepoort and Seokangwana belts correspond, in a general way, to the average composition of rhyolite and to the composition of the Lebombo rhyolite, although differences in the major-element chemistry of the various felsites exist. A trend towards extreme alumina-oversaturation is present in the lavas which are also enriched in K_2O but deficient in Na_2O and CaO. It is concluded that the felsites have undergone alteration, possibly during lower greenschist metamorphism, in which the loss of Na and Ca from the system accounted for the Al-oversaturation.

Consideration of the regional structure of the Transvaal suggests that the Ventersdorp Supergroup of the west-central Transvaal and southeastern Botswana was deposited in a southeast-trending downwarp, for which the name Swartruggens trough has been proposed. As the distribution of the Kanye Volcanic Group is apparently restricted to the limits of the Swartruggens trough, it has been tentatively suggested that the Kanye volcanics may constitute the proto-basinal phase of the Ventersdorp Supergroup.

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I. INTRODUCTION

In the west-central Transvaal, the Ventersdorp Supergroup outcrops in three distinct belts :

(i) the Derdepoort belt which extends southeastwards from the Marico River (the border with the Republic of Botswana), in the vicinity of Derdepoort, for approximately 25 km (Figure 1); this belt has a maximum width of 6 km;

(ii) the Tshwene-Tshwene belt which is a continuous, east-west-striking belt of exposures that extends from west of the Ganskuil platform for 43 km and pinches out above the Gaborone Granite Complex (Figure 1), where it is overlain by the Seokangwana belt; this belt has a maximum width of 6,5 km; and

(iii) the Seokangwana belt which extends westwards for 26 km from the Tshwene-Tshwene belt to the Ngotwane River (Figure 1); this belt is almost 6 km wide along the Ngotwane River (the Botswana border).

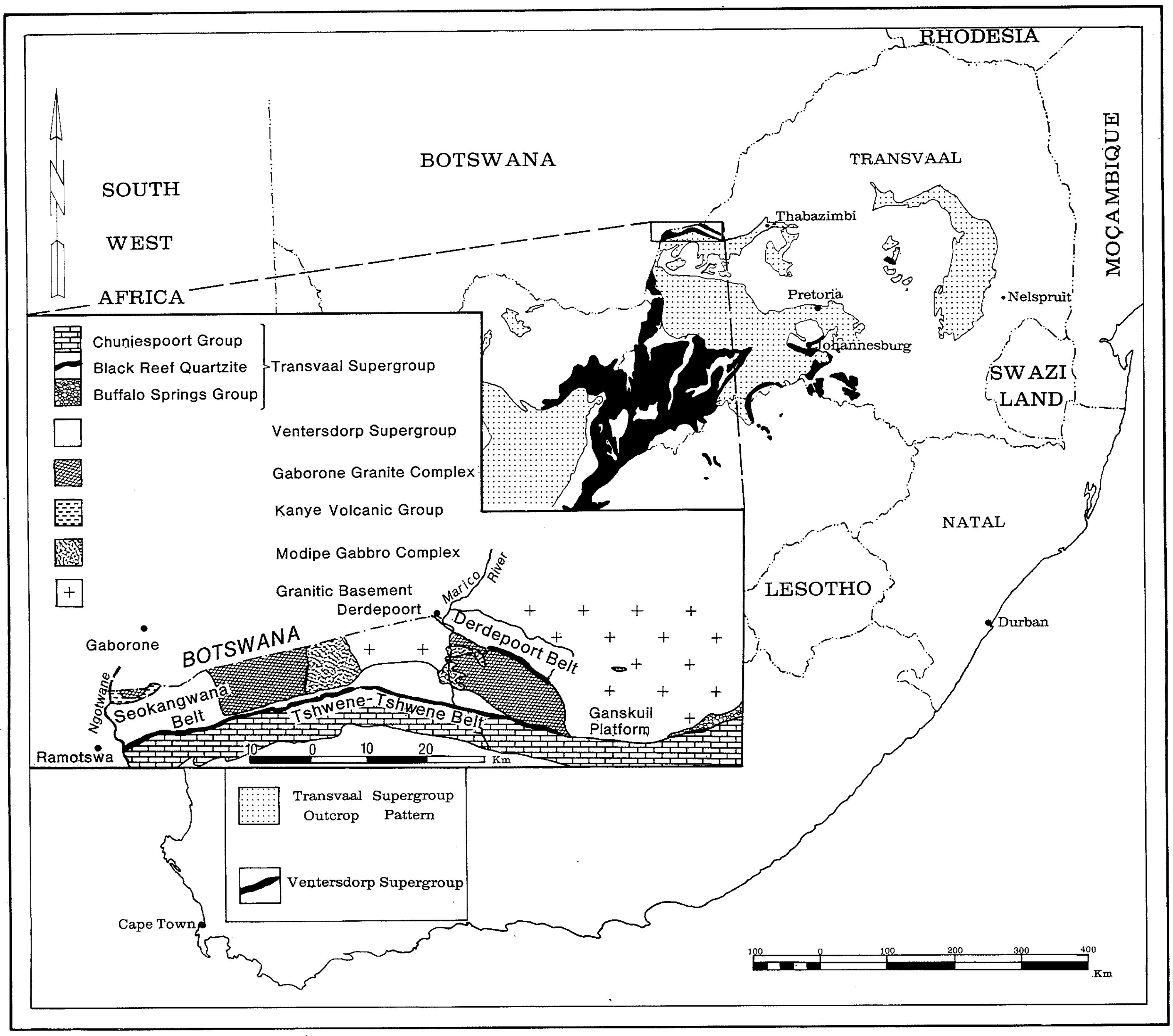

Figure 1 : Location and geological setting of the Ventersdorp Supergroup in the west-central Transvaal.

The isolated Derdepoort belt is separated from the Tshwene-Tshwene occurrence by an 8 km wide valley which is underlain by granitic and basic rocks. A continuous belt of outcrops links the Seokangwana and the Tshwene-Tshwene occurrences. Midway along this exposure significant change in the lithology of the Ventersdorp Supergroup occurs. To the east of this point (the Tshwene-Tshwene belt), lavas with basic-to-intermediate compositions dominate the succession; to the west (the Seokangwana belt), acid lavas and pyroclastic rocks predominate.

In the west-central Transvaal, the Ventersdorp Supergroup is comprised of a heterogeneous pile of basic-to-acid volcanics and immature sediments, which is unconformably overlain by the Black Reef Quartzite of the Transvaal Supergroup. The Ventersdorp Supergroup rests on the Archaean Basement, on the Modipe Gabbro Complex, on the Gaborone Granite Complex, and on the Kanye Volcanic Group (Figure 1). It is characterized by laterally-discontinuous outcrops and by large areas of poor exposure. Moderate exposures are found along the Derdepoortrant in the Derdepoort district, along the Rant van Tshwene-Tshwene, and in the Seokangwana range of the Thebe Reserve, Bophutatswana. In addition, poor-to-moderate outcrops are found on the slopes below the scarp capped by the Black Reef Quartzite.

A. Historical Background of the Ventersdorp Supergroup in the West-Central Transvaal

In 1903, Hatch examined a succession of lavas, pyroclastics, and boulder beds in the vicinity of Ventersdorp. For this succession, he proposed the name "Ventersdorp Beds". In 1904, Hatch stated that "beds of exactly the same character consisting of volcanic breccias and conglomerates, crop out .... along a belt of broken country, culminating in the double-peaked mass of Zuni-Zuni" (Tshwene-Tshwene). He correlated these breccias and conglomerates with the Ventersdorp Beds he had described in 1903.

Following on the work of Hatch, there appeared a large volume of published information in which the Ventersdorp succession, as found in southern Transvaal, in the Orange Free State, and in the northern Cape Province, was discussed in great detail. As this work has been reviewed recently (Winter, 1976), it is not proposed to make further reference to the literature concerning the more southerly exposures of the Ventersdorp Supergroup.

Kynaston (1912) recognized that, in the Marico District of the west-central Transvaal, the Transvaal System unconformably overlies an alternating succession of acid and basic lavas and intercalated sediments, which he assigned to the Ventersdorp System. He recorded the massive felsites now correlated with the Kanye Volcanic Group, as well as the granites of the Gaborone Complex. Knyaston regarded the massive Kanye felsites as part of the Ventersdorp. In addition, he stated that the Ventersdorp assemblage has no regular succession or constant characteristic across the whole area.

Truter (1949) correlated the lavas and sediments of the Derdepoort belt (Figure 2) with the Onverwacht Series. The Tshwene-Tshwene and Seokangwana lavas were correlated with the Dominion Reef System, and the sediments overlying the so-called Dominion Reef on Tshwene-Tshwene were correlated with the Uitkyk and Wolkberg formations.

Poldervaart and Green (1952) and Poldervaart (1952) correlated the lower andesitic lavas of the Derdepoort and Tshwene-Tshwene belts (Figure 2) with the Onverwacht Series. The acid volcanics and sediments of the Derdepoort belt were grouped with the Dominion Reef System, and the Tshwene-Tshwene sediments were assigned to the Witwatersrand System and the Wolkberg Formation.

In Botswana, no distinction was made between the siliceous igneous rocks of the Kanye Volcanic Group and the Ventersdorp succession, prior to 1959. Up to this date, these rocks had been collectively correlated with the Ventersdorp System (du Toit, 1939) and with the Dominion Reef System (du Toit, 1946; Truter, 1949; Poldervaart and Green, 1952). Wright (1956, 1961) recognized differences between the two assemblages, and, while still correlating the siliceous igneous rocks with the Dominion Reef System, he proposed the local formational name of "Lobatsi Volcanic Series". A unit within the Ventersdorp Supergroup, the Mogobane Series, comprising conglomerates and shales, was recognized by Boocock (1955) and by Wright (1961).

The work of Boocock (1959) indicated that the Lobatsi Volcanic Series contained elements both older and younger than the Gaborone Granite Complex, rendering the former formational name obsolete. The pre-Gaborone rocks were named the Kanye Volcanic Group by the Geological Survey of Botswana, and the post-Gaborone rocks were assigned to the Ventersdorp Supergroup by Crockett (1971).

Schutte (1963), working in the vicinity of the Marico River, correlated the rocks now assigned to the Ventersdorp Supergroup with the Onverwacht Series (andesitic lavas of the Tshwene-Tshwene and Derdepoort belts), the Moodies System (sediments of the Derdepoort belt), and the Wolkberg Formation (sediments of the Tshwene-Tshwene belt) (Figure 2).

In 1974, the Geological Survey of South Africa published its Thabazimbi Sheet, on which it assigned the whole of the pre-Black Reef volcanic-sedimentary assemblage to the Ventersdorp Supergroup. Tyler (1978a), after a detailed stratigraphic analysis of the post-Archaean, pre-Black Reef succession, concluded that the assemblage to the east of the Ganskuil platform (the Buffalo Springs Group, Figure 1) was conformable beneath, and graded into, the Black Reef Quartzite. This sequence, therefore, was concluded to constitute the proto-basinal phase of the development of the Transvaal Supergroup and was correlated with the Wolkberg Group. To the west of the Ganskuil platform (Figure 1), the volcanic-sedimentary assemblage was found to be unconformably overlain by the Transvaal Supergroup and was correlated with the Ventersdorp Supergroup (Tyler, 1978a).

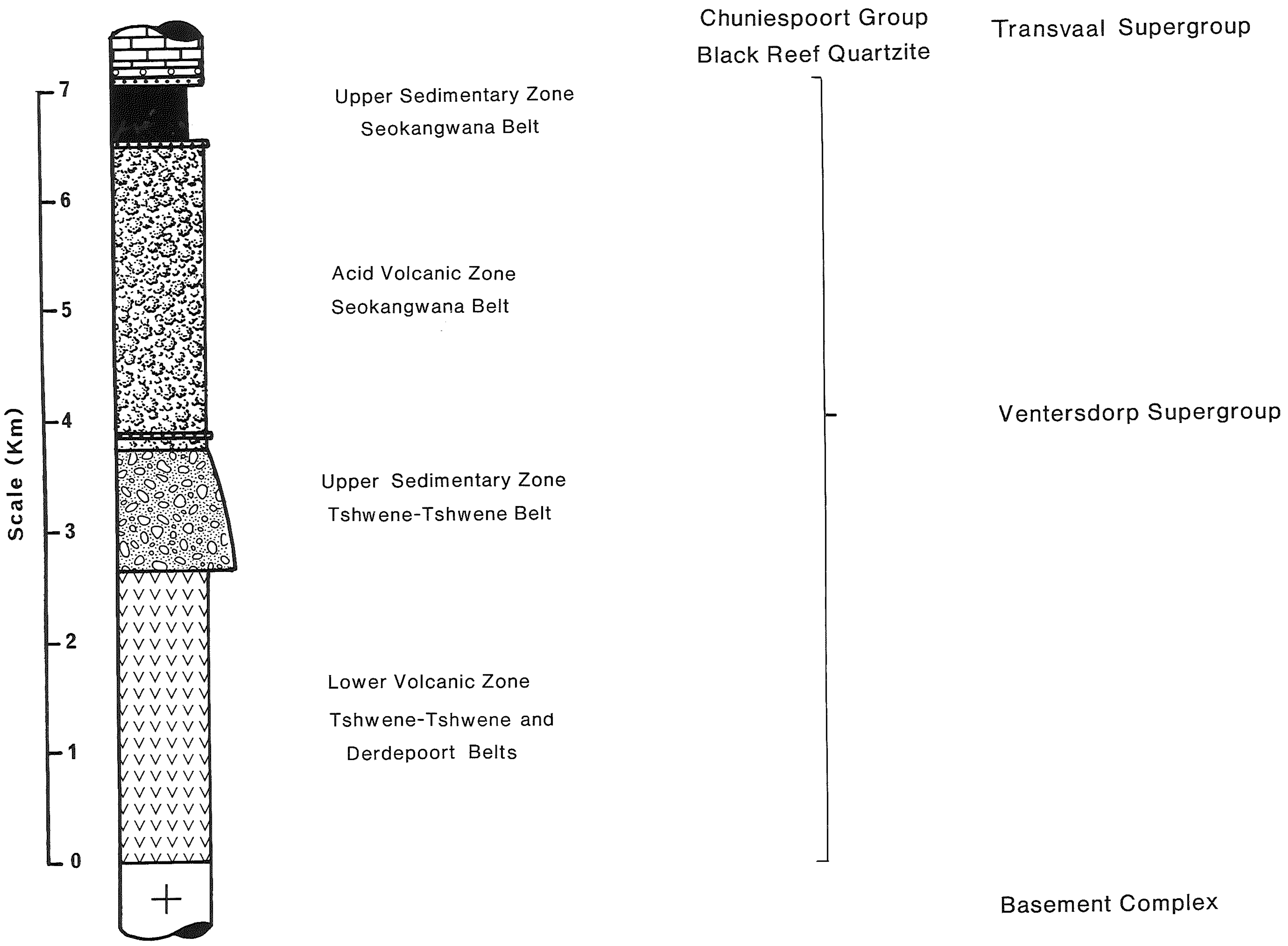

Figure 2 : *Stratigraphic column illustrating the maximum thicknesses of the units developed in the Ventersdorp Supergroup of the West-Central Transvaal.*

B. Age of the Ventersdorp Supergroup

Table 1 summarizes the geochronological data on the Ventersdorp Supergroup in Botswana, up to the end of 1975 (Key, 1976). A bimodal age pattern, spanning 400 m.y., is apparent. A similar discrepancy has been observed in the geochronology of the Ventersdorp rocks in South Africa. Van Niekerk, in 1964 (according to Winter, 1976), obtained a uranium-lead radiometric date of 2 300 m.y. on a quartz-porphyry near Klerksdorp. In 1968, van Niekerk and Burger (quoted in Winter, 1976) dated the acid lavas of the Zoetlief locality, using the lead-isotope method, at 2 500-2 700 m.y., once again indicating an age discrepancy of between 200 and 400 m.y. in the geochronology of the Ventersdorp Supergroup.

Harding et al. (1974) and Key (1977) favour an age of 2 300 ± 80 m.y. for the Ventersdorp volcanism in Botswana. Van Niekerk (quoted in Winter, 1976) holds that the 2 500-2 700 m.y. Zoetlief date is more acceptable. Considering the age of the Transvaal Supergroup - the Ongeluk lava has been dated at 2 224 ± 21 m.y., using the Rb-Sr whole-rock method (Crampton, personal communication to Button, 1976) - it seems evident that the Ventersdorp Supergroup might be older than the 2 300 m.y. favoured by Key (1977) and Harding et al. (1974).

TABLE 1

Geochronology of the Ventersdorp Supergroup in Botswana

Rock/Mineral Dated	Locality	Method	Age (m.y.)	Analyst/Institute
Quartz-feldspar porphyry (whole-rock)	Lobatse Quarry	Rb-Sr	2 200 ± 100	Snelling, Oxford
Quartz-feldspar porphyry (whole rock)	Nuane Dam	Rb-Sr	2 215 ± 110	Snelling, Oxford
Quartz-feldspar porphyry	Plantation Quarry	Rb-Sr	2 230 ± 120	Snelling, Oxford
Isochron based on last three samples	Plantation Quarry	Rb-Sr	2 208 ± 210	Snelling, Oxford
Quartz-feldspar porphyry (whole rock)	Lobatse Quarry	Rb-Sr	2 695 ± 125	Snelling, Oxford
Felsite (whole-rock)	Lobatse	Pb^{207}-Pb^{206}	2 630 ± 100	Van Niekerk, N.P.R.L.
Quartz porphyry (zircon)	Lobatse	U-Pb	2 630 ± 100	Van Niekerk, N.P.R.L.
Felsite lava (zircon)	Lobatse	U-Pb	2 640 ± 100	Van Niekerk, N.P.R.L.

(after Key, 1976)

C. Structure

1. *The Derdepoort Belt*

The Derdepoort belt has been subjected to two periods of pre-Black Reef Quartzite folding and at least one major episode of faulting. The belt is comprised of a northern asymmetrical syncline, followed by a tightly-folded anticline, with parallel fold axes trending east-southeast (115 degrees east of true north). The eastward-plunging synclinal closure on the farm Kameelboom 91 KP suggests that a subsequent episode of folding warped the Derdepoort syncline into a gently-dipping basin structure. Fold axes of the second phase of folding are obliquely inclined to the axes of the first episode of folding. Since the Black Reef Quartzite rests unconformably upon the lower and middle volcanic zones and on both the synclinal and anticlinal structures of the Derdepoort belt, the deformation can be dated as pre-Transvaal Supergroup in age.

The origin of the Derdepoort belt is somewhat problematical as a consequence of poor exposures of the contacts of the belt with the enveloping granites. The extension of the belt into Botswana has been mapped by Jones (1960, p. 21) who stated that, in the vicinity of Sequani (Derdepoort), "two WNW-ESE trending strike faults about 1,5 miles (2,5 km) apart bring a belt of Ventersdorp System lavas and sediments against rocks of the Basement Complex". Schutte (1963) confirmed the presence of strike-faulting immediately to the south of the belt. The 1974 Thabazimbi Sheet of the Geological Survey of South Africa tentatively positions a southward-dipping strike-fault immediately to the south of the Derdepoort belt. If the WNW-ESE-trending faults mapped by Jones (1960) and Schutte (1963) are projected towards the east, it can be observed that the sediments of Rustenburgkop fall within the area bounded by the two faults. It is suggested that the preservation of the Ventersdorp succession in the Derdepoort belt, together with the sediments of the Buffalo Springs Group that are developed on Rustenburgkop and the Black Reef Quartzite south of the Derdepoort belt, result from post-Black Reef, graben-style faulting. A graben is typically long, relative to its width - this being a feature of the Derdepoort belt (40 km long, but only 5 km wide).

2. *The Seokangwana Belt*

The gross structure of the Seokangwana belt, when traced from the west-central Transvaal into southeastern Botswana, is basin-like. The strike of the layered succession gradually swings from northwest, in the Transvaal, to northeast, in the vicinity of Lobatse. Deformation within the Seokangwana basin in the west-central Transvaal is limited to several pre- and post-Black Reef Quartzite, left- and right-lateral transverse faults, with small displacements, and to small-scale, pre-Black Reef folds (Tyler, 1978a).

D. Correlation of the Ventersdorp Assemblage in the West-Central Transvaal with the Ventersdorp Supergroup in the Type-Area

The assemblage of basalts, rhyolitic felsites, pyroclastics, and sediments exposed beneath the Black Reef Quartzite in the Derdepoort-Seokangwana area is thought to represent the Ventersdorp Supergroup, for three principal reasons :

(i) the assemblage is unconformably overlain by the Black Reef Quartzite;

(ii) exposures of the group can be followed, almost without a break, along an arcuate outcrop belt through southeastern Botswana to the Ventersdorp type-area in the southern Transvaal and the northern Cape Province; and

(iii) the lithological assemblage (basic and acid lavas with volcaniclastic sediments) is typical of the Ventersdorp succession (Tyler, 1978a).

In the type-area, the Ventersdorp Supergroup consists mainly of effusive igneous rocks. According to Winter (1966), only in the Bothaville area is the complete succession developed; elsewhere, some formations have pinched out and are not represented. Areal variations in the stratigraphy, in the form of local lenticularity, local excessive thicknesses of rock-types, unconformities, and overlaps (Winter, 1976), are common and have increased the difficulty of comparison of isolated exposures with the type-area in the Bothaville area. Rocks of the Ventersdorp Supergroup in the west-central Transvaal are situated more than 330 km north of the type-area, and, thus, major differences in the succession may be expected.

The simplified succession of the Ventersdorp Supergroup in the west-central Transvaal consists of an alternation of lavas and sediments (Figure 3). The assemblage commences with a basal basalt, overlain by sediments which are succeeded by acid volcanics, and these, in turn, are also overlain by sediments (the Tshwene-Tshwene assemblage overlain by the Seokangwana assemblage). The Derdepoort belt (Figure 3) has a basal basalt which is separated from the overlying acid volcanics by a sericitic palaeosoil layer. This is thought to represent a significant unconformity. Coarse clastics and shale overlie the acid volcanics.

Ventersdorp Supergroup in the Bothaville Region (after Winter, 1976)		Tshwene-Tshwene and Seokangwana belts	Derdepoort Belt
	ALLANRIDGE ANDESITE FORMATION		
	BOTHAVILLE FORMATION	Upper Sedimentary Zone (Seokangwana Belt)	
PLATBERG GROUP	RIETGAT FORMATION		
	MAKWASSIE QUARTZ PORPHYRY FORMATION	Lower Acid Volcanic Zone (Seokangwana Belt)	Upper Sedimentary Zone Middle Acid Volcanic Zone
	KAMEELDOORNS FORMATION	Upper Sedimentary Zone (Tshwene-Tshwene Belt)	
KLIPRIVIERSBERG GROUP		Lower Volcanic Zone (Tshwene-Tshwene Belt)	Lower Volcanic Zone

Figure 3 : *The type-stratigraphy of the Ventersdorp Supergroup (after Winter, 1976) and the proposed correlation of the rocks of the Ventersdorp Supergroup developed in the Derdepoort, Tshwene-Tshwene, and Seokangwana regions of the west-central Transvaal.*

Tyler (1978a) correlated the basal basalts of the Derdepoort and Tshwene-Tshwene belts with the Klipriviersberg Group, as described by Winter (1976) and Wyatt (1976). Sediments of the Tshwene-Tshwene belt are similar to those of the Kameeldoorns Formation that overlies the Klipriviersberg Group in the type-area. Winter (1976) described the Kameeldoorns Formation as an assemblage of immature, coarse, volcaniclastic conglomerates and sands which were deposited in fault-bounded basins. The environment of deposition of the coarse Tshwene-Tshwene sediments (proximal alluvial-fan) probably resulted from a tectonically-uplifted source-area similar to the provenance of the Kameeldoorns fault-block sediments.

Acid volcanics of the Seokangwana belt (Figure 3) have been assigned to the Makwassie Quartz Porphyry Formation (Tyler, 1978a). Although quartz porphyry predominates in the Makwassie acid volcanic formation, quartz-free porphyritic and non-porphyritic rocks and minor bodies of sediments are present in the type-area. In the acid volcanic rocks of the west-central Transvaal, quartz porphyries are absent, and porphyritic and non-porphyritic felsites predominate.

The sediments of the Seokangwana belt (Figure 3) are correlated with the Bothaville Formation which consists of a conglomeratic base and an upper shaly zone that is often capped by a 5 m thick conglomerate (Winter, 1976). The Bothaville Formation is almost identical to the succession developed in the Mogobane area, as described by Wright (1961) and Crockett (1971). Both the Bothaville and Seokangwana sediments appear to have evolved in a relatively quiet, flood-basin environment.

Acid volcanics of the Derdepoort belt are correlated with the Makwassie Quartz Porphyry Formation (Tyler, 1978a). Sediments in this formation in the type-area are coarse and immature (Winter, 1976) and were probably deposited in a fluvial environment. The volcaniclastic rocks overlying the acid porphyries of the Derdepoort belt are also thought to have had high-energy fluvial origins, as distinct from the low-energy flood-basin depositional settings of the Seokangwana sediments. For this reason, sediments of the Derdepoort belt are tentatively assigned to the Makwassie Quartz Porphyry Formation (Figure 3).

II. STRATIGRAPHY

A. The Klipriviersberg Group (the Lower Volcanic Zones of the Derdepoort and Tshwene-Tshwene Belts)

Basic lavas dominate the stratigraphy of the lower volcanic zones of the Derdepoort and Tshwene-Tshwene belts. Other rock-types present in accessory amounts are feldspar porphyries, with accretionary lapilli, pyroclastics, basalt breccias, and boulder conglomerates (Table 2). Capping the lower volcanic zone of the Derdepoort belt is a palaeosoil layer which forms a distinctive marker unit.

TABLE 2

Idealized Stratigraphy of the Derdepoort, Tshwene-Tshwene, and Seokangwana Belts of the Ventersdorp Supergroup in the West-Central Transvaal

DERDEPOORT BELT	TSHWENE-TSHWENE BELT	SEOKANGWANA BELT
UPPER SEDIMENTARY ZONE Cobble Conglomerate Shale Volcaniclastic Conglomerate (and Coarse Sand)	UPPER SEDIMENTARY ZONE Siltstone and shale Andesitic Basalt Lava Coarse Clastics Cobble and Boulder Conglomerates	UPPER SEDIMENTARY ZONE Siltstones and Shales Clastics
MIDDLE ACID VOLCANIC ZONE Pyroclastics Volcanic Sediments Porphyritic Felsite		LOWER ACID VOLCANIC ZONE Granular Felsites with Feldspar Porphyry, Variolitic Felsite, Tephra and Clastics Porphyritic Felsite Coarse Clastics and Shales Massive, Red Felsite Basal Felsites with Intercalated Feldspar Porphyry and Sediments
LOWER VOLCANIC ZONE Palaeosoil Lithic Tuff Feldspar Porphyry Basalt	LOWER VOLCANIC ZONE Basalt Breccia and Boulder Conglomerate Basalt	

The estimated maximum thickness of the lower volcanic zone of the Derdepoort belt is approximately 2 000 m. However, the outcrop pattern suggests that the thickness of the unit may show considerable variation because of the palaeotopography of the Makoppa Dome.

Stratigraphic profiling across the lower volcanic zone of the Tshwene-Tshwene belt (Figure 4) indicates that a maximum thickness of 2 650 m is exposed beneath the Black Reef Quartzite on the farms Onverwacht 89 KP and Mooiplaats 94 KP. The unit thins rapidly to the east, where it overlies granitic rocks correlated by Schutte (1963) with the Gaborone Granite Complex, and to the west, where the zone almost pinches out over the Gaborone Road Arch.

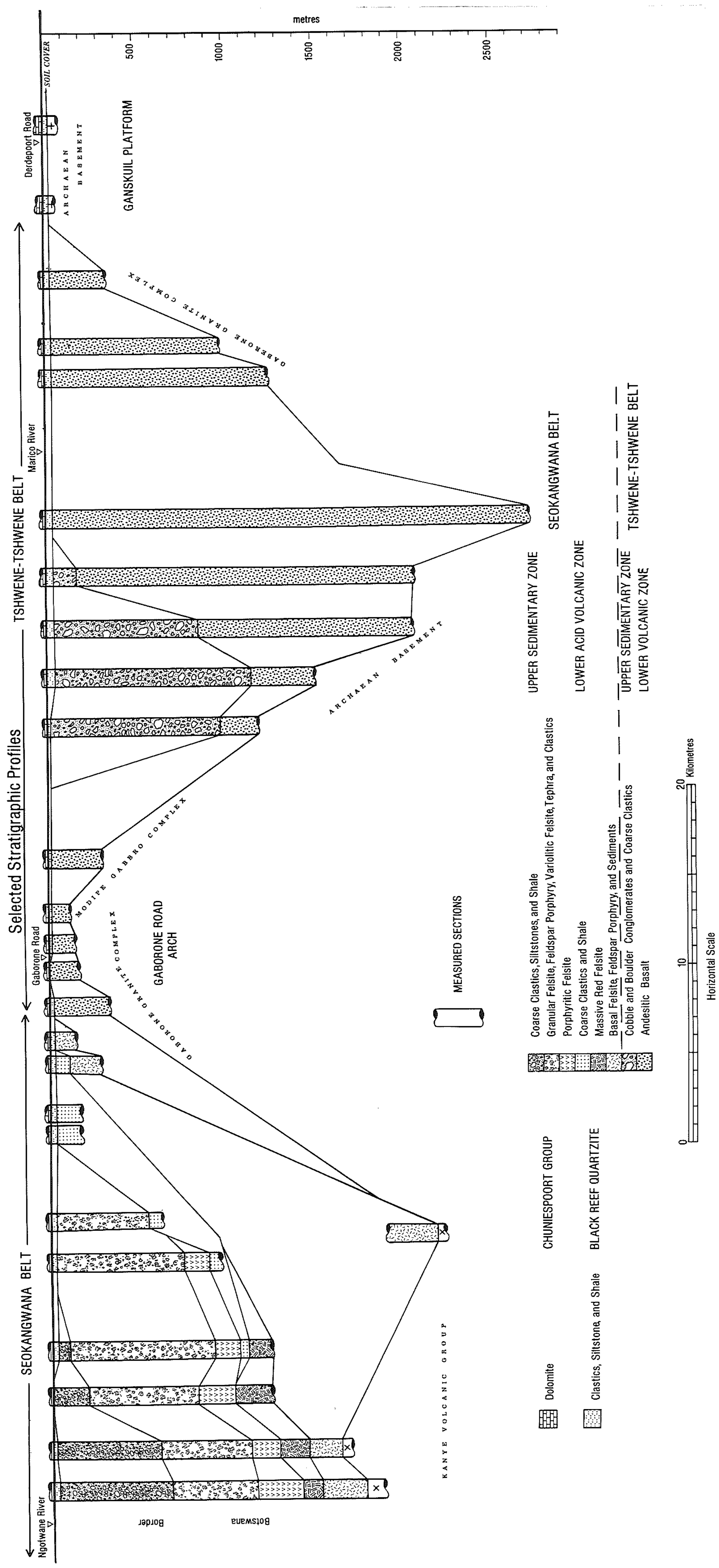

Fig. 4 : VENTERSDORP SUPERGROUP AND BLACK REEF QUARTZITE

1. *The Basic Lavas*

In the Derdepoort belt (Figure 1), the basalts rest upon the poorly exposed Archaean Basement along the northern slopes of the Derdepoortrant. Other exposures are found on Elandskop and Klein Elandskop. Lavas of the lower volcanic zone of the Tshwene-Tshwene belt are moderately exposed along the Black Reef escarpment, and on isolated hillocks to the north of this scarp. Throughout the larger part of the area, the lower volcanic zones of the Derdepoort and Tshwene-Tshwene belts are extremely poorly exposed. The basal member of the Tshwene-Tshwene belt rests on the Archaean basement and on granites correlated with the Gaborone Granite Complex (Schutte, 1963), and thins dramatically over the Gaborone Road Arch (Figure 4).

The basaltic lavas outcrop as hard, chocolate-brown-weathering, rounded boulders. When fresh, the colour of the lava varies between greenish-grey and dark green. Individual flows are frequently amygdaloidal (Plate IA), and, on rare pavements or cliff faces, it can be seen that the amygdales define the upper contacts of individual lava flows. Amygdales range up to 5 cm in length and are often horizontally aligned, with their long axes sub-parallel. Commonly, the amygdales are filled with chert, and occasionally with primary chlorite (with alteration rims of epidote) or calcite. The basaltic groundmass consists of a felted mass of microlites of calcic plagioclase and prisms of pyroxene, and is clouded by a dusting of magnetite. Quartz, chlorite, calcite, and pyrite are common accessory minerals. Subhedral pyroxene phenocrysts are largely altered to penninite.

Intercalated within the relatively fresh basalt is a fine-grained, altered basalt, containing light-coloured 2 to 3 cm thick bands of coarsely-crystalline carbonate. In thin-section, the groundmass consists of felsitic-textured chloritic material, primary magnetite, and accessory quartz. However, the most striking feature of this basalt is the presence of quartz-, calcite-, and pumpellyite-filled vugs. The fibrous pumpellyite is lightly pleochroic, with a characteristic growth pattern in the form of radiating needles. The vugs are invariably mantled by cherty material and include, as accessory minerals, chlorite and dust-like magnetite particles.

2. *Feldspar Porphyry with Accretionary Lapilli*

Outcropping several metres below the crestline of the northern slopes of the Derdepoortrant is a thin, impersistently-developed, feldspar porphyry. Euhedral pink plagioclase phenocrysts, partially altered to a clay mineral, are randomly scattered throughout the cherty-textured matrix which varies in colour from faintly reddish-tinted to grey. In thin-section, the groundmass is composed of quartz, feldspar, accessory chlorite, and a dusting of very fine-grained iron oxides. Also present are zoned amygdales, and circular-to-ellipsoidal structures which are not zoned, but are defined by elongate microlites (thought to be shards) curved around a coarser-grained structureless core of quartz and chlorite (Plate IB). The cryptocrystalline-textured microlites comprise several concentric layers in some of the structures, and long axes of the ellipsoids are generally aligned parallel to one another.

The characteristics of these structures are very similar to the accretionary lapilli in volcanic rocks of the western United States as described by Moore and Peck (1962). Each lapillus contains a core with a diameter more than one half the total diameter. This nucleus is a structureless mass of volcanic ash (quartz and chlorite, above) that is coarser-grained than the rim. One or more thin, concentric, layers surround the core of the lapillus. Nearly all of the accretionary lapilli observed by Moore and Peck (1962) were oblate spheroids flattened in the plane of the bedding. The genesis of the Ventersdorp accretionary lapilli may be compared to the development of hailstones in a thundercloud. During volcanism clouds of ash, rich in water vapour, rise to great heights where they cool causing the condensation of water vapour within the cloud. The condensed moisture produces agglutinization of ash within the cloud, forming the nuclei of accretionary lapilli. As each embryonic lapillus falls through the eruptive cloud (according to Moore and Peck, 1962), an outer shell is built up by ash sticking to the moistened surface of the lapillus. Platy and linear shards and microlites adhere along their largest surface to the outer surface of the growing lapillus. Turbulence within the eruptive cloud may lift the lapillus into the higher reaches of the cloud, resulting in repeated accretionary events and, in doing so, form a number of thin layers in the outer shell.

A significant difference between the accretionary lapilli of the lower volcanic zone of the Derdepoort belt and those described by Moore and Peck (1962) is that the Ventersdorp accretionary lapilli occur in an acid volcanic, whereas those in the western United States are found in poorly-stratified tuffs. However, acid lavas are highly viscous and according to Barth (1962) either flow very slowly, or do not flow at all. This suggests that some acid volcanics, which are extruded over large areas, may have originated as glowing ash-flow tuffs and not as lava flows. A similar mechanism of formation is envisaged for the feldspar porphyry, with deposition of airborne lapilli into the glowing ash-flow deposit inferred to have occurred whilst the tuff was either flowing or unconsolidated.

3. *Lithic Tuff*

In the nose of the syncline of the Derdepoort belt is a light-grey weathering, impersistently-developed, lithic tuff. Fresh surfaces have diffuse red blemishes and, when dampened, basaltic fragments, ranging in size up to 1 cm, become visible in a fine-grained ash matrix. The unit is 5 m thick.

4. *Basaltic Breccia and Boulder Conglomerate*

Outcropping to the east of the Zeerust-Gaborone road in the Tshwene-Tshwene belt, is a northwest-striking marker unit, the northwestern extension of which is intruded by the Wonderboom Porphyry. The base of the unit rests on massive basalt, and is composed of 5 m thick basaltic breccia, consisting of angular-to-subrounded basalt fragments in an amygdaloidal basalt matrix. The blocks range up to 60 cm in diameter and higher in the sequence they become rounded. At 22 m above the base of the unit a boulder conglomerate scours into the breccia. Boulders in the conglomerate are well-rounded and range up to 40 cm in diameter. The clasts are comprised of acid volcanics, vein quartz, and basalt, and are set in a sericitic matrix.

5. *Palaeosoil*

The upper boundary of the lower volcanic zone of the Derdepoort belt is marked by a distinctive, dark lime-green coloured band which outcrops just north of the crestline of the Derdepoortrant. Rocks of the 25 m thick unit are sericitic and are delicately laminated. The lower 8 m of the unit are brecciated into angular 2-3 cm sized fragments. Brecciation occurred after consolidation, as the angular fragments fit together in a jig-saw pattern. Fragmentation was probably caused by the fine silica-vein stockwork which permeates the lower reaches of the band. Stratigraphically upwards, the intensity of brecciation decreases. The middle part of the unit is massive, but is characterized by sub-horizontal joints which dip southwards. The upper parts of the band are intensely sheared. Deformation of the unit was probably caused by interstratal movement of the middle acid volcanic zone over the lower volcanic zone.

In thin-section, the rock is composed of a fine-grained mass of sericite with very fine-grained dusty magnetite disseminated throughout the groundmass. Iron-ore also occurs as coarser clusters associated with slightly coarser sericite and as euhedral crystals. Opaque leucoxene is common. The delicate lamination seen in hand-specimen is defined by alternating iron-ore-poor and ore-rich layers.

The characteristics of this unit are typical of weathering profiles developed on basic volcanics, and are composed almost exclusively of sericite (Button and Tyler, in press). Chemical weathering of the underlying basalts during the hiatus before the extrusion of the middle acid volcanic zone of the Derdepoort belt is thought to have resulted in the development of a residual, clayey, saprolite (Tyler, 1978a). On compaction and diagenesis the saprolite was transformed into the stable sericite layer.

B. Major-Element Chemistry of the Basaltic Lavas and Palaeosoil of the Lower Volcanic Zones of the Derdepoort and Tshwene-Tshwene Belts

Three new analyses of Ventersdorp basalt and one analysis of the palaeosoil above the basalt of the lower volcanic zone of the Derdepoort belt are presented in Table 3.

1. *Basalts*

Table 3, columns 1, 2, 3, are analyses of Ventersdorp basalt. Comparison of the composition of the lavas reveals that the basalt of the Tshwene-Tshwene belt is enriched in SiO_2 and Al_2O_3, but is deficient in total iron oxide and CaO, relative to the lower lavas of the Derdepoort belt. Although there are slight differences in the geochemistry of the basalts of the two belts (Table 3, columns 1, 2, and 3), their average composition (column 4) compares rather well with the average composition of the upper Klipriviersberg Formations of the Ventersdorp Supergroup (Table 3, column 7).

The average Ventersdorp basalt has a silica concentration (56,1 per cent) intermediate between that of average continental tholeiite (51,5 per cent) and average andesite (60,0 per cent) (Table 3, columns 4, 5, and 6). Al_2O_3 is relatively deficient in the Ventersdorp basalts from the study-area and from the Klipriviersberg locality, when compared with average andesite and average continental tholeiite. The most distinctive geochemical attribute of the Ventersdorp basalts centres about their relatively high K_2O content which is 2,3 times greater than the K_2O in tholeiite and andesite.

The relatively high K_2O and low Al_2O_3 contents of Ventersdorp basalts from the west-central Transvaal have two possible explanations. Firstly, lavas of the upper Klipriviersberg formations (Table 3, column 7) are also enriched in K_2O and deficient in Al_2O_3 relative to the average composition of andesite and tholeiite. This regional pattern of apparent K_2O enrichment and Al-deficiency may indicate that the Ventersdorp lavas are inherently more potassic and alumina-deficient than average tholeiites and andesites. The second possible explanation takes into account the strongly-potassic nature of the acid lavas of the Derdepoort and Seokangwana belts. In the discussion that follows later the acid lavas are shown to be altered, probably under the lower grades of greenschist metamorphism. The alteration processes that influenced the chemistry of the acid volcanics may also have modified the pristine major element chemistry of the basalts. From this study it is suggested that the high K_2O contents of the Ventersdorp lavas are probably the result of alteration under greenschist metamorphic conditions.

Wyatt (1976, p. 73), working on the Klipriviersberg volcanics at the base of the Ventersdorp Supergroup, south of Johannesburg, concluded that because of (i) the low alumina content (less than 15 per cent Al_2O_3), (ii) the high total iron content, (iii) the intermediate magnesian content, and (iv) the low-to-intermediate silica content, the Klipriviersberg volcanics could be referred to as alkali-rich tholeiitic basalts, although they also have affinities with calc-alkaline basalts. Wyatt considered that the Klipriviersberg volcanics represent Precambrian flood basalts resulting directly from the partial melt of a "wet Precambrian mantle".

TABLE 3

Major-Element Geochemistry of Basalt and Basaltic Palaeosoil from the Ventersdorp Supergroup in the West-Central Transvaal, with Selected Comparative Analyses

	1	2	3	4	5	6	7	8
Sample No.	73c *	51e *	51g *	Average of 1, 2, 3	Average Continental Tholeiite	Average Andesite	Ventersdorp Volcanics	53c *
SiO_2	57,69	55,26	55,32	56,09	51,50	60,00	57,27	46,80
TiO_2	0,58	1,30	1,34	1,07	1,20	1,04	0,93	1,02
Al_2O_3	15,32	14,39	14,37	14,69	16,30	16,00	14,62	34,35
Total Fe as Fe_2O_3	9,53	13,09	11,28	11,30	10,70	8,09	10,29	3,34
MnO	0,13	0,12	0,14	0,13	0,17	0,16	0,14	0,03
MgO	4,99	2,49	3,54	3,67	5,90	3,90	4,92	0,00
CaO	5,80	7,02	8,44	7,08	9,80	5,87	7,51	0,00
Na_2O	2,97	2,02	3,23	2,74	2,50	3,85	2,91	0,23
K_2O	1,22	3,77	1,12	2,04	0,86	0,87	1,64	9,05
P_2O_5	0,10	0,16	0,17	0,14	0,21	0,23	0,18	0,14
LOI	1,89	1,21	1,66	1,59	0,81	-	2,80	4,71
TOTAL	100,22	100,83	100,61	100,54	99,95	100,00	100,21	99,67

* Analyst - N. Tyler

Columns :
1. Basalt, Weltevreden 95 KP, Tshwene-Tshwene belt, Marico District.
2. Basalt, Schots 196 KP, Derdepoort belt, Thabazimbi District.
3. Basalt, Schots 196 KP, Derdepoort belt, Thabazimbi District.
4. Average composition of Ventersdorp basalt (average of analyses 1, 2, and 3).
5. Average continental tholeiite (Manson, 1968, p. 223).
6. Average andesite from 4 Archaean volcanic belts (Irvine and Baragar, 1971, p. 546).
7. Average composition of the Upper Klipriviersberg Formations (tholeiitic basalts) (Wyatt, 1976, p. 64).
8. Possible palaeosoil, Kameelhoek 174 KP, Thabazimbi District.

The geochemistry of the Ventersdorp basalt from the west-central Transvaal is similar to that of the tholeiitic basalts of the Klipriviersberg Group. Thicknesses in excess of 2 000 m of uninterrupted volcanic activity possessing consistent chemistry and the rarity of products of explosive volcanicity lead the writer to conclude that the basalts of the west-central Transvaal were also extruded as Precambrian flood basalts. Subsequent alteration is believed to have caused an enrichment in K_2O and a depletion in Al_2O_3 relative to typical continental tholeiite.

2. *The Palaeosoil Layer Capping the Lower Volcanic Zone, Derdepoort Belt*

Sericite, iron ore and leucoxene are the principal minerals of the palaeosoil. Major-element chemical analyses reflect the composition of the palaeosoil layer with SiO_2 (46,8 per cent) and Al_2O_3 (34,35 per cent) being the dominant constituents (Table 3, column 8). The high K_2O content (9,05 per cent) accords with the degree of sericitization seen in the rocks. Iron and titanium oxides of 3,34 per cent and 1,02 per cent, respectively, reflect the presence of disseminated ore granules and amorphous leucoxene. A loss on ignition of 4,7 per cent (Table 3, column 8) indicates the presence of water in the crystal lattice of muscovite.

Three oxides, SiO_2, Al_2O_3 and K_2O comprise over 90 per cent of the rock while other elements, such as CaO, Na_2O, MgO, and MnO, make up less than 0,5 per cent. The rock was therefore formed in an environment which allowed for the removal of some elements from the system and also allowed the less-mobile constituents, such as Al_2O_3, SiO_2, and TiO_2, to concentrate together with the volatile components such as water.

The sericite layer is thought to have formed by the weathering of the underlying lavas which degenerated to clay minerals. Leaching of the soil removed the mobile elements, but not potassium, which may have been held in the lattice of a clay mineral, such as illite. Following leaching, an illitic soil with some titanium and iron oxides remained. Subsequently, diagenesis of the clay minerals resulted in crystallization of fine-grained sericite.

C. The Kameeldoorns Formation (Upper Sedimentary Zone of the Tshwene-Tshwene Belt)

Coarse clastics of the upper sedimentary zone of the Tshwene-Tshwene belt (Figure 1, inset) outcrop along the main mass of the Tshwene-Tshwene range where they comprise a heterogeneous pile of coarse sandstones and cobble and boulder conglomerates, with a maximum thickness of 1 100 m (Figure 4). The zone thins rapidly to the east and west, along a 14 km long belt of exposures.

Towards the central part of the outcropping zone, the basal 60 m of sediment consists of chaotic, non-stratified, cobble and boulder conglomerate. Subrounded-to-rounded, but ill-sorted boulders, mostly of sericitized felsite, vary up to 50 cm in diameter. The red-brown-weathering matrix is also very poorly sorted and consists of relatively fine-grained, volcanic fragments and quartz grains. This poorly-packed, clast-supported, massive basal unit thins to approximately 20 m on the eastern limb of the occurrence, where weathered and fresh andesitic basalt, vein-quartz, and arenite pebbles were observed in addition to felsite cobbles and pebbles.

Above the chaotic basal clastics the sediments are poorly stratified with ill-sorted conglomerate bands fining upward into very coarse-grained sands. Higher in the succession, the coarse-grained sands (which are characterized by randomly-scattered pebbles) occasionally grade upwards into silty, brown-weathering shales. The shales are thinly laminated, with 1 cm thick, upward-fining, graded beds and occasional mud-cracked surfaces. Intercalated within the stratified cobble conglomerates and sands are 2-5 m thick boulder beds of light-coloured, acid felsite boulders ranging up to 110 cm across. The boulder beds occur as bands of muddy-matrix-supported, well-rounded boulders, rarely in close proximity to each other. The upper parts of the zone consist of coarse, sericitic volcaniclastic sands, with intercalated, moderately-packed conglomerates. The upper sedimentary zone of the Tshwene-Tshwene belt therefore has an overall upward-fining trend from coarse conglomerates at the base to coarse sand, with scattered pebbles and conglomerate lenses, in the upper parts.

Internal bedding structures are rarely observed within the heterogeneous pile of sediments. This is due, partly, to the fact that the sediments are extremely coarse-grained and chaotic and also because of the weathered nature and poor exposure of the finer-grained clastics. Towards the top of the zone, tabular-crossbed sets (with a maximum observed thickness of 50 cm) are present in upward-fining cycles in which planar-bedding predominates (Figure 5). These graded cycles vary up to 7 m in thickness and are erosively truncated by the overlying conglomeratic unit. Crude cut-and-fill structures are common within the stratified conglomerates and sands.

Due to the lack of cross-stratification within the sediments only a small amount of palaeocurrent work has been done. Five palaeocurrent measurements from one station indicate that the dispersive currents flowed towards the southeast.

Basalt flows are exposed in the upper parts and along the eastern margins of the zone. The flows vary up to 8 m in thickness and are exposed as brown-weathering, rounded boulders which are massive or amygdaloidal. The lavas are of limited extent and make up a relatively small fraction of the upper sedimentary zone.

The areally-restricted, immature, and lithologically varied clastics of the upper sedimentary zone of the Tshwene-Tshwene belt are considered to be the product of alluvial-fan sedimentation (Tyler, 1978a). The zone grades upwards from an unstratified basal conglomerate (deposited under upper-flow-regime conditions) to an essentially fluvially-deposited conglomerate and sandstone unit. Intermittent mud-flows are thought to have transported large boulders into this unit to form boulder beds. The alluvial-fan is considered to have originated from basin-margin faulting which, on palaeocurrent evidence, occurred to the northwest of the Tshwene-Tshwene sediments (Tyler, 1978a).

D. The Makwassie Formation (Middle Acid Volcanic Zone, Derdepoort Belt, and the Lower Acid Volcanic Zone, Seokangwana Belt)

Acid volcanics correlated with the Makwassie Quartz Porphyry Formation (see Figure 3) comprise the middle acid volcanic zone of the Derdepoort belt, and the lower acid volcanic zone of the Seokangwana belt (Figure 1, inset). In the Derdepoort area, acid volcanics concordantly overlie the sericitic palaeosoil and are overlain, in turn, by the upper sedimentary zone (Figure 3). Moderate exposures are found along the crest of the Derdepoortrant as well as to the south where the lavas are

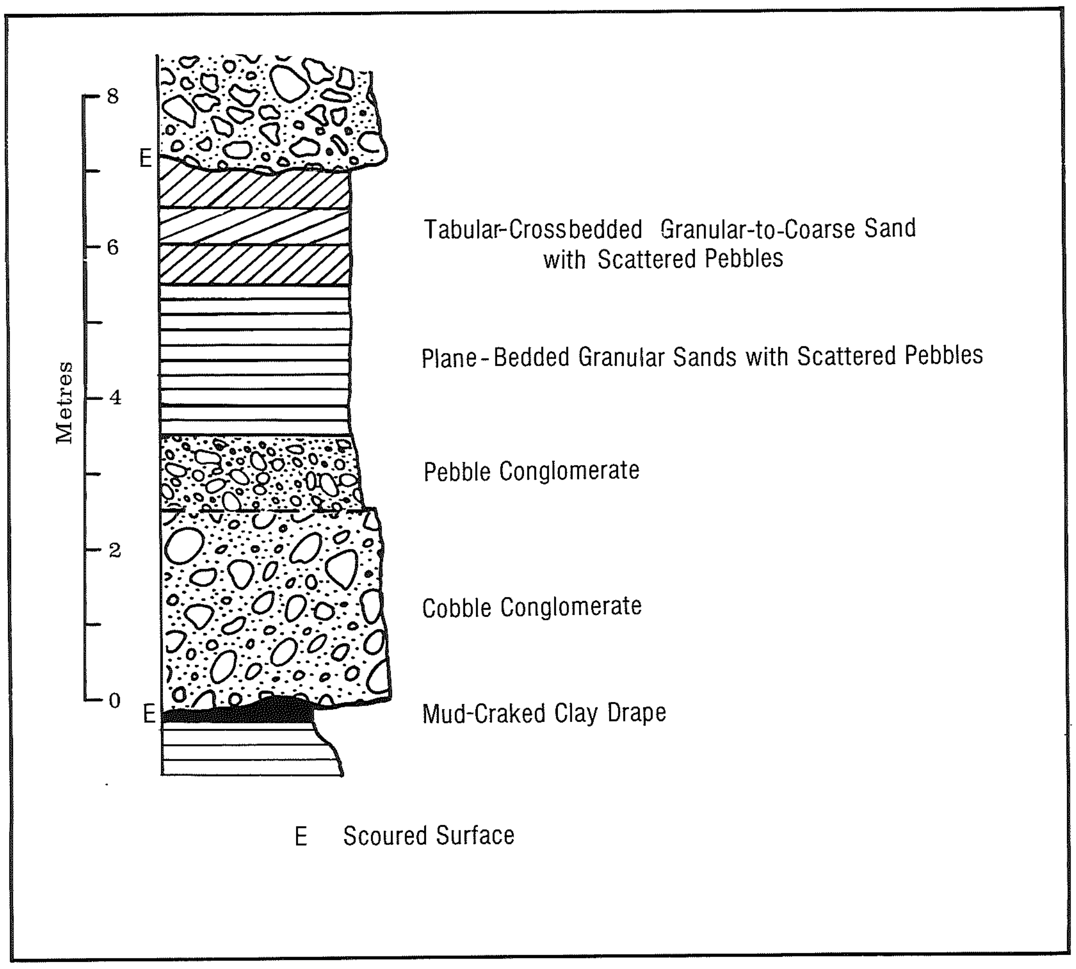

Figure 5 : *Upward-fining sedimentary cycle in the higher parts of the upper sedimentary zone, Tshwene-Tshwene belt. Mud-cracked clay-drapes do not have a high preservation potential and are rarely seen (Zuni-Zuni 96 KP).*

exposed by the upwarping of the Derdepoort anticline. Porphyritic felsites dominate the zone which is 50 m thick and minor sediments and pyroclastic rocks are also present. In the Seokangwana belt, the lower acid volcanic zone is exposed along the main mass of the Seokangwana range. Scattered outcrops are also found in the valley between the Kanye Volcanic Group and the Seokangwana hills. The zone is composed of a heterogeneous pile of felsites, pyroclastics, tuffs, and intercalated sediments.

1. *The Middle Acid Volcanic Zone of the Derdepoort Belt*

Light-coloured felsites of the Derdepoort belt commonly have a distinctive pock-marked surface caused by the weathering of sericitized microperthite phenocrysts. The felsites are strongly-jointed and are exposed as angular blocks. Scouring into the felsites are several upward-fining clastic lenses. These lenses comprise 30 m wide, 8 m deep channels (Figure 6), in places up to one kilometre apart, and often displaying several upward-fining cycles present within each channel. In one of the lenses, the upper 3 m of shale is characterized by highly contorted bedding (Plate IC). Since the underlying and overlying beds are not disturbed, the contorted bedding is thought to be the result of penecontemporaneous slumping of the unconsolidated shales, possibly during the subsequent volcanism.

Intercalated within the acid volcanics of the Derdepoort belt is a pyroclastic layer with clasts ranging up to 15 cm in size. The clasts are predominantly lithic (porphyritic felsite), although smaller and more angular accidental fragments (including sericitic palaeosoil) are also present. Interbedded lapilli tuff bands within the agglomerate have occasional clasts of primary magmatic origin (essential fragments). These crudely-sorted clasts have the classic onion-shaped texture of bipolar fusiform lapilli (MacDonald, 1967), with the sharp extremities of the clasts being either frayed or single projections. MacDonald (1967) stated that the majority of bipolar fusiform lapilli are ejected as lava ribbons, portions of which may divide and be subjected to local thickening during flight.

Overlying the acid volcanics of the Derdepoort belt are the clastics of the upper sedimentary zone. The sediments were deposited in a high-energy, fluvial environment and are correlated with the coarse conglomerates that occur near the base of the Makwassie Quartz Porphyry Formation (Winter, 1976) in the type area (Tyler, 1978a). Epiclastic conglomerates (Plate ID) and grits dominate the 50 m thick zone, with shale and cobble conglomerate being minor constituents.

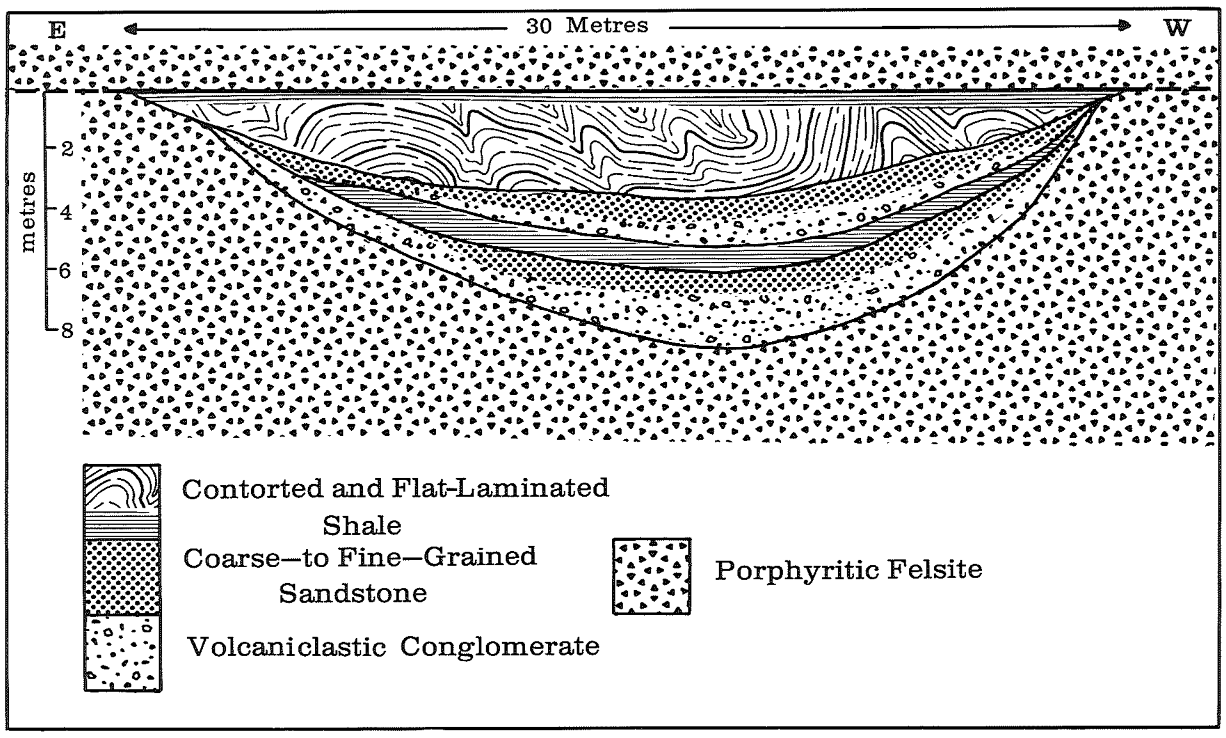

Figure 6 : *Sediment-filled scour channel in the porphyritic felsites of the middle acid volcanic zone, Derdepoort belt.*

2. *The Lower Acid Volcanic Zone of the Seokangwana Belt*

The acid volcanics of the Seokangwana belt outcrop along the Seokangwana range (Figure 1, inset), and in Botswana, where they are referred to as the Lower Volcanic Assemblage (Crockett, 1971). The stratigraphy of the zone is provided in Table 2, and the field and microscopic characteristics of the more important units are summarized in Table 4.

Fine-grained, homogeneous, felsite is the characteristic rock-type of the basal felsites (Tables 2 and 4). Readily-weathered variolitic textures are present in some of the darker-coloured felsites, and feldspar porphyry bands up to 10 m thick, have also been encountered. The weathered surfaces of the porphyries often consist of pure sericite. Coarse- and fine-grained sediments, of limited extent, are interbedded within the lavas. The true thickness of the basal felsites is difficult to estimate because of poor exposure. In the central parts of the outcropping belt maximum thickness of 1 200 m is thought to be present, but towards the east where the basal felsites pass unconformably under the cover of the Black Reef Quartzite, only 170 m of felsite were observed (Figure 4). Along the Botswana border a thickness of 250 m is estimated.

Massive, red felsite (Tables 2, 4) outcrops as isolated pavements in the valley between the hills of the Kanye Volcanic Group and the Seokangwana range. Intercalated within the red felsite are dark-grey, sericitized porphyritic bands. The massive, red felsite has a maximum thickness of 200 m but pinches out towards the east and towards the Ngotwane River where it is only 100 m thick (Figure 4).

Coarse-grained clastics and flinty shales, with intercalated acid lavas, outcrop beneath the Black Reef Quartzite at the eastern extension of the Seokangwana belt (Figure 4). At this locality, the immature sediments occur typically as coarse, ill-sorted, poorly-packed, volcaniclastic conglomerates and granular sands, with mud-cracked clay drapes. The clastics grade both vertically and laterally (towards the west) into fine-grained sandstones, siltstones, and slaty shales. Where exposed under the Black Reef Quartzite, the coarse clastics have an estimated thickness of more than 300 m, but this figure decreases rapidly towards the centre of the belt where the unit pinches out (Figure 4).

Porphyritic felsite (Tables 2, 4) characterizes the foothills of the Seokangwana range, where, in the east, the unit rests upon coarse clastics and in the west on massive, red felsite. The porphyritic felsite is a wedge-shaped unit, thickening to 250 m at the Ngotwane River (Figure 4). It is composed of prominent, ovoidal plagioclase phenocrysts, that comprise between 15 to 20 per cent of the rock (Plate IE) set in a fine-grained, dark-reddish brown coloured matrix of quartz, feldspar, sericite, and biotite. Weathered surfaces, towards the upper parts of the porphyritic felsite, are banded (jointed ?) on a 2-3 cm scale (Plate IF), whereas the lower parts of the felsite are massive (Plate IE).

Granular felsites (Tables 2, 4) are exposed over a large part of the Seokangwana range where they overlie porphyritic felsite. The granular felsites have an estimated total thickness of 800 m

TABLE 4

Summary of Field and Microscopic Characteristics of Some of the More Important Ventersdorp Acid Volcanics from the West-Central Transvaal

	Derdepoort Belt	Seokangwana Belt				
	Porphyritic Felsite	Basal Felsite	Massive, Red Felsite	Porphyritic Felsite	Granular Felsite	Feldspar Porphyry
Hand-Specimen						
Fresh colour	Lime green-to-grey occasional red	Yellow, grey, brown	Red	Red, grey	Light grey, green	Dark grey
Weathered colour	Light green-yellow-dark brown	Greenish-brown, reddish-brown, dusky red	Dark-or-dusky red	Reddish-brown	Light grey, white	Light brown
Phenocrysts	White, euhedral 30%	Accessory	Accessory, white	Ovoidal, white 35%	White, accessory	White, angular 25%
Size:	Up to 8 mm	3-4 mm	Up to 8 mm	Up to 1,3 cm	Less than 1 cm	Up to 2 mm
Bedding	Absent	Flow banding	Absent	Banded on a 2-3 cm scale	Flow banding	Delicately laminated
Amygdales	Absent	Common (quartz, occasional calcite)	Absent	Absent	Occasional	Absent
Thin-Section						
Mineralogy (Major)	Orthoclase, quartz, chlorite	Orthoclase, quartz sericite, biotite	Sericitized feldspar	Quartz, sericitized feldspar, sericite, biotite	Muscovite, quartz, sericitized feldspar	Partially sericitized feldspar and quartz. Biotite and magnetite
Accessory Minerals	Zircon, leucoxene, iron ore	Apatite, zircon	Chlorite, muscovite, iron oxides, tourmaline	Apatite, zircon, calcite	Granular ore, chlorite, calcite	Zircon
Phenocrysts	Microperthite, quartz	Sericitized	Sericitized feldspar and hornblende	Plagioclase altered to sericite, calcite	Sericitized plagioclase and microperthite	Euhedral plagioclase, microperthite, quartz
Matrix	Extremely fine-grained, felsitic-textured	Extremely fine-grained, felsitic-textured	Extremely fine-grained, cryptocrystalline	Felsitic-textured	Very fine-grained, felsitic-textured	Equigranular

but vary to as little as 400 m thick (Figure 4). Granular felsite is a term used to describe the poorly exposed, generally light-weathering, acid volcanic rocks that characterize the upper 700-800 m of the lower acid volcanic zone (Table 2). The outer surface of the felsite commonly has a granular texture (i.e. the weathered surfaces are rough to the touch). Amygdales and porphyritic bands are occasionally present. Intercalated within the granular felsites is a 35 m thick feldspar porphyry unit, several variolitic lavas, and, in the eastern hills of the Seokangwana range, numerous discontinuous bands of volcanic ejecta. The pyroclastic bands carry ash, lapilli and bomb-sized clasts. Two types of agglomerate are distinguishable :

(i) agglomerates characterized by ill-sorted, angular blocks of siliceous material, with very little fine-grained matrix and no recognizable stratification; these are thought to be pyroclastics that originated from an explosive vent; and

(ii) agglomerates in which chaotic, subrounded, heterolithologic siliceous clasts occur in a schistose shaly matrix; agglomerates of this type are predominantly developed immediately below the upper sedimentary zone. The characteristics of these agglomerates are typical of laharic breccias (Parsons, 1969). Laharic breccias result from volcanic mudflows which form by mass-movement of water-saturated tephra on the slopes of volcanic vents. The lubricated material moves rapidly downslope and is deposited as chaotic, matrix-supported breccias.

3. *The Environment of Extrusion of the Acid Volcanic Zones of the Derdepoort and Seokangwana Belts*

An examination of the environments of deposition of the sediments intercalated within the acid volcanics is critical to the discussion of the environment of extrusion of the acid lavas. In the Derdepoort belt, the lenses of immature, coarse, volcaniclastic sediments which scour into the underlying volcanics have characteristics typical of fluvially-deposited sediments. The coarse clastic and shale unit of the Seokangwana belt is characterized by upward-fining cycles terminating in mud-cracked shales. Laterally (towards the west), the clastics grade into a mud-cracked silt and shale facies. Allowing for the limitations imposed by poor exposure and structural deformation, the depositional setting most compatible with the features of the unit is the meandering-fluvial system. The coarse clastics were deposited as channel-lags and point-bars in migrating meander channels; the shaly sediments were deposited in the flood-basin of the fluvial system. Deposits with similar characteristics in recent alluvial sediments have been described by Allen (1965), who stated that flood-basin deposits represent the accumulation of fines suspended in floodwaters that become stilled after reaching low-lying basins flanking alluvial ridges. Desiccation of flood-basin shales is common because of repeated exposure.

Within the pyroclastics of the middle acid volcanic zone of the Derdepoort belt are bipolar fusiform clasts of primary magmatic origin, the shape of which, according to MacDonald (1967), is caused by localized thickening of ejected lava ribbons during flight. This confirms that the pyroclastics were subaerially extruded. Similarly, both varieties of pyroclastics within the Seokangwana belt are considered to have originated within the vents of explosive volcanoes and as subaerial laharic breccias.

In the acid volcanic rocks the presence of amygdales, flow banding, and the absence of pillow structures leads the writer to conclude that the acid volcanics and intercalated sediments of the Ventersdorp Supergroup in the west-central Transvaal were subaerially deposited.

E. Major-Element Chemistry of the Acid Volcanic Zones of the Derdepoort and Seokangwana Belts

Ten new analyses of acid volcanic rocks from the Ventersdorp Supergroup, developed in the west-central Transvaal, are presented in Table 5. The felsites correspond, in a general way, to the composition of rhyolites (Table 5, columns 11, 12). Small variations between the different felsite varieties are evident in the table. Apart from silica concentrations which range between 71 and 79 per cent, the largest variations are found in the iron contents which range from less than 1 per cent to over 7 per cent.

The variations in the Na_2O content is strongly related to rock-type. Porphyritic felsite from the Derdepoort belt and the massive, red felsite from the Seokangwana belt have Na_2O contents similar to that of Lebombo rhyolite and bluish-grey Kanye felsite (Table 5, columns 1-4, 11 and 13). The remaining felsites are all deficient in Na_2O when compared with rhyolite from the Lebombo range. Small variations in Al_2O_3 and K_2O contents are present in all of the Ventersdorp volcanics. CaO is deficient in the upper parts of the Seokangwana belt (Table 5, columns 6-9), when compared with the CaO content of massive, red felsite (Table 5, columns 2-4) in the lower parts of the acid volcanic stratigraphy.

The analysis of porphyritic felsite, which unconformably overlies the coarse clastic and shale unit and the massive, red felsite, is given in Table 5, column 5. The porphyritic felsite has a rhyolitic composition, but is rich in potassium (6,26 per cent). Enrichment of potassium probably occurred at the expense of sodium which has an appreciably lower concentration than the Na_2O content of the rhyolitic, massive, red felsites. In thin-section, the phenocrysts are composed of sericite and minor amounts of calcite. The sericite in the phenocrysts, which by visible estimates comprise 20 per cent of the rock, probably account for the increased K_2O-content of the porphyritic felsites.

TABLE 5

Major-Element Geochemistry of the Acid Volcanics of the Derdepoort and Seokangwana Belts, Ventersdorp Supergroup, with Selected Comparative Analyses

	1	2	3	4	5	6	7	8	9	10	11	12	13
	53F *	92A *	93D *	94A *	85A *	85C *	94D *	107A *	101C *	93B *			98A *
SiO_2	74,97	72,98	71,78	73,13	73,32	77,72	73,35	74,79	79,40	74,40	75,33	74,56	70,03
TiO_2	0,36	0,43	0,46	0,46	0,47	0,45	0,43	0,50	0,36	0,45	0,35	0,17	0,45
Al_2O_3	12,42	12,41	13,16	12,41	11,90	12,03	12,13	14,70	13,00	12,53	11,55	12,58	15,18
Total iron as Fe_2O_3	2,96	4,86	4,56	4,52	3,35	4,00	7,29	3,06	0,95	4,76	2,84	2,32	5,07
MnO	0,04	0,09	0,05	0,04	0,10	0,08	0,11	0,06	0,01	0,11	0,00	0,05	0,10
MgO	0,00	0,00	0,00	0,00	0,57	0,00	0,00	0,00	0,00	0,00	0,00	0,11	0,00
CaO	0,22	0,73	0,71	0,77	0,71	0,11	0,13	0,06	0,05	1,57	0,81	0,61	1,41
Na_2O	2,43	3,68	3,90	3,06	1,54	0,39	0,21	0,49	0,36	1,68	2,79	4,13	4,11
K_2O	5,26	4,72	5,10	4,87	6,26	4,21	6,20	4,91	4,18	4,76	6,15	4,73	2,66
P_2O_5	0,06	0,10	0,11	0,20	0,13	0,15	0,12	0,08	0,07	0,14	0,18	0,07	0,12
LOI	0,71	0,37	0,45	0,16	0,83	1,75	1,05	2,24	1,80	0,58	-	0,66	0,56
TOTAL	99,43	100,37	100,28	99,62	99,18	100,89	101,02	100,89	100,18	100,98	100,00	99,99	96,69

* Analyst - N. Tyler

Columns :
1. Porphyritic felsite, Derdepoort Belt, Kameelhoek 174 KP, Thabazimbi District.
2. Massive, red felsite, Wildebeestkop 2 KO, Marico District.
3. Massive, red felsite, Alewynskop 3 KO, Marico District.
4. Massive, red felsite, Wildebeestkop 2 KO, Marico District.
5. Porphyritic felsite, Hartebeestfontein 102 KP, Marico District.
6. Variolitic felsite, Schoonlaagte 4 KO, Marico District.
7. Granular felsite, Schoonlaagte 4 KO, Marico District.
8. Granular felsite, Alewynskop 3 KO, Marico District.
9. Sericitized granular felsite, Hartebeestfontein 102 KP, Marico District.
10. Feldspar porphyry, Alewynskop 3 KO, Marico District.
11. Lebombo rhyolite, Mozambique (Cox et al. 1965, Table 40, column 45, p. 198).
12. Average composition of 21 rhyolites (Nockolds, 1954, Table 1, p. 1012).
13. Bluish-grey, massive felsite, Kanye Volcanic Group (Tyler, 1978a, Table 4).

(Analyses in columns 2 to 10 are of felsites from the Seokangwana Belt).

The felsites and feldspar porphyry of the granular felsite unit in the Seokangwana belt, have small variations in major-element chemistry. Na_2O contents are low. Variolitic felsite (Table 5, column 6) has higher silica than the fresh granular felsite, but is slightly deficient in Al_2O_3, total iron oxide, and K_2O. Sericitized granular felsite (Table 5, column 9) is enriched in SiO_2, but notably deficient in total iron oxides (less than one per cent as compared to over five per cent) relative to the composition of granular felsite. In addition, although the sericitized granular felsite has a higher sericite content than the fresh granular felsite, the K_2O-content of the former is slightly lower than that of the latter. The mechanism of alteration of the rock was probably through the process of mineral hydrolysis (hydrogen metasomatism) and not potassium metasomatism. The reaction of an aqueous solution with potassium feldspar is sufficient to cause sericitization through the following chemical reaction :

$$3KAlSi_3O_8 + 2H^+ \rightarrow KAl_2AlSi_3O_{10}(OH)_2 + 2K^+ + 6SiO_2$$

(orthoclase) (sericite) (Meyer and Hemley, 1967)

Potassium and silica are released by the reaction. The liberated silica may have crystallized in the quartz-rich granular felsite, whereas the potassium cation was discharged, creating a relative potassium deficiency in the sericitized felsite. The massive removal of iron oxides from the altered felsite may be the result of iron-leaching by solutions rich in H^+.

Compared with the average composition of rhyolite (Nockolds, 1954, p. 1012, 21 analyses) and the volcanic rocks of the Kanye Group of Table 5, column 13 , the felsites of the Derdepoort and Seokangwana acid volcanic zones are generally enriched in K_2O and total iron-oxides. The felsites, including the Lebombo rhyolite, are deficient in Na_2O, relative to Nockold's average rhyolite composition. In addition, MgO and CaO are also relatively depleted, or, in the case of MgO, absent. The overall pattern that emerges, when comparing the felsites in the study area with the average composition of rhyolite, is one of iron- and potassium-enrichment and of Na_2O, CaO, and MgO depletion. Graphical representation illustrates the anomalous nature of the system even more strikingly. Figure 7, an An-Ab'-Or projection (after Irvine and Baragar, 1971) of the Ventersdorp sub-alkaline rocks, confirms that the rhyolites are potassic, whereas the massive, red felsites, which have comparatively high Na_2O-contents, are classified as "average rocks". According to Irvine and Baragar the diagram is sensitive to changes imposed by alteration or metamorphism because of its dependency on Na_2O-content.

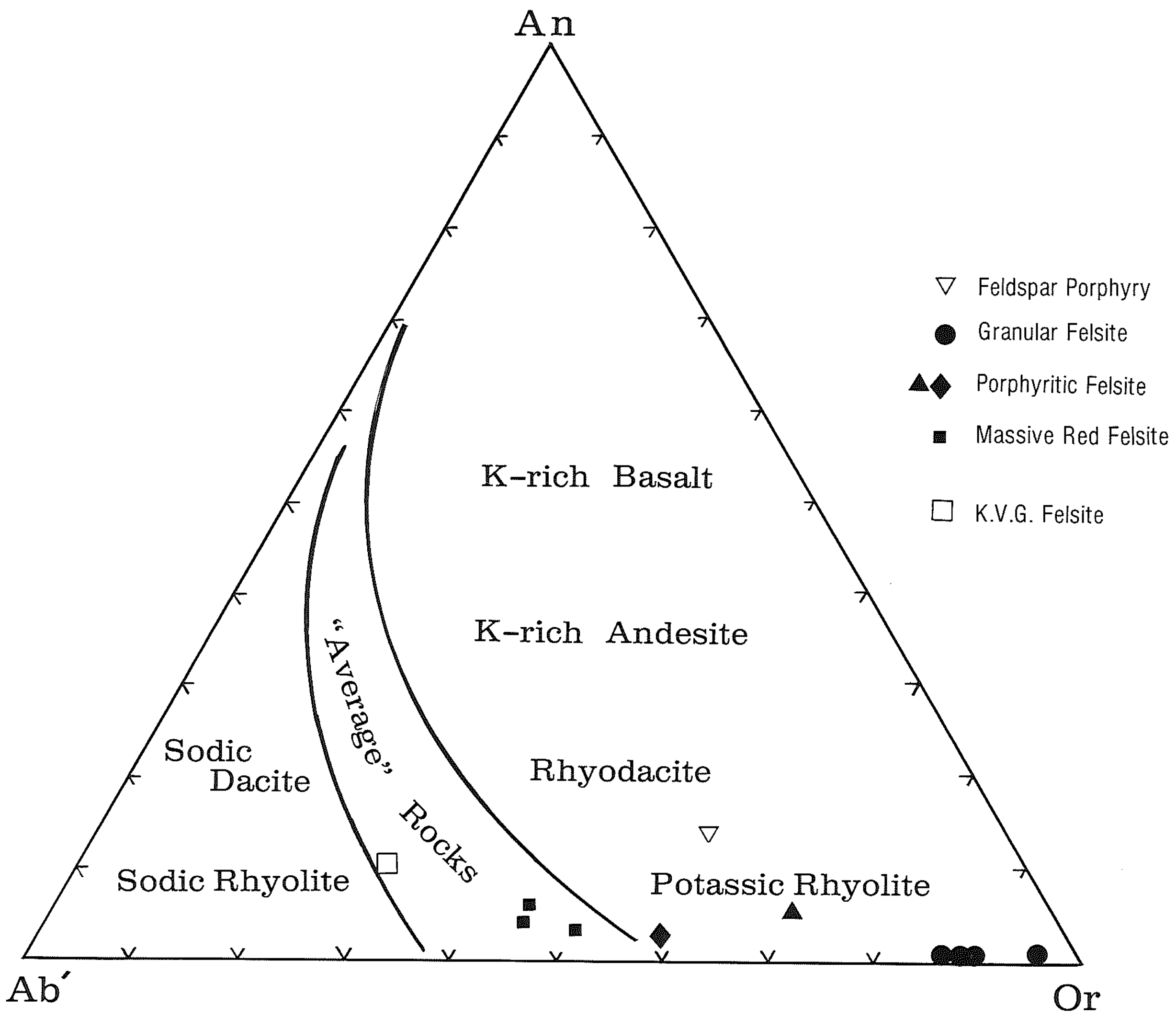

Figure 7 : *An-Ab'-Or projection of the sub-alkaline volcanics of the Ventersdorp Supergroup from the Derdepoort area. Felsites of the Kanye Volcanic Group (K.V.G.) and the massive, red felsites are "average rocks", whereas the other felsites are potassic. Ab' is normative Ab plus $^5/_3$ normative nepheline (after Irvine and Baragar, 1971).*

The pattern of enrichment in total iron oxides and K_2O, and deficiency in Na_2O, CaO, and MgO, when compared with the average composition of rhyolite, suggests that the rocks of the Ventersdorp succession have been altered. Cornell (1977) studied lavas and tuffs from the Zoetlief Series (now placed in the Platberg Group, Winter, 1976) and found that they are severely altered, with a trend towards extreme alumina-oversaturation. The Zoetlief quartz-feldspar porphyries have near-pelitic compositions, with up to 12 weight per cent normative corundum, whereas, according to Cornell (1977), normal igneous rocks rarely have any. Cornell concluded that the Zoetlief lavas have been subjected to alteration in which they essentially lost Ca and gained some K. It was suggested that the alteration could have occurred during the hydrous transport of elements under greenschist-grade metamorphic conditions.

In the west-central Transvaal, a trend towards extreme alumina oversaturation has also been recognized (Table 6). Alumina-oversaturation increases with height in the stratigraphic column, such that the uppermost felsites, which are overlain by the upper sedimentary zone, have normative corundum values of almost 9 weight per cent. Plots of major-elements against an Al-oversaturation index (Figure 8) show that, with increasing normative corundum contents, Na_2O and CaO decrease systematically from 3,9 to 0,5 per cent and from 0,77 to 0,06 per cent, respectively . This loss accounts for the alumina-oversaturation, as the other major elements fluctuate without any regular pattern. Thus, it becomes apparent that the Ventersdorp acid volcanics in the area under review have been subjected to alteration in which they lost Ca and Na.

TABLE 6

Alumina-Oversaturation in Ventersdorp Acid Volcanics from the Derdepoort and Seokangwana Belts

Sample No.			Normative Corundum Content (Wt. per cent) (Alumina Oversaturation)
107A	Granular Felsite	Granular Felsite Unit	8,76
101C	Sericitized Granular Felsite		8,09
85C	Variolitic Felsite		7,05
94D	Granular Felsite		5,09
93B	Feldspar Porphyry		2,07
85A	Porphyritic Felsite	Porphyritic Felsite Unit	1,65
94A	Massive, Red Felsite	Massive, Red Felsite Unit	1,18
93D	Massive, Red Felsite		0,21
92A	Massive, Red Felsite		0,17
53F	Porphyritic Felsite - Derdepoort Belt		2,51

Cornell (1977) suggested that alteration of the Zoetlief lavas occurred in a process of plagioclase breakdown under greenschist-grade metamorphic conditions. Ca was released, but, in Fe, Mg-poor rocks unable to form actinolite, the Ca was lost when the formation of zoisite was inhibited by an overabundant supply of K from the surrounding sediments, causing muscovite to form instead. In the Seokangwana acid volcanics, breakdown of intermediate plagioclases released both Na and Ca. The abundance of chlorite and sericite and the presence of biotite within many of the acid lavas suggest that the Ventersdorp volcanics from the study-area have also been subjected to metamorphism in the lower greenschist facies. It is apparent that, as in the case of the Zoetlief lavas, the Ventersdorp acid volcanics of the west-central Transvaal were altered during lower greenschist metamorphism following a process involving the breakdown of plagioclase and the liberation of Na and Ca. As neither zoisite nor actinolite is present in the extremely fine-grained matrix of the lava, it is evident that Na and Ca were removed from the system.

F. The Bothaville Formation (the Upper Sedimentary Zone of the Seokangwana Belt)

Clastics of the Upper Sedimentary Zone of the Seokangwana belt (Figure 1, inset) are extremely poorly exposed in the valley which lies between the Seokangwana range and Black Reef escarpment in the vicinity of the Ngotwane River. The sediments are exposed in Botswana where they are known as the Mogobane assemblage (Wright, 1961; Crockett, 1971). In Botswana, the clastics rest on a thin basal conglomerate. In the presumed centre of the Mogobane palaeobasin, a thick succession of shales is developed. Towards the northeast, upward-fining graded beds, from siltstones to mudstones, are common. In the west-central Transvaal the outcrops are limited to coarse clastics. Shales and siltstones are thought to underlie the sand-covered valley south of Seokangwana. In addition to lateral grain-size changes, the zone shows a gross, upward-fining trend, from a basal coarse arenite to shales. A conglomerate is frequently developed directly beneath the Black Reef Quartzite. The zone has a maximum thickness of 630 m in the vicinity of the Ngotwana River (Figure 4). Tyler (1978a) concluded that the sediments of the Bothaville Formation of the west-central Transvaal and southeastern Botswana were deposited in a meandering-fluvial setting. The immature conglomerates which grade into coarse volcaniclastic sands, were inferred to have originated as point-bar or channel-fill deposits. Overlying

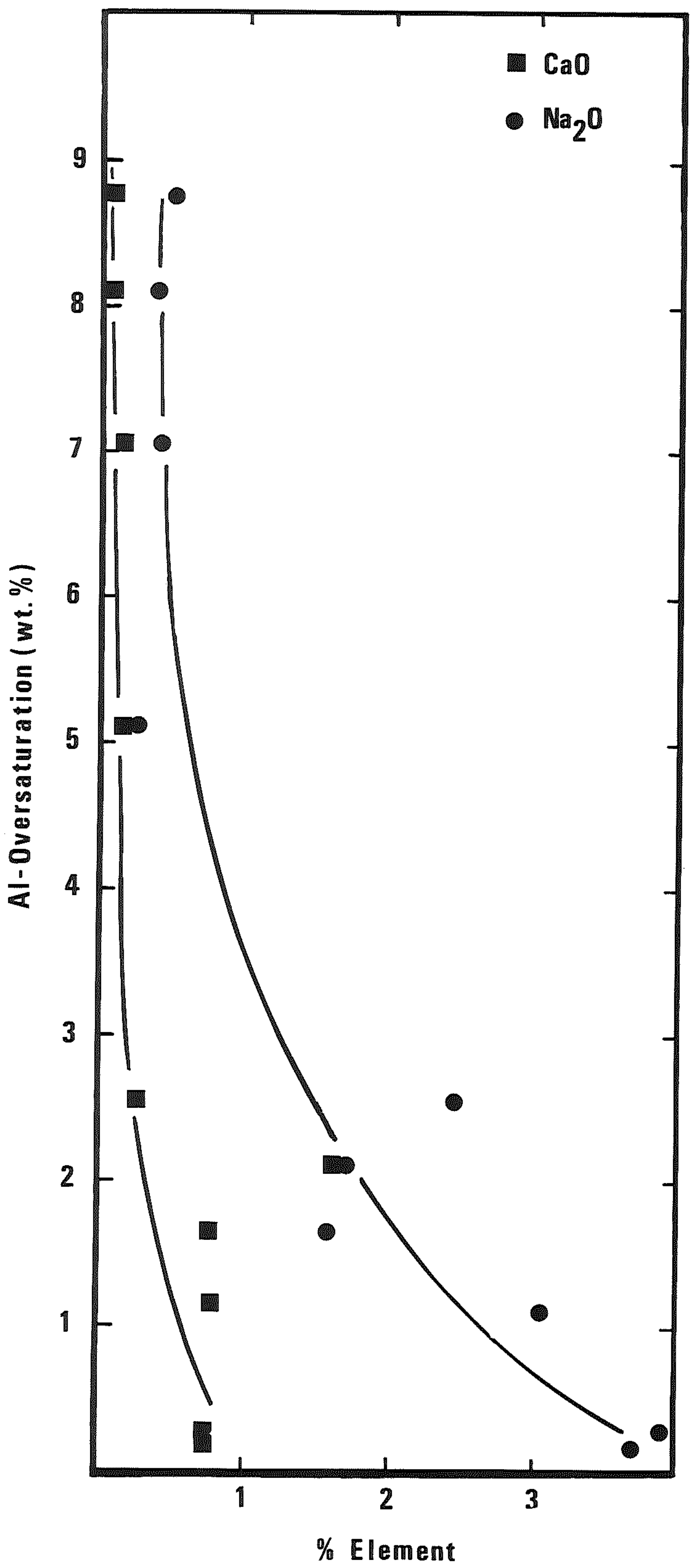

Figure 8 : *Smoothed decrease in Na_2O and CaO contents with increasing Al-oversaturation (or normative corundum values) in the acid volcanics of the Seokangwana and Derdepoort belts. Al-oversaturation corresponds with increasing stratigraphic height, or proximity to the sediments.*

the channel deposits are overbank or flood-basin siltstones and shales. It was suggested (Tyler, 1978a), that the dominantly massive shale, which grades laterally into siltstones and shales, characterized by stacked sets of graded beds, was situated some distance from the channel that supplies sediment to the flood-basin. Deposition of the slightly coarser siltstone occurred in close proximity to the source of overbank sediment, whereas, in the central parts of the flood-basin, shale was dominantly deposited. The upper coarse clastics and conglomerate which underlie the Black Reef Quartzite in the west-central Transvaal and in Botswana were inferred to represent the lateral accretion of the meander-channel deposits over the flood-basin shales.

G. The Intrusive Wonderboom Porphyry

Outcropping less than one kilometre west of the Zeerust-Gaborone road, is a quartz-feldspar porphyry stock intrusive into the basalts of the lower volcanic zone of the Tshwene-Tshwene belt. On the 1974 Thabazimbi sheet (Geological Survey of South Africa), the porphyry was mapped as part of the Modipe Gabbro Complex, with a faulted contact against the Ventersdorp volcanics. The stock is approximately 500 m long by 300 m wide and outcrops as two, linked, rounded hillocks. Intrusion of the porphyry terminates the northwest-trending basaltic breccia and boulder conglomerate of the Tshwene-Tshwene lower volcanic zone. Exposures of the quartz-feldspar porphyry occur as light-brown-weathering angular boulders with randomly scattered interstitial knots of brown biotite. The intrusive is holocrystalline, with light-green-tinted feldspar and quartz phenocrysts varying up to 10 mm in diameter. Contact metamorphism of the Ventersdorp basalts has altered their appearance such that they outcrop as hard, angular slabs rather than rounded boulders. Sand-cover conceals the contacts with enveloping rocks to the north, east, and west.

The intrusion of the post-Ventersdorp Wonderboom Porphyry is thought to pre-date deposition of the Transvaal Supergroup. South of the porphyry, the Black Reef Quartzite thins and wedges out, so that the dolomites of the Chuniespoort Group rest directly on the Ventersdorp basement. The porphyry stock possibly acted as a palaeotopographic high during the deposition of the Black Reef Quartzite, resulting in a sedimentary pinch-out to the south of the stock.

III. THE EARLY-PROTEROZOIC EVOLUTION OF THE KAAPVAAL CRATON IN THE WEST-CENTRAL TRANSVAAL

Two discrete depositional basins, filled by sediments and volcanics of the Ventersdorp Supergroup and the Buffalo Springs Group respectively, have been recognized in the west-central Transvaal (Tyler, 1878a). Separating the two troughs of deposition is a positive crustal feature composed of Archaean granites and greenstone remnants, for which the name the Ganskuil platform has been coined. The sediments and volcanics of the Ventersdorp and Buffalo Springs assemblages pinch out against this platform. It has been shown (Tyler, 1978a, b) that to the northeast of the Ganskuil platform the Buffalo Springs Group grades upwards into the base of the Black Reef Quartzite and that the Buffalo Springs succession is the correlative of the proto-basinal phase of Transvaal sedimentation, the Wolkberg Group. Figure 9 illustrates the outcrop pattern of the Wolkberg and Buffalo Springs groups as well as the probably subsurface distribution of this initial basin of Transvaal deposition. The axis of incipient deposition of the Transvaal sediments from isopach evidence in the west-central Transvaal (Tyler, 1978a) and from the northeastern Transvaal (Button, 1973) is apparently curvilinear, trending east-west in the central parts of the basin, and towards the northeast and northwest in the eastern and western extremities of the basin, respectively (Figure 9).

Deposition of the Ventersdorp Supergroup occurred to the west of the Ganskuil platform. Examination of the pattern of preservation of the Ventersdorp lavas and sediments in the study-area, in southeastern Botswana, and in the Johannesburg-Heidelberg district of the southern Transvaal (Figure 9) indicates that a second axis of deposition, perpendicular to the major axis of Ventersdorp deposition and preservation, was present during early-Proterozoic times on the northern segment of the Kaapvaal craton. In the region between Kanye and Heidelberg the Ventersdorp Supergroup broadens beyond its normal limits of preservation into two important lobes - the Kanye and Heidelberg lobes (Figure 9). This suggests that the region was a zone of comparatively rapid downwarping, when compared with the subsidence over the Ventersdorp basin as a whole. The name Swartruggens trough is proposed for this zone of increased subsidence (Figure 9).

It is possibly significant that the Kanye Volcanic Group of southeastern Botswana and the west-central Transvaal appears to be localized along the northwestern extension of the Swartruggens trough (Figure 9). The deposition of the Kanye lavas into this localized zone of subsidence confirms that downwarping of the Swartruggens trough was initiated before the evolution of the Kanye Volcanic Group and continued during the development of the Ventersdorp Supergroup. The localization of the Kanye Volcanic Group into a zone of increased Ventersdorp deposition may indicate that the Kanye lavas comprise the proto-basinal phase of the Ventersdorp Supergroup. Similar relationships have been observed in other early-Proterozoic basins on the Kaapvaal Craton, where a volcanic-sedimentary sequence forms the initial stages of development of the assemblage. These initial or proto-basinal phases of deposition are confined to the deepest parts of the basins (that is, zones of maximum downwarping), for example, the Dominion Reef Group of the Witwatersrand Supergroup in the Orange Free State and the Buffalo Springs and Wolkberg groups of the Transvaal Supergroup. Further investigation of the Kanye Volcanic Group-Ventersdorp Supergroup relation is required to confirm the suggestion that the Kanye lavas form the initial pulse of Ventersdorp volcanicity. However, this suggestion may explain why three apparently discrete igneous episodes cluster into the 2 750-2 500 m.y. (Gaborone Granite Complex/Kanye Volcanic Group-Ventersdorp Supergroup) time-span. Following, or possibly during the late stages of extrusion of the Kanye Volcanic Group, continued downwarping of the Swartruggens trough may have been sufficient to instigate mobilization of the granitic source of the Kanye lavas, leading to the intrusion of the Gaborone Granite Complex, possibly in a diapiric manner.

In summary, evidence from the west-central Transvaal suggests that the evolution of the Kaapvaal craton during the early-Proterozoic was affected by several episodes of downwarping with complementary volcanicity and sedimentation. The development of the Ventersdorp Supergroup was strongly influenced by the subsidence of the Swartruggens trough, into which the Kanye Volcanic Group was also localized. Uplift caused the focus of subsidence to shift northwards, where the incipient downwarping of the Transvaal basin was heralded by the sedimentation and volcanicity of the Buffalo Springs Group. The northern limits of development of the Ventersdorp Supergroup and the southern boundary of the Buffalo Springs Group were strongly influenced by a significant positive crustal feature, the Ganskuil platform, which ceased to play an important role in the stratigraphic development of the west-central Transvaal only after the marine transgression of the Black Reef Quartzite.

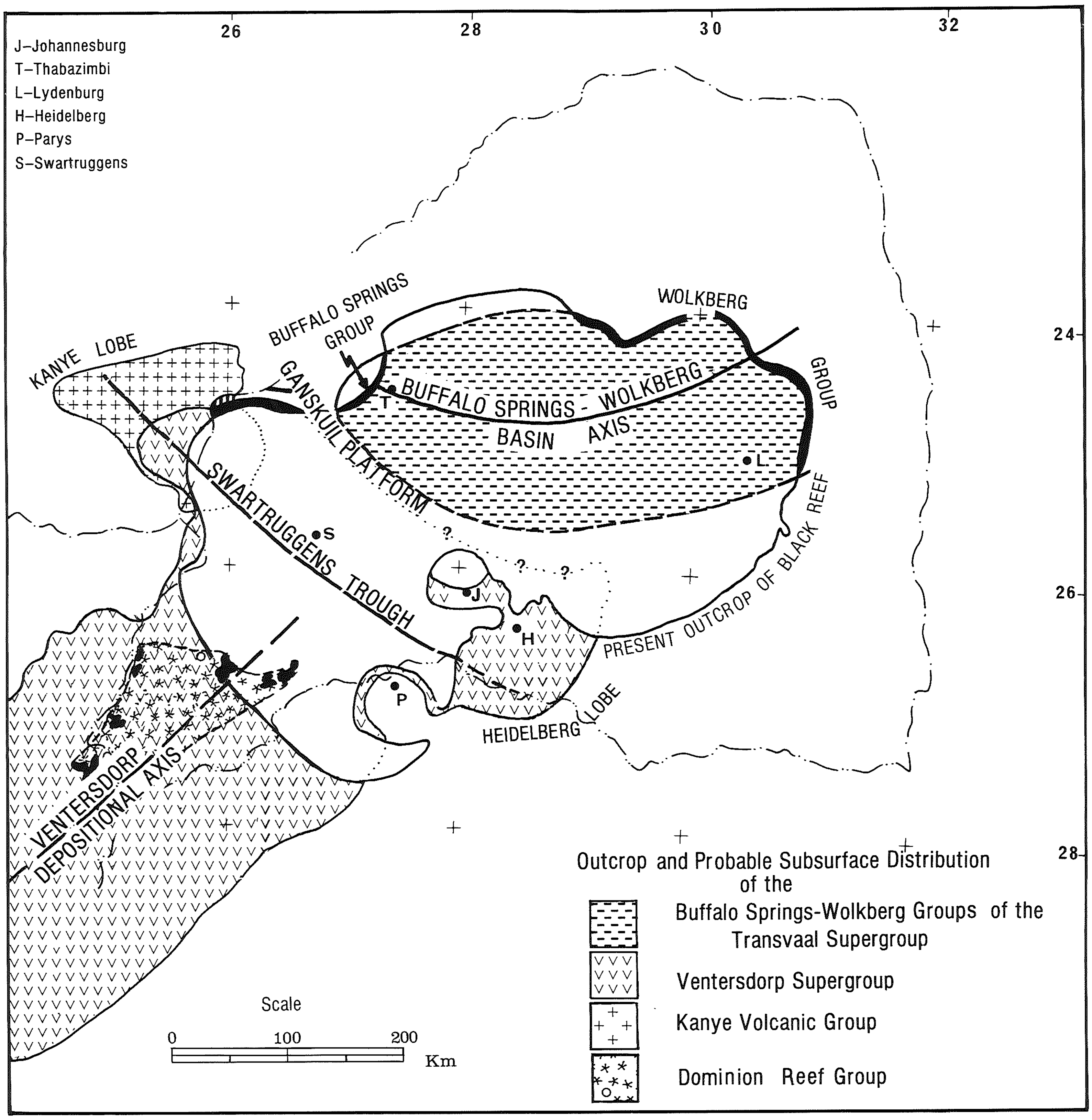

Figure 9 : *Outcrop and suboutcrop distribution patterns of the Dominion Reef Group, the Ventersdorp Supergroup and the Buffalo Springs-Wolkberg Group, illustrating their major basins of deposition.*

IV. CONCLUSIONS

Developed along a 70 km long belt of exposure from Ganskuil (75 km southwest of Thabazimbi) to the Ngotwane River south of Gaborone, is an assemblage of extrusive and sedimentary rocks correlated with the Ventersdorp Supergroup. The volcanic rocks range from tholeiitic basaltic lavas to rhyolitic felsites, together with pyroclastics and laharic breccias, all of which were subaerially deposited. Geochemical investigation of the acid volcanics revealed that the lavas are alumina-oversaturated, but deficient in Na_2O and CaO. Alteration of the lavas is thought to have occurred during low-grade greenschist metamorphism, in a process of breakdown of plagioclase, liberating Na and Ca. The lavas are enriched in total iron oxides and K_2O, when compared with the average composition of rhyolite.

Sediments intercalated within the assemblage are considered to be fluvially deposited. The clastics range from the extremely coarse, alluvial-fan facies, through the braided- and meandering-fluvial environments, to siltstones and shales of the floodbasin facies.

The tholeiitic basaltic lavas are correlated with the Klipriviersberg Group and the Seokangwana alluvial-fan sediments are correlated with the Kameeldoorns Formation. The lower acid volcanic zone of the Seokangwana belt, the middle acid volcanic zone, and the upper sedimentary zone of the Derdepoort belt are assigned to the Makwassie Quartz Porphyry Formation, whereas the upper sedimentary zone of the Seokangwana belt has been included with the Bothaville Formation of the Ventersdorp Supergroup (as defined in its type-area in the Bothaville region).

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KEY TO PLATE I

A. Heavily-jointed basalt, with elongate, silica-filled amygdales up to 5 cm long in the lower volcanic zone, Derdepoort belt. (Klipriviersberg Group, Elandskop, Schots 196 KP, Marico district).

B. Photomicrograph of spheroidal accretionary lapilli defined by curved cryptocrystalline microlites thought to be shards (Thaba 55A, lower volcanic zone, Derdepoort belt, Batavia 176 KP, Polars not crossed, 30X magnification).

C. Contorted shale caused by soft-sediment slumping in a volcaniclastic lens of the middle acid volcanic zone of the Derdepoort belt (Makwassie Quartz Porphyry Formation, Batavia 176 KP, Marico district).

D. Clast-supported volcaniclastic conglomerate that dominates the upper sedimentary zone of the Derdepoort belt (Makwassie Quartz Porphyry Formation, Kameelboom 91 KP, Marico district).

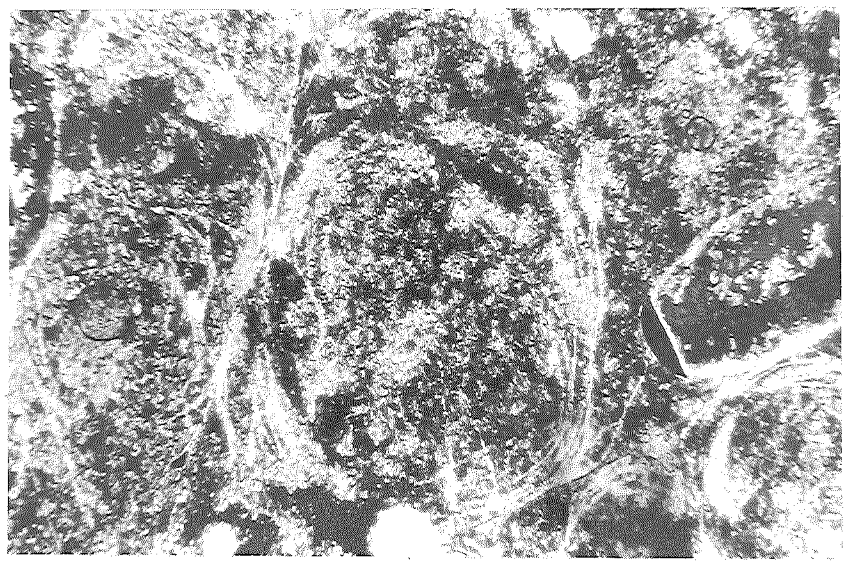
E. Pavement of porphyritic felsite, with ovoidal feldspars varying up to 2 cm in diameter (lower acid volcanic zone, Seokangwana belt, Hartebeestfontein 102 PO, Marico district, Makwassie Quartz Porphyry correlative).

F. Banded porphyritic felsite with quartz-filled fractures aligned at right angles to the banding, which is best seen on weathered faces. (Alewynskop 3 KO, Marico district, lower acid volcanic zone, Seokangwana belt).

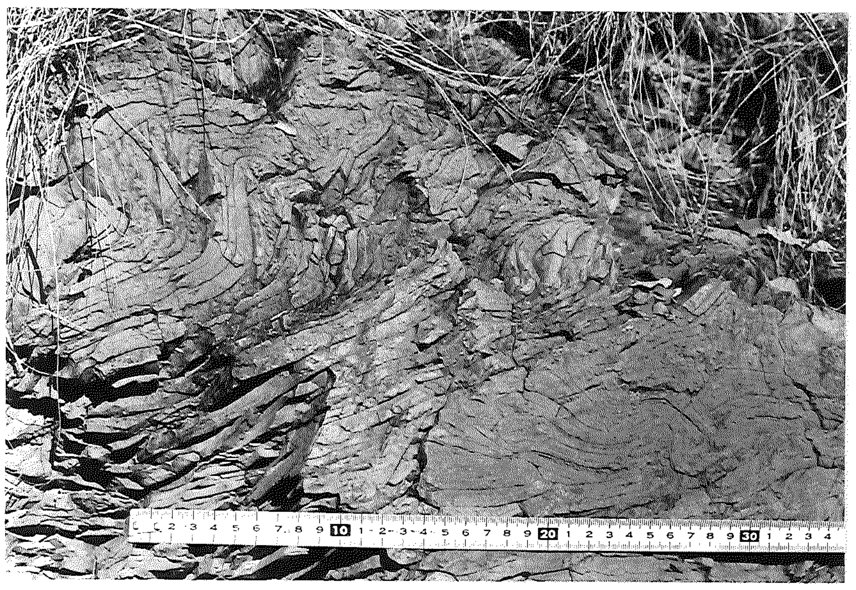
PLATE I

A

B



C



D

E

F