UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

STRATIGRAPHY, ORIGIN, AND CORRELATION OF THE KANYE VOLCANIC GROUP IN THE WEST-CENTRAL TRANSVAAL

by

N. TYLER
(*Research Assistant, Economic Geology Research Unit*)

ECONOMIC GEOLOGY RESEARCH UNIT
INFORMATION CIRCULAR No. 130
January, 1979

STRATIGRAPHY, ORIGIN, AND CORRELATION OF THE KANYE VOLCANIC GROUP IN THE WEST-CENTRAL TRANSVAAL

ABSTRACT

The oldest early-Proterozoic assemblage developed in the Derdepoort area of west-central Transvaal is the Kanye Volcanic Group. The Group is well-exposed along the Botswana border in the vicinity of Gaborone and is composed of bluish-grey, massive, felsites of dacitic composition, and a siliceous agglomerate. Intrusive into the Kanye Volcanic Group is the Gaborone Granite Complex, which in the west-central Transvaal, comprises a coarsely-crystalline red granite. Contact metamorphism of the enveloping felsites, following the intrusion of the granite, altered their physical and geochemical nature from massive, bluish-grey dacite to red porphyritic felsite of rhyolitic composition. During this process, SiO_2 and K_2O were added to the dacites while at the same time, there was a sympathetic removal of iron oxides and Al_2O_3.

Consideration of the outcrop and suboutcrop distribution patterns of the Kanye Volcanic Group and the Ventersdorp Supergroup suggest that the Kanye Volcanic Group is localized in the Swartruggens Trough and that the group constitutes the proto-basinal phase of the development of the Ventersdorp Supergroup.

* *

STRATIGRAPHY, ORIGIN, AND CORRELATION OF THE KANYE VOLCANIC GROUP IN THE WEST-CENTRAL TRANSVAAL

CONTENTS

* * * * * * * * * * * * * * * * *

ISBN 0 85494 546 6

STRATIGRAPHY, ORIGIN, AND CORRELATION OF THE KANYE VOLCANIC GROUP
IN THE WEST-CENTRAL TRANSVAAL

I. INTRODUCTION

The Kanye Volcanic Group comprises the acid igneous rocks which outcrop between the Gaborone Granite Complex and the Ventersdorp Supergroup. The Group is pre-Gaborone Granite in age and generally occurs as a mantle around the Gaborone Granite Complex (Figure 1). Homogeneous felsite is the dominant rock-type. The acid igneous rocks were previously considered to be intrusive, but evidence from the west-central Transvaal suggests an extrusive mechanism of formation. The Group derives its name from the village of Kanye, in southeastern Botswana (Figure 1).

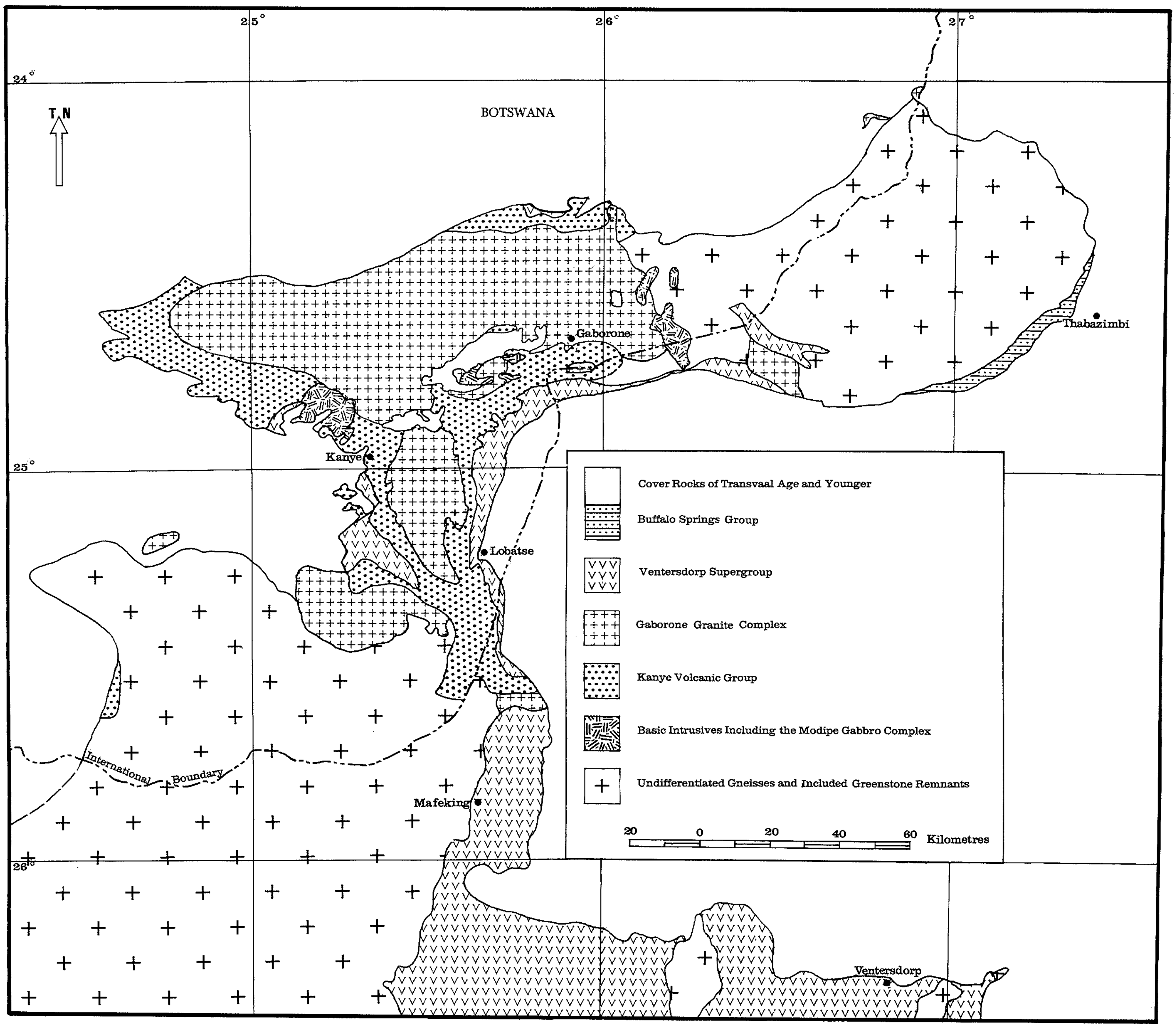


Figure 1 : Location and geological setting of the Kanye Volcanic Group in southeastern Botswana and west-central Transvaal.

The Kanye Volcanic Group extends from Botswana into the Transvaal south of Gaborone, becoming narrower in an easterly direction. The Group crosses the Botswana border under sand cover and is partly exposed over a distance of 18,5 km on the farms Schuinsdam 1 KO, Wildebeestkop 2 KO, and Nicolaasdoorns 76 KP (Figure 2). The quality of exposure along the outcrop belt varies considerably. The Kanye

Volcanics are well-exposed in the broken terrain along the Botswana border but further south outcrops are scattered and poorly exposed in the sand-covered Schuinsdam valley.

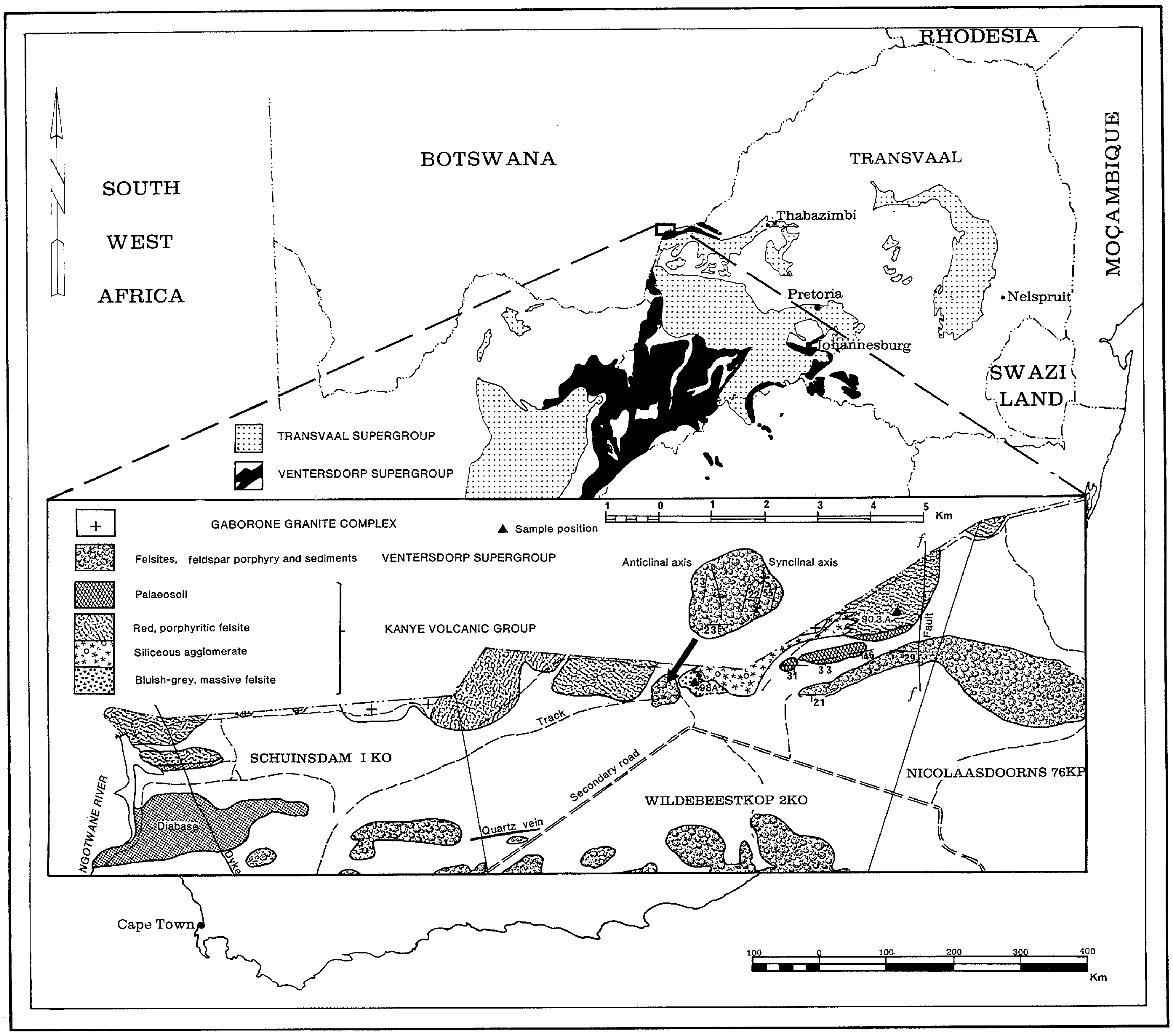


Figure 2 : Geological map of the Kanye Volcanic Group exposed in the far west-central Transvaal

A second belt of Kanye lavas, previously mapped as Dominion Reef, is preserved beneath Transvaal cover, and extends into South Africa midway between Lobatse and Mafeking (Figure 1).

II. HISTORICAL BACKGROUND

Rocks now assigned to the Kanye Volcanic Group by the Geological Survey of Botswana were previously not distinguished from the siliceous igneous rocks which are now recognized as belonging to the lower parts of the Ventersdorp succession. Du Toit (1939) correlated the combined group of volcanic rocks with the Ventersdorp System, but, in 1946, assigned the group to the Dominion Reef System. Truter (1949) and Poldervaart and Green (1952) agreed with this correlation, as did McConnel (1955) who proposed the local formational name of Lobatse (previously spelt Lobatsi) Volcanic Series for felsitic lavas and tuffs of the Gaborone district. Wright (1956) recognized that in the Gaborone area, the Lobatse Volcanic Series was subdivisible into a western belt of uniform, massive felsites and an eastern belt of diverse lava flows, tuffs, and agglomerates. Boocock (1959) showed that the massive felsites were older than the Gaborone Granite Complex, and the local formational name of Kanye Volcanic Group was given to these pre-Gaborone Granite siliceous rocks by the Botswana Geological Survey (Crockett, 1971).

The confusion in the earlier attempts at the correlation of the Kanye Volcanics is partly due to the nature of the lower and upper contacts of the Group. The lower contact with the Gaborone Granite is generally obscure or gradational. This makes it difficult to decide where to draw a boundary between them. Few sharp contacts have been mapped. The upper boundary with the Ventersdorp Supergroup is, in places, equally as indistinct, and it is very commonly not possible to map a distinct boundary between the two formations (Crockett, 1971).

III. AGE OF THE KANYE VOLCANIC GROUP

Table 1 summarizes the Rb-Sr whole-rock geochronology available on the Kanye Volcanic Group up to the end of 1975. A great range is apparent in the dates which appear to form clusters, the first at slightly older than 3 000 m.y. the second at 2 400 m.y. The 1 831 m.y.-isochron, quoted by Key (1976), was from eight samples of felsites. Since these felsites are demonstrably pre-Transvaal Supergroup in age and, hence, older than about 2 000 m.y., the best-fit line is clearly not an isochron (Harding et al., 1974).

TABLE I

The Geochronology of the Kanye Volcanic Group, Republic of Botswana

	Locality	Method	Age (m.y.)	Analyst/Institute
Felsite (isochron 8 whole rock points)	Kanye	Rb-Sr isochron	1831 ± ?	Snelling, Oxford
Felsite (whole rock)	9,0 km southwest of Lobatse	Rb-Sr	2386 ± 100	Snelling, Oxford
Felsite (whole rock)	Neneke ridge south of Kanye	Rb-Sr	2402 ± 110	Snelling, Oxford
Felsite (whole rock)	Oki Pan	Rb-Sr	2412 ± 95	Snelling, Oxford
Felsite (whole rock)	9,5 km southwest of Lobatse	Rb-Sr	2431 ± 100	Snelling, Oxford
Felsite (whole rock)	Neneke ridge south of Kanye	Rb-Sr	2719 ± 120	Snelling, Oxford
Felsite (whole rock)	Neneke ridge south of Kanye	Rb-Sr	3196 ± 100	Snelling, Oxford
Felsite (whole rock)	Neneke ridge south of Kanye	Rb-Sr	3249 ± 100	Snelling, Oxford
Felsite (whole rock)	Neneke ridge south of Kanye	Rb-Sr	3421 ± 150	Snelling, Oxford

(after Key, 1976).

The direct evidence for the age of the Kanye Volcanic Group that may be obtained from radiometric dating methods is rather poor. Crockett (1971) suggested that the ages in excess of 3 000 m.y. may reflect the true age of the Kanye Volcanic Group. The geochronological age clusters noted above may then be due to the effects of younger thermal episodes, such as the intrusion of the Gaborone Granite Complex and the extrusion of Ventersdorp lavas and pyroclastics. Lithologically similar samples of the Kanye Volcanic Group, taken a few hundred metres apart, have given widely differing geochronological ages. This suggests that, assuming similar initial $^{87}Sr/^{86}Sr$ ratios, the samples may not have remained closed chemical systems and may have suffered gains of rubidium or losses of radiogenic strontium. Unfortunately, as Harding et al. (1974) state, "in the absence of any distinctive petrographic criteria, there is no objective way of deciding which samples may have been open chemical systems with regard to rubidium and strontium. In consequence no meaningful conclusions can yet be drawn as to the geochronological age of the Kanye Volcanic Group".

Field evidence for the age of the Kanye Volcanics indicates that they are older than the Gaborone Granite Complex as the granites incorporate xenoliths of Kanye felsite, and are, in places, intrusive into the group (Crockett, 1971). As the Central Assemblage of the Gaborone Granite has been dated at 2 750 m.y. (8 point Rb-Sr whole-rock isochron), the Kanye felsites may be regarded as being older than the Ventersdorp Supergroup. The maximum age of the Kanye Volcanic Group has not been clearly defined because of the poor exposures of the group's contact with the Basement Complex. It has been suggested (Crockett, 1971) that the Kanye Volcanic Group may be as old as the Swaziland Supergroup as defined in the Barberton Mountain Land.

IV. STRUCTURE

Jointing is the dominant structure in the Kanye Volcanic Group. The homogeneous nature of the red porphyritic felsite and the lack of marker units within the group make it extremely difficult to recognize any evidence of folding or displacement. Crockett (1971, p. 43) stated that the Kanye Volcanic Group was probably strongly folded before the emplacement of the Gaborone Granite Complex, but subsequent recrystallization has obscured signs of tectonic structure. It is debatable whether the Kanye Group was strongly deformed, as the metamorphic imprint required to totally homogenize the rocks and remove all traces of folding would have had to be extremely high.

In Botswana, the general concordance in strike of the granite/red porphyritic felsite and the red porphyritic felsite/bluish-grey felsite boundaries indicates comparable dips (Wright, 1961). The boundaries vary from horizontal to a southeast dip of up to 40 degrees. In the area under review, similar orientations were observed, with no direct evidence for the distortion of either boundary being present. Indirect evidence of folding in the group is indicated by an anticlinal fold structure in the palaeosoil unit on the farm Wildebeestkop 2 KO (Figure 2). The unit dips southwards at angles varying between 33 and 46 degrees, but is sharply folded at the western extremity of the body, to dip westwards at 70 degrees. Contortion of the laminae within the unit suggest that slumping also occurred, probably during periods of crustal instability related to Gaborone Granite intrusion or Ventersdorp extrusion.

The structural imprint that is most conspicuous in the Kanye Volcanic Group is the rectilinear pattern of horizontal and vertical, or sub-vertical, joints. These joints are clearly visible on aerial photographs and on outcrops. The horizontal structures resemble bedding planes. On closer examination, the structures were observed to pass through lapilli and blocks of the siliceous agglomerate unit and are therefore joints. The trend of the sub-vertical or vertical joints is east-northeast and south-southwest. Major joint systems may be traced for several kilometres.

Post-Ventersdorp, left- and right-lateral dislocations were also observed in the region. These are exposed as shear zones, or dyke-filled, fault planes.

V. DESCRIPTION OF ROCK-TYPES

In Botswana, the Kanye Volcanic Group is typically a succession of homogeneous felsites, with no lithologic differentiation having been recognized throughout its vertical and areal extent. In the west-central Transvaal, however, a pyroclastic phase of the Kanye Volcanic Group has been observed. In addition to the pyroclastic rocks, variations in colour and phenocryst content were found to correspond with significant differences in the geochemical nature of the felsites which range in composition from dacites to rhyolites.

The Kanye Volcanic Group is thought to have weathered *in situ*, forming a clay-rich residual soil. Outcrops of this palaeosoil are observed directly below the Ventersdorp succession.

A. Bluish-Grey, Massive Felsite

Bluish-grey, massive, felsite outcrops on the farm Wildebeestkop 2 KO (Figure 2). Although this variety of felsite is typical of the Kanye Volcanic Group in Botswana, in the area under review dark felsite is confined to one relatively small dome-like outcrop. The bluish-grey, massive, felsite generally weathers to smooth, dark brown surfaces. Even where weathered, the rock is hard and exhibits a flinty fracture. Outcrops occur typically as large, bare pavements, with rounded boulders scattered randomly over the surfaces. The felsite is fine-grained, often appearing almost cherty in hand-specimen. Only rarely are white feldspar phenocrysts, up to 0,5 cm in length, seen to be dispersed throughout the matrix. At the centre of the outcrop on Wildebeestkop 2 KO the bluish-grey felsite is massive and structureless; towards the extremities of the exposure the rock is banded. This banding is more easily recognizable on weathered surfaces; on rough, fresh surfaces the rocks appear structureless.

Scattered randomly over the outcrop pavements are zoned, circular features (Plate 1A) reminiscent of varioles that have been observed in basaltic komatiitic lavas of the Onverwacht Group, in the Swaziland Supergroup (Ferguson and Currie, 1972). Varioles also occur in the Archaean tholeiitic lavas of the Abitibi metavolcanic belt, Canada (Gélinas et al., 1976) and in the Buffalo Springs Group, west-central Transvaal (Tyler, 1978). The zoning observed in these varioles, which range between 4 and 6 cm in diameter, is due to textural variations within the structures. The concentric outer rings are fine-grained and are more resistant to weathering than the coarser core. Both the core and outer ring comprise intergrowths of quartz and feldspar. Aggregates of ferro-magnesian minerals, on dissolution, leave small pockmarks on the surface of the pavement.

In thin-section, the bluish-grey felsite is characterized by a few small phenocrysts in a felsitic groundmass. The holocrystalline groundmass is composed predominantly of quartz-feldspar intergrowths. Other minerals present in varying amounts are biotite, pyroxene, amphibole, and chlorite. Accessory minerals are sphene, zircon, leucoxene, and an opaque mineral, probably iron ore. Bands comprising biotite concentrations, usually associated with ore and accessory sphene, alternate with quartz-feldspar-rich, biotite-poor bands, to impart an indistinct streaky appearance to the rock.

The feldspar phenocrysts consist of micro-antiperthite. They are usually less than 3 mm in length, but range up to 5 mm, and are subhedral to rounded in shape. The phenocrysts do not exhibit a constant concentration throughout the groundmass, but form randomly scattered clusters. Under the microscope extinction of the phenocrysts is uneven and patchy, particularly in the phenocryst aggregates where growth of one crystal is inhibited by its neighbour. Sutured boundaries between adjacent phenocrysts were also observed.

In the field, massive, bluish-grey, non-porphyritic felsite grades gradually into red, porphyritic felsite.

B. Red Porphyritic Felsite

In the Transvaal, red porphyritic felsite is exposed along the Botswana border as a discontinuous 17 km-long belt (Figure 2). The felsite outcrops either as low rounded hillocks, such as the one found on the western boundary of the farm Schuinsdam 1 KO, or as a range of hills with a maximum elevation of 200 m above the surrounding plain. This range of hills extends eastwards from the north-eastern boundary of Schuinsdam 1 KO to Nicolaasdoorns 76 KP. Small, scattered outcrops on the sand-covered plain south of the range of hills indicate that part of the red, porphyritic felsite is concealed.

The red porphyritic felsite varies in colour from red to dark purple. Close to the transition zone with the bluish-grey, massive felsite, darker colours predominate. The felsites weather to brown, smooth-surfaced, rounded boulders or pavements, commonly with dull-white phenocrysts scattered over the weathered surface. Apart from the colour of the two felsites, the major difference between them is the development of phenocrysts. The red porphyritic felsite has numerous scattered, vitreous-lustred phenocrysts, varying up to 10 mm in length, whereas the bluish-grey, massive felsite has fewer isolated phenocrysts dispersed throughout the matrix of the rock. This difference is obvious in the field. In addition, the phenocrysts of the red felsite are larger (usually greater than 5 mm in length). The increase in phenocryst content in the transition zone between the bluish-grey and red felsites is as gradual as the colour change.

Microscopically, the red porphyritic felsite is holocrystalline and is composed of a groundmass of quartz and feldspar, with amphibole (hornblende), chlorite, and magnetite. Accessory minerals are epidote, sphene (in euhedral grains), and muscovite. A significant difference between bluish-grey felsite and red, porphyritic felsite is the absence of biotite in the groundmass of red felsite. Phenocrysts in the red porphyritic felsite are also micro-antiperthite. Surrounding the phenocrysts are coarser, radiating masses of quartz-feldspar intergrowths which have a dusting of an opaque mineral. Away from these intergrowths, the groundmass is felsitic-textured, but isolated micrographic-textured patches, with cuneiform intergrowths of quartz and feldspar, have been observed (Tyler, 1978). Small, green, pleochroic hornblende laths are scattered throughout the groundmass. In some instances, hornblende is partially altered to chlorite and secondary, dusty magnetite. Where primary iron ore and hornblende are in contact, the magnetite is often mantled by high-relief epidote which is derived from the alteration of the amphibole. The phenocrysts in the rock vary in shape from euhedral to rounded and occasionally they contain inclusions of an opaque mineral, thought to be an iron ore. These inclusions are visible in hand-specimen and impart a poikilitic texture to the phenocryst.

Wright (1961), working in the Gaborone area, showed that red porphyritic felsite occurs as a nearly-continuous belt between the bluish-grey, massive felsites and the Gaborone Granite Complex. Field relations on the South African side of the border indicate that a similar pattern exists. Although exposure is only moderate, it appears that outcrops of Gaborone Granite are enveloped by red porphyritic felsite, with the bluish-grey, massive felsite developed around this envelope.

Due to the lack of stratification within the felsite, thickness estimates are extremely difficult. If the unit is assumed to be sub-horizontal, a minimum thickness of 200 metres is indicated by the height of the highest hill over which red felsite outcrops continuously.

C. Siliceous Agglomerate

Siliceous agglomerate outcrops along the Botswana border-fence, on the farm Wildebeestkop 2 KO (Figure 2). The agglomerate is well-exposed in a narrow, three kilometre-long belt of hills and is flanked to the east and west by red porphyritic felsite.

When fresh, the agglomerate varies in colour from red, through dark greenish-grey, to a black, almost chert-like, rock. On weathering, the colour becomes dark brown, with the pyroclastic fragments standing out in positive relief (Plate 1B). The clasts are generally light brown in colour.

The character of the fragments in volcanic breccias is extremely significant in determining their mode of emplacement and their origin. In size, the particles range, according to the Blythe Scale (Table 2), from fine ash to blocks up to 12 cm in length. Most of the fragments are lapilli-sized. The shape of the ejecta is generally angular and blocky, although some fragments are subrounded (Plate 1B). Blocks and lapilli are easily recognizable on weathered surfaces, as the fragments have sharply defined boundaries. On fresh surfaces, the clast boundaries are less distinct.

Most of the ejecta are laminated, with some of the bands exhibiting preferential weathering. Fresh surfaces of the clasts are rhythmically banded with shades of red to pale purple alternating with

TABLE 2

Blythe's (1940) Size Classification of Volcanic Fragmental Material

(after Ross and Smith, 1961)

Size in Millimetres	Name
>32	Block
32 to 4	Lapilli
4 to 0,5	Coarse Ash
0,5 to 0,05	Fine Ash
<0,5	Volcanic Dust

light or dark grey. Laminae vary from 1 to 2 mm thick, and are occasionally slightly contorted (flow-banded ?). The larger blocks show possible evidence of a previous amygdaloidal state, with quartz- or quartz-feldspar-filled cavities around which the laminae are bent. In general, no preferred orientation of the lapilli and blocks was observed. Although red felsite fragments predominate, siliceous-to-cherty, dark grey, massive felsite clasts are also present.

The groundmass of the tephra is composed of red, fine-grained ash and dust of the same nature as the fragments. Siliceous veins cut across the groundmass and the fragments causing local brecciation of some of the larger blocks.

Although the siliceous agglomerate is predominantly unstratified, some variation in the structural character of the unit is present. Poorly-defined graded beds were observed, as well as impersistent, fragment-free bands. Towards the extremities of the body, siliceous agglomerate inter-fingers with red, porphyritic felsite. The boundary of the siliceous agglomerate is not sharp but shows a gradual transition from agglomerate to red felsite.

The thickness of the agglomerate body is difficult to determine, due to the absence of well-defined stratification. Assuming the body is sub-horizontal, a minimum thickness of 100 m is indicated by the height of the hill on which the agglomerate outcrops. Unfortunately, it is not known how far the body extends into Botswana, so the areal extent of the exposure cannot be calculated. However, the siliceous agglomerate developed on Wildebeestkop indicates that extrusive activity was an important factor in the genesis of the Kanye Volcanic Group.

D. Palaeosoil

Outcropping south of the siliceous agglomerate and the red porphyritic felsite on the farm Wildebeestkop 2 KO is a thinly-laminated unit that was originally considered to be a fine-grained tuff. Although the upper contact is concealed by alluvium, the bed is thought to be directly overlain by volcanic rocks correlated with the Ventersdorp Supergroup. The lower contact is with a soft, weathered, non-descript acid volcanic, probably a red porphyritic felsite.

The unit is characteristically exposed as thinly-laminated (Plate 1C), yellowish-brown outcrops which weather to smooth surfaces. It is extremely fine-grained, soft, easily scratched, and has a talcose feel. Fresh faces are colour-banded in shades of green. Contortion of the bands was observed on outcrop. Microscopic examination reveals that the unit consists of microcrystalline muscovite (sericite) flakes, with scattered opaque minerals. The banding observed in outcrop is due to pure sericite laminae alternating with thicker, opaque mineral-rich sericitic layers. No shards or pyroclastic fragments were observed.

The origin of the unit is somewhat problematic. The dominantly sericitic nature of the rock-type, when considered together with the stratigraphic location of the horizon (resting on a soft and altered acid volcanic and overlain by the Ventersdorp succession), suggests that the unit might be the product of saprolite-forming processes. Chemical weathering of volcanic material produces soils rich in clays (Papadakis, 1969) by breaking down the crystalline structure of the silicates and releasing silica, iron, alumina, and the bases. If leaching is intense and temperatures are high, the bases and much of the silica are leached away. The remaining silica combines with alumina to form clays poor in silica (Papadakis, 1969).

It is suggested that these sericitic rocks represent residual clay soils formed on the Kanye Volcanic Group during a period of chemical weathering preceding the extrusion of the Ventersdorp Super-group. Similar palaeosoil horizons have been noted within the Transvaal Supergroup, above the Ongeluk Lava of the Pretoria Group (Button, 1973). The alternating light and dark green bands may possibly be ascribed to mineral segregation processes active during subsequent diagenesis of the soil horizon.

VI. CHEMISTRY OF THE KANYE VOLCANIC GROUP

A number of analyses of the Kanye Volcanic Group have been published by Wright (1956), Harding et al. (1974), and Hutton et al. (1974). In addition, Crockett added to the geochemistry of the Group in numerous unpublished reports of the Geological Survey of Botswana during the period 1961 to 1971. During the course of this study, two further samples from the Kanye Volcanic Group were analyzed for major-elements (Table 3, Columns 1 and 5).

TABLE 3

Major-Element Geochemistry of the Kanye Volcanic Group, with Selected Comparative Analyses

	1	2	3	4	5	6	7
	98A*				90.3.A*		
SiO_2	70,03	70,98	69,68	73,23	73,05	72,90	71,24
TiO_2	0,45	0,49	0,36	0,24	0,41	0,47	0,72
Al_2O_3	15,18	13,96	15,21	14,03	12,75	12,10	11,18
Total Fe Oxide as Fe_2O_3	5,07	4,38	2,98	2,30	3,92	3,96	8,98
MnO	0,10	0,10	0,04	0,02	0,14	0,18	0,18
MgO	0,00	0,36	0,91	0,35	0,16	0,38	0,75
CaO	1,41	0,95	2,70	1,32	0,78	0,88	0,58
Na_2O	4,11	3,99	4,47	3,94	3,85	3,50	2,87
K_2O	2,66	4,53	3,01	4,08	5,60	5,22	0,66
P_2O_5	0,12	0,13	0,10	0,05	0,11	0,07	0,20
LOI	0,56	0,58	-	-	0,13	0,73	2,34
TOTAL	99,69	100,45	99,46	99,56	100,90	100,39	99,65

* Analyst - N. Tyler

1. Bluish-grey, massive felsite, Wildebeestkop 2 KO, Marico District (Figure 2).
2. Massive felsite, Entry No. 140 (Bulletin 3, Hutton et al., 1974), Gaborone Road, Gaborone District.
3. Average dacite, Cascade Volcanoes (Carmichael, 1964, *in* Irvine and Baragar, 1971, Appendix II).
4. Average rhyolite, Cascade Volcanoes (Carmichael, 1964, *in* Irvine and Baragar, 1971, Appendix II).
5. Red porphyritic felsite, Wildebeestkop 2 KO, Marico District (Figure 2).
6. Kanye Volcanic Group felsite, Ramotswa District, Botswana (Harding et al., 1974, Sample No. K.V.G. 10, Table 9).
7. Rhyolite, Dominion Reef Group, Odendaalsrus District (Handbook 5, Column 942, Visser, 1964).

Columns 1 and 2 of Table 3 represent massive bluish-grey felsite analyzed by the writer and Wright (1956), respectively. The two analyses show a high degree of similarity. Columns 3 and 4 are averaged analyses of Cascade dacite and rhyolite (Irvine and Baragar, 1971) whereas Columns 5 and 6 list the geochemistry of red porphyritic felsite samples analyzed by the writer and by Harding et al., (1974), respectively.

The bluish-grey, massive felsite is geochemically similar to the average composition of dacite. However, the samples represented in Columns 1 and 2 are slightly richer in the total iron oxides and somewhat deficient in calcium and magnesium oxide, when compared with Cascade dacite. The red porphyritic felsite (Columns 5 and 6) compares favourably with the average chemical composition of Cascade rhyolite, although the Al_2O_3 content of the red felsite, which averages 12,43 per cent, is lower than the aluminium oxide content of rhyolite. Total iron and potassium oxides are relatively enriched.

The transition of bluish-grey dacite to red porphyritic rhyolite is marked by significant increases in silica content (an addition of approximately 3 per cent, on average) and in K_2O content (an addition of 1,5 per cent, on average). The aluminium oxide content decreases by approximately 2 per cent, total iron oxide by less than 1 per cent, and oxides of Ti, Mn, Mg, Ca, Na, and P remain relatively constant.

Irvine and Baragar (1971) reviewed the chemical classification of the common volcanic rocks. They subdivided those compositional types most frequently encountered into two major divisions, the sub-alkaline and alkaline rocks, with a third, minor category, the per-alkaline rocks. The approach used by the authors was to devise graphical plots whereby the different rocks may be distinguished and named according to compositional fields. The method has limitations because of the difficulties of representing chemically complex systems on graphs and because many of the longstanding rock-names have not been used in a consistent way over the years (Chayes, 1970, quoted in Irvine and Baragar, 1971). However, satisfactory classifications were obtained for the rocks examined in this study, the dacites and rhyolites of the Kanye Volcanic Group falling into the sub-alkaline field of the calc-alkali series (Table 4 and Figure 3).

TABLE 4

$Na_2O + K_2O$ and SiO_2 Contents of Samples Listed in Table 3

	$Na_2O + K_2O$	SiO_2
1	6,77	70,03
2	8,52	70,98
3	7,48	69,68
4	8,02	73,23
5	9,46	73,05
6	8,72	72,90

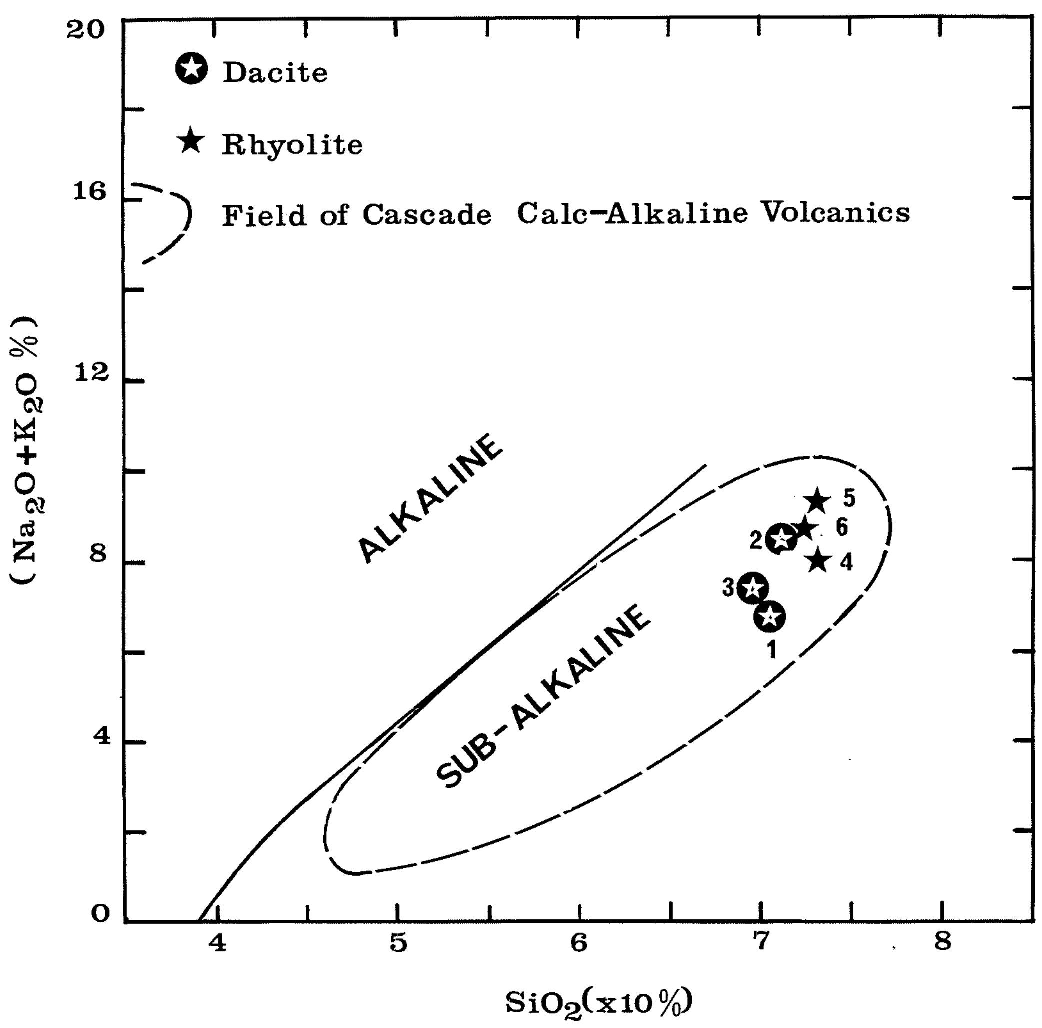


Figure 3 : Rhyolite and dacite of the Kanye Volcanic Group fall within the sub-alkaline field, as defined by Irvine and Baragar (1971). Sample numbers are listed in Table 3.

In summary, the felsites of the Kanye Volcanic Group are of intermediate-to-acid composition. Rhyolitic, porphyritic felsite occurs along the interface between the Gaborone Granite Complex and the dacitic, bluish-grey, massive felsite. The rocks are classified as sub-alkaline and fall within the calc-alkali series as defined by Irvine and Baragar (1971).

VII. DISCUSSION

A. Siliceous Agglomerate

Recognition of the genetic types of volcanic breccias is based upon the structure of the deposit and the character of the fragments and groundmass. The siliceous agglomerate of the Kanye Volcanic Group is unstratified, largely chaotic, but with occasional crudely-defined graded beds. No macro-structure, indicative of a palaeo-cone, was observed. The fragments are mono-lithologic (more than 50 per cent of the lapilli are of the same nature and are similar in texture), range in size from blocks of fine ash, and are angular to sub-rounded. In extent, the deposit has a minimum volume of 3×10^8 cubic metres - the agglomerate is 3 km long, at least 100 m thick, and has a minimum outcrop width of 100 m to the Botswana border. Non-fragmental bands present within the deposit are thought to be the result of pulses of lava flowage.

The characteristics of the Kanye agglomerate correspond best with features described in pyro-clastic-flow breccias (as summarized by Parsons, 1969, p. 279-281; p. 299). These volcanic breccias are deposited from suspension in volcanic, liquid-gas mixtures or in gravity flows which may not have appreciable amounts of gas. The principal characteristic of these deposits is their occurrence in relatively thick, typically unsorted and non-bedded units. In the instance of the Kanye agglomerate, banding in the fragments indicates that the ejecta were previously consolidated and are predominantly lithic. Blocky, pyroclastic-flow deposits are characterized by a mingling of fragments of many sizes, some of which become rounded during the flow process. Most large pyroclastic-flow deposits are mono-lithologic with regard to the texture and general character of fragments (Parsons, 1969). A considerable number of exotic fragments (for example the bluish-grey, massive felsite blocks in the Kanye agglomerate) may have been picked up during the extrusion or flow processes. The groundmass of these breccias consists of small particles, down to dust size, of the same material.

The agglomerate of the Kanye Volcanic Group is composed predominantly of lithic (banded, red felsite) lapilli, with accessory accidental (bluish-grey, massive felsite) fragments. Although most glowing pyroclastic-flow breccias are composed largely of porous pumice, lithic flow-breccias have been recorded. The Peléan avalanche deposits are typically lithic (Taylor, 1958, quoted in Parsons, 1969), with fragments being derived from growing domes associated with the centre of the volcano. Intercalated within the siliceous agglomerate are non-fragmental bands. These are thought to be dacitic lava flows, which were periodically extruded over the breccias.

In summary, the siliceous agglomerate of the Kanye Volcanic Group is thought to be the product of deposition of fragments from glowing, pyroclastic-flow avalanches. The non-fragmental bands observed within the agglomerate probably are the result of single lava flows across the volcanic terrane. These flows were subsequently covered by later avalanche deposits.

B. The Origin of the Kanye Volcanic Group

The intimate areal association of the Gaborone Granite core and the enveloping Kanye felsites, coupled with the gradational boundary between them, suggest a common origin for these rocks. Wright (1961), Crockett (1971), and Harding et al. (1974) have considered the petrogenesis of the felsites and the granites to be intimately related. Although not within the scope of this paper, it is necessary to briefly examine the nature of the Gaborone Granite Complex.

Crockett (1971) and Harding et al. (1974) discussed the geochronology and chemical and physical features of the Complex in detail. The work of Crockett (1971), reflecting the current view of the Geological Survey of Botswana, divided the rocks of the Gaborone Granite Complex into three assemblages (Table 5).

The age of emplacement of the central assemblage, on the basis of Rb-Sr whole-rock isochrons, is thought to be 2 748 ± 75 m.y. (Key, 1976). Samples of the inner marginal assemblage yielded an excellent isochron of 2 249 ± 44 m.y. (Harding et al., 1974). Thus, the granites of the Gaborone suite appear to have had as complex a history as the Kanye Volcanic Group.

Three theories regarding the origin of the Kanye Volcanic Group have been published. Wright (1961) completed a detailed petrological study on the rocks of the Gaborone district, examining the Gaborone Granite Complex and the "Lobatsi Volcanic Series". He grouped the pyroclastics and lavas, now correlated with the Ventersdorp Supergroup, and the felsites of the Kanye Volcanic Group into one succession, the Lobatsi Volcanic Series. Wright concluded that the entire succession of granites, felsites, agglomerates, and lavas was part of an evolving, single magma-mass which was emplaced under a thin cover of tuffs and agglomerates. According to Wright (1961, p. 35), the character of the felsites surrounding the Gaborone Granite Complex does not suggest an extrusive origin. Wright postulated that

TABLE 5

Subdivisions of the Gaborone Granite Complex

Name	Characteristics of Assemblage
1. Central Assemblage	complex assemblage of coarse-grained rapakivitic granite and associated microgranites
2. Inner Marginal Assemblage	homogeneous assemblage of coarse-to-medium-grained, pink-coloured granite
3. Outer Marginal Assemblage	porphyritic granophyric rock and recrystallized felsite

(after Crockett, 1971).

the felsites were emplaced as a viscous liquid in a laccolithic sheet under the cover of effusive rocks. Subsequent differentiation within the original felsitic magma produced granophyre (red porphyritic felsite, Tyler, 1978) and the marginal granite of the Gaborone Complex. A further pulse of magma-introduction led to the formation of the Central Granite.

The second model for the genesis of the Kanye Volcanic Group and the Gaborone Granite Complex holds that the central mass of the complex was intrusive into the Kanye Group. Poldervaart (1952) originally proposed the theory. Subsequently, Crockett (1971) expanded on the model. Crockett's objections to Wright's postulate were, firstly, that the tuffs and volcanics regarded by Wright as co-magmatic with the granites were shown by the work of Boocock (1959) to be very much younger than the latter and as belonging to the Ventersdorp Supergroup and, secondly, that the radiometric evidence, although not conclusive, suggested that a long interval of time separated the extrusion of the Kanye Volcanic Group rocks and the mobilization of the Gaborone Granite Complex.

In brief, Crockett envisaged the sequence of events as follows :

(i) the effusion of the Kanye Volcanics (the extrusion mechanics of which are unknown due to subsequent metamorphism);

(ii) The migration upwards of a mass of granitic magma from unknown depths, which forced its way physically into the pre-existing Kanye felsites; a second possible magma-source was postulated by Crockett (1971, p. 18), who stated that the felsites themselves may have been mobilized; this mobilized granitic magma forms the central mass of the complex and is known as the Central Assemblage; and

(iii) the physical reconstitution of the Kanye felsites by the intrusion of the mobilized granite, to form the Inner and Outer Marginal Assemblages of the Gaborone Granite Complex; roughly, these assemblages correspond to the red porphyritic felsite and Wright's zone of granophyre and marginal granite.

The third postulate regarding the origin of the Kanye Volcanic Group was tentatively proposed by Harding et al. (1974) who suggested that the homogeneous Kanye felsites and the Gaborone Granite Complex originated as a single magma. The authors suggested that the felsites seen at the present day actually represent a hypabyssal phase and that the truly effusive part of the sequence has been removed. They felt that the felsites crystallized under a thin primordial crust with a steep geothermal energy gradient. Harding and co-authors speculated that in a situation where hot, volatile-charged, granite magma was being rapidly transferred from its source at the base of the thin crust to the much cooler environment of emplacement near the surface, much of the magmas fluid content would be retained. Rapid loss of its considerable vapour content would be likely to occur in the zone of consolidation because of the proximity of the planetary surface, resulting in little opportunity for the formation of coarse-grained phases. At slightly greater depths, in zones protected by already solidified felsites would magma crystallize into the coarse-grained and more differentiated phases of the Gaborone Granite.

Some of the uncertainties regarding the genesis of the Kanye Volcanic Group may be resolved by the findings in the area under review. Banding of the fragments in the Kanye agglomerate are indicative of flowage in a viscous magma. The contortion of some bands into fold-like structures and the presence of possible amygdales indicate an extrusive nature for at least part of the Kanye Volcanic Group. Similarly, the formation of pyroclastic-flow breccias is a subaerial process. Variolitic structures, found in the bluish-grey, massive felsite, are commonly observed in lavas. Most, if not all, of the Kanye volcanics exposed in the area under review are thus thought to have been formed by extrusive processes, as lava flows, and by flowing, pyroclastic-flow avalanches.

The boundary between the two Kanye felsites is gradational (Figure 4), with an increase in phenocryst content and an almost imperceptible colour change from grey to red. Apart from these changes, the macroscopic characteristics of the bluish-grey and red felsites are similar. The felsites weather in an identical manner, and both exhibit marked rectilinear jointing on outcrop- and airphoto-scales. In thin section, some of the phenocrysts in the red porphyritic felsite have a distinctly poikilitic texture; while others are mantled by cuneiform intergrowths of quartz and feldspar. This texture is more common in close proximity to the felsite/granite contact.

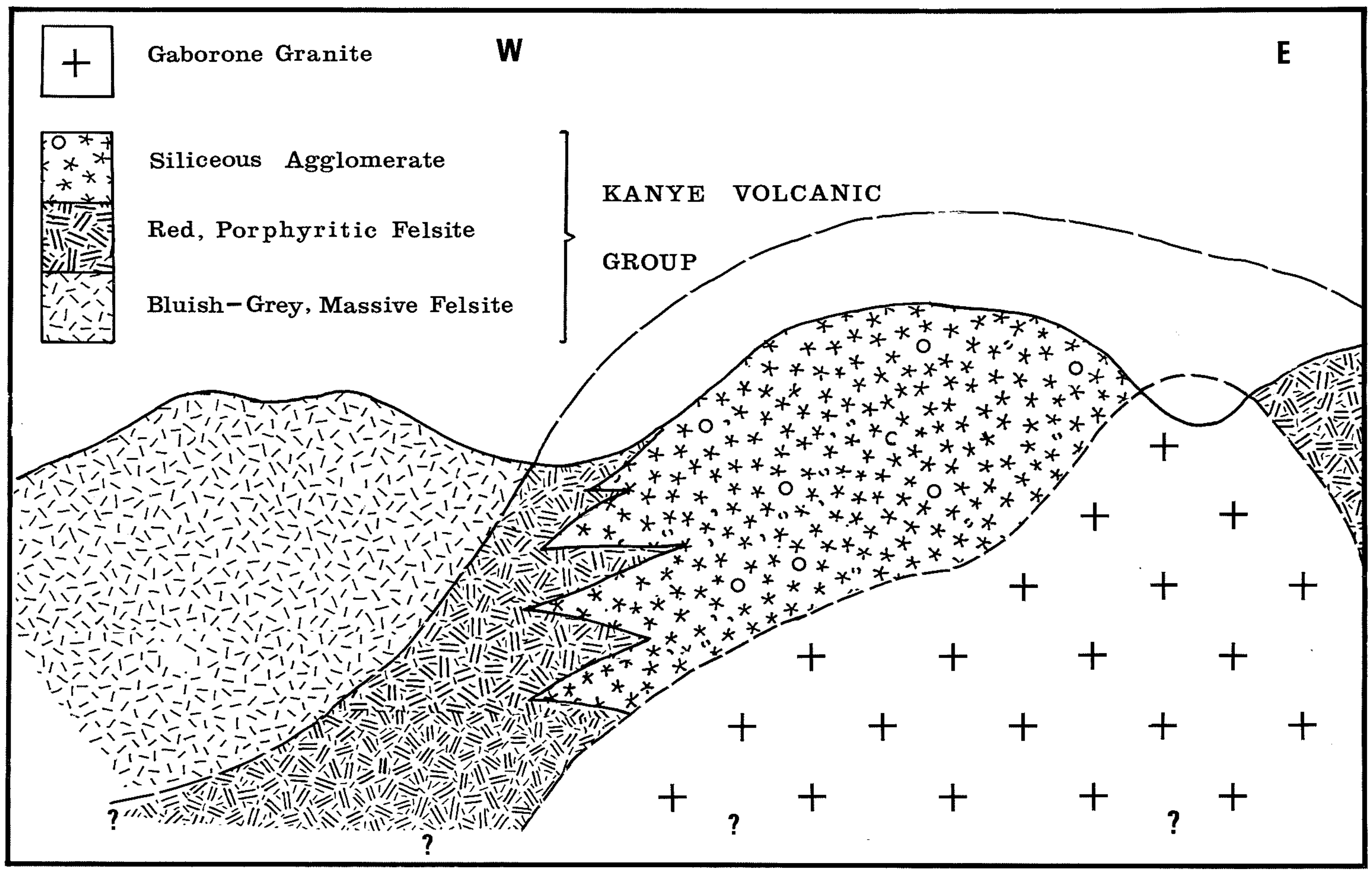


Figure 4 : Schematic representation of the gradational boundary between bluish-grey, massive felsite and red porphyritic felsite. Siliceous agglomerate interfingers with red porphyritic felsite. (Wildebeestkop 2 KO, E-W section, not to scale).

Consideration of the outcrop characteristics in the field, the gradual boundary between bluish-grey and red felsites, and hand-specimen and microscopic features of the Kanye felsites leads the writer to agree, in part, with the model proposed by Crockett (1971). At some stage, subsequent to the outpourings of Kanye lavas, the group was intruded by the Gaborone Granite Complex. The resulting contact metamorphism of the Kanye felsites physically and chemically transformed the dacitic bluish-grey, massive felsites into the rhyolitic red porphyritic felsite.

A similar type of transition occurs in the Rooiberg Felsite, north of Middelburg, where felsite is intruded by gabbroic rocks of the Bushveld Layered Sequence. Von Gruenewaldt (1968) has divided the Rooiberg Felsite into three zones :

(i) a *lower felsite zone* of micrographic and microcrystalline felsite which becomes coarser on approaching the felsite/gabbro boundary;

(ii) a *middle felsite zone* of amygdaloidal, porphyritic felsites, with subordinate tuffs and sediments; and

(iii) an *upper felsite zone* of porphyritic felsite.

In addition, granophyric rocks consisting of micrographophyre, granophyre, and granophyric granite are intrusive into the lower and middle zones. Von Gruenewaldt (1968, p. 164) concluded that the granophyre, the fine-grained granite, and the microgranophyre are palingenetic products of the Rooiberg Felsites and that each one represents only a different manifestation of the same original rock. Where fusion was complete, the material moved away from its place of origin and consolidated as coarse granophyre. Where there was fusion, but no movement, the microgranophyre displays a gradual transition into the middle felsite zone.

In the Kanye Volcanic Group, it seems that reconstitution of the bluish-grey, massive felsite was sufficient to transform it into red porphyritic felsite, but was unable to mobilize the felsite to form intrusive granophyric or microgranitic sheets. A gradational boundary between the fused and unfused felsites can, therefore, be expected in both the Kanye and Rooiberg felsites. The grain-size in the

Rooiberg Felsite increases with proximity to the intrusive gabbroic rocks, while the Kanye felsites become more porphyritic.

In situ fusion of the Rooiberg Felsites by the intrusion of the gabbroic rocks of the Bushveld Layered Sequence is postulated by von Gruenewaldt (1968) to have caused the physical reconstitution and mobilization of the felsites. The temperature of crystallization of gabbroic melts is in the vicinity of 1 200°C and is substantially higher than the crystallization temperature of the granitoid system, which is approximately 600°C (Turner and Verhoogen, 1960). The heat-flow from the Gaborone Granite was sufficient to partially fuse the felsites of the Kanye Volcanic Group, but was inadequate to cause mobilization.

Apart from indirect methods (such as geochronology), it is difficult to tell when the intrusion of the Gaborone Granite occurred. Crockett (1971) believed that the granite intruded 250 m.y. after the extrusion of the Kanye Volcanic Group, that is, 2 750 m.y. ago. As has been noted previously, the geochronology of the Kanye Volcanic Group is internally inconsistent, and, although the unit is tentatively dated at older than 3 000 m.y., it may be considerably younger. In this event, the Kanye lavas and the Gaborone granites may have had the same source. This possibility is enhanced by the nature of Kanye Volcanic/Gaborone Granite field associations. It is difficult to envisage a mobilized granite intruding fortuitously into the middle of a discrete volcanic centre without any external control. The writer therefore agrees, in part, with the hypotheses advanced by Wright (1961), and Harding et al. (1974) that the source of the Kanye Volcanic Group and the Gaborone Granite Complex was probably one and the same. Intrusion of the Gaborone Granite followed shortly after the consolidation of the lava pile, with subsequent metamorphism of the bluish-grey felsites producing an envelope of red porphyritic felsite around the Central Assemblage of the Gaborone Granite Complex.

The reconstitution of Kanye Volcanic Group rocks was accompanied by the migration of certain elements. Silica and potassium are relatively enriched in the red porphyritic felsite relative to the bluish-grey, massive felsite. Aluminium and iron are relatively deficient in the red porphyritic felsite. This may be the result of a limited amount of potassium metasomatism. Iron and aluminium are thought to have migrated outwards into the face of the advancing potassic front.

C. Correlation of the Kanye Volcanic Group

The correlation of the widely distributed Kanye Volcanic Group with other Precambrian assemblages developed in southern Africa has presented severe problems to earlier investigators. Initially, the Kanye felsites were not distinguished from the siliceous igneous rocks which are now recognized as belonging to the Ventersdorp Supergroup and, according to Crockett (1971), the combined group of rocks were collectively assigned to this assemblage. Subsequently, Truter (1949) and Poldervaart and Green (1952) correlated this combined group of igneous rocks with the Dominion Reef "System". The work of Boocock (1959) indicated that these igneous rocks included portions both older and younger than the Gaborone Granite Complex. Boocock's work led to the rocks of pre-Gaborone Granite age being given the name Kanye Volcanic Group by the Geological Survey of Botswana (Crockett, 1971). Recently Harding et al. (1974) examined the relationship between the Gaborone Granite Complex and the enveloping Kanye felsites and tentatively proposed that the Gaborone Granite Complex is analogous to the G.4. or hood granite of Swaziland. Evidence as to the nature of the roof over the G.4 granite is lacking in the hood granite conceptual model, and it has been suggested that the Kanye Volcanic Group felsites may be similar to the kind of roof that once may have existed over the Swaziland hood granite (B.C. King personal communication to Harding et al., 1974).

The difficulty in the correlation of the Kanye Volcanic Group is accentuated by the fact that little is known about the contacts of the unit other than with the Gaborone Granite Complex. Crockett (1971) states that it is not possible to map a distinct boundary between the Kanye felsites and the Ventersdorp Supergroup. Evidence from the west-central Transvaal suggests that a distinct hiatus (during which the Kanye Volcanics weathered to form the sericitic palaeosoil unit) separated the consolidation of the felsites from the extrusion of the Ventersdorp lavas. The intrusion and reconstitution of the Kanye Volcanic Group by the 2 700 m.y. Gaborone Granite Complex imposes a younger age limit on the assemblage. An indication of the upper limits of the age of the Kanye succession is given by the fact that the siliceous igneous rocks apparently lack any pronounced deformational effects and are therefore considered to be post-tectonic with respect to the last major structural episode that affected the Basement Complex.

Consideration of the outcrop and suboutcrop distribution patterns of the Dominion Reef Group, the Ventersdorp Supergroup, and the Buffalo Springs Group (Figure 5), has suggested that the Ventersdorp Supergroup has two axes of deposition. The major northeast-trending axis is truncated in the north by the Swartruggens Trough (Figure 5), which appears to be a southeast-trending zone of comparatively rapid downwarping. This is indicated by the fact that 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 5). Tyler (1979) considered it significant that the Kanye Volcanic Group of southeastern Botswana and the west-central Transvaal is restricted to the northwestern extension of the Swartruggens Trough (Figure 5). The localization of the Kanye lavas and pyroclastics into this 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 stage 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 (Figure 5).

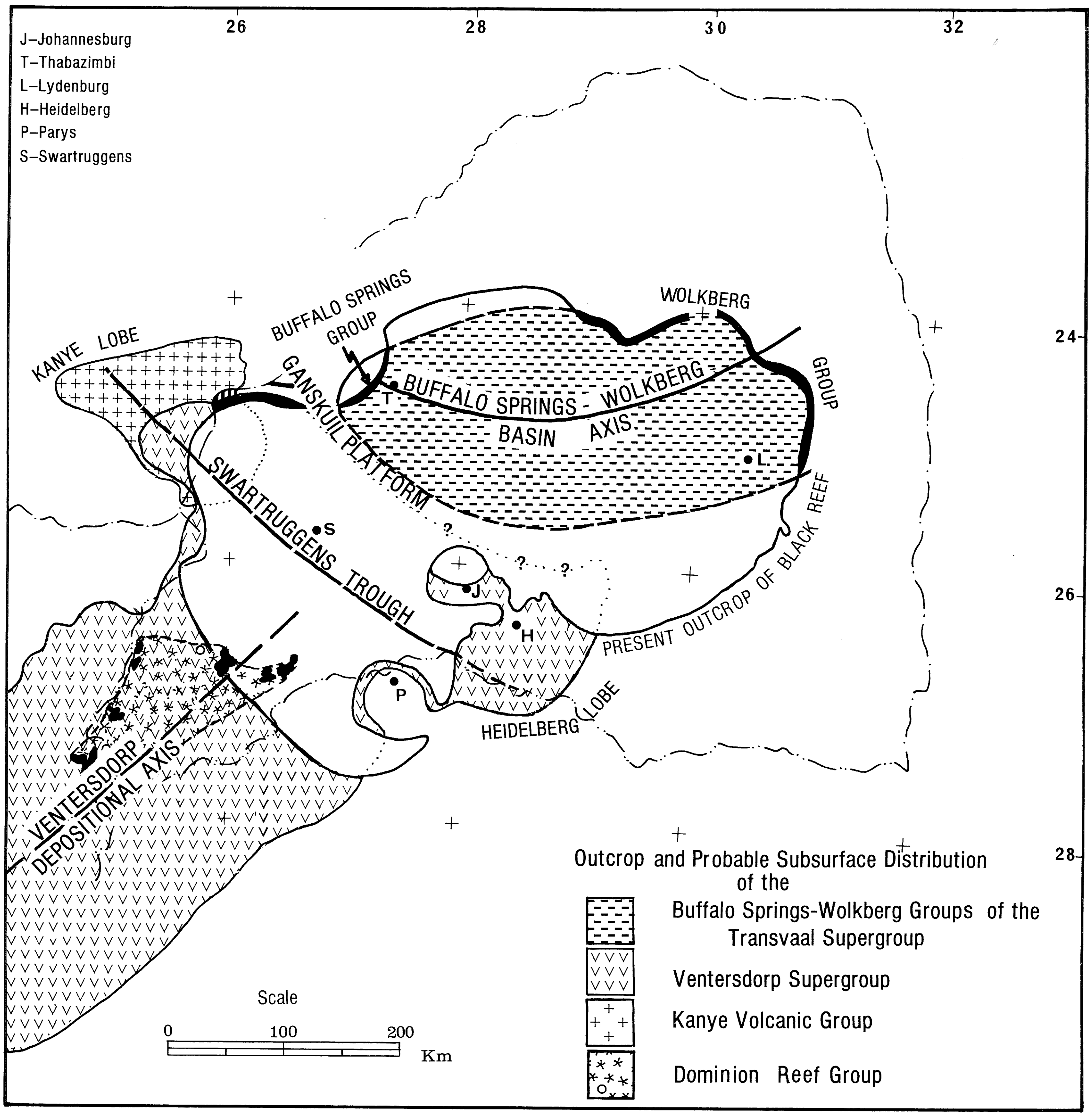


Figure 5 : Outcrop and suboutcrop distribution patterns of the Dominion Reef Group, the Ventersdorp Supergroup and the Buffalo Springs-Wolkberg Group, illustrating their major basins of deposition.

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. timespan (Gaborone Granite Complex/Kanye Volcanic Group-Ventersdorp Supergroup). 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, it is suggested that the Kanye Volcanic Group constitutes the proto-basinal phase of deposition of the Ventersdorp Supergroup and therefore should be correlated with the Ventersdorp Supergroup. Continued downwarping along the axis of deposition of the Kanye lavas (the Swartruggens Trough), possibly coupled with the extrusion of the Ventersdorp Supergroup, may have been sufficient to cause the remobilization of the source of the Kanye Volcanic Group and the intrusion of the Gaborone Granite Complex.

VIII. CONCLUSIONS

The Kanye Volcanic Group in west-central Transvaal is represented by an assemblage of dacitic to rhyolitic lavas and pyroclastic rocks which envelop, and constitute the roof of, the Gaborone Granite Complex. Three theories regarding the origin of the intimately related Kanye felsite and Gaborone granite have previously been proposed, each with a foundation of field and petrochemical evidence. Two of the theories disregard the geochronological evidence (which suggests that the felsites were formed 250 m.y. before granite intrusion) and postulate that the felsites and granites evolved from a single magma source (Wright, 1961, and Harding et al., 1974). The third theory accepts the geochronological evidence and postulates that the granites were fortuitously intruded into an earlier igneous centre (Crockett, 1971).

Evidence from the west-central Transvaal indicates that all three theories may be partially correct. Pyroclastics, variolitic structures and flow banding in the Kanye volcanics of the present study-area confirm that the felsites were subaerially extruded. Alteration of the felsites in close proximity to the Gaborone Granite Complex from dacitic to rhyolitic is accompanied by the incipient development of granophyric textures in the felsites, the addition of SiO_2 and K_2O, and the sympathetic removal of iron oxides and Al_2O_3. This chemical alteration and physical reconstitution of the felsites is thought to be the result of contact metamorphism of the Kanye Volcanic Group following the intrusion of the Gaborone Granite Complex and may be responsible for the inconsistencies in the geochronology of the Kanye Volcanics.

The writer suggests that the Kanye Volcanic Group is localized into the Swartruggens Trough - a zone of increased Ventersdorp deposition, and that the lavas and pyroclastics of the Kanye Volcanic Group constitute the proto-basinal phase of the Ventersdorp Supergroup. Continued downwarping along this axis caused the remobilization of the source of the Kanye Volcanic Group and the intrusion of the Gaborone Granite Complex. Alteration and possible partial melting of the lavas produced the transitional zones between the Gaborone Granite Central Assemblage and the bluish-grey, massive felsites of the Kanye Volcanic Group in the study area.

In the brief time interval between the cessation of the Kanye and Gaborone igneous activity and the inception of Ventersdorp volcanicity, the felsites of the Kanye Volcanic Group weathered to form a clay-rich soil. The soil was later deformed by gravity-induced slumping and was then folded.

* *

ACKNOWLEDGEMENTS

This study represents portion of a regional stratigraphic investigation of the early-Proterozoic assemblage developed around the Makoppa Dome of west-central Transvaal. The author is indebted to the Johannesburg Consolidated Investment Company Limited, for funding, and to Professor D.A. Pretorius of the Economic Geology Research Unit for instigating the project. Mrs. L. Tyler is thanked for typing the manuscript.

* *

REFERENCES

Boocock, C. (1959). Ann. Rep. geol. Surv. Bech. Prot., Lobatse : 16 pp.

Button, A. (1973). A regional study of the stratigraphy and development of the Transvaal basin in the eastern and northeastern Transvaal. Unpub. Ph.D. Thesis, Univ. Witwatersrand, Johannesburg : 352 pp.

Crockett, R.N. (1971). The geology of the country around Gaborone and Lobatse, Botswana. (Explanation of quarter degree sheets, Nos. 2425D and 2525B). Unpub. Rept. geol. Surv. Bech. Prot., Lobatse : 63 pp.

Du Toit, A.L. (1939). Geology of South Africa. 2nd Ed., Oliver and Boyd, Edinburgh : 539 pp.

Du Toit, A.L. (1946). Discussion of "Die korrelasie van sekere voor-Transvaalse gesteentes in die distrik Schweizer Renecke" by O.R. van Eeden. Trans. geol. Soc. S. Afr., 49 : 289.

Ferguson J. and Currie, K.L. (1972). Silicate immiscibility in the ancient "basalts" of the Barberton Mountainland, Transvaal. Nature phys. Sci., 235(57) : 86-89.

Gélinas, L., Brooks, C. and Trzcienski, W.E. (1976). Archean variolites - quenched immiscible liquids. Can. J. Earth Sci., 13(2) : 210-230.

Harding, R.R., Crockett, R.N. and Snelling, N.J. (1974). The Gaborone Granite, Kanye Volcanics and Ventersdorp Plantation Porphyry, Botswana : geochronology and review. Inst. Geol. Sci. Rept. No. 74/5 : 26 pp.

Hutton, L.G., Key, R.M. and Hutton, S.M. (1974). Chemical analyses of rocks, ores and minerals of Botswana. Bull. geol. Surv. Bots., 3.

Irvine, T.N. and Baragar, W.R.A. (1971). A guide to the chemical classification of the common volcanic rocks. Can. J. Earth Sci., 8(5) : 523-548.

Key, R.M. (1976). Radiometric age measurements on rocks from Botswana up to the end of 1975. Bull. geol. Surv. Bots., 6 : 16 pp.

McConnell, R.B. (1955). Ann. Rept. Geol. Surv. Bech. Prot., Lobatse : 10.

Papadakis, J. (1969). Soils of the World. Elsevier Publishing Co., Amsterdam : 208 pp.

Parsons, W.H. (1969). Criteria for the recognition of volcanic breccias : review. p. 263-304, in : Larsen, L.H., Prinz, M. and Manson, V. (eds.), Igneous and Metamorphic Geology. Mem. Geol. Soc. Amer., 115 : 56 pp.

Poldervaart, A. (1952). The Gaborones Granite (South Africa). C.R. 19e Congr. geol. Intern., Alger 1952. Fasc 20 : 315-355.

Poldervaart, A. and Green, D. (1952). An outline of the geology of the Bechuanaland Protectorate. C.R. 19e Congr. geol. Intern. Alger. 1952. Fasc. 20 : 53-66.

Ross, C.S. and Smith, R.L. (1961). Ash-flow tuffs : their origin geologic relations and identification. Prof. Pap. U.S. Geol. Surv., 366 : 77 pp.

Truter, F.C. (1949). A review of volcanism in the geological history of South Africa. Proc. geol. Soc. S. Afr., 52, xxix-lxxxix.

Turner, F.J. and Verhoogen, J. (1960). Igneous and Metamorphic Petrology. 2nd ed., McGraw-Hill Book Co., Inc., New York : 694 pp.

Tyler, N. (1978). A stratigraphic analysis of the pre-Chuniespoort Group strata around the Makoppa Dome, west-central Transvaal. Unpub. M.Sc. thesis, Univ. Witwatersrand, Johannesburg : 206 pp.

Tyler, N. (1979). Correlation, stratigraphic relations and geochemistry of the Ventersdorp Supergroup in the Derdepoort area, west-central Transvaal. Inform. Circ., Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg (in press).

Visser, J.N.J. (Compiler) (1964). Analyses of rocks, minerals and ores. Handbk. Geol. Surv. S. Afr., 5 : 409 pp.

Von Gruenewaldt, G. (1968). The Rooiberg felsite north of Middelburg and its relation to the layered sequence of the Bushveld Complex. Trans. geol. Soc. S. Afr., 71(2) : 153-172.

Wright, E.P. (1956). Geology of the Gaborones district. Rep. geol. Surv. Bech. Prot., Lobatse : 12-20.

Wright, E.P. (1961). Geology of the Gaborones district. Unpub. Ph.D. thesis, Univ. of Oxford : 265 pp.

* *

KEY TO PLATE I

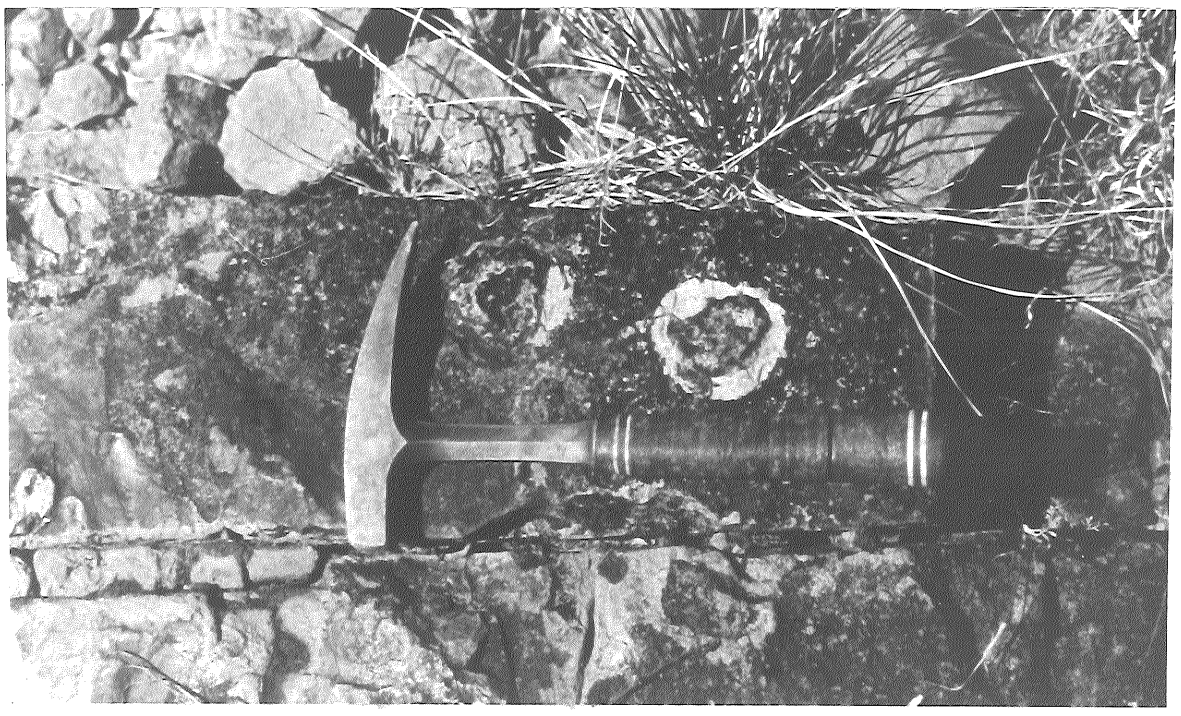
A. Zoned, circular variole in bluish-grey, massive felsite (Wildebeestkop 2 KO, Marico district).

B. Light-coloured block and lapilli-sized, subangular, laminated fragments in siliceous agglomerate. Note the preferential weathering of laminae in the larger blocks (Wildebeestkop 2 KO, Marico district).

C. Thinly-laminated, sericitic palaeosoil which overlies and was derived from weathered felsites of the Kanye Volcanic Group (Wildebeestkop 2 KO, Marico district).

PLATE I

A



B

C