

**ECONOMIC GEOLOGY
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GEOLOGICAL, GEOCHEMICAL AND ISOTOPIC
CHARACTERISTICS OF THE ARCHAEN KAAP VALLEY
PLUTON, BARBERTON MOUNTAIN LAND,
SOUTH AFRICA

L.J. ROBB, J.M. BARTON, Jr.,
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MOUNTAIN LAND, SOUTH AFRICA

by

L.J. ROBB¹, J.M. BARTON, Jr.², E.J.D. KABLE³ and R.C. WALLACE⁴

- (1. *Economic Geology Research Unit, University of the Witwatersrand*
2. *Bernard Price Institute of Geophysical Research, University of*
the Witwatersrand
3. *Nuclear Physics Research Unit, University of the Witwatersrand*
4. *Geological Survey of South Africa, Pretoria*)

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ABSTRACT

Formed approximately 3500 Ma ago, the Kaap Valley tonalite pluton is one of the oldest and the largest of a suite of tonalite-trondhjemite gneiss plutons in the immediate environs of the Barberton greenstone belt. Although similar in many respects to the other members of this suite, the Kaap Valley pluton is distinctively more mafic in composition, containing hornblende instead of biotite as its dominant mafic mineral and being enriched in rare earth elements. These characteristics are not compatible with an origin simply involving a greater degree of partial melting than that required to form more felsic trondhjemites from the same precursor. The parental magma to the Kaap Valley tonalite is considered, rather, to have been a trondhjemitic magma somewhat enriched in P_2O_5 , ZrO_2 and possibly dissolved CO_2 vapour, and also contaminated by a mafic component. The form and composition of hornblendes are inconsistent, however, with a xenocrystic origin by incomplete digestion of surrounding mafic metavolcanic rocks and consequently the contamination is inferred to have taken place prior to magma emplacement. Possible contamination mechanisms include magma mixing and/or complete assimilation at depth of mafic rocks. A subdued form of crystal fractionation occurred during solidification of this magma resulting in the segregation of discrete hornblende and hornblende + biotite tonalite phases. The tonalite was subsequently diapirically emplaced into its present position, perhaps about 3200 Ma ago, a process which resulted in deformation of the surrounding greenstone belt successions. Diapirism also perturbed the original, probably sub-horizontal compositional zoning, the present geometry of which can best be explained in terms of an orthogonal pattern of intersecting structural lineaments.

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I. INTRODUCTION

Archaean tonalite-trondhjemite gneiss plutons form an integral part of typical granite-greenstone terranes and in most areas represent the oldest granitoid component. As such, this suite has been much studied although there has been a bias towards investigations dealing with the petrogenesis of these rocks as a whole (e.g. Arth and Hanson, 1972; Arth and Barker, 1976; Barker and Arth, 1976; Bridgwater and Collerson, 1976; Condie and Hunter, 1976; Collerson and Bridgwater, 1979; Glikson, 1979; Hunter, 1979; Payne and Strong, 1979; Tarney *et al.*, 1979). Seldom documented are detailed studies of individual Archaean gneiss plutons, in part because it is often difficult to define the extent and nature of a "pluton" in deformed terranes (Robb and Anhaeusser, 1983). The Kaap Valley pluton is the largest and most distinctive of the numerous tonalite-trondhjemite gneiss bodies in the vicinity of the Barberton greenstone belt (Fig. 1). Its elliptical shape, covering an area of over 400 km², is almost completely outlined by supracrustal metavolcanic successions of the Swaziland Supergroup.

The Kaap Valley pluton consists predominantly of a homogeneous, weakly foliated, hornblende-bearing tonalite (Fig. 2). It is among the oldest granitoid bodies yet recognized in the environs of the Barberton greenstone belt, yielding $^{207}\text{Pb}/^{206}\text{Pb}$ mineral ages of about 3300 Ma (Oosthuizen, 1970) and a Rb-Sr whole rock isochron age of about 3500 Ma (Barton *et al.*, 1983a) (Table I). Other units in the Barberton granite-greenstone terrane to have yielded similar Rb-Sr ages are the leucocratic orthogneisses of the Bimodal Suite of the Ancient Gneiss Complex (Barton *et al.*, 1980; Carlson *et al.*, 1983) and the trondhjemitic gneisses of the Stolzburg and Theespruit plutons (Barton *et al.*, 1983a).

The Kaap Valley pluton is distinctive in many respects. Whereas all other gneiss plutons in the area are characterized by a trondhjemitic bulk composition with mafic mineralogies dominated by biotite (Robb and Anhaeusser, 1983), the Kaap Valley pluton is tonalitic in bulk composition* with hornblende (\pm minor biotite) as its major mafic phase. It is, therefore, significantly more mafic than typical gneiss plutons of most Archaean granite-greenstone terranes, a factor which in itself presents difficulties in attempting to relate current ideas on Archaean tonalite-trondhjemite petrogenesis to its origin.

Footnote : *For the purposes of the present study, the distinction between "tonalite" and "trondhjemite" is based on the guidelines established by Barker (1979), namely that a trondhjemite be defined as a leucotonalite. Barker stipulated that trondhjemites have SiO₂ greater than 68 per cent with Fe₂O₃ + MgO less than 3,4 per cent and *vice versa* for tonalites.

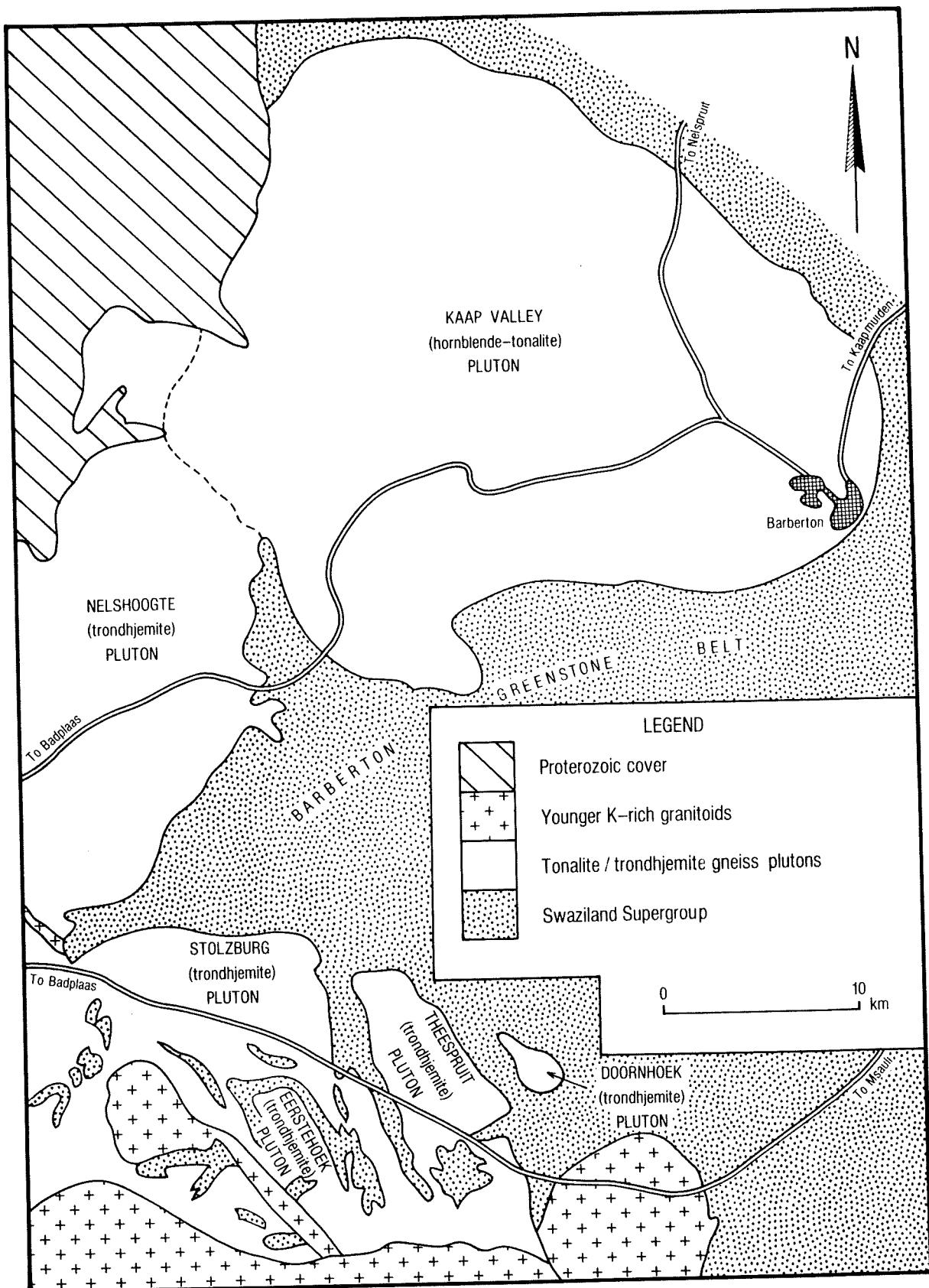


Figure 1 : The locality of the Kaap Valley tonalite pluton in relation to the Barberton greenstone belt and other trondhjemite plutons in the region.

TABLE I

ISOTOPIC AGE DATA, KAAP VALLEY AND OTHER UNITS, BARBERTON GRANITE-GREENSTONE TERRANE*

	$^{207}\text{Pb}/^{206}\text{Pb}$ versus $^{206}\text{Pb}/^{204}\text{Pb}$	$\text{SUMS}/(n-2)**$	Rb-Sr Whole Rock Isochron	Initial $^{87}\text{Sr}/^{86}\text{Sr}$	Rb-Sr Biotite Whole Rock
Kaap Valley Pluton	3211 +405/-559 (wr) 3191 +52/-60 (wr) 3270 \pm 20 (zircon) ³ 3310 \pm 80 (apatite) ³ 3260 \pm 70 (apatite + sphene) ³	2.9 (2.45) .18 (4.4)	3491 \pm 166 ¹	0.7001 \pm 0.0023 ¹	3138 \pm 63
Stolzburg Pluton	3407 +60/-63 (wr)	2.7 (3.1)	3481 \pm 92 ¹	0.7002 \pm 0.0013 ¹	
Theespruit Pluton			3432 \pm 135 ¹	0.7000 \pm 0.0019 ¹	
Leucocratic Orthogneiss, Bimodal Suite Ancient Gneiss Complex	3289 +121/-155 (wr)	4.4 (3.1)	3555 \pm 111 ²	0.6999 \pm 0.0016 ²	

* Ages in Ma. Uncertainties expressed as 2 sigma. wr = whole rock.

** For the whole rock Pb-isotopic isochrons and errorchrons. The appropriate F-variates are shown in brackets.

¹ Data from Barton *et al.* (1983a).

² Data from Barton *et al.* (1980).

³ Data from Oosthuizen (1970).

Prior to this study, very little detailed work had been carried out on the Kaap Valley pluton. Anhaeusser (1966, 1969) was the first to recognize the intrusive nature of the pluton and envisaged that its emplacement was largely responsible for the deformation of the surrounding greenstone supracrustal sequences. Anhaeusser also documented the distinctive mineralogy and chemistry of the pluton and suggested that stoping and assimilation of the surrounding mafic country rocks was responsible for the high ferromagnesian character of the tonalite. Thus, the dominance of hornblende over biotite was considered to be the result of interaction between an intruding magma and surrounding amphibolitic metabasalts. A more recent petrogenetic study was carried out on the Kaap Valley and other tonalite-trondhjemite gneiss plutons in the Barberton area by Condie and Hunter (1976). These workers concluded that the Kaap Valley pluton was compositionally anomalous, particularly in terms of its rare earth element (REE) signature, and supported Anhaeusser's (1966, 1969) view that this was a result of contamination of a normal trondhjemitic magma by mafic and ultramafic metavolcanic wall rocks.

In this paper, we present the results of a detailed geological, geochemical and Pb-isotopic study of the Kaap Valley pluton. Questions relating to the origin of the body are considered, with an emphasis on the formation of a tonalitic magma which is more mafic than those typically encountered in the region. Although exposure does not permit a detailed structural study of the gneiss pluton consideration is given to its mode of emplacement.

II. GEOLOGY

The Kaap Valley pluton was mapped at a scale of 1:30 000 with the resultant data being compiled on to the map in Fig. 2. The pluton underlies relatively flat terrain (Plate 1A) which is broken by low ridges formed by north-westerly-trending Proterozoic diabase dykes. The tonalite is remarkably homogeneous in texture and appearance, with the only discernible variations being due to fluctuations in the mafic mineral compositions. In the field the Kaap Valley tonalite can be subdivided into a hornblende-bearing phase and a hornblende + biotite-bearing phase. The former, more mesocratic, phase occurs predominantly in a broad crescent-shaped zone centred around the town of Barberton in the south-eastern quadrant of the pluton (Fig. 2). Two less-well defined occurrences of hornblende-bearing tonalite are located in the north-western quadrant of the pluton. Elsewhere, the Kaap Valley pluton comprises hornblende + biotite-bearing tonalite which is typified by a lower mafic mineral content than the hornblende-bearing phase. In addition, individual outcrops of either phase may contain dykelets of medium-to-fine-grained tonalite which possess similar mineral constituents to the host granitoid (Plate 1C). As indicated in Fig. 2 (see dotted line), these intrusions, which possibly represent volumetrically insignificant late-stage differentiates of the tonalite pluton, occur predominantly, but sporadically, over a large area in the centre of the body. A fourth granitoid phase, the Goede Hoop trondhjemite, has been identified in the extreme west-central portion of the Kaap Valley pluton (Fig. 2). This phase is texturally quite unlike the Kaap Valley tonalite and compositionally is markedly more leucocratic than the latter; the Goede Hoop phase is considered to be genetically unrelated to the Kaap Valley pluton although contacts have not been found.

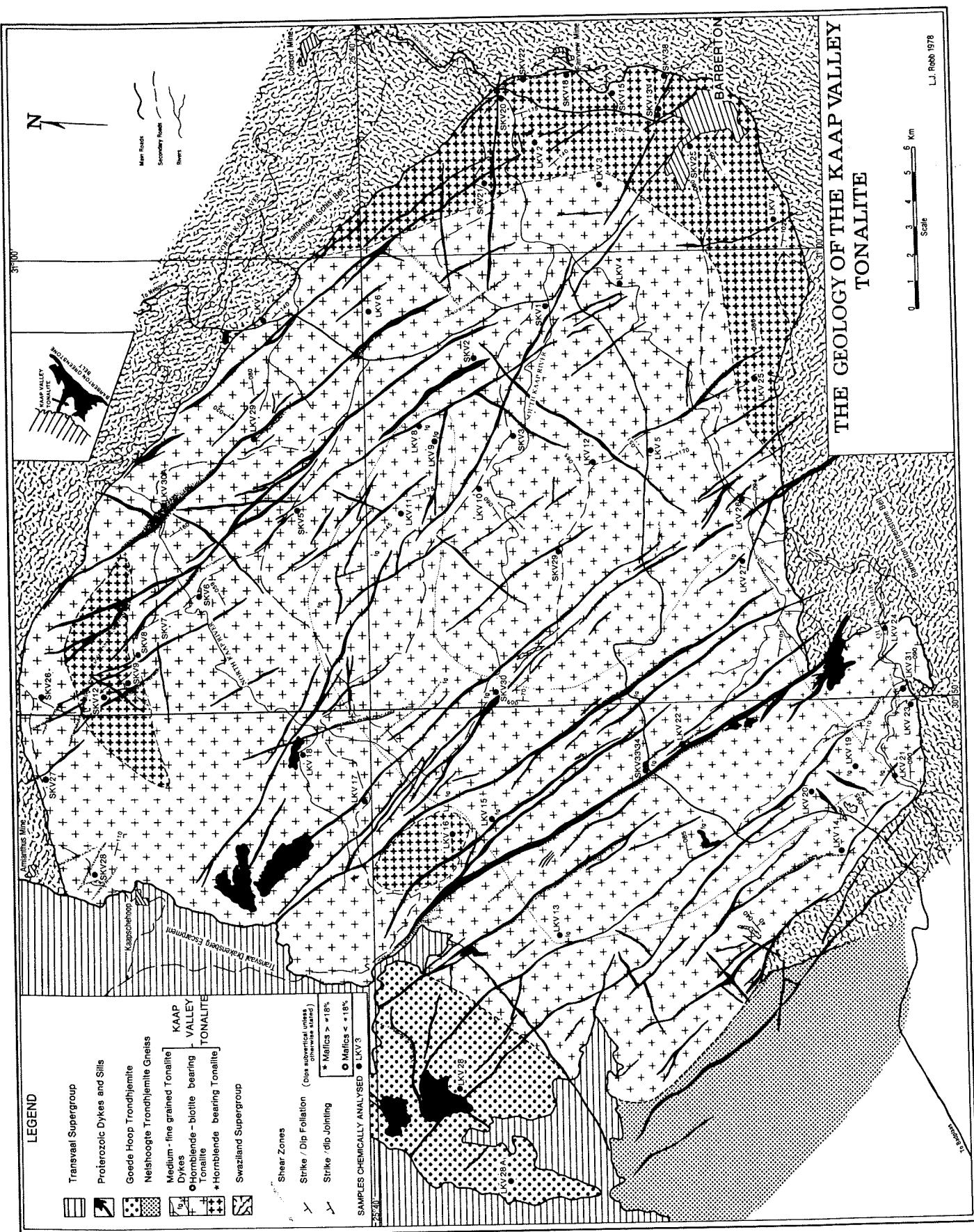
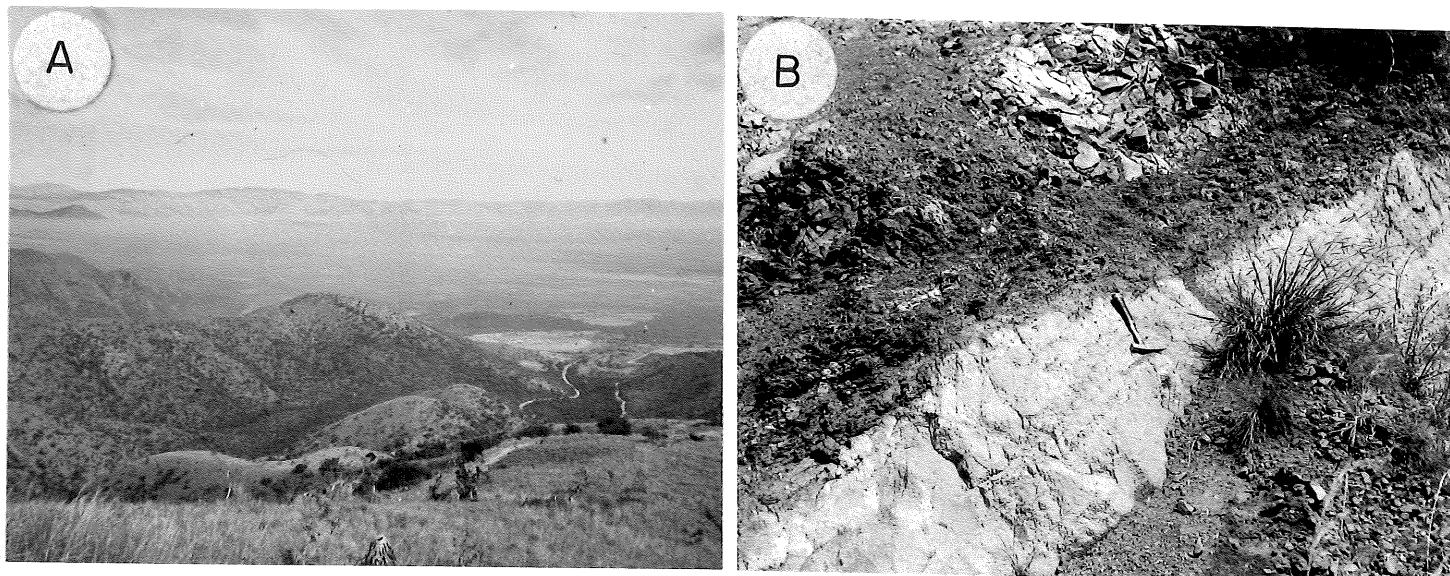
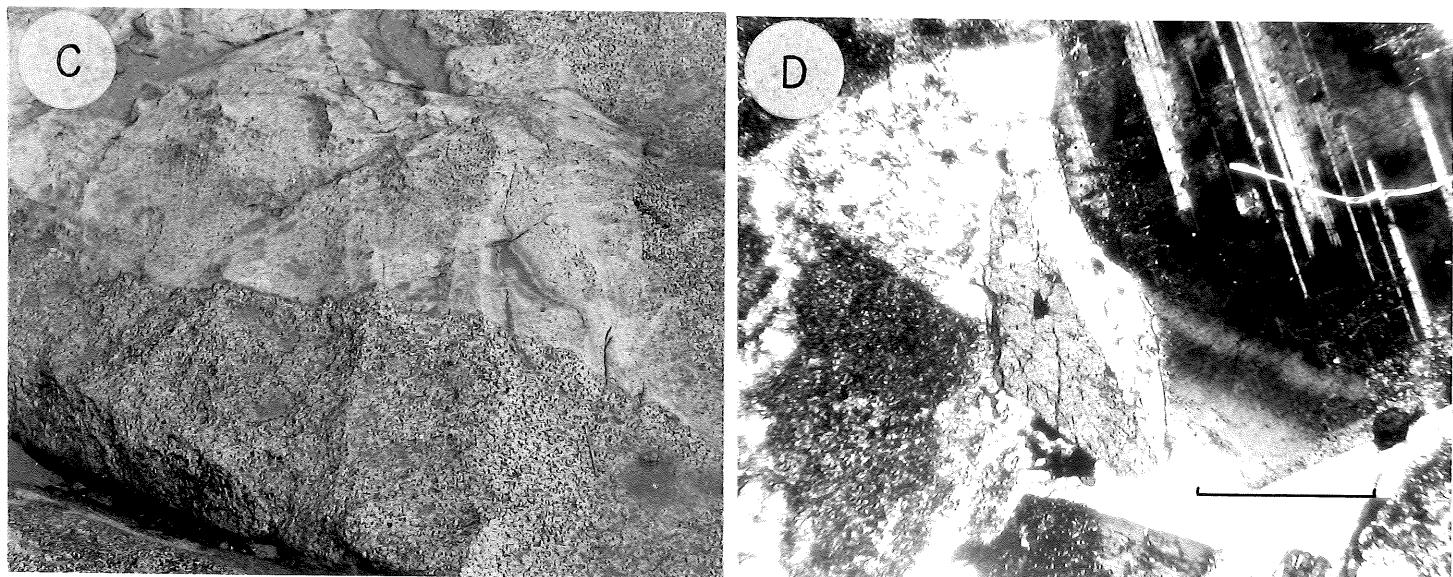


Figure 2 : The geology of the Kaap Valley tonalite pluton.



- A. General view, from the north-east, of the flat-lying terrane underlain by the Kaap Valley tonalite pluton. The hills surrounding the pluton comprise metavolcanic-metasedimentary units of the Barberton greenstone belt.
- B. Sheared contact between metavolcanic schists of the lower Onverwacht Group (left) and weathered Kaap Valley tonalite (right) in the vicinity of sample LKV23 (see Fig. 2). Dip of the contact is approximately 45°S.



- C. Fine-grained tonalite dykelet (about 1 m wide) intrusive into coarse-grained Kaap Valley tonalite at locality SKV30 (see Fig. 2).
- D. Twinned, euhedral, poikilitic hornblende surrounded by quartz and plagioclase. Photomicrograph taken under crossed nicols; bar length represents approximately 0.5 mm.

The Kaap Valley tonalite is characterized by a poor- to moderately-well-developed mineral fabric which is more pronounced along the contacts with the surrounding greenstones. The fabric is typically planar although a mineral lineation is present in places, this being sub-parallel to that developed in schists of the adjacent greenstone successions (Anhaeusser, 1966; 1969; 1976). The foliation is also sub-parallel to the granite-greenstone contact suggesting that both units have been penecontemporaneously deformed. It is interesting to note that the preferred north-westerly orientation of Proterozoic dykes is at right angles to the predominant fabric of the greenstone belt. This relationship is common to many Archaean granite-greenstone terranes and has been used by Halls (1978) to infer a component of horizontal crustal compression during the tectonic evolution of greenstone belts.

The contact between the tonalite pluton and enveloping greenstones is not well preserved although Anhaeusser (1966, 1969) reported crosscutting and *lit-par-lit* intrusive relationships along the southern margin of the Jamestown Schist Belt (Fig. 2). Generally, however, the contacts show little evidence of magmatic intrusion and juxtaposed rock-types are invariably highly sheared (Plate 1B). This relationship suggests that the emplacement of this pluton, at least to its present position, was accomplished in a near-solid-state, probably by diapirism. Evidence suggesting that this mode of emplacement applied to other gneiss plutons in the Barberton Mountain Land is documented by Robb (1981) and may indeed have characterized Archaean gneiss domes in general (Drury, 1977; Fyson *et al.*, 1978). The greenstone successions fringing the Kaap Valley pluton are characterized by a narrow metamorphic aureole ascribed in part to contact phenomena and in part to regional deformation (Anhaeusser, 1966, 1969). Rocks immediately adjacent to the contact have been described as belonging to a hornblende-hornfels facies whereas the development of an albite-epidote hornfels facies and subsequently greenschist facies metamorphism characterize rocks progressively further away from the contact. The occurrence of enveloping rocks with aspects of both local contact and regional dynamothermal metamorphic styles support the view that the Kaap Valley pluton was emplaced, at least to its present position, in the form of a hot solid diapir.

A number of amphibolite and serpentinite xenoliths occur within the Kaap Valley pluton. The larger of these xenoliths may represent roof-pendants, whilst the smaller variety, which are often seen in various stages of digestion and reaction with the surrounding tonalite, are viewed as possibly being cognate inclusions.

The hornblende tonalite has plagioclase, quartz and hornblende as its principal components; biotite is generally absent but may occur in very minor quantities in some samples. Plagioclase occurs as large euhedral laths which are usually preferentially sericitized towards their more calcic centres. Hornblende is typically euhedral, twinned and poikilitic and contains small inclusions of quartz and feldspar (Plate 1D). Small amounts of interstitial microcline and accessory apatite and sphene are present. The hornblende + biotite tonalite has a greater proportion of biotite with the hornblende/biotite ratios usually greater than unity. In only four samples examined did biotite exceed hornblende. In both the hornblende and hornblende + biotite tonalites amphibole grains are euhedral-to-subhedral and give no indication of having been derived by the digestion of a mafic precursor. Furthermore, their distribution through the rock is even and regular with no evidence of "clotting" or reaction with the host tonalitic magma. In all respects, therefore, the hornblende has the appearance of being primary and not xenocrystic.

The finer-grained tonalitic dykelets and veins are mineralogically identical to their host rock. Most of the tonalite dykes contain both hornblende and biotite although one sample (LKV9, Table II), which is characterized by high SiO_2 , has biotite but is devoid of hornblende.

III. GEOCHEMISTRY

A. Analytical Techniques

In all 47 samples were collected and analysed for major and selected trace element concentrations (i.e. Rb, Sr and Ba). These concentrations were determined by standard X-ray fluorescence (XRF) techniques utilizing equipment available in the Department of Geology, University of the Witwatersrand. The accuracy and precision of the analytical methods are reported in McCarthy (1976). The geochemical data are listed in Table II; this table also provides the mesonormative compositions of each of the analysed samples as calculated by a standard computer programme made available by Dr. R.G. Cawthorn of the Department of Geology, University of the Witwatersrand.

A subset of 21 samples was further analysed for the rare earth elements (REE) and U and Th using the instrumental neutron activation technique developed at the Nuclear Physics Research Unit, University of the Witwatersrand (Fesq *et al.*, 1973; Rasmussen and Fesq, 1973; Watterson, 1975; Erasmus *et al.*, 1977). The REE data are presented in Table III. These data also include a set of three duplicate samples analysed by instrumental neutron activation at the Institut für Kernchemie, University of Cologne. The similarities in the duplicated analyses reflect the reliability of the analytical technique used. The zirconium data listed in Table II were also obtained by neutron activation techniques at the University of Cologne.

Individual minerals from selected samples were analysed using the JEOL 50A electron microprobe at the Geological Survey of South Africa in Pretoria. The accelerating voltage was 15 kV with a beam current of approximately 0,255 mA. On-line data processing, with corrections for absorption, fluorescence, atomic number and current drift (Bence and Albee, 1968), was carried out with respect to wollastonite (Si, Ca), feldspar (Na, K) and oxide (Al, Ti, Mg, Fe, Mn) standards. Compositions of plagioclase, hornblende and biotite are presented in Tables IV, V and VI, respectively.

The results from a suite of 13 samples collected specifically for whole rock Rb and Sr isotopic analysis are reported by Barton *et al.*, (1983a). All but one of these samples were also analysed for their whole rock Pb-isotopic compositions. Biotite, separated from the coarse crush of one sample (B-79-15B) was analysed for its Rb and Sr elemental and isotopic composition. For comparison, whole rock sample powders from the trondhjemite Stolzburg pluton and the granodioritic leucocratic orthogneisses of the Bimodal Suite of the Ancient Gneiss Complex, previously analysed for their Rb and Sr isotopic compositions (Barton *et al.*, 1980; 1983a), were also analysed for their Pb-isotopic compositions. These analyses were carried out at the Bernard Price Institute of Geophysical Research at the University of the Witwatersrand using the techniques described by Barton *et al.*, (1983b). Total method blanks during this study were approximately 2 nanogram total Pb and no blank corrections to

the data were made. Regression of the data was by the techniques of York (1966; 1969) using a correlation coefficient of 0,94 (Ludwig, 1980). The uncertainties, based on complete replicate analyses, of the $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ ratios are $\pm 0,1$ per cent (1σ) while that of the $^{208}\text{Pb}/^{204}\text{Pb}$ ratio is $\pm 0,15$ per cent (1σ). The analytical results are listed in Table VII and are plotted on Fig. 3. The regression results are listed in Table I.

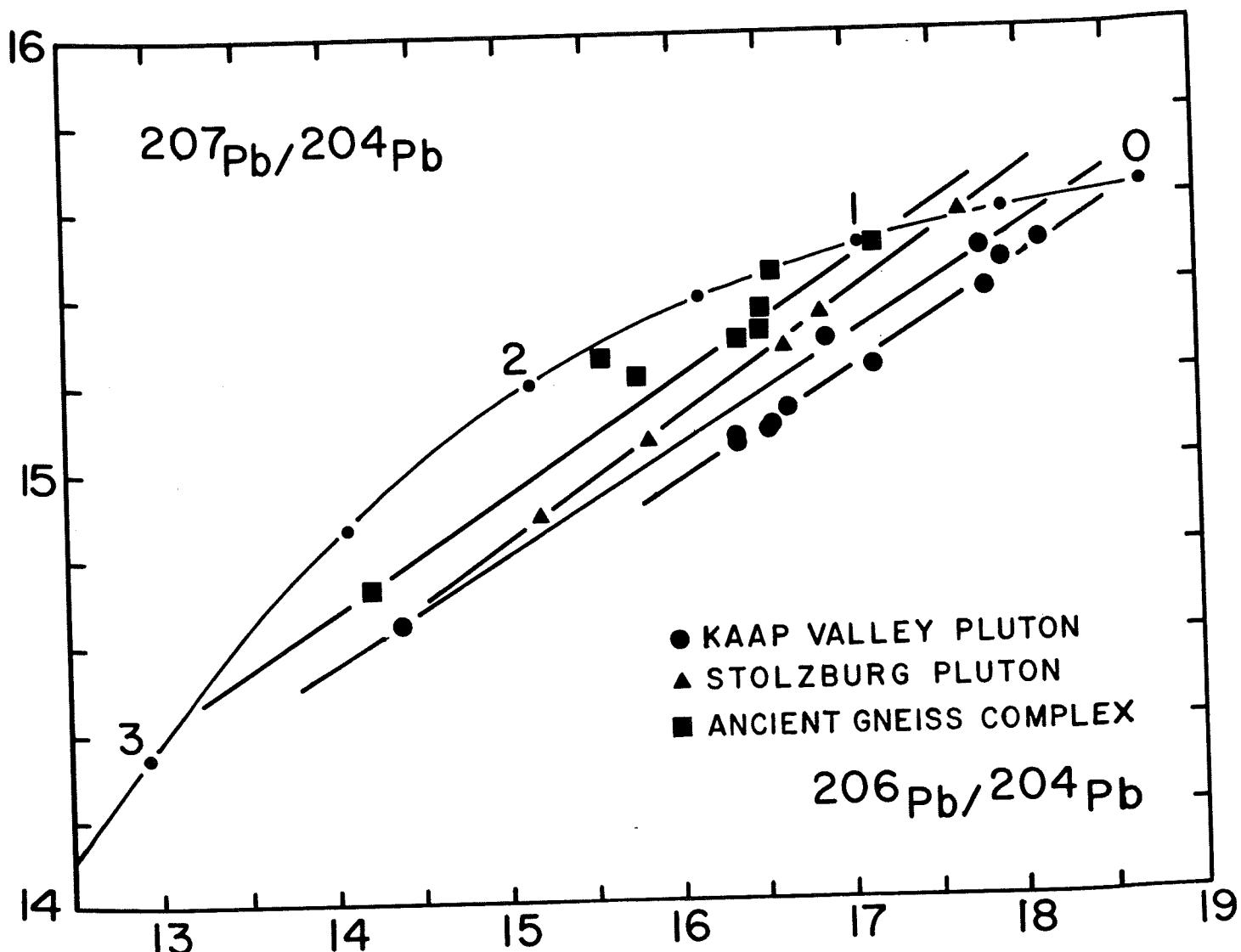


Figure 3 : $^{207}\text{Pb}/^{204}\text{Pb}$ versus $^{206}\text{Pb}/^{204}\text{Pb}$ diagram showing the data from Kaap Valley and Stolzburg plutons and the leucocratic orthogneiss component of the Bimodal Suite of the Ancient Gneiss Complex. The two stage Pb-isotopic evolution curve of Stacey and Kramers (1975), calibrated in 10^9 years, is shown for comparison.

B. Major Elements

Besides being distinguishable on the basis of their hornblende/biotite ratios, the two phases of the tonalite can be differentiated in terms of their major element compositions. The hornblende tonalite typically has SiO_2 contents less than 65 per cent, MgO contents greater than 2,5 per cent and total iron contents in excess of 4,5 per cent whereas the hornblende

TABLE II

 CHEMICAL ANALYSES OF SAMPLES FROM THE KAAP VALLEY
 TONALITE PLUTON AND RELATED PHASES

	ψ	LKV 1	LKV 2	LKV 3	LKV 4	LKV 5	LKV 6	LKV 7	LKV 8	LKV 9	LKV 10	LKV 11	LKV 12	LKV 13	LKV 14	LKV 15A	LKV 15B	LKV 16	LKV 17	LKV 18	LKV 20
SiO ₂	64,11	63,63	64,12	66,94	65,07	68,37	72,71	65,25	66,98	63,95	63,70	67,01	69,59	67,85	63,45	66,36	63,59	68,51			
TiO ₂	0,52	0,58	0,49	0,44	0,48	0,36	0,22	0,47	0,43	0,59	0,42	0,40	0,32	0,36	0,53	0,47	0,47	0,45			
Al ₂ O ₃	15,90	15,03	15,98	15,25	15,47	15,12	14,41	16,41	16,18	15,53	17,50	15,69	15,66	15,95	16,19	15,30	16,49	15,20			
Fe ₂ O ₃ †	4,81	5,28	4,09	3,86	4,03	3,15	1,70	3,91	3,49	4,76	3,10	3,59	2,80	2,77	4,70	3,62	4,28	3,65			
Wt.% MnO	0,02	0,06	0,09	0,01	0,01	<0,01	<0,01	0,09	0,10	0,09	<0,01	0,10	0,06	0,01	0,06	<0,01	0,06	0,09			
MgO	3,14	3,12	2,36	2,22	2,14	1,81	0,78	2,25	1,98	2,47	2,08	2,10	1,46	0,97	2,92	2,15	2,44	2,18			
CaO	4,67	5,04	4,48	3,61	4,23	3,04	2,18	4,56	4,30	4,35	3,74	3,74	3,46	3,78	4,77	4,18	4,14	4,01			
Na ₂ O	4,62	4,72	5,79	5,06	5,52	5,85	6,04	5,38	4,63	5,56	6,43	5,24	5,79	6,61	4,87	5,23	5,17	4,89			
K ₂ O	1,12	1,71	1,26	1,74	1,37	1,90	1,70	1,42	1,30	2,03	0,79	0,98	0,67	0,98	0,91	0,71	1,23	1,70			
P ₂ O ₅	0,18	0,21	0,18	0,18	0,15	0,13	0,10	0,18	0,17	0,19	0,14	0,13	0,14	0,15	0,23	0,18	0,20	0,17			
L.O.I.	1,91	1,52	1,58	1,76	1,25	1,12	1,32	1,01	0,81	1,26	2,04	2,19	1,43	1,18	1,63	1,91	1,55	0,65			
TOTALS	101,00	100,90	100,42	101,07	99,72	100,86	101,17	100,66	100,08	100,78	99,95	101,17	101,29	100,06	100,26	100,11	99,52	101,50			
ppm	Rb	42	63	39	62	53	40	44	55	52	70	35	35	28	35	30	31	29	36		
	Sr	574	576	628	573	609	467	534	659	621	511	760	639	731	734	616	631	551			
	Ba	327	479	424	466	390	148	259	424	401	369	196	212	261	178	457	389	386	219		
	Zr	-	157	-	131	-	-	-	89	-	127	93	114	-	-	-	-	-	-		
Wt.-%	Qtz	21,6	14,7	13,0	22,7	15,9	18,7	23,9	16,5	26,9	11,0	14,7	24,8	26,4	17,0	19,8	23,8	20,2	23,4		
	Ab	39,5	40,3	49,5	43,0	47,4	49,5	52,8	45,6	39,2	47,4	55,4	44,8	48,2	56,2	41,8	45,0	44,6	41,0		
	Or	0,0	9,5	7,2	5,2	7,9	10,2	10,0	6,7	0,2	12,1	0,0	0,0	0,0	5,8	0,0	0,0	0,0	6,7		
	An	17,7	6,8	7,7	11,7	7,7	5,4	4,7	10,8	19,7	4,6	16,7	15,5	14,9	8,7	18,3	13,8	18,3	10,9		
	Hb1de	6,6	24,9	19,9	7,5	18,4	13,0	6,3	15,6	0,8	21,5	1,8	3,5	2,0	7,9	6,2	8,8	1,9	11,2		
	Biot	10,0	1,0	0,4	7,7	0,4	1,6	0,0	2,6	11,3	0,0	7,1	8,8	5,9	0,0	8,2	6,4	11,1	4,9		
	Opx	2,1	0,0	0,0	0,0	0,0	0,0	1,3	0,0	0,0	0,0	2,4	0,9	1,2	0,0	3,1	0,2	1,5	0,0		
	Mgt	2,2	2,4	1,9	1,8	1,4	0,8	1,8	1,6	2,2	1,4	1,6	1,3	1,3	2,2	1,7	2,0	1,6			
	Ap	0,3	0,4	0,3	0,3	0,3	0,2	0,2	0,3	0,3	0,4	0,3	0,2	0,3	0,2	0,3	0,4	0,3	0,3		

† Total iron as Fe₂O₃

ψ Hornblende tonalites

* Hornblende + biotite tonalites

fg Fine-grained tonalite dykes

Sample localities all appear on Fig. 2

TABLE II (contd)

		*	*	*	*	*	*	fg	*	*	*	SKV 1	SKV 2	SKV 5	SKV 6	SKV 8	SKV 9	SKV 12
	LKV21	LKV23	LKV24	LKV25	LKV27	LKV29	LKV30											
S10 ₂	64,40	66,24	64,20	61,75	64,99	68,74	65,53	64,83	63,87	68,96	66,68	65,76	63,22	62,96				
TiO ₂	0,49	0,42	0,42	0,64	0,16	0,39	0,47	0,45	0,45	0,36	0,42	0,43	0,51	0,56				
Al ₂ O ₃	16,27	15,90	14,98	15,34	15,74	15,18	15,15	15,96	15,28	14,98	15,27	15,52	15,10	15,29				
Fe ₂ O ₃ *	4,47	3,52	3,86	5,46	4,07	3,38	2,91	3,91	3,85	3,11	3,59	4,29	4,38	4,61				
MnO	0,06	<0,01	0,14	0,12	0,06	0,08	0,08	0,09	0,08	0,05	0,01	0,12	0,01	0,12				
Wt.%	MgO	2,50	1,75	2,26	3,61	2,02	1,87	2,26	2,20	1,65	1,64	1,94	2,09	2,98	3,24			
	CaO	4,67	3,72	2,86	4,37	4,33	3,87	4,14	4,30	3,54	2,93	3,59	4,35	3,72	4,03			
	Na ₂ O	5,18	5,73	6,86	4,10	6,53	5,10	5,29	4,60	6,53	5,29	5,52	4,86	5,42	4,70			
	K ₂ O	1,50	0,77	1,23	1,81	1,19	1,42	1,28	1,80	1,65	2,36	1,96	1,89	1,72	0,65			
	P ₂ O ₅	0,20	0,14	0,20	0,28	0,15	0,14	0,16	0,18	0,19	0,14	0,13	0,18	0,17	0,18			
	L.O.I.	1,01	1,48	1,64	2,21	1,31	1,12	1,67	2,12	1,96	1,40	1,64	1,79	1,80	2,44			
TOTALS	100,75	99,67	98,55	99,69	100,55	101,29	99,32	100,44	99,25	101,22	100,75	101,28	99,03	98,78				
Rb	40	23	24	56	31	29	48	57	51	72	54	63	59	28				
ppm	Sr	654	614	529	536	579	533	601	615	628	438	635	564	523	615			
	Ba	423	216	259	795	173	247	241	494	468	403	453	393	354	157			
	Zr	-	101	-	154	-	125	-	-	118	111	-	-	-	109	-		
	Qtz	16,7	22,0	10,2	21,6	11,5	24,0	19,2	21,9	10,5	22,0	17,0	18,9	15,3	20,9			
	Ab	43,9	49,3	60,9	40,9	55,8	43,0	45,9	39,6	57,0	44,7	47,1	41,4	47,1	41,8			
	Or	5,4	0,0	7,6	0,0	7,1	5,7	6,4	5,3	10,0	11,4	11,2	9,3	6,4	0,0			
	An	12,5	14,3	0,1	17,0	6,3	11,2	9,4	15,6	3,5	7,5	6,1	10,4	7,3	19,5			
	Hb/de	13,8	5,1	18,3	5,3	12,7	10,3	15,5	7,2	13,7	8,9	16,1	14,8	15,5	9,3			
	Biot	5,2	6,9	0,0	16,6	0,0	4,0	2,0	8,3	0,0	3,8	0,6	2,9	6,1	6,1			
	Opx	0,0	0,0	0,4	4,4	0,0	0,0	0,0	0,0	3,1	0,0	0,0	0,0	0,0	0,0			
	Mgt	2,0	1,6	1,8	2,6	1,9	1,5	1,3	1,8	1,8	1,4	1,6	1,9	2,0	2,2			
	Ap	0,4	0,3	0,4	0,5	0,3	0,2	0,3	0,03	0,4	0,2	0,3	0,3	0,3	0,3			

TABLE II (contd)

+ biotite-bearing tonalite has a higher SiO_2 content, in the range 65-70 per cent and concomitantly lower iron and magnesium content (Table II, and Fig. 4). The Harker plots in Fig. 4 also demonstrate a slight compositional hiatus between the two tonalite phases, particularly in the case of MgO . This relationship may be partly a result of a decrease in the hornblende/biotite ratio commensurate with the incoming of biotite late in the crystallization history of the magma. The fact that certain samples are characterized by an absence of biotite whilst others contain coexisting hornblende and biotite is indicative of a sequential crystallization mode. If real, such a process should be reflected in the regional distribution of major elements across the pluton. Computer drawn contour diagrams, illustrating the geographic distribution of SiO_2 , MgO , CaO and K_2O , are illustrated in Fig. 5 a-d and clearly reflect the occurrences of hornblende and hornblende + biotite tonalite phases (compare Fig. 5 with Fig. 2). Unlike some granite plutons documented in the literature (see later), the Kaap Valley pluton is neither simply nor concentrically zoned. The lowest values of SiO_2 occur in the north-west and south-east quadrants of the pluton, a feature which is conversely mirrored with respect to the CaO and MgO contents. Regional variation of K_2O is less systematic but lower concentrations occur in the north-west and south-east portions of the pluton. This relationship between element distributions and mineralogy is taken to infer an *in situ* crystal fractionation mode involving the early formation of more mafic hornblende tonalites and the later crystallization of the hornblende + biotite tonalite phase as the residual magma became enriched in K_2O . Evidence in detail for this mechanism is lacking and it appears unlikely, from the patterns on Fig. 5, that simple progressive inward crystallization occurred. What is more probable, particularly when it is considered that the pluton may have been diapirically mobile subsequent to solidification, is that the original configuration of compositional zoning has been disrupted by deformation. This topic is discussed in more detail later.

The compositions of medium-to-fine-grained tonalite dykelets are compared with the bulk Kaap Valley tonalite samples in Fig. 4. The dykelets are similar in composition to the hornblende + biotite tonalites but have lower contents of Fe_2O_3 , MgO and TiO_2 . They, therefore, have the characteristics of a more felsic differentiated liquid penecontemporaneously intruded during the latter stages of solidification of the pluton. The dykelets are not, however, enriched in elements such as K and Rb.

C. Trace and Rare Earth Elements

Unlike the major elements, the Rb, Sr and Ba contents of samples from the Kaap Valley pluton do not clearly distinguish the hornblende tonalites from the hornblende + biotite tonalites. Among the samples analysed for Rb-Sr isotopic compositions, the hornblende tonalites have slightly higher Rb and Sr contents than do the hornblende + biotite tonalites (Table VII). This relationship is not evident in the data from the more representative suite of samples analysed (Table II). In addition, the Rb contents of the samples for isotopic analyses are lower (average 35,1 ppm) than those of the samples chemically analysed (average 45 ppm). Sr contents range between 500 ppm and 700 ppm and Ba ranges between 150 ppm and 800 ppm (Tables II and VII). Rb/Sr ratios are relatively constant and range from about 0,05 to about 0,07 for the isotopically analysed samples and are about 0,09 for the XRF analyses. Rb/Sr ratios in the Theespruit trondhjemite pluton are somewhat higher, averaging 0,11, whereas those of

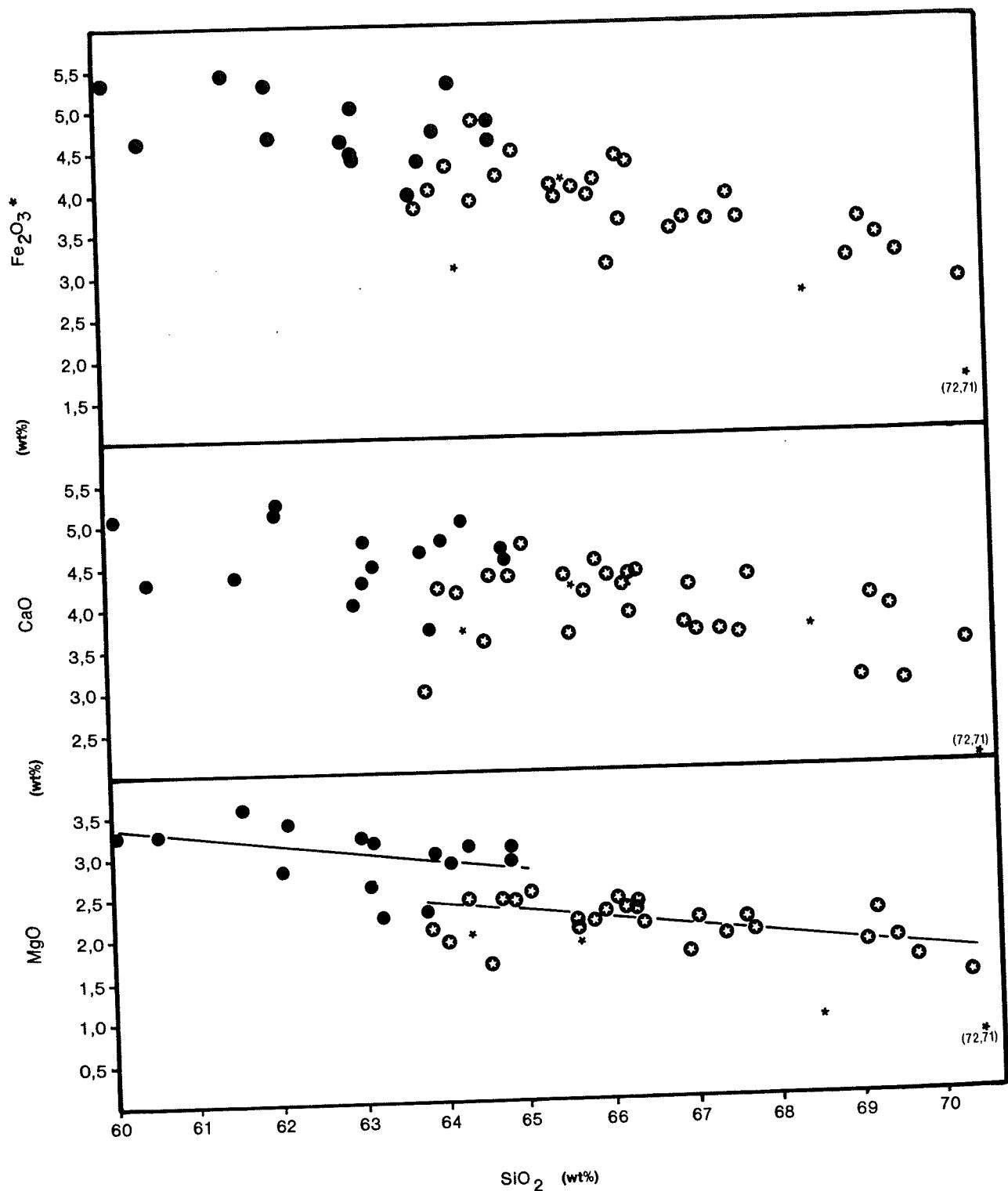


Figure 4 : Selected Harker plots of chemical data from the Kaap Valley tonalite and related phases. Solid dots represent the hornblende tonalite, encircled stars the hornblende + biotite tonalite and asterisks the medium-to-fine grained tonalite dykelets. $\text{Fe}_2\text{O}_3^* =$ total iron.

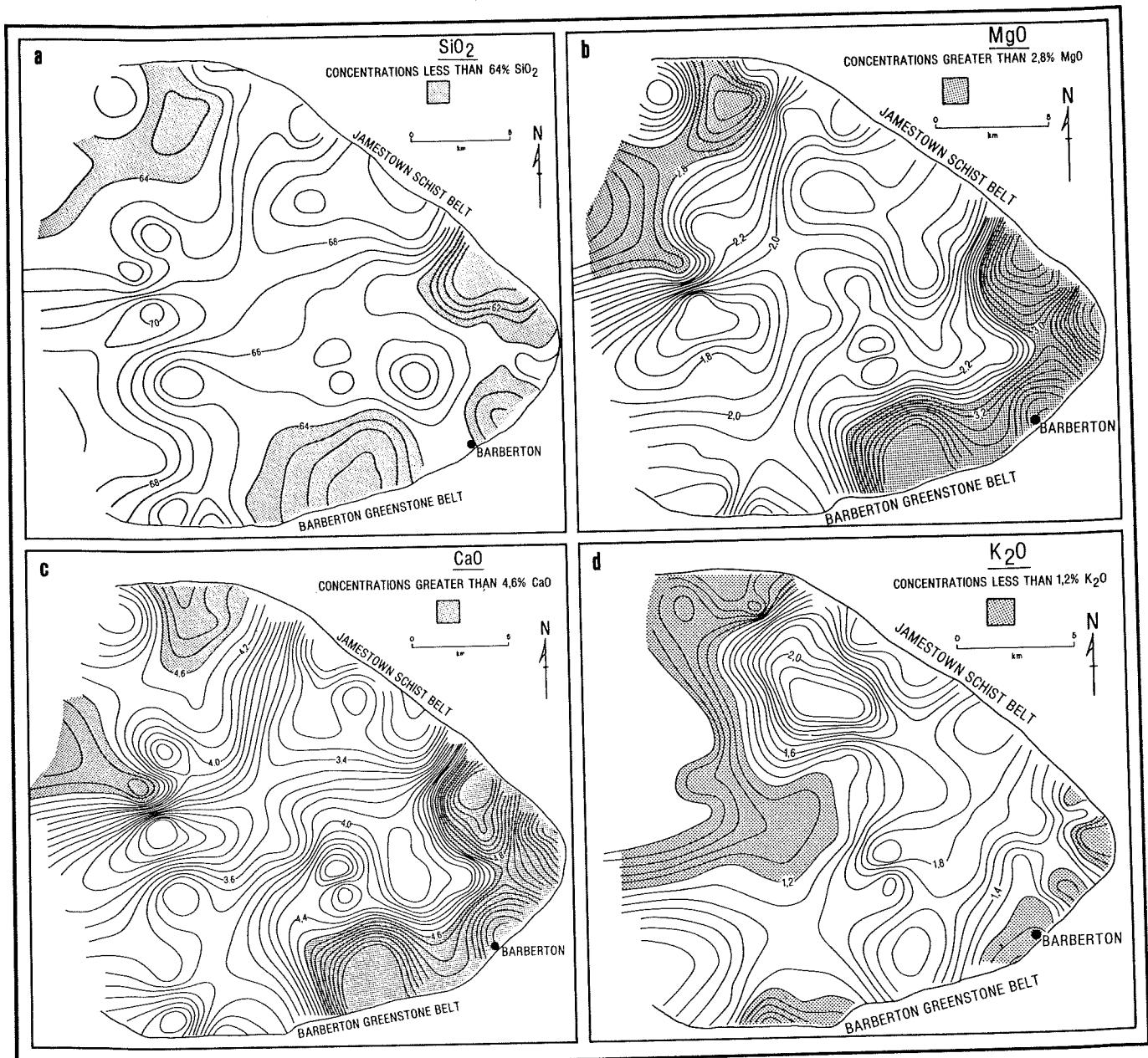


Figure 5 : Computer-drawn contour plots of SiO_2 , MgO , CaO and K_2O distributions over the Kaap Valley tonalite pluton. Contour intervals are variable and indicated by the values posted on the individual plots.

the Stolzburg and Nelshoogte plutons are similar, both averaging about 0.07 (Barton *et al.*, 1983a). Zr contents in the Kaap Valley tonalite pluton range between 89 ppm and 186 ppm (Table II) with an average of 124 ppm. The Theespruit trondhjemite pluton has an identical average Zr content whereas the Stolzburg and Nelshoogte plutons have lower average values of 102 ppm and 88 ppm respectively (Table VIII).

The REE contents of 21 samples of the Kaap Valley tonalite pluton listed in Table III also do not enable the hornblende tonalites to be distinguished from the hornblende + biotite tonalite phases. This is illustrated in Fig. 6 where the envelopes of samples from the two phases are plotted and are seen to be entirely overlapping. The Kaap Valley tonalite has a linear REE trace on a log normalized plot with moderate enrichment of the light elements and no Eu anomaly. On average, the hornblende tonalites are slightly less enriched in the light REE, and have marginally higher contents of the heavy REE than the hornblende + biotite tonalites, but these differences are insignificant in terms of inter-sample variations (Table III).

It is noteworthy that the Kaap Valley tonalite is enriched in the REE compared with the typical, more felsic trondhjemite gneisses in the immediate vicinity. This feature was established previously by Condie and Hunter (1976) and is confirmed here in terms of a much larger sample population. In Fig. 6, the average trace of 11 samples from the Nelshoogte, Stolzburg and Theespruit trondhjemite gneiss plutons (Fig. 1) is seen to be depleted (with the possible exception of La) in all REE compared to the envelopes of the Kaap Valley data. This places an important constraint on the genesis of the Kaap Valley magma, at least in terms of a simple melting model which attempts to incorporate both the tonalite and trondhjemite rock types.

D. Mineral Analyses

The Kaap Valley tonalite consists mainly of plagioclase, quartz, hornblende and biotite. Analyses of these minerals (with the exception of quartz) are presented in Tables IV, V and VI respectively.

1. Plagioclase

Analyses of 10 samples from the different phases of the Kaap Valley pluton were undertaken to demonstrate the variability in composition of plagioclase, both between the various phases and also between the cores and margins of individual grains. A complete listing of these data is available in Robb (1981). In this paper the data from only three samples, each one representative of the hornblende, the hornblende + biotite and the medium-to-fine- grained dyke-like tonalite phases, are presented in Table IV.

The variations in plagioclase compositions, evident in Table IV and Fig. 7, reflect, almost entirely, the nature of zoning in this mineral. Plagioclase cores were invariably found to be more calcic than the margins of the same grains, this feature being evident also in terms of the preferential sericitization of the grain interiors. Figure 7 shows the composition of the Kaap Valley plagioclase in terms of theoretical end-member

TABLE III

RARE EARTH ELEMENT AND U AND TH ANALYSES OF SELECTED SAMPLES
FROM THE KAAP VALLEY TONALITE PLUTON AND RELATED PHASES

ppm			La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	U	Th
LKV	1	Ψ	14,8	30	14	3,4	1,12	0,40	0,8	0,14	0,48	1,8
LKV	3	*	19,5	44	16	4,3	1,38	0,52	0,9	0,10	0,38	2,3
LKV	4	*	12,6	28	13	3,3	1,03	0,40	0,7	0,12	0,84	3,4
LKV	6	*	13,7	30	13	2,9	0,88	0,37	0,8	0,13	0,60	1,7
LKV	12	*	18,4	43	16	5,8	1,22	0,55	1,1	0,17	0,48	3,4
LKV	15(A)	*	11,9	23	9	2,4	0,79	0,26	0,5	0,06	0,26	1,4
LKV	18	*	17,5	32	14	3,3	1,14	0,37	0,7	0,10	0,46	1,9
LKV	20	*	15,4	31	11	2,8	0,88	0,32	0,8	0,10	0,46	2,7
LKV	23	*	12,9	25	10	2,4	0,87	0,30	0,6	0,10	0,31	1,6
LKV	25	Ψ	14,0	33	15	3,3	1,07	0,43	1,0	0,15	0,60	2,8
LKV	30	*	11,1	23	9	2,3	0,72	0,27	0,6	0,10	0,43	3,0
SKV	5	*	21,1	42	13	2,8	0,84	0,28	0,6	0,11	0,86	4,5
SKV	8	*	14,4	32	13	2,8	0,95	0,34	0,8	0,15	0,55	3,3
SKV	12	Ψ	13,6	30	12	3,2	0,98	0,38	0,9	0,13	0,39	1,8
SKV	13	Ψ	14,9	34	14	3,2	1,09	0,41	1,0	0,16	0,59	2,1
SKV	22	Ψ	15,2	31	11	2,9	0,92	0,35	0,7	0,11	0,36	1,8
SKV	28	*	14,0	24	9	2,4	0,83	0,30	0,7	0,10	0,28	1,5
SKV	34	*	18,1	36	15	3,8	1,11	0,43	0,6	0,11	0,44	2,5
LKV	9	fg	15,8	29	9	2,1	0,59	0,19	0,3	0,05	0,61	3,0
LKV	15(B)	fg	8,4	19	9	2,2	0,70	0,29	0,6	0,08	0,43	1,2
LKV	27	fg	12,8	27	11	2,9	0,95	0,35	0,8	0,11	0,43	1,0
LKV	4	}	12,3	11	-	3,3	1,03	0,28	-	-	-	-
LKV	15A		11,6	-	21	2,9	0,79	0,21	-	-	-	-
SKV	5		19,9	35	21	3,3	0,89	0,22	-	-	-	-

dup. - duplicate samples (for explanation see text)

Ψ - Hornblende-bearing tonalites

* - Hornblende + biotite-bearing tonalites

fg - Fine-grained tonalitic dykes

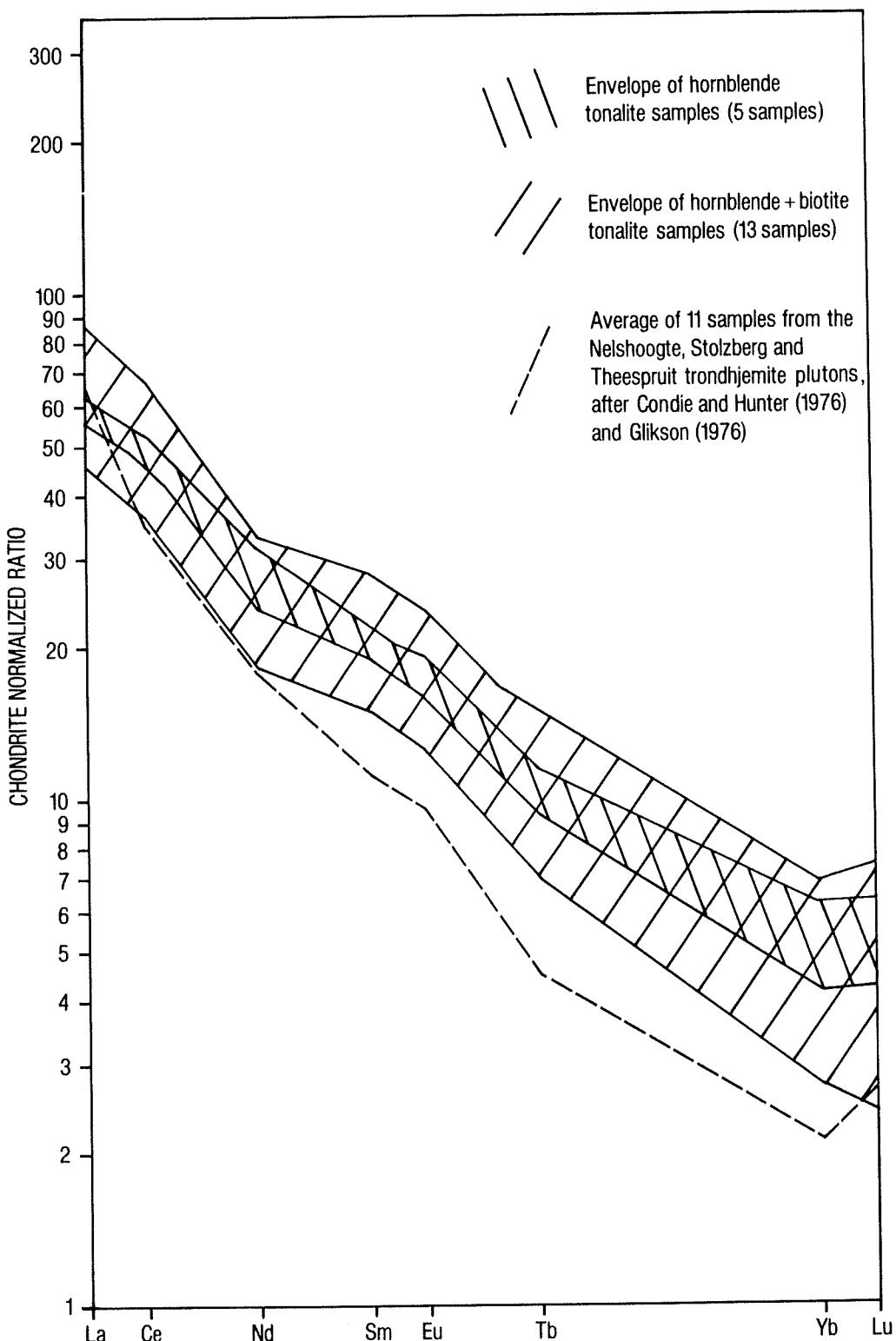


Figure 6 : Chondrite normalized rare earth element plot for data from the Kaap Valley tonalite pluton. Data are from Table III.

TABLE IV

 PLAGIOCLASE COMPOSITIONS IN SAMPLES FROM THE
 KAAP VALLEY TONALITE AND RELATED PHASES

	Ψ	Ψ	Ψ	Ψ	*	*	*	*	*	*	fg	fg	fg
	LKV25 (C)	LKV25 (C)	LKV25 (I)	LKV25 (M)	LKV29 (M)	LKV29 (C)	LKV29 (C)	LKV29 (I)	LKV29 (C)	LKV15B (C)	LKV15B (I)	LKV15B (C)	
SiO ₂	61,08	59,00	62,16	66,38	67,06	59,53	53,36	61,75	62,61	64,11	62,70		
Al ₂ O ₃	23,31	25,32	23,09	20,50	19,60	25,20	23,63	23,83	23,61	22,15	23,06		
FeO†	0,38	0,27	0,16	0,10	0,09	0,17	0,19	0,21	0,20	0,17	0,21		
Wt.%													
CaO	6,06	7,68	4,34	0,98	1,00	5,79	3,83	4,55	4,72	3,25	4,59		
Na ₂ O	7,81	6,99	8,90	10,78	10,83	8,10	9,39	8,71	8,79	9,63	8,88		
K ₂ O	0,56	0,30	0,24	0,31	0,12	0,52	0,24	0,33	0,42	0,31	0,31		
TOTALS	100,20	99,56	98,85	99,05	98,70	99,31	100,64	99,38	100,35	99,62	99,75		
Structure ϕ	32	32	32	32	32	32	32	32	32	32	32		
Si	10,859	10,588	11,121	11,741	11,882	10,586	11,132	11,013	11,064	11,356	11,126		
Al	5,094	5,356	4,871	4,274	4,093	5,331	4,894	5,008	4,916	4,623	4,835		
Fe	0,056	0,040	0,025	0,014	0,013	0,026	0,028	0,031	0,030	0,026	0,031		
Ca	1,155	1,477	0,833	0,186	0,189	1,113	0,722	0,867	0,894	0,616	0,875		
Na	2,691	2,431	3,090	3,698	3,720	2,821	3,194	3,012	3,011	3,308	3,029		
K	0,127	0,070	0,056	0,070	0,028	0,118	0,053	0,076	0,094	0,069	0,072		
% An	30,1	38,1	21,5	4,9	5,0	28,8	19,0	22,5	23,4	17,4	22,8		

φ - Number of oxygens for structural formulae
 † - Total iron as FeO
 % An - Calculated in terms of wt.% CaO
 Ψ - Hornblende tonalites
 * - Hornblende + biotite tonalites
 fg - Fine-grained tonalitic dykes

} not necessarily of the same grain

} In-between

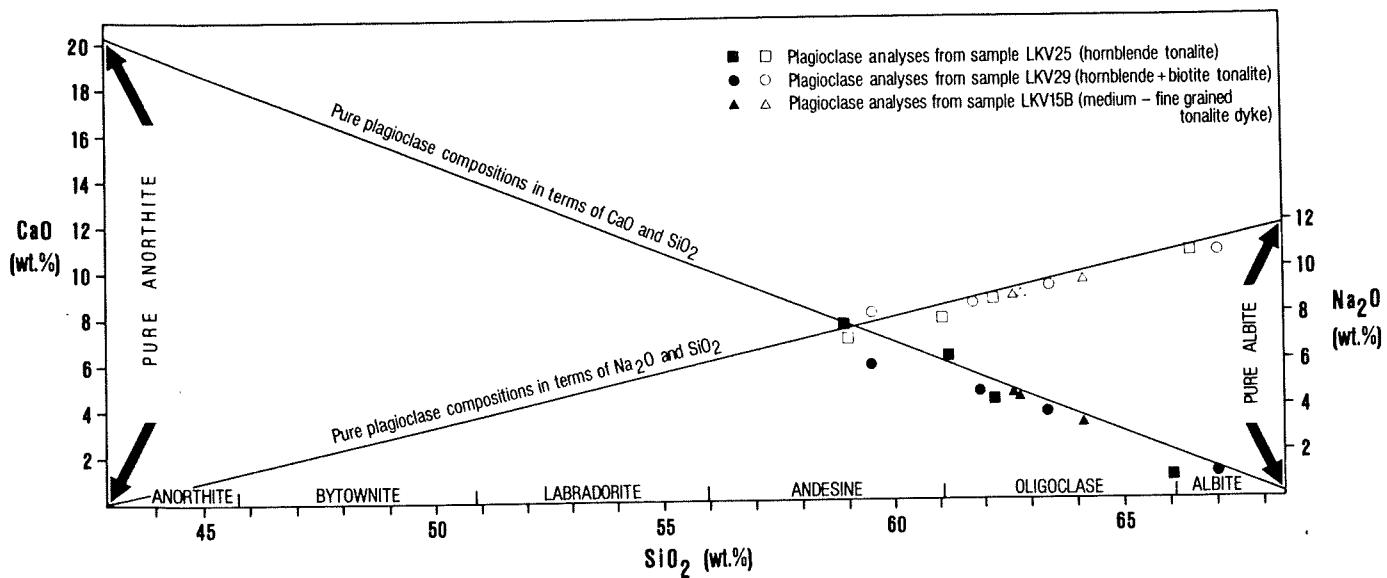


Figure 7 : The compositions of plagioclases in the Kaap Valley tonalite with respect to SiO_2 , CaO and Na_2O variations in the plagioclase-series. Solid symbols represent $\text{CaO}-\text{SiO}_2$ variations and open symbols $\text{Na}_2\text{O}-\text{SiO}_2$ variations. Data are from Table IV.

compositions. The plagioclases range from albite to andesine with the majority of samples falling in the oligoclase range. The compositions of plagioclases from the three phases of the Kaap Valley pluton are indistinguishable. Furthermore, no case can be made, in terms of the data presently available, for the existence of significantly more anorthitic cores in plagioclases from, for example, the more mafic hornblende tonalites. It is possible that certain of the plagioclase grains may have nucleated around xenocrystic remnants which might reflect the nature of the source from which the Kaap Valley magma was derived. White and Chappell (1977) suggested, for example, that the existence of anorthitic cores was indicative of an I-type granite derived from a mafic precursor. However, no such xenocrystic relics were detected in the Kaap Valley tonalite as these would be expected to have compositions considerably more calcic than the andesine compositions actually observed. The variations in plagioclase composition can, therefore, be attributed solely to systematic changes in the composition of the liquid from which plagioclase was crystallizing.

2. Hornblende and Biotite

The compositions of hornblende and biotite from a number of samples of the Kaap Valley tonalite are presented in Tables V and VI. The hornblende compositions need be considered in the light of previous suggestions that

TABLE V

HORNBLENDE COMPOSITIONS IN SAMPLES FROM THE KAAP VALLEY
TONALITE PLUTONS AND RELATED PHASES

	Ψ	*	*	fg	Ψ
	LKV 2	LKV11	LKV15A	LKV15B	LKV25
Wt.%	SiO ₂	47,33	47,61	48,22	46,77
	TiO ₂	1,50	1,47	1,04	1,21
	Al ₂ O ₃	7,02	6,43	6,34	7,05
	FeO †	15,25	15,43	14,06	16,72
	MnO	0,45	0,48	0,66	0,51
	MgO	13,35	13,40	13,16	12,63
	CaO	10,83	10,69	10,97	11,69
	Na ₂ O	1,40	1,47	1,18	1,36
	K ₂ O	0,59	0,49	0,55	0,61
	TOTALS	97,72	97,47	96,18	98,55
Structure ϕ					
Si					
Ti					
Al					
Fe					
Mn					
Mg					
Ca					
Na					
K					

ϕ - Number of oxygens for structural formulae

† - Total iron as FeO

Ψ - Hornblende tonalites

* - Hornblende + biotite tonalites

fg - Fine-grained tonalitic dykes

this mineral may be xenocrystic and that the mafic character of the Kaap Valley tonalite as a whole could be due to assimilation of wall-rock metavolcanics. In a plot of Al versus (Na + K), hornblende compositions are seen to be relatively invariant and plot in a tight cluster within the hornblende field (Fig. 8). Slight variations in hornblende compositions cannot be correlated with the bulk composition of the rock from which they were derived. Hornblendes from the Kaap Valley tonalite are compared with amphiboles derived from metabasaltic greenstone xenoliths and remnants from a number of localities in the Barberton Mountain Land (Robb, 1981). These hornblendes are encompassed in a much

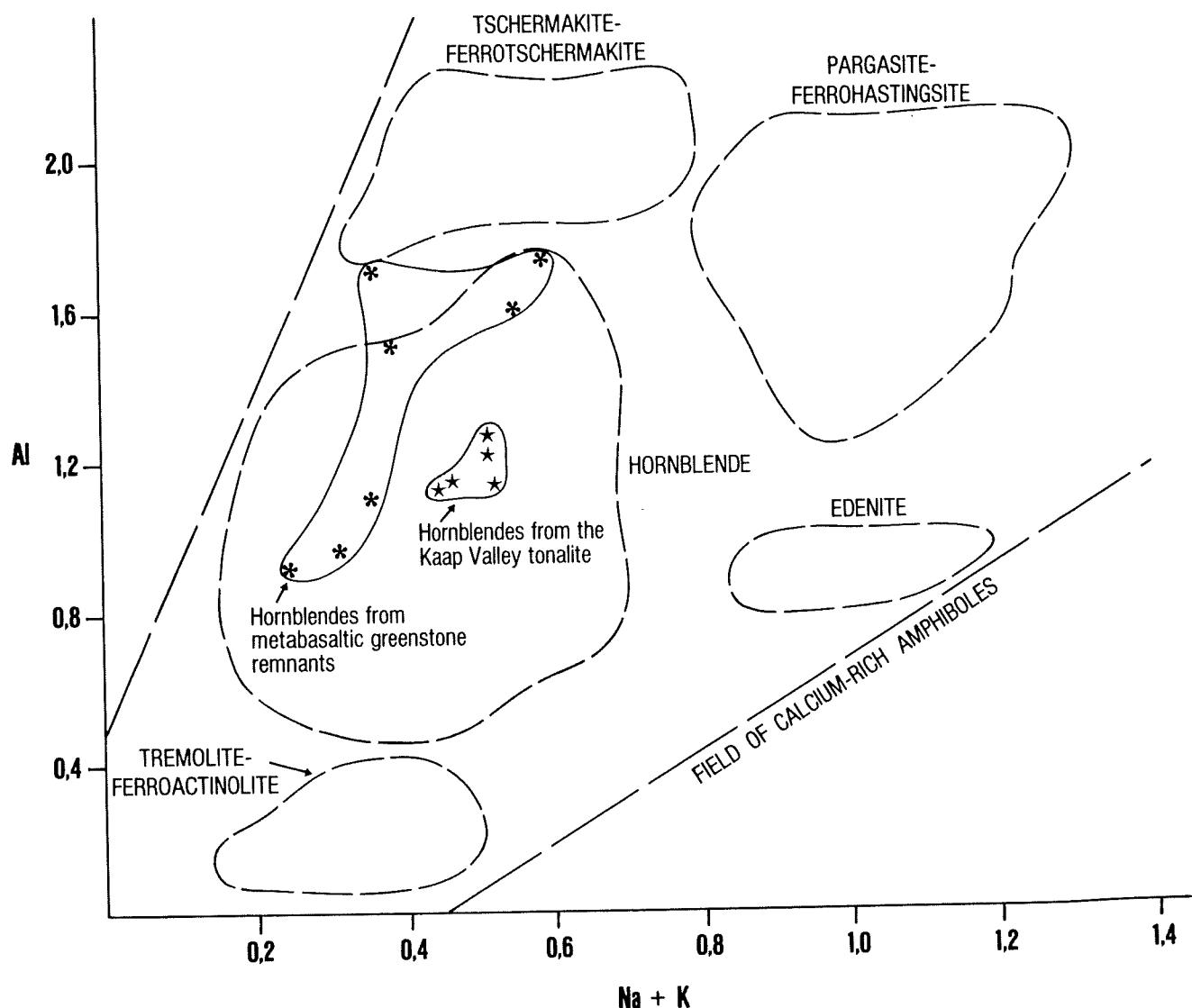


Figure 8 : The compositions of hornblendes from the Kaap Valley tonalite in terms of an Al versus (Na + K) plot. Also shown are the compositions of amphiboles derived from metabasaltic greenstone xenoliths and remnants at a number of localities in the Barberton Mountain Land. Data are from Table V and Robb (1981). Amphibole fields are from Deer et al. (1971).

TABLE VI

BIOTITE COMPOSITIONS IN SAMPLES FROM THE KAAP VALLEY
TONALITE PLUTON AND RELATED PHASES

	fg	fg	*	*	fg
	LKV 9	LKV 9	LKV11	LKV15A	LKV15B
SiO ₂	35,95	36,04	37,10	37,50	36,43
TiO ₂	4,13	4,15	3,77	3,52	3,74
Al ₂ O ₃	13,80	14,67	15,36	14,90	14,98
FeO †	18,79	19,64	19,24	17,21	18,87
MnO	0,57	0,52	0,15	0,25	0,34
Wt.%	MgO	11,28	10,10	11,75	11,93
	CaO	0,07	0,07	0,06	0,08
	Na ₂ O	0,11	0,09	0,09	0,10
	K ₂ O	9,96	10,41	9,64	10,06
	TOTALS	94,66	95,69	97,16	95,55
	Structure ϕ	22	22	22	22
Si	5,556	5,535	5,537	5,652	5,543
Ti	0,480	0,479	0,423	0,399	0,427
Al	2,514	2,656	2,701	2,646	2,686
Fe	2,429	2,522	2,401	2,168	2,401
Mn	0,075	0,068	0,020	0,032	0,044
Mg	2,598	2,313	2,614	2,680	2,524
Ca	0,013	0,012	0,010	0,013	0,011
Na	0,034	0,026	0,027	0,030	0,030
K	1,963	2,040	1,836	1,936	1,986

ϕ - Number of oxygens for structural formulae

† - Total iron as FeO

* - Hornblende + biotite tonalites

fg - Fine-grained tonalitic dykes

broader compositional field which is quite distinct from that of the Kaap Valley equivalents. On this basis, it is reasonable to conclude that the amphibole component of the tonalite is not xenocrystic but probably crystallized directly from the magma. The hornblendes from the metabasaltic remnants, on the other hand, are metamorphic in origin and formed in response to variable pressures, temperatures and interaction with felsic magmas or fluids. The latter can, therefore, be expected to exhibit a broader range in composition.

Compositional differences between the hornblendes of the Kaap Valley tonalite and those from metabasaltic greenstone remnants are also emphasized in the plot of Al versus 100.Fe/(Fe + Mg) in Fig. 9. The tonalitic hornblendes show a small variation in terms of Fe/(Fe + Mg) ratio but again, this is not correlatable with bulk compositional variations. It is interesting that biotite grains from the hornblende + biotite and dyke-like tonalite phases exhibit similar proportionate changes in their Fe/(Fe + Mg) ratios. Coexisting biotite and hornblende can, for example, be coupled with sub-parallel tie-lines suggesting equilibrium between these two phases during crystallization. This observation also, therefore, militates against the possibility that the hornblende grains are xenocrystic and did not crystallize directly from the original tonalite magma.

E. Isotopic Analyses

The available isotopic age data from the Kaap Valley tonalite pluton are summarized in Table I. Analytical results of both the hornblende and hornblende + biotite tonalite phases define a single Rb-Sr whole rock isochron of 3491 ± 166 Ma (2σ) with an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7001 ± 0.0023 (2σ) (Barton *et al.*, 1983a), indicating that the two phases were in Sr-isotopic equilibrium. The small initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio severely limits the amount of crustal prehistory possible for this unit and strongly suggests that the Kaap Valley pluton formed about 3500 Ma ago from a mafic source such as amphibolite. The Rb-Sr biotite-whole rock age of about 3140 Ma dates the time elapsed since the pluton last cooled below about 250° C. Crystallization, diapiric emplacement and cooling, therefore, may have occurred during a span of about 350 Ma and the Kaap Valley pluton has been at approximately its present crustal level since about 3140 Ma ago.

The whole rock Pb-Pb isotopic data for the Kaap Valley pluton (Table VII) define two sub-parallel linear trends on a plot of $^{207}\text{Pb}/^{204}\text{Pb}$ versus $^{206}\text{Pb}/^{204}\text{Pb}$ (Pb-Pb) (Fig. 3) that may be interpreted as secondary isochrons corresponding to ages of about 3200 Ma (Table I). However, most of the data show an element of scatter that cannot be attributed to experimental uncertainties alone, as is shown by the fact that the value of $\text{SUMS}/(n-2)$ exceeds the value of the appropriate F-variate (Brooks *et al.*, 1972) for the trend comprising most of the data points (Table I). This nine-point data array is an errorchron with a large uncertainty that overlaps the Rb-Sr whole rock isochron age. The other three points define an isochron with a small uncertainty but may not represent a meaningful data population. Data from both the hornblende and hornblende + biotite phases plot on each trend, indicating that at least locally the two phases are in near Pb-isotopic equilibrium. Despite the scatter and the large uncertainties, the approximate ages indicated by the secondary isochrons are thought to be meaningful because they are in reasonable agreement with the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of minerals separated from the tonalite (Oosthuizen, 1970). These ages are also not much different from the Rb-Sr biotite-whole rock ages for this unit. Several possibilities exist to explain the age differences but the preferred suggestion is that the Rb-Sr whole rock

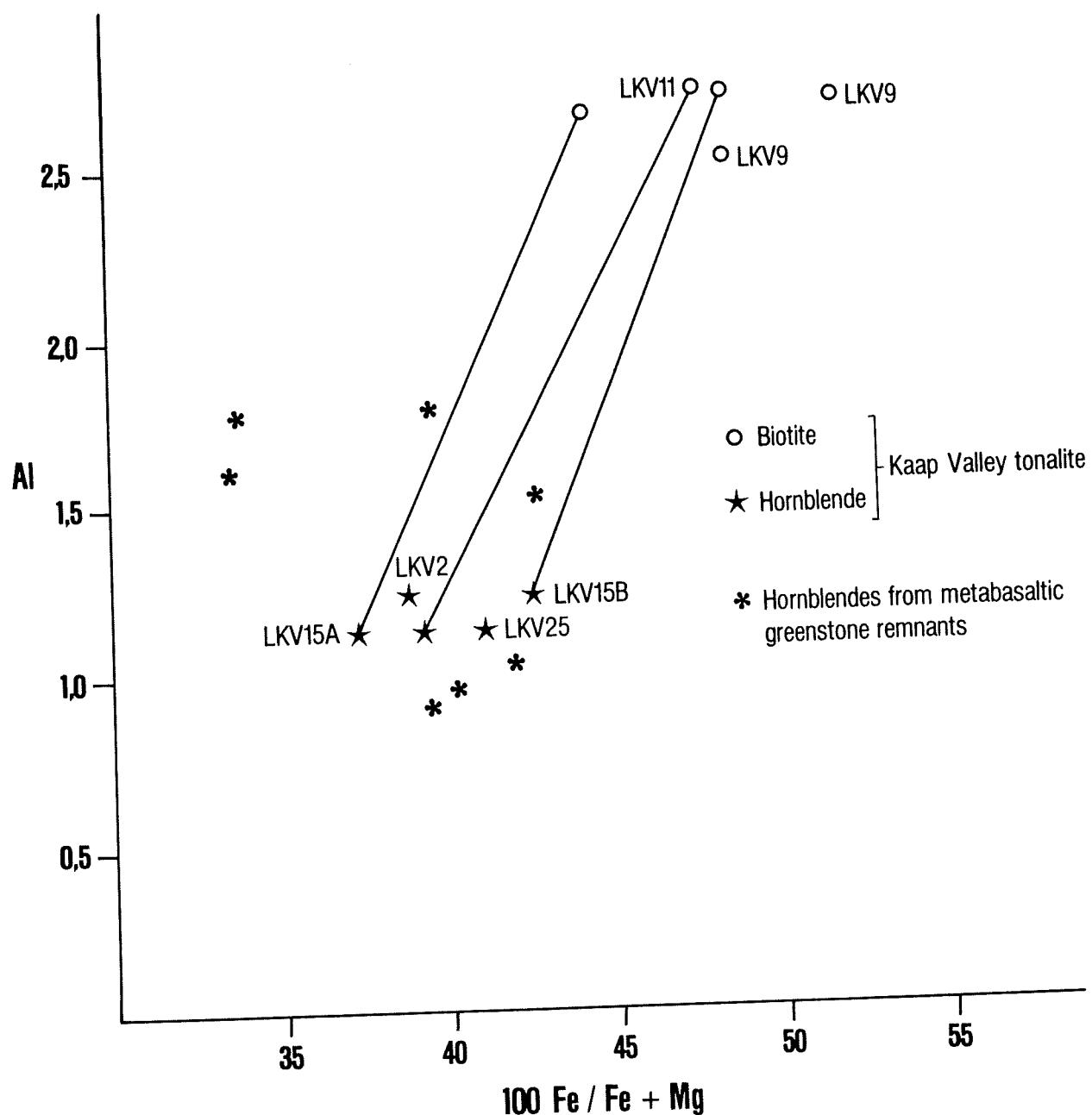


Figure 9 : The compositions of hornblendes and biotites from the Kaap Valley tonalite in terms of Al versus 100. Fe / (Fe + Mg). Tie-lines join coexisting hornblende and biotite. Data are from Table VI and Robb (1981).

TABLE VII

ISOTOPIC DATA, KAAP VALLEY PLUTON AND OTHER UNITS, BARBERTON GRANITE-GREENSTONE TERRANE

Unit	Rb (ppm)	Sr (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$
Kaap Valley Pluton							
Hornblende + Biotite Phase							
B-79-15A	35.1*	565*	0.1795*	0.7092*	16.35	15.08	35.62
B-79-15B	35.1*	573*	0.1767*	0.7092*	16.56	15.10	36.07
B-79-15B biotite	208.	51.2	12.36	1.2644			
B-79-15C'	30.8*	532*	0.1671*	0.7086*	17.78	15.51	36.73
B-79-15D'	31.1*	605*	0.1484*	0.7075*	16.89	15.28	36.33
B-79-15E	37.0*	590*	0.1813*	0.7090*	18.09	15.52	37.61
B-79-15F	33.8*	527*	0.1854*	0.7094*	17.90	15.46	37.90
B-79-15G	35.0*	536*	0.1911*	0.7098*			
B-79-15H	24.1*	546*	0.1275*	0.7066*	17.81	15.40	37.42
B-79-15I'	36.0*	480*	0.2162*	0.7110*	14.40	14.66	33.72
Hornblende Phase							
B-79-15J	38.2*	584*	0.1889*	0.7097*	16.35	15.05	35.56
B-79-15K	37.3*	584*	0.1848*	0.7093*	16.65	15.14	35.99
B-79-15L	41.0*	604*	0.1959*	0.7100*	16.53	15.09	35.52
B-79-15M	41.6*	624*	0.1924*	0.7098*	17.15	15.24	35.87
Stolzburg Pluton							
B-80-1A	54.7*	608*	0.2595*	0.7136*	17.65	15.58	34.78
B-80-1B	55.2*	603*	0.2647*	0.7136*	16.64	15.28	34.49
B-80-1C	44.4*	601*	0.2134*	0.7110*	16.85	15.37	35.07
B-80-1D	61.2*	609*	0.2903*	0.7150*	15.21	14.89	34.24
B-80-1E	86.2*	573*	0.4346*	0.7220*	15.87	15.05	34.04
Leucocratic Orthogneiss, Bimodal Suite, Ancient Gneiss Complex							
B-79-8A	77.3**	256**	0.8596**	0.7441**	17.16	15.51	39.78
B-79-8B	86.0**	262**	0.9357**	0.7389**	16.50	15.36	38.50
B-79-8C"	72.7**	274**	0.7539**	0.7389**	16.56	15.45	37.82
B-79-8D"	97.9**	222**	1.2592**	0.7653**	15.56	15.38	41.55
B-79-8E	88.6**	275**	0.9185**	0.7475**	16.37	15.29	41.42
B-79-8F	97.3**	365**	0.7583**	0.7390**	14.23	14.73	35.73
B-79-8G	86.4**	273**	0.9021**	0.7466**	16.49	15.30	39.37
B-79-8H"	71.3**	272**	0.7468**	0.7388**	15.77	15.25	38.09

' Analyses used in second Pb-isotopic age calculation.

" Data not used in Pb-isotopic age calculation.

* Data from Barton *et al.* (1983a).

** Data from Barton *et al.* (1980).

system reflects the age of crystallization while the Pb-isotopic and Rb-Sr biotite-whole rock ages reflect conditions during diapiric emplacement of the unit. In this case, the diapiric emplacement occurred about 3200 Ma ago, about 300 Ma after original crystallization. The fact that the data display an element of scatter in excess of that amount predicted from experimental uncertainties alone is consistent with this interpretation and suggests that locally near homogeneous Pb-isotopic compositions were established during remobilization.

Results of whole rock Pb-isotopic analyses (Table VII) of samples of the leucocratic orthogneiss component of the Bimodal Suite of the Ancient Gneiss Complex and the Stolzburg pluton are also plotted on Fig. 3. These data also define trends that may be interpreted as secondary isochrons even though only the data for the Stolzburg pluton scatter by an amount predicted from experimental uncertainties. If this assumption is correct, then the whole rock Pb-isotopic isochron age of the leucocratic orthogneiss is younger than the Rb-Sr whole rock isochron age for that unit whereas the two ages are nearly identical in the case of the Stolzburg pluton (Table I). This relationship suggests that the tectonic history of the leucocratic orthogneiss is more complex than that of the Stolzburg pluton, the latter crystallizing and being diapirically emplaced over a relatively short time period about 3500 to 3400 Ma ago.

It is significant that the Pb-isotopic data for the leucocratic orthogneiss and the Stolzburg pluton plot away from the two trends which define the Kaap Valley data (Fig. 3). This relationship implies that the sources of the first two units were characterized at some time in their histories by higher μ values than the source of the Kaap Valley pluton. This is an important observation in terms of the petrogenesis of the Kaap Valley tonalite and is discussed later in more detail. Furthermore, the $^{208}\text{Pb}/^{204}\text{Pb}$ ratios do not show a linear relationship with respect to $^{206}\text{Pb}/^{204}\text{Pb}$ ratios for data from the Kaap Valley and Stolzburg plutons and the Bimodal Suite of the Ancient Gneiss Complex (Table VII). This indicates that U and Th within these units have not been chemically coupled. U and Th concentrations for the Kaap Valley pluton are listed in Table III and suggest that the present Th/U ratio (average 4,7) for these rocks is slightly greater than the crustal average of about 3,5 to 4,0. This fact implies that U has been removed preferentially to Th from the system, but the exact timing of this event cannot be ascertained from the existing data.

IV. PETROGENESIS

In terms of its sodic composition, style of deformation, nature of emplacement, age and isotopic character, the Kaap Valley tonalite pluton is not unlike the trondhjemite gneiss plutons elsewhere in the Barberton granite-greenstone terrane. In detail, however, there are certain diagnostic features which set it aside and pose problems with respect to existing models for the genesis of typical Archaean tonalite-trondhjemite rocks. The following features are regarded as relevant in any petrogenetic considerations regarding the Kaap Valley tonalite pluton:-

- (i) the ubiquitous presence of hornblende and the *originally* more mafic composition of the Kaap Valley magma in comparison to other trondhjemite gneisses in the region which contain biotite as their predominant mafic phase;

- (ii) the apparent antiquity (about 3500 Ma) and very low initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (R₀ about 0.7001) of this unit;
- (iii) the somewhat anomalous Pb-isotopic compositions, at least with respect to the limited data available for comparative purposes;
- (iv) REE contents that are, on average, significantly higher than those of the more felsic trondhjemite gneisses in the region;
- (v) major element distribution patterns suggestive of subdued crystal fractionation during cooling; and
- (vi) structural indications that the pluton was diapirically emplaced into its present position.

The following sections provide some thoughts on magma genesis, crystallization and emplacement of the Kaap Valley pluton.

A. Origin of the Kaap Valley Tonalite Magma

Most studies of the genesis of Archaean tonalite and trondhjemite gneisses indicate a derivation by partial melting of a mafic precursor and a number of lines of evidence support this contention. In typical Archaean granite-greenstone terranes, tonalite and trondhjemite gneisses represent the earliest granitoid component. The apparent absence of earlier sialic crust renders it unlikely that these rocks could have been derived from a primitive felsic source. Moreover, tonalite and trondhjemite gneisses exhibit a common spatial association with metabasaltic remnants, a relationship which infers a genetic link between the two (Barker and Peterman, 1974; Barker and Arth, 1976). Low initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios also characterize Archaean tonalite and trondhjemite gneisses (Moorbath, 1977; Barton, 1981; 1983). Ratios of the order of 0.701 or less have often been used to indicate a lack of previous crustal prehistory, although cogent arguments by Collerson and Fryer (1978) indicate that this is not necessarily always the case. Further indications of the viability of a genetic link between basalts and tonalites and trondhjemites come from quantitative trace and REE models which show that the latter may be derived by partial melting of either eclogitic (Arth and Hanson, 1975; Condie and Hunter, 1976) or amphibolitic metabasalt (Arth and Barker, 1976). Finally, convincing evidence comes from laboratory experiments which demonstrate that primary tonalite-like melts can be generated from a variety of natural basaltic compositions (Helz, 1973; 1976).

The low initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of the Kaap Valley magma (about 0.7001) and relatively low μ values of its sources are compatible with this unit being derived either directly from mantle of bulk earth or depleted composition or from an intermediate rock type that itself was such a mantle derivative. If the latter case is true, as is necessary to derive a tonalite magma by partial melting of a basaltic or amphibolitic source, then the elapsed time between basalt or amphibolite genesis and partial melting must have been short.

There are a number of possibilities available which could explain the complexities indicated by the Kaap Valley Pb-isotopic data. The first

is that the data are meaningless and have no time significance. The fact that the main data trend (Fig. 3) defines an errorchron and that the data resolve into two apparently distinct trends could be taken as an indication that heterogeneities and discrepancies exist in the Pb-isotope system. However, as mentioned previously, the ages indicated by the secondary Pb isochron are in broad agreement with various mineral ages (Table I) suggesting that the data may in fact be meaningful. It could further be argued that there is merit in discarding the circa 3500 Ma Rb-Sr whole-rock age in favour of a younger age for both formation and subsequent diapiric emplacement of the pluton. However, in terms of the quality of the Rb-Sr whole-rock data (Barton *et al.*, 1983a) and arguments put forward below, there is no logic in this viewpoint and an additional possibility needs to be considered.

The model favoured in the context of all the existing data is that the majority of the Pb-isotopic data for the Kaap Valley pluton approximate a secondary isochron consistent with a three stage history. The first two stages approximate those implied in the Stacey and Kramers (1975) model and require an approximately bulk earth μ value for the average source of the Kaap Valley magma and the magma itself. The formation of the Kaap Valley tonalitic magma is considered to have occurred from two sources about 3500 Ma ago with an approximately bulk earth μ value being maintained. The third stage began about 3200 Ma ago (i.e. the age indicated by the secondary isochron) with the removal from the tonalite of significant U compared to bulk earth. This period of U-loss could reflect the time of diapirism. The remaining data, falling on a parallel trend in Fig. 3, can only be interpreted as having a three-stage history if, at the beginning of the third stage about 3200 Ma ago, in addition to U-loss, crustal Pb was added to these samples. The lowermost volcanic rocks of the Barberton greenstone belt have an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of about 0.7000 (Barton *et al.*, 1980; Barton, 1983) and have initial Pb-isotopic compositions that plot on the second stage of the Stacey-Kramers model. Rocks with Pb- and Sr-isotopic compositions similar to the Barberton greenstones are thus one possible source for the Kaap Valley tonalite. The more radiogenic Pb-isotopic compositions of the Stolzberg trondhjemite pluton and leucocratic orthogneiss of the Bimodal Suite of the Ancient Gneiss Complex indicate that these two units had a more complex history involving at least four stages. These rocks, with their higher initial Pb-isotopic compositions, could have been the second source of Pb in some of the Kaap Valley samples. However, mass mixing calculations based on the probable compositions of these two envisaged sources suggest that a large proportion, perhaps even the majority, of the Pb in some of the Kaap Valley rocks comes from the first (i.e. mafic) source. Because this is improbable in terms of bulk compositions it would appear that the Barberton greenstones do not represent the first source of Pb, but instead that source is some rock with a depleted μ composition. In summary, this model suggests that the Kaap Valley tonalite formed about 3500 Ma ago and is characterized by Pb-isotopic compositions indicative of two sources, one similar to that from which the Stolzberg trondhjemite pluton was derived and the other presumably a mafic rock with a depleted μ value. The observed secondary Pb-Pb isochrons are interpreted as reflecting the age of diapiric emplacement during which some form of chemical alteration, at least with respect to U and Pb, occurred.

The interpretation of Kaap Valley Pb data would appear to have something of an analogue in a study by Moorbath *et al.*, (1981) who discuss a dual source model for Pb in a late-stage granite pluton from West Greenland.

In their example, however, the Rb-Sr whole rock isotopic data yield the same age as does the secondary Pb-Pb isochron. Logic would argue that agreement between the Rb-Sr and U-Pb isotopic systematics might be expected when anatexis occurs in dual medium domains such as apparently characterized the source of the Kaap Valley magma. The fact that agreement between the isotopic systems does not exist for the Kaap Valley pluton suggests that the latter was indeed characterized by a tectonic event (i.e. diapiric emplacement) at about 3200 Ma during which time the U-Pb system was disturbed. Another rock suite that may be relevant to the interpretation of the isotopic data from the Kaap Valley pluton is the Bimodal Suite of the Ancient Gneiss Complex in Swaziland. In this unit, the Rb-Sr and Sm-Nd ages agree at about 3500 Ma (Barton *et al.*, 1980; Carlson *et al.*, 1983). As shown in Fig. 3, the U-Pb system is, however, at least locally disturbed, indicating an event occurring about 3200 Ma ago (Table I). This younger age is indistinguishable from the whole rock Rb-Sr and U-Pb isochron ages of the Granodiorite Suite and Tsawela Gneiss (Barton *et al.*, 1983c; Barton unpubl. data), both of which intrude the Ancient Gneiss Complex. In this case where discrete, albeit compositionally similar, rock units coexist in a geologically complex environment, it is inferred that the Rb-Sr and Sm-Nd systems were more resistant to disruption by metamorphism than was the U-Pb system. This again is analogous to the preferred interpretation for the Kaap Valley Pb-isotope data. In the case of the Stolzburg trondhjemite pluton, however, both the Rb-Sr and U-Pb whole rock data define old isochron ages of about 3500-3450 Ma (Table I). Clearly, in this instance there is no evidence for disruption of either system.

The significantly higher total REE content of the Kaap Valley tonalite compared to the more leucocratic trondhjemites in the region also suggests that their modes of origin were somewhat different. Particularly untenable in this light would be any model which envisaged the Kaap Valley tonalite magma as having been produced simply by a greater degree of partial melting of the same source that produced the more felsic trondhjemitic magmas. This feature is illustrated in Fig. 10 where model curves A and B, representing 20 and 30 per cent partial melts of a hornblende-bearing basaltic komatiite source, are compared with average traces of hornblende and hornblende + biotite tonalites, as well as an average of various trondhjemite gneisses in the region. The model curves clearly become progressively depleted in light and intermediate REE content with increased melting and, thus increasingly unlike the Kaap Valley trace (Fig. 10 and Appendix).

An alternative approach to understanding the REE pattern of the Kaap Valley tonalite is to attempt to model the origin of the magma in terms of a basaltic source with an *eclogitic* mineralogy. This approach has been utilized by Condie and Hunter (1976) and their model is shown as curve D in Fig. 10. Their solution, which invokes 10 per cent partial melting of a clinopyroxene + garnet-bearing source rock, is remarkably similar to the average trondhjemite gneiss curve (curve 3, Fig. 10) and can certainly be used in support of proponents who favour melting at relatively deep crustal levels (e.g. Arth and Hanson, 1975). However, as evident in Fig. 10, and as Condie and Hunter themselves pointed out, this model cannot adequately account for the Kaap Valley tonalite for the same reason as that discussed above. In order to account for the chemical characteristics of the Kaap Valley tonalite, Condie and Hunter (1976) proposed that the body could best be explained in terms of contamination by mafic rocks and that this was consistent "..... with field observations which suggest that the Kaap Valley has partially digested parts of the Onverwacht mafic and ultramafic volcanics". However, the evidence presented in this paper tends to discount digestion of mafic volcanic wall rocks as an explanation for the ubiquitous presence of horn-

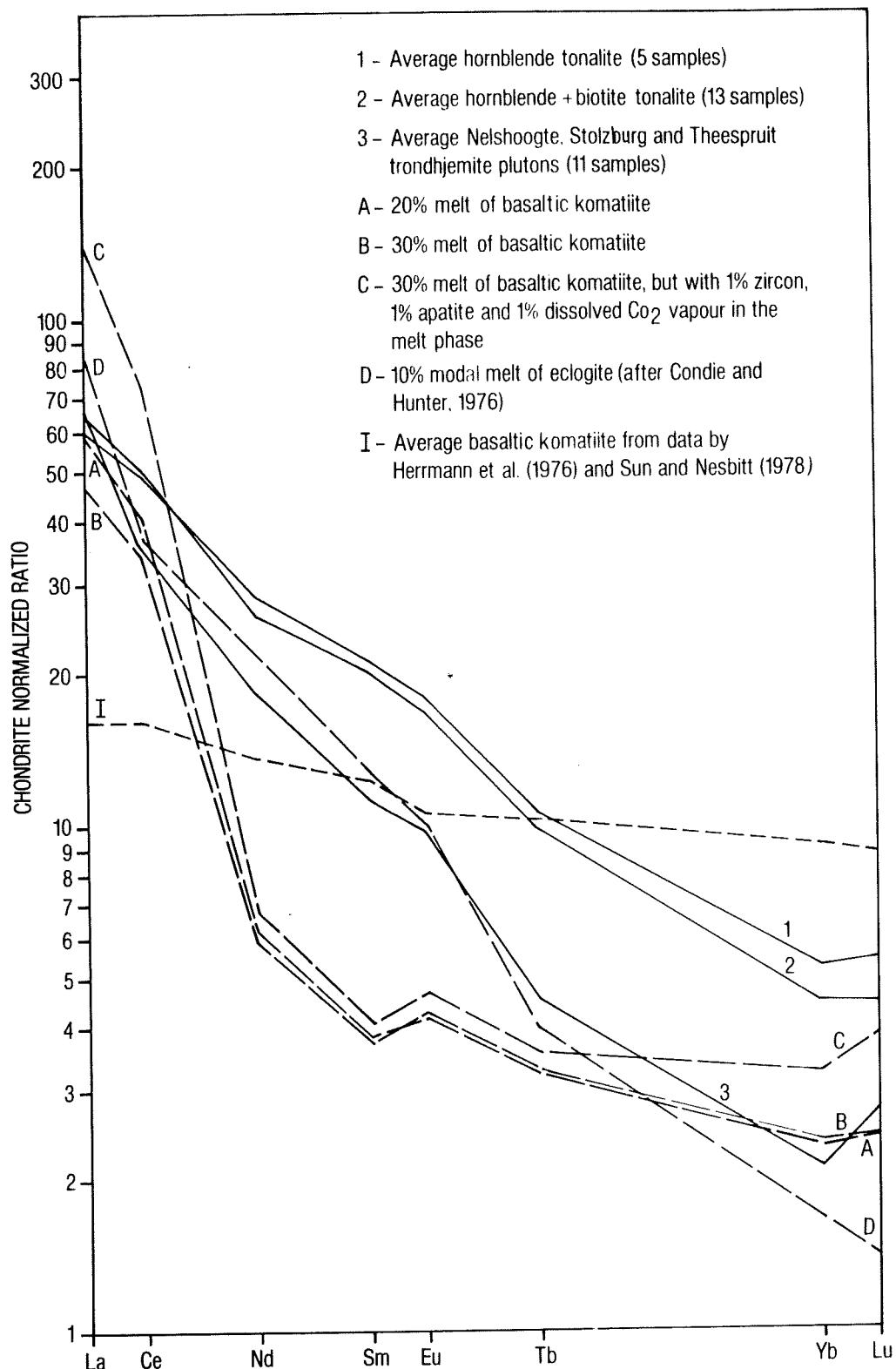


Figure 10 : Chondrite normalized rare earth element plot of data from the Kaap Valley tonalite, various trondhjemite gneiss plutons and an average basaltic komatiite. Model curves A-D are calculated in accordance with the parameters outlined in the Appendix (part A).

blende and the more mafic composition of the Kaap Valley tonalite pluton. Clearly, another explanation is required to adequately explain all the facets of this body.

Many workers have stressed the important effects that minor accessory phases such as zircon and apatite have on the distribution of REE during melting processes (e.g. McCarthy and Kable, 1978). Furthermore, it has recently been shown that the presence of CO_2 , perhaps dissolved in the magma, may have a marked effect on REE concentrations in resulting rocks (Collerson and Fryer, 1978; Wendlandt and Harrison, 1979). Consideration of these points, which are often overlooked in REE modelling, may be relevant to the petrogenesis of the Kaap Valley tonalite, a view substantiated by consideration of comparative P, Zr and CO_2 contents between the Kaap Valley tonalite pluton and other trondhjemite plutons in the Barberton Mountain Land. Table VIII provides average P and Zr data for the Kaap Valley tonalite and compares these figures with averages for the Theespruit, Nelshoogte and Stolzburg trondhjemite plutons. The Kaap Valley tonalite body is seen to have significantly higher P and marginally higher Zr contents than the three trondhjemite plutons, features which confirm petrographic observations of higher apatite and zircon contents in the former. Furthermore, preliminary analyses for CO_2 in samples of the Kaap Valley and Theespruit plutons suggest that the former has a significantly higher vapour phase content than the latter. Consequently, specific consideration of the "minor" phases may, at least in part, explain the somewhat anomalous REE endowment of the Kaap Valley tonalite in relation to other trondhjemite bodies in the region. In Fig. 10, model curve C depicts a 30 per cent partial melt of a hornblende-bearing basaltic komatiite (as in model curve B) but incorporates 1 per cent each of zircon, apatite and dissolved CO_2 vapour in the melt phase. The presence of these minor phases significantly alters the bulk partition coefficients of REE in the tonalitic melt phase (see Appendix) and consequently results in a trace which is more enriched in REE than the equivalent 30 per cent partial melt represented by curve B (Fig. 10). However, on its own, this model curve still does not resemble the Kaap Valley trace, the latter being considerably flatter in aspect than the suggested model curve.

None of the models discussed above adequately accounts for all of the characteristics evident in the Kaap Valley tonalite. However, when viewed collectively, certain of these considerations may combine to provide a more feasible model. It is apparent in Fig. 10 that mixing of a typical trondhjemitic magma (derived, for example, by partial melting of an eclogite, as suggested by Condie and Hunter, 1976) with an average basaltic komatiite composition (curve I, Fig. 10) would adequately account for the high *heavy* REE content of the Kaap Valley tonalite, but *not* the intermediate or light REE concentrations. If, however, the contaminated tonalitic melt phase also contained a significant proportion of apatite and zircon as well as dissolved CO_2 vapour, its total REE content, including the light REE would be considerably enhanced. Consequently, some form of mixing, to yield a model REE trace essentially intermediate in aspect between the average basaltic komatiite (curve I, Fig. 10) and model curve C, the latter representing a normal partial melt but with somewhat higher Zr, P and CO_2 contents, could be considered. Whilst not identical to the actual Kaap Valley trace, such a model curve, derived by combination of two other model parameters, would more closely resemble the latter than any other single model curve considered. Combining aspects such as some form of mafic contamination and enhanced Zr, P and CO_2 contents not only accords with the petrological characteristics of the Kaap Valley tonalite but is consistent with the isotopic data discussed earlier. However, in view of previous statements negating the likelihood of partial digestion of mafic material in the Kaap Valley tonalite, it becomes necessary to qualify the mechanism by which contamination of the Kaap Valley magma occurred. As put

TABLE VIII

AVERAGE P, Zr AND CO₂ CONTENTS OF THE KAAP VALLEY TONALITE
AND OTHER TRONDHJEMITE PLUTONS IN THE BARBERTON MOUNTAIN LAND

	P (ppm)	n	Zr (ppm)	n	CO ₂ (wt.%)	n
Kaap Valley Tonalite Pluton	792	(42)	124	(13)	0.25	(4)
Theespruit Trondhjemite Pluton	528	(26)	124	(26)	0,07	(4)
Stolzburg Trondhjemite Pluton	352	(1)	102	(1)	-	
Nelshoogte Trondhjemite Pluton	396	(2)	88	(2)	-	

Notes : (1) n = number of samples analysed.

(2) P and Zr data for Kaap Valley pluton from Table II.

(3) Zr data for Theespruit pluton after Meyer (Unpubl. data).

(4) P data for Theespruit pluton after Anhaeusser and Robb (1983).

(5) P data for Stolzburg and Nelshoogte plutons after Anhaeusser (unpubl. data) and Glikson, (1976).

(6) Zr data for Stolzburg and Nelshoogte plutons after Glikson (1976) and Meyer (unpubl. data).

(7) CO₂ data after Meyer and Robb (unpubl. data).

forward in one of the arguments pertaining to the isotopic data, contamination is viewed as being a process of either complete digestion of depleted mafic material by a trondhjemite magma or mixing of two magmas, one trondhjemite and the other a melt of depleted mantle. By either process, it would be possible to yield a relatively mafic tonalite magma from which hornblende (and biotite) would crystallize, rather than biotite only as is the case of more felsic uncontaminated trondhjemite magmas.

In summary, it is evident that the REE patterns of the Kaap Valley tonalite pluton are difficult to account for in terms of a simple petrogenetic model. Total REE contents are significantly higher than those in the more common trondhjemite gneisses, suggesting an influence from light REE compatible minor phases and contamination by relatively enriched heavy REE mafic material. In support of this the Pb-isotopic data appear to indicate that the tonalite is characterized by Pb from two sources and it is argued that one of these was similar to that from which the more felsic trondhjemite magmas were derived whilst the other represents depleted mafic material. Because partial digestion of mafic metavolcanic wall rocks is not compatible with the chemical and mineralogical characteristics of hornblendes in the Kaap Valley tonalite, it is inferred that either complete digestion of mafic material at depth, or magma mixing, was the mechanism by which this contamination occurred.

B. Crystallization and Emplacement of the Kaap Valley Tonalite

Compositions of granitoid bodies have traditionally been regarded as reflecting the composition of the liquid from which they crystallized. With this assumption in mind, any compositional zoning that may have been evident could readily be attributed to marginal assimilation of country rock. In recent years, however, many studies have emphasized the fact that geochemical trends in magmatic granites are the result of crystal fractionation mechanisms which are often operative *in situ*. These mechanisms are generally related either to progressive inward nucleation of crystals (McCarthy and Robb, 1978; Bateman and Chappell, 1979) or to subtle gravity or convection-induced stratification (Taylor, 1975; Tindle and Pearce, 1981). In either case, geochemical trends may be quantitatively modelled in terms of either fractional crystallization, equilibrium crystallization or a crystallization mode that is intermediate between these two extremes (McCarthy and Hasty, 1976). The Kaap Valley tonalite pluton is characterized by distinctive compositional zoning (Figs. 4 and 5 a-d) which is enhanced by a two-fold mineralogical sub-division which recognizes hornblende and hornblende + biotite-bearing tonalites. Because the chemical and petrographic characteristics of hornblendes in the Kaap Valley body are inconsistent with their derivation by partial digestion of mafic country-rock, it would appear that geochemical trends within the body may be most profitably interpreted in terms of a crystal fractionation mechanism.

1. Crystal Fractionation in the Kaap Valley Tonalite

Compositional variations in the Kaap Valley tonalite are illustrated in the form of Harker diagrams (Fig. 4) and contoured plots (Fig. 5 a-d). Assuming that the Harker trends represent a liquid-line-of-descent, it is evident that a sequential form of crystallization occurred within the tonalite. Because the hornblende + biotite tonalites are generally more siliceous than the hornblende tonalites, it appears that biotite appeared on the liquidus only at a relatively advanced stage of crystallization.

The late appearance of biotite and a subsequent decline in the hornblende/biotite ratio is not an uncommon feature of fractionating granitic assemblages (Piwinski, 1968; McCarthy and Fripp, 1980) and can probably be related to residual enrichment of potash in differentiated liquid phases. It was suggested earlier that the apparent hiatus between Harker trends in the two tonalite phases (in particular the MgO versus SiO₂ plot, Fig. 4) may reflect the sudden appearance of biotite on the liquidus.

Given that geochemical trends in the Kaap Valley tonalite were influenced by crystal fractionation, it would be pertinent to establish the mode of crystallization, as perhaps reflected in the nature of trace element distributions. The relationship between fractional and equilibrium crystallization modes and the distribution of, for example, Rb, Sr and Ba between fractionating solid and rest liquid, are well established (McCarthy and Hasty, 1976; Tindle and Pearce, 1981). In Fig. 11, a quantitative model which distinguishes between equilibrium and fractional crystallization for an assemblage comprising 60 per cent plagioclase, 22 per cent quartz, 12 per cent hornblende, 3 per cent biotite and 3 per cent K-feldspar, is shown in terms of Rb versus Sr and Rb versus Ba plots. For both crystallization modes, Rb and Ba increase in concentration whilst Sr decreases with progressive fractionation. However, in the case of equilibrium crystallization these changes are considerably smaller than in the case of fractional crystallization, over the same range of crystallization. When the data from the Kaap Valley tonalite are superimposed over these model trends (Fig. 11), it is apparent that the slopes, trends and ranges of concentrations are more compatible with an equilibrium rather than a fractional crystallization mode.

The above considerations provide some insight into the mechanisms of solidification of the tonalite. The incoming of hornblende and biotite on the liquidus appears to have been sequential and is probably related to differentiation of the tonalite magma. However, the distribution of trace elements indicates that fractionation of mineral phases was not severe and it is inferred that crystals remained effectively in equilibrium with the liquid from which they formed. Thus, it is envisaged that fractionation was a subdued process and probably occurred by filter pressing as portions of the magma chamber became "more solid" than others. The question arises as to the mechanism and geometry of the crystallization process and this is discussed in the next section.

2. Major Element Distributions, Structural Trends and Possible Relationship to Crystal Fractionation Mechanisms

The distribution of major elements such as SiO₂, MgO, CaO and K₂O over the Kaap Valley pluton (Fig. 5 a-d) is closely related to the occurrences of hornblende and hornblende + biotite tonalites (Fig. 2), and is, therefore, a manifestation of crystal fractionation. As described earlier, the element distribution is not concentrically zoned and is unlikely to reflect simple inward nucleation of crystal growth. Furthermore, the Kaap Valley pluton has been deformed and probably structurally emplaced into its present position as a diapir. Thus, present element distribution patterns must be regarded as a combined function of crystallization, deformation style and geometry, and the present level of erosion.

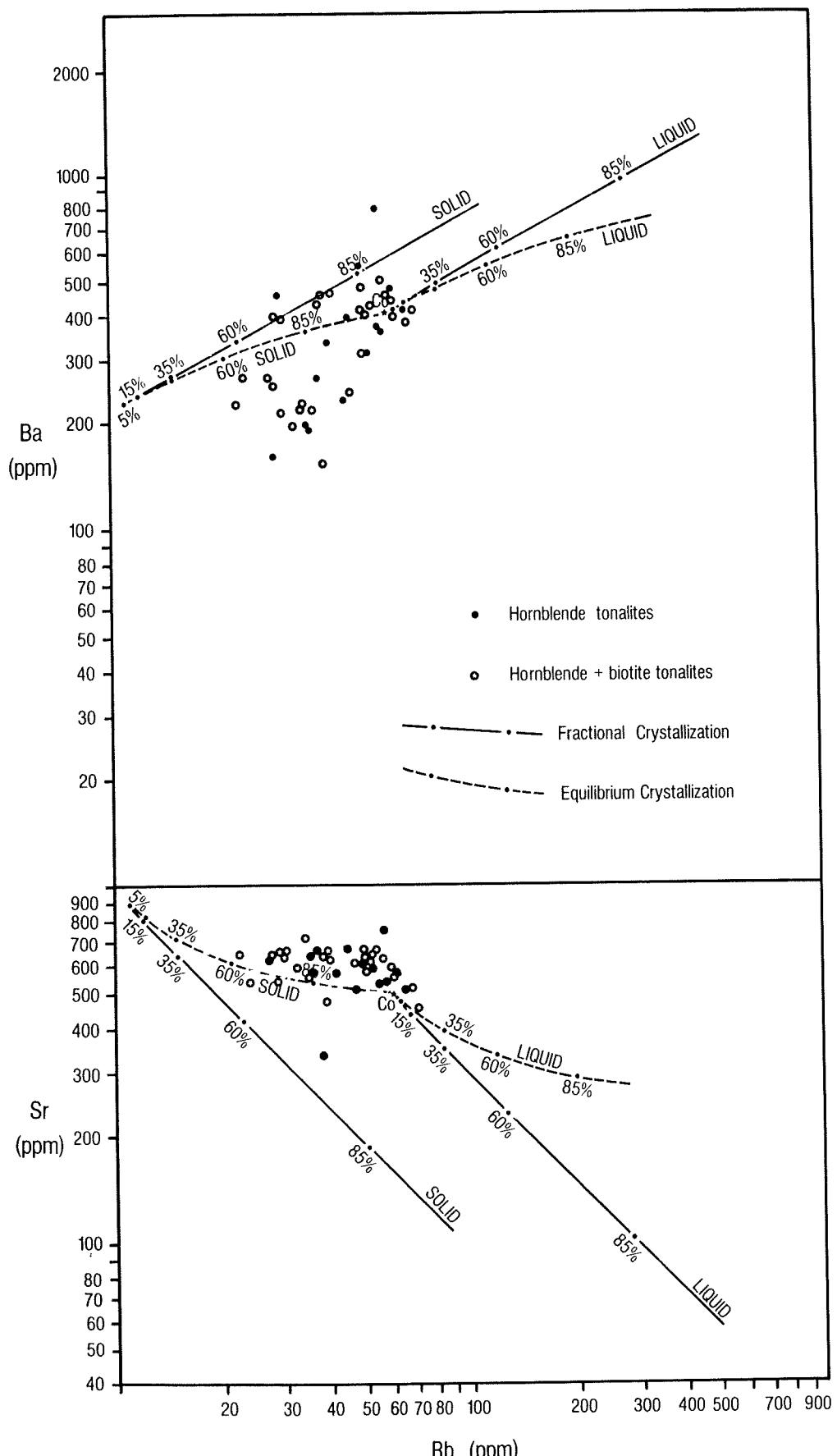


Figure 11 : Plots of Rb versus Sr and Rb versus Ba for data from the Kaap Valley tonalite pluton. Data are from Table II. Superimposed are model curves for the distribution of Rb, Sr and Ba during fractional and equilibrium crystallization. These curves are calculated in accordance with the parameters outlined in the Appendix B. The numbers 5%, 15%, 35% etc., refer to the crystallization increments for which the model curves were calculated.

Figure 12 presents a schematic map showing actual and inferred structural trends over the Kaap Valley tonalite pluton. These trends are derived from a number of sources which include the known synclinorial aspect of the Jamestown and Nelshoogte schist belts (i.e. trends C-C' and D-D' respectively, Fig. 12), the regional structural interpretation of Anhaeusser (1969) and a structural interpretation of the tonalite-greenstone contact along the southern margin of the Kaap Valley pluton by Wuth (1980). A more detailed account of the derivation of this structural scheme can be found in Robb (1981). If the envisaged structural trends over the Kaap

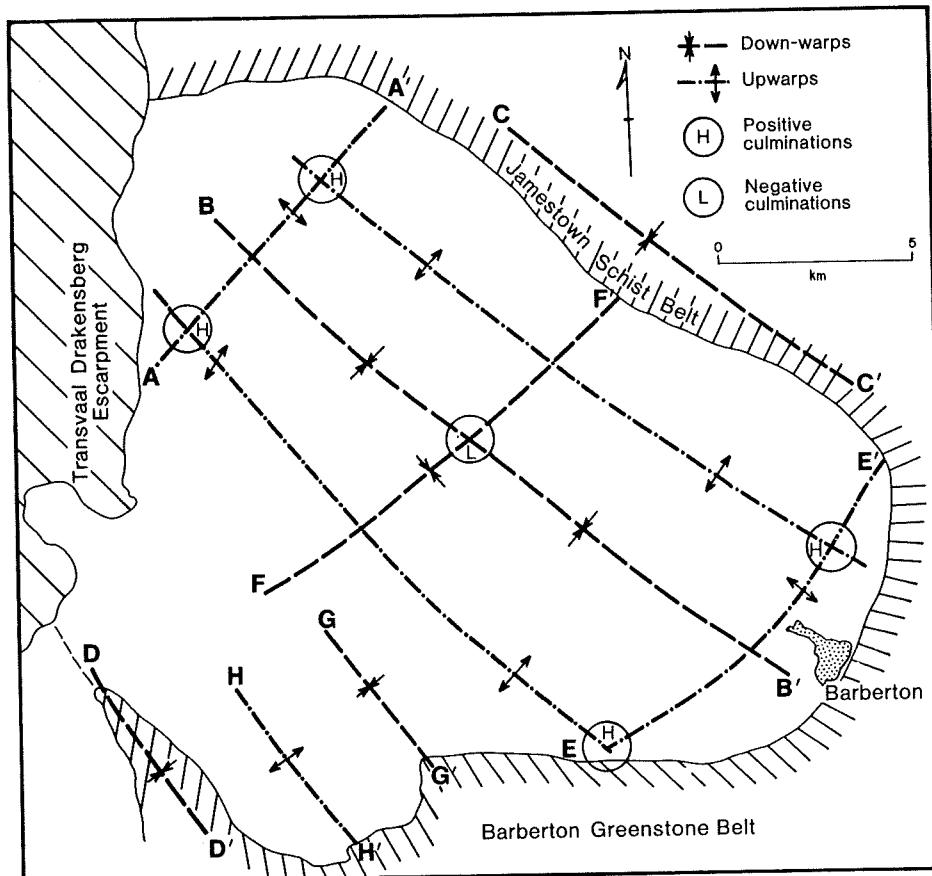


Figure 12 : Schematic diagram showing the suggested structural lineaments over the Kaap Valley tonalite pluton. Trends C-C' and D-D' (the Jamestown and Nelshoogte schist belts respectively) represent greenstone synclinoria. The positions of positive and negative culminations should be compared to the geological map (Fig. 2) and also the contoured distribution of elements in Fig. 5.

Valley pluton, and in particular the position of areas of positive and negative culmination (i.e. domes and basins), are compared with the element distribution maps, an interesting correlation emerges. Areas of positive culmination coincide with the more mafic portions of the body (cp. Fig. 12 with the MgO contours in Fig. 5b) which also represent those areas dominantly underlain by the hornblende tonalites. Conversely, the centrally-disposed region of negative culmination in Fig. 12 broadly coincides with high K₂O contents (Fig. 5d) and is underlain by hornblende + biotite tonalites. Consequently, because areas of positive culmination will expose deeper portions and negative culmination will preserve

shallower levels, the element distribution pattern, when viewed in the light of structural trends, may reflect an originally sub-horizontal compositional layering. Thus, earlier-formed, dominantly hornblende-bearing tonalites appear to have occupied the lowermost portions of the magma chamber, whilst progressive fractionation resulted in the formation of hornblende + biotite tonalites in an upward direction. Thus, although not clearly apparent, the mechanism of crystal fractionation in the Kaap Valley tonalite appears to be a consequence of mineral pseudo-layering rather than inward nucleation of crystals, a feature which may have been induced by both gravity and convection.

V. SUMMARY AND CONCLUSIONS

A total of 13 tonalite and trondhjemite gneiss plutons have been recognized in the immediate environs of the Barberton greenstone belt (Robb and Anhaeusser, 1983). On these, 12 are dominantly characterized by trondhjemitic compositions whilst only one, the Kaap Valley pluton, is tonalitic. The 13 bodies can be likened in terms of their sodic compositions, their penetrative mineral fabric and distinctive diapiric style of emplacement and, in most cases, their low initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios. The Kaap Valley body, however, differs significantly in terms of its more mafic overall composition, the fact that hornblende is its dominant mafic mineral (compared to biotite in the trondhjemites), its higher total REE content and apparently anomalous (at least in terms of the limited data available) Pb isotopic compositions.

The broad similarities between the Kaap Valley tonalite and other trondhjemite gneiss bodies in the Barberton Mountain Land (in particular low initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios; see Barton, 1981; 1983) indicate a similar scenario in terms of their origin, namely, partial melting of a primitive mafic precursor possibly akin to the metavolcanic assemblages forming the lowermost portions of adjacent greenstone belts. However, features such as the higher REE content of the Kaap Valley tonalite and the dual sources of Pb preclude it from being related to the more felsic trondhjemites by simply considering a greater degree of partial melting of the same precursor. Both the REE and isotope data appear to support derivation of the Kaap Valley tonalite by contamination of an originally more felsic trondhjemitic magma by mafic material which may well have been the residue of partial melting of a typical greenstone assemblage. It is necessary, however, to qualify the nature of the contamination mechanism in the light of petrographic and chemical evidence indicating that the hornblende component of the tonalite was not simply derived by partial digestion of pre-existing mafic metavolcanic rocks, but crystallized from the magma. It is inferred, therefore, that either, complete digestion of mafic material prior to emplacement, or magma mixing, was responsible for the contamination process.

The existence of hornblende and hornblende + biotite tonalite phases and their segregation both in terms of space and major element Harker-type trends is indicative of *in situ* crystal fractionation involving the sequential appearance of hornblende and biotite on the liquidus. The slopes, trends and ranges of trace element distributions suggest that solidification of the Kaap Valley magma occurred by equilibrium rather than fractional crystallization. Crystal fractionation is envisaged, therefore, as being a subdued process which probably occurred by filter pressing as certain portions of the magma chamber solidified before others.

In this regard, it should be noted that the medium-to-fine grained tonalitic dykelets are not significantly fractionated with respect to their host tonalites.

The contact between the Kaap Valley tonalite pluton and surrounding volcanic rocks of the Barberton greenstone belt is generally sheared and lacks evidence of magmatic emplacement. The pluton is, therefore, considered to have been diapirically emplaced into its present position about 3200 Ma ago, an event which was largely responsible for the deformation of the surrounding greenstone succession (Anhaeusser, 1966; 1969; 1976). Although paucity of outcrop does not allow for detailed structural analysis, several independent lines of evidence appear to indicate that a set of orthogonal structural trends exist which may reflect systematic perturbations in the central region of a rising diapiric mass (Schwerdtner *et al.*, 1978; *pers. comm.*) Areas of intersection of these trends are correlatable with the occurrences of hornblende and hornblende + biotite phases as well as contoured distribution patterns of major elements. From this relationship, it is tentatively suggested that compositional zoning in the Kaap Valley pluton was originally stratified but was subsequently modified by deformation.

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APPENDIX

A. Partial Melting Models for the Rare Earth Elements

	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
Chondritic normalizing values (1)	0.2446	0.6379	0.4738	0.1540	0.0580	0.0374	0.1650	0.0254 ppm
Average Theespruit, Nelshoogte and Stolzburg trondhjemite plutons (2)	15.8	22.4	8.5	1.73	0.56	0.17	0.35	0.07 ppm
Average basaltic komatiite (3)	3.9	10.3	6.5	1.89	0.61	0.39	1.49	0.22 ppm
20% partial melt of basaltic komatiite (4)	13.9	26.1	2.9	0.58	0.25	0.12	0.38	0.06 ppm
30% partial melt of basaltic komatiite	11.2	22.3	2.8	0.57	0.26	0.12	0.38	0.06 ppm
K _D 's - basaltic komatiite (5)	0.14	0.27	2.20	3.20	2.70	3.30	3.90	3.60
K _D 's - tonalitic melt phase	0.29	0.39	0.72	0.91	2.11	0.90	1.07	0.98
30% melt of basaltic komatiite, but with 1% each of zircon, apatite and dissolved CO ₂ vapour in the melt phase	32.9	47.4	3.19	0.62	0.27	0.13	0.53	0.10 ppm
K _D 's - tonalitic melt + minor phases	1.07	1.18	1.15	1.64	2.53	1.88	4.19	5.39
10% modal melt of eclogite (6)	19.2	23.6	-	1.98	0.58	0.15	0.27	0.04 ppm

- Notes:-
- (1) Chondritic normalizing values after Evenson *et al.* (1978).
 - (2) Average derived from data by Glikson (1976) and Condie and Hunter, (1976).
 - (3) Average derived from data by Herrmann *et al.* (1976) and Sun and Nesbitt (1978).
 - (4) Distribution of trace elements during partial (batch) melting calculated using equations derived by Shaw (1970). Modal mineralogy of basaltic komatiite source taken as 80% hornblende, 10% plagioclase; 10% quartz. Modal mineralogy of derived tonalite melt taken as 66% plagioclase, 21% hornblende and 13% quartz.
 - (5) Bulk partition coefficients (K_D's) calculated using data compiled by Hanson (1980) and Arth and Hanson (1975).
 - (6) Eclogitic partial melting model is that described in Condie and Hunter (1976).

B. Crystallization Model in Terms of Rb, Sr and Ba

F (3)	Equilibrium Crystallization (1)		Fractional Crystallization (2)		
	Concentration solid	Concentration liquid	Concentration solid	Concentration liquid	
5%	Rb	11	63	11	63
	Sr	887	479	885	479
	Ba	225	409	225	409
15%	Rb	12	68	12	68
	Sr	820	443	806	435
	Ba	236	429	237	430
35%	Rb	15	84	15	85
	Sr	713	385	641	347
	Ba	261	475	267	486
60%	Rb	21	118	23	127
	Sr	612	331	424	229
	Ba	301	548	332	604
85%	Rb	36	198	51	284
	Sr	537	290	185	100
	Ba	356	648	517	939

- Notes : (1) Distribution of trace elements during equilibrium crystallization calculated using equations derived by Albarede and Bottinga (1972).
- (2) Equations for fractional crystallization from Greenland (1970).
- (3) F = the degree of crystallization.
- (4) Crystallizing assemblage considered to be 60% plagioclase, 12% hornblende, 22% quartz, 3% biotite and 3% K-feldspar. The bulk partition coefficients used for this assemblage were: Rb-0.18, Sr-1.85 and Ba-0.55. The original composition of the liquid was assumed to be: Rb-60 ppm, Sr-500 ppm, Ba-400 ppm.

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