ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
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ASPECTS OF THE GEOCHEMISTRY OF THE ACID PHASE OF THE CENTRAL AND EASTERN BUSHVELD COMPLEX

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UNIVERSITY OF THE WITWATERSRAND

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by

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ABSTRACT

Reconnaissance geochemical investigations, linked to geological mapping, were undertaken on the Sekukuni plateau, and in the Mutue Fides-Stavoren, Moloto, Dennilton, Sustersstroom, Naboomspruit, Zwartkloof, and Cyferfontein areas, where the Bushveld granites crop out in exposures that range from poor to moderately good. Geochemical data are presented for thirty-five samples collected on the Sekukuni plateau and from the Mutue Fides and Moloto areas.

The granites on the Sekukuni plateau have a distinctly lower concentration of Sn that approaches the clarke. The Moloto granites have higher concentrations, averaging 7 ppm. In both areas, the coefficient of variance is lower than that reported from the stratiform granites at Potgietersrus. It is suggested that these differences may play a significant role in the localization of economically viable tin deposits.

In addition to tin, analytical data for the following elements were obtained : Ba, Ce, Co, La, Nb, Rb, Sc, Sr, Y, Zn, and Zr. Eight of the samples were also analyzed for K_2O and Na_2O.

Radiometric surveys show that the coarse-grained grey granites have low counts (in μr/h). There is an increase in activity in the finer-grained, red granites, while the felsites have low counts. Where fluorspar is present in the granites, high counts were recorded.

* *

[The late D.H. Lenthall had completed much of his field and laboratory work for his Ph.D. thesis at the time he was killed. The results reported in this Information Circular are incomplete. However, it was felt that the preliminary findings should be placed on record. Consequently, observations and comments set down in field note-books were combined with the laboratory results to prepare the very generalized conclusions which follow.]

ASPECTS OF THE GEOCHEMISTRY OF THE ACID PHASE OF THE CENTRAL AND EASTERN BUSHVELD COMPLEX

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ASPECTS OF THE GEOCHEMISTRY OF THE ACID PHASE OF THE CENTRAL AND EASTERN BUSHVELD COMPLEX

INTRODUCTION

As part of an extensive investigation of the geochemistry of the acid phase of the Bushveld Complex, aimed at understanding some of the controls of tin mineralization, a preliminary reconnaissance survey was undertaken of the Bushveld granites cropping out in Sekukuniland and in the Moloto and Mutue Fides areas. In addition, studies of the lithologic variations of the Bushveld granites were made along sections at Dennilton, Sustersstroom, and Naboomspruit, and on the farms Zwartkloof and Cyferfontein, west of Warmbaths (Figure 1).

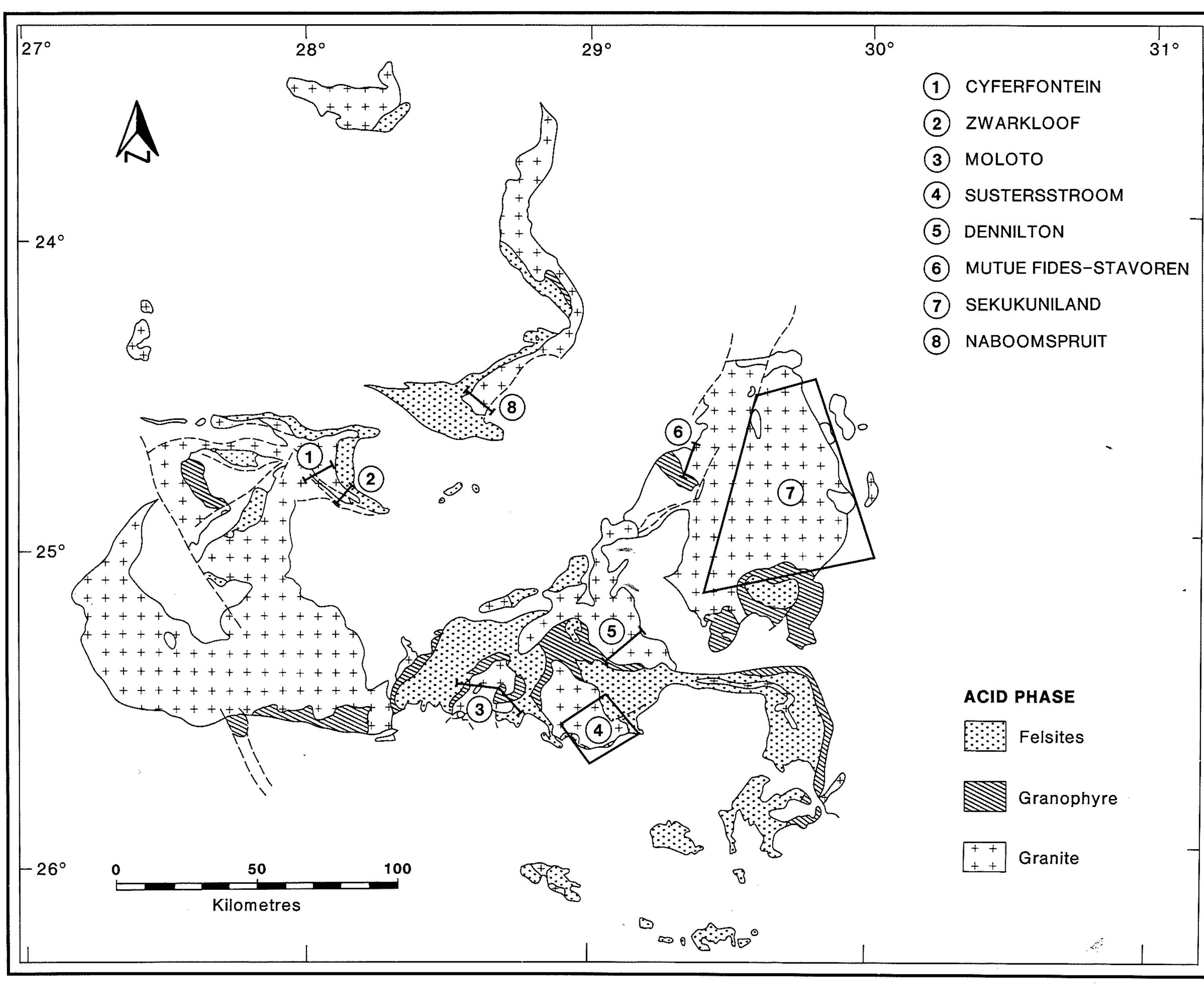

Figure 1 : Location of the areas examined in reconnaissance.

THE GEOCHEMISTRY OF THE ACID PHASE

(a) *Sekukuniland*

Bushveld granite builds the Sekukuni plateau, lying to the northeast of Groblersdal. The plateau is gently undulating, and forms a prominent scarp along its eastern margin, where the granites overlie the Mafic Phase of the Bushveld Complex, with metamorphosed and deformed beds of the Transvaal Supergroup occupying the interface between the granites and underlying gabbroic rocks. Xenoliths of these sedimentary rocks are found in the granites, the largest and most prominent, topographically, being at Malope Hill in the valley of the Olifants River. The Sekukuni plateau becomes less conspicuous towards the north, where it descends to a sand-covered plain, diversified by isolated, boulder-strewn hills. Outcrops of granite become less common in the valley of the Olifants River, which forms the western limit of the Sekukuniland plateau region. Granophyre and felsite underlie the southern part of the Sekukuni plateau. These rock-types extend westward towards Groblersdal, and form the high ground along the east side of the Olifants River, near Groblersdal, and along the north side of the Bloed River valley.

The main lithologic varieties of the Bushveld granite are shown in Figure 2. Lithology was recorded as 293 stations in the following manner. By using a graduated plastic sheet that could be laid over outcrops, the average grain-size of the feldspars forming the groundmass was estimated. Where porphyritic grains were found, their size was estimated separately. In Figure 2, the groundmass grain-size has been contoured. An estimate of the percentage of mafic minerals was made, again employing a graduated plastic grid. Finally, the colour and the absence or presence of granophyric textures were noted. These methods provided the means whereby a provisional map of the granite could be constructed from a rapid reconnaissance.

Mesocratic granite containing more than 5 percent mafic minerals occupies a belt approximately 10 km wide, that follows the arcuate eastern contact of the granite with the mafic phase. This belt is not uniformly mesocratic, for light-coloured granites occupy a large area north of Jane Furse. Granites with as much as 15 percent mafic minerals were found to occupy a zone approximately 1 500 m wide from the Spitskop alkaline complex to the Pokwani-Jane Furse road. In the south, the mesocratic granite is closely coincident with a grain-size (based on the groundmass feldspar) of less than 35 mm^2, but, in the extreme north, granites with a grain-size greater than 70 mm^2 have a content of mafic minerals in excess of 5 percent.

The 25-mm^2-grain-size isopleth follows the arcuate eastern contact of the Bushveld granite, and swings in the south to parallel the granophyre contact. Coarser-grained granites are, however, in contact with granophyre south and southwest of the Spitskop alkaline complex. Southwest of Mpudulle, porphyritic granite, in which individual feldspar phenocrysts reach more than 50 mm^2 in a much finer-grained groundmass, are in contact with granophyre. West of Mpudulle, finer-grained, red granophyric granite intervenes between the coarser-grained granite and the granophyre. Granite with a grain-size of 25 mm^2 is poorly exposed in the contact zone with granophyre east of Groblersdal.

Coarse-grained leucogranite, with a grain size larger than 50 mm^2, occupies a broad zone from Nebo to the north. Separately distinguished within this coarse-grained zone is the Nebo-type granite, which has a pale pinkish hue, as distinct from the general greenish-grey colour of the granites on the Sekukuni plateau. As no contact relationships could be found with the greenish-grey granites, it is not possible to interpret the significance of this colour change in the Nebo-type granite. It appeared that there was a gradational change from greenish-grey to pale pink in some outcrops at the northern end of the area occupied by Nebo-type granite.

Aplitic granites, often forming sheet-like bodies, are common in the southwestern portion of the plateau. Commonly, these granites are red in colour. Their presence is reflected in the high radioactivity counts recorded in that area (Figure 3).

There is a closely sympathetic relationship between the limit of the mesocratic granites and the 20 $\mu r/h$ isopleth (Figure 3). Apart from the slightly higher counts associated with the presence of aplitic granites, there is a tendency for higher counts to be recorded in granites immediately beneath granophyric granite in the southwest. With these exceptions, the level of the counts throughout the plateau is uniform and low. In all, the gamma-flux density was measured at 293 stations within an area of approximately 600 km^2.

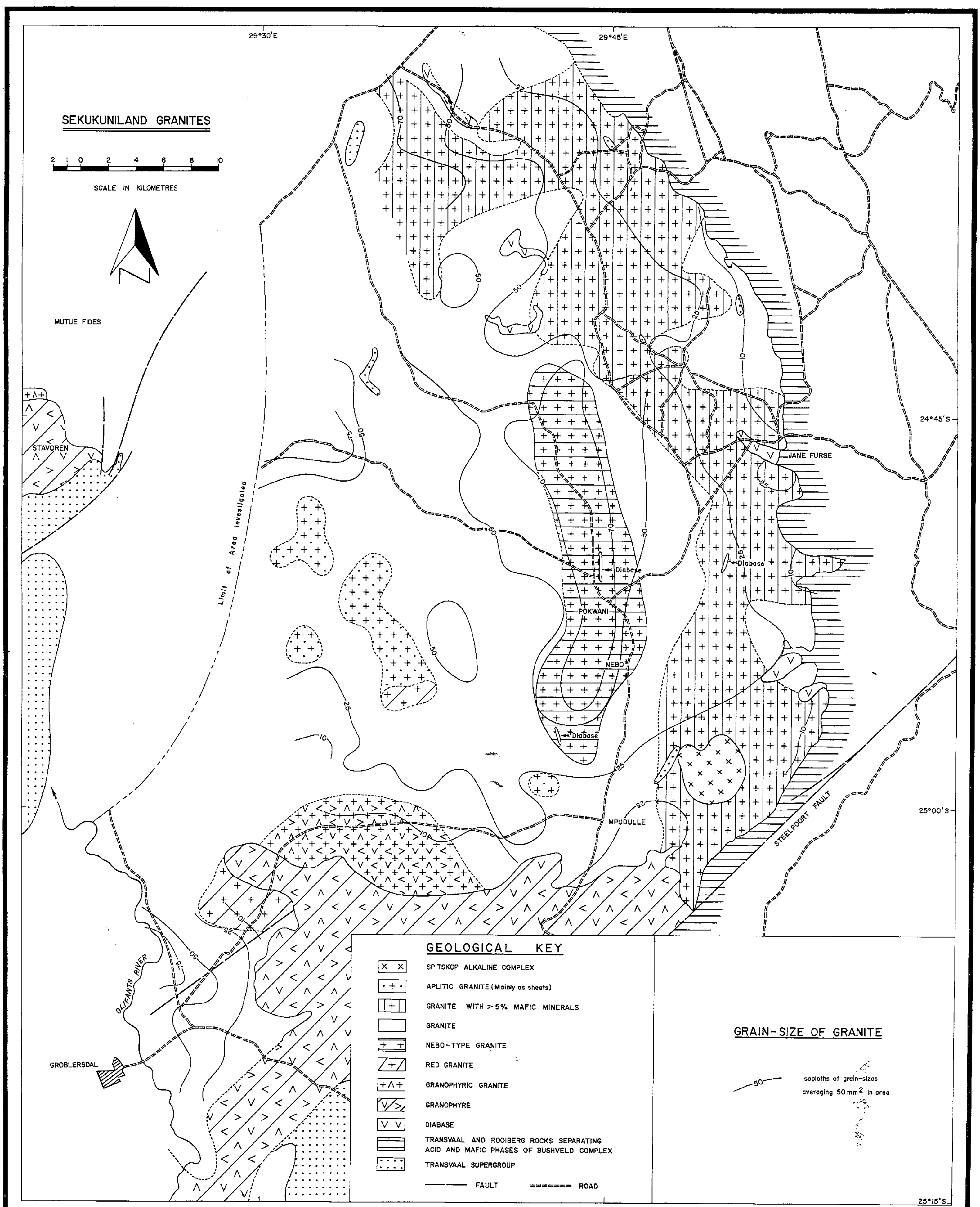

Figure 2 : *Generalized map of the Sekukuniland plateau, showing the distribution of the lithological varieties of granite and of grain-size isopleths.*

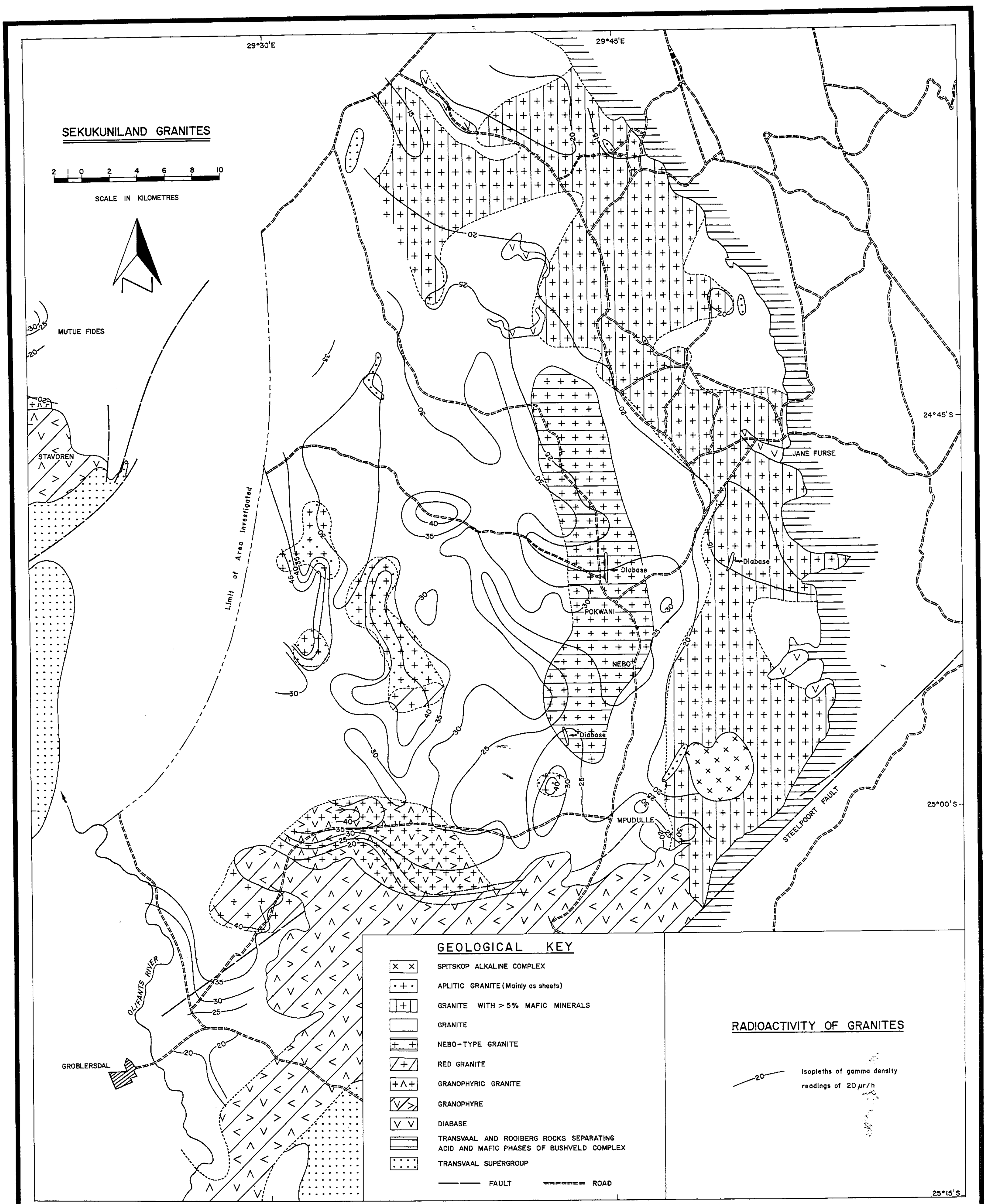

Figure 3 : Gamma-flux-density isopleths of the granites on the Sekukuni plateau.

Seventeen samples were collected for trace-element analysis, the locations of the samples being shown on Figure 4. The results of these analyses, together with additional analytical data derived from Liebenberg (1961) and Kaye and others (1965), are listed in Tables I and II.

TABLE I : Analytical Data for Sekukuniland Granites

	Ba	Ce	Co	La	Nb	Rb	Sc	Sn	Sr	Y	Zn	Zr	K_2O%	Na_2O%
Group I														
DS. 1	1822	182	8	51	24	127	5	2	141	57	98	560	4.50	3.65
VG. 2	1502	121	7	30	-	120	2	1	101	32	72	466	-	-
VG. 1	1202	189	7	49	18	113	3	3	90	63	100	577	-	-
Lb.24	1200	-	-	150	-	176	-	-	100	-	-	250	4.50	3.20
Lb. 6	2400	-	-	93	-	210	6	-	190	-	-	500	4.40	3.20
Group II														
RP. 1	846	386	5	147	17	156	4	1	87	69	46	438	-	-
UK. 4	754	222	5	71	18	177	2	3	58	67	52	320	4.80	3.50
Group III														
KS. 1	419	316	4	109	28	249	4	3	84	125	47	380	-	-
WG. 1	509	347	2	109	31	241	11	6	42	116	57	384	-	-
GB. 2	644	244	3	67	22	224	2	5	40	122	64	405	-	-
BL. 2	454	196	5	57	17	247	2	4	35	76	50	254	-	-
VF. 1	482	394	5	113	22	223	2	7	30	104	79	218	-	-
GT. 1	436	110	5	53	36	315	0	3	34	109	49	350	4.70	3.05
GF. 1	395	146	0	35	13	291	1	4	36	117	48	208	-	-
B.23	600	-	-	150	-	265	2	-	54	-	-	300	4.96	3.17
Group IV														
AG. 1	193	300	9	96	31	319	2	4	14	168	53	319	5.00	3.10
VB. 1	68	274	3	77	44	306	2	6	13	101	52	274	-	-
P. 3	196	261	5	90	28	306	1	5	44	103	38	244	-	-
B.21	300	-	-	-	-	250	-	-	20	-	-	-	5.42	3.01
Group V														
P. 1	125	1060	2	400	37	271	3	6	6	199	38	230	-	-
P. 2	145	222	3	73	52	306	1	3	6	173	31	258	-	-
MEANS	700	290	4.5	101	27	231	3	4	58	106	57	347	4.78	3.23

Analyses numbered Lb. 6 and Lb. 24 are from Liebenberg (1961). Analyses numbered B.21 and B.23 are from Kaye and others (1965), except for B.23 where La and Sc data are from Liebenberg (1961), and Na_2O and K_2O represent mean values from Liebenberg (1961) and Kay and others (1965).

TABLE II : Mean Compositions (A) and Element Ratios (B)

(A)	Ba	Ce	Co	La	Nb	Rb	Sc	Sn	Sr	Y	Zn	Zr
Group I	1508	164	7	43	21	120	3	2	111	51	90	534
Group II	800	309	5	109	17.5	166	3	2	72	68	49	379
Group III	477	250	3	78	24	256	3	4.5	46	110	56	314
Group IV	152	278	6	88	34	310	2	5	24	124	48	279
Group V	135	641	2.5	236	44	288	2	4.5	6	186	35	244

(B)	K/Rb	K/Ba	Ba/Rb	Ba/Sr	Rb/Sr	Na/K	Nbx10^3/Zr
Group I	294	24.8	12.5	13.6	1.08	0.77	39.3
Lb.24	212	31.1	6.8	12.0	1.76	0.63	-
Lb. 6	174	15.4	11.4	12.6	1.105	0.65	-
Group II	225	52.8	4.8	11.1	2.30	0.65	46.2
Group III	126	89.4	1.8	10.3	5.56	0.58	76.4
B.23	158	69.8	2.26	11.1	4.91	0.58	-
Group IV	130	215	0.5	6.3	12.91	0.55	121.8
B.21	180	150	1.2	15.0	12.50	0.50	-
Group V	-	-	0.4	22.5	48.00	-	180.3

* (A) *Data from Liebenberg (1961) and Kaye and others (1965) excluded.*

** (B) *K/Rb, K/Ba, and Na/K ratios based on data from Samples DS.1 (Group I), UK.4 (Group II), GT.1 (Group III) and AG.1 (Group IV). Element ratios for Samples Lb.6, Lb.24, B.21, and B.23 are included for comparison.*

The analyses have been grouped into five types, based on their geochemical characteristics. The three analyses in Group I, together with Lb. 24, are all located within the mesocratic border granite. They are distinguished by high contents of Ba and by Rb/Sr ratios close to unity. Lb. 6 was collected near the contact of the granite southeast of Groblersdal, and has features similar to those in the mesocratic zone on the plateau. In the remaining groups, the Ba and Sr contents decrease, while Rb becomes increasingly enriched. The rare earths, Ce and La, together with Y, increase until they reach their maximum concentration in two samples that are red in colour and have a grain-size close to 10 mm^2.

There are a number of features that distinguish the granites on the Sekukuni plateau from those investigated in the Zaaiplaats area, near Potgietersrus. The mean contents of Co and Sr are higher, whereas the mean concentrations of Sn and Zn are lower, in the case of Groups I, II, and III (Table III). There are only limited analytical data available for the alkalis, but inspection of Table I shows that the ratio of potassium to sodium in the Sekukuniland granites is slightly lower than at Potgietersrus. Despite the fewer number of samples, the analyses of the Sekukuni granites reflect a greater degree of variance in Ba, Ce, Rb, and Zr. Conversely, elements such as Co, Sn, and Sr have lower coefficients of variance.

The mean concentration of Sn in the Sekukuni granites closely approaches the clarke for low-Ca granites. In contrast, the Potgietersrus granites are distinctly stanniferous, and have a considerably greater coefficient of variance. If the model proposed for the generation of tin mineralization in the Potgietersrus area is correct, it requires the granitic magma to have an inherently stanniferous character. The Sekukuni granite has a consistently low concentration of tin, as shown by its mean and coefficient of variance. It follows that the prospects of locating economic concentrations of tin would appear to be poor on the Sekukuni plateau. This is further supported by the mean concentration of tin in Groups III and IV which reflect some of the

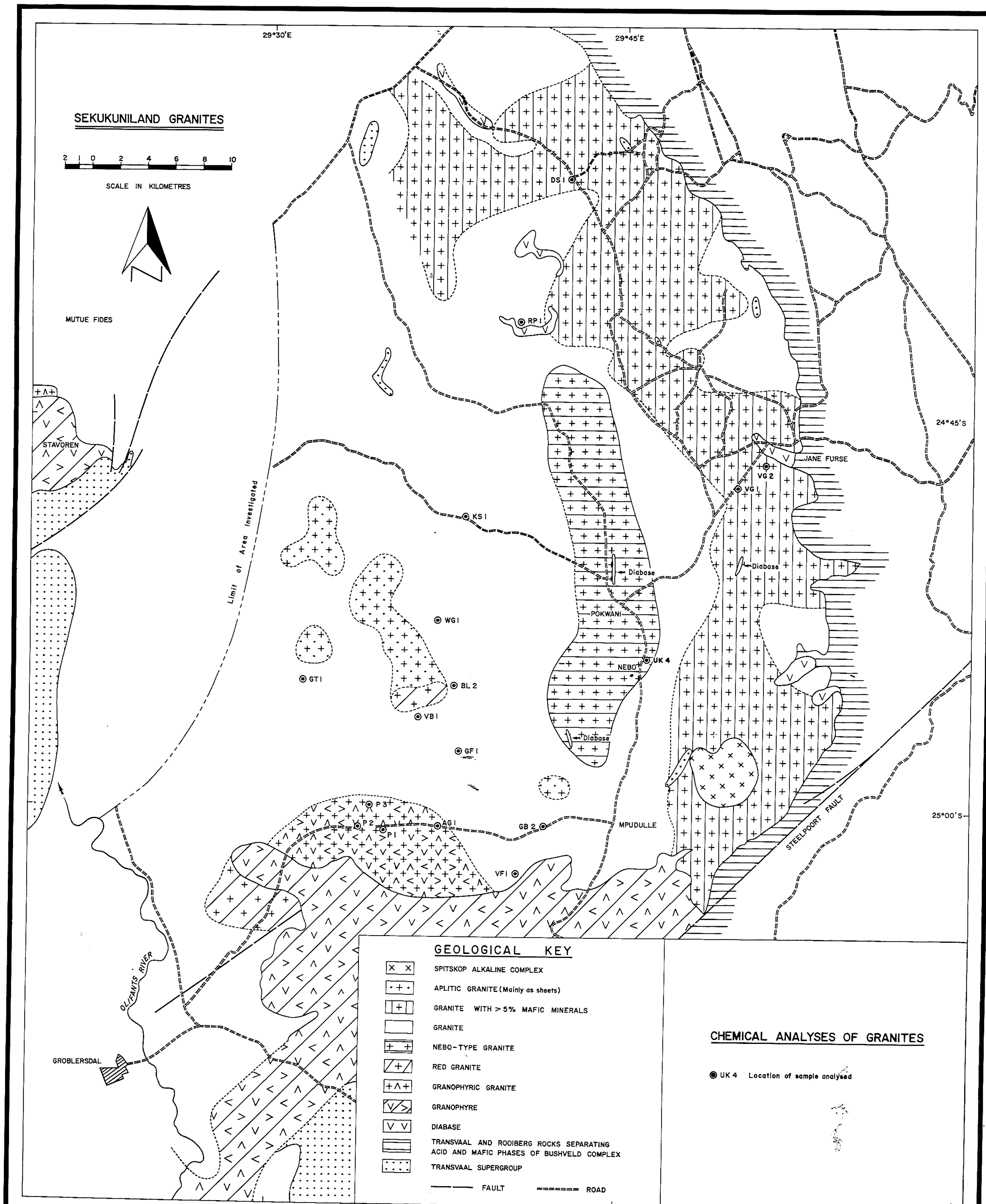

Figure 4 : *Location of samples analyzed on the Sekukuni plateau.*

TABLE III : Comparison of Means, Standard Deviations, and Coefficients of Variance of the Sekukuniland and Potgietersrus Granites

	Sekukuniland Groups I, II, and III			Potgietersrus			Sekukuniland Groups IV and V		
	Mean	SD	CV%	Mean	SD	CV%	Mean	SD	CV%
Ba	789	454.0	57	896	322.6	36	145	47.4	32
Ce	238	95.9	40	269	55.9	20	423	319.3	75
Co	4.6	2.1	46	2	1.3	66	4.4	2.5	57
La	74	35.0	47	100	36.8	37	147	126.7	86
Nb	22	6.6	30	24	7.2	29	38	8.7	23
Rb	207	64.6	31	225	33.7	15	302	16.1	5
Sc	3	2.7	90	3	1.6	52	2	0.7	35
Sn	3.5	1.75	50	8.5	7.2	85	4.8	1.2	24
Sr	65	33.75	52	39	56.9	146	17	14.1	83
Y	88	29.6	34	97	33.7	35	149	39.6	27
Zn	63.5	18.75	29	91	37.3	41	42	8.6	20
Zr	380	115.0	30	433	51.0	12	265	30.7	11

* *Data from Sekukuniland granites excludes analyses Lb.6, Lb.24, B.21, and B.23 of Table I.*

features of the stanniferous Bobbejaankop granite, with respect to the low concentrations of Ba and Sr. There is a significant enrichment in Ce, La, Nb, and Y, but the tin concentration and its coefficient of variance are both very low. It is not yet clear whether the different characteristics of the granites in the two areas are due to (i) the generation of the Potgietersrus granites from an originally more stanniferous parent, if, indeed, the Bushveld granites are the products of partial melting of an older sialic basement, (ii) the addition of tin from some deep-seated source, its migration being facilitated by the uprise of the granite magma and its localization being due to structural controls, or (iii) a difference in time of emplacement, so that greater concentrations of volatiles were formed at a late stage. In respect to the last alternative, the lack of visible fluorite grains in the Sekukuni granites generally lends some support to this view, although it is presumed that volatiles were available to initiate the red discoloration of the granite west of Mpudulle. There seems to be no evidence to support a proposal that the Potgietersrus granites represents the products of significantly more advanced fractionation (Table IV).

TABLE IV : Comparison of Element Ratios in Sekukuniland Granites (1 and 2) and Potgietersrus Stratiform Granites (3)

	Sekukuniland		Potgietersrus
	1	2	3
K/Rb	191	170	181
K/Ba	50.3	49.2	45.4
Ba/Rb	3.8	3.4	3.9
Ba/Sr	12.1	12.9	23.0
Rb/Sr	3.2	3.77	5.7
Na/K	0.66	0.63	0.55
$Nb \times 10^3/Zr$	57.9	69.76	55.4

* *Based on data given in Table III (Column 1) and means of analyses of DS.1, UK.4, GT.1, and AG.2 (Column 2).*

It could be argued that the Sekukuni granites may represent a deeper level of Bushveld granite, that has been depleted in tin. However, the same sequence that proceeds upwards from granite through granophyric granite and granophyre to felsite is represented in the Sekukuni area. This suggests that the levels of exposure are similar in both localities. The more limited development of oxidized, red granites on the Sekukuni plateau may reflect a lower activity of the volatile phases necessary for the concentration of tin, which is further supported by poverty in fluorite, but the light lanthanides that may be expected to be associated with volatiles are significantly enriched in several of the analyses of Sekukuni granite.

Additional geochemical data (Liebenberg, 1961; Kaye and others, 1965), summarized in Table V, lend some support to the view that the Sekukuni granites have a geochemical finger-print that distinguishes them from the Potgietersrus granites. Lithium appears to have a lower concentration in the Sekukuni granites, whereas nickel is significantly higher.

TABLE V : Additional Geochemical Data from Sekukuniland Granites Compared with Relevant Data from the Potgietersrus Stratiform Granites

	Ca%	Cr	Cs	Cu	Ga	Li	Ni	Pb	Ti	Tl	V
Lb. 6	1.19	15	4.5	9	19	8	23	12	2380	-	5
Lb.24	0.81	11	4	3	15	26	16	13	1190		n.d.
B.21	0.67	-	-	-	-	18	-	30	-	1.1	-
B.23	0.86	-	-	-	-	38	-	35	-	1.3	-
Means (Sekukuni)	0.82	17	5	7	19	26	22	22	1545	1.2	3
Potgietersrus	0.51	-	2.7	-	-	34	1	-	1173	-	-
Low-Ca granite	0.61	4.1	4	10	17	40	4.5	19	1200	2.3	44

* *Low-Ca granites (Turekian and Wedepohl, 1961).*

(b) Mutue Fides-Stavoren

The Mutue Fides-Stavoren area, lying to the west of the Olifants River, forms part of the Sekukuni granite area. The granites are generally poorly exposed, although prominent outcrops of coarse-grained granite (> 50 mm^2) are found along the west side of the Olifants River. The feldspar in these granites commonly has a pinkish hue. There is a possibility that this discoloration is related to faults, the presence of which is marked by prominent quartz veins. Flat pavements of coarse-grained granite, often cut by aplitic granite, are found north and east of Mutue Fides.

From Mutue Fides to Stavoren the lithologic variation in the granites is :

1. medium-grained (< 50 mm^2) grey granite, with finer-grained, more aplitic variants.
2. medium-grained (< 50 mm^2) pinkish granite, locally porphyritic.
3. medium- to-fine-grained red granite with few mafic minerals.
4. medium-grained, grey granite, the contacts with the underlying red granite being apparently gradational.
5. medium-grained red granite similar to (3) above.
6. granophyric, fine-grained, red granite with chlorite in patches and as laths.
7. granophyric finer-grained granite, paler in colour than (6) above, with lesser amounts of macroscopic quartz and more chlorite.

8. dark-coloured granophyre with chlorite.
9. red granophyre.

The radioactivity count along this section is low, averaging 20 µr/h, but in the vicinity of the dormant Mutue Fides mine, the count increases to 30 µr/h, where the lithology of the granite changes to a brick-red colour. Chloritization is often intense. The nature of the contact between this granite and the more widespread grey granites has not been seen.

Orthoclase was separated from 12 samples collected in the Mutue Fides-Stavoren area, and subjected to X-ray diffraction study to determine the separation of the 131 and $1\bar{3}1$ reflections. The results are summarized below, adopting Vorma's (1971) provisional classification of reflection or structural types :

Sample No.	Structural State	Obliquity Value
Coarse-grained Granite		
50	III/V	0.752
51	III/V	-
Medium-grained Granite		
59 (grey)	V	0.747
60 (red)	V	0.781
63 (grey)	III/V	0.770
64 (grey)	III/V	0.706
Granophyric Granite		
52	V	0.842
55	V	0.900
58	V	0.710
68	V	0.804
Granophyre		
62	III/V	0.769
73	V	0.791

These results compare with those obtained in the Potgietersrus area, indicating a general increase in the degree of Al/Si ordering in the feldspars, as the roof of the granite is approached.

Seven samples of granite from the vicinity of the dormant Mutue Fides mine were analyzed for trace elements. Two of the samples were also analyzed for Na_2O and K_2O. The results are given in Tables VI and VII.

The stanniferous granite at Mutue Fides has a close geochemical similarity with the Bobbejaankop granite and with the Group IV and V granites on the Sekukuni plateau, particularly in regard to their impoverishment in Ba and Sr and enrichment in Rb (Table VII). The Groups IV and V granites, however, do not have the same depletion in Sr relative to either Ba or Rb, except in the case of the two samples constituting Group V (Table I). The Mutue Fides granite shows a high coefficient of variance for Sn, although not as high as in the Bobbejaankop granite. There are insufficient analyzed samples of Group V granites from Sekukuniland to determine whether this feature is also true in these granites. Mean Sn contents are significantly low in both the Mutue Fides and Group V granites.

Table VI : Analytical Data for Granites in Vicinity of Mutue Fides Tin Mine, Olifants Tin-field, with Means, Standard Deviations, Coeffients of Variance, and Ratios of Elements

	Ba	Ce	Co	La	Nb	Rb	Sc	Sn	Sr	Y	Zn	Zr	K_2O%	Na_2O%
MF.1	270	119	1	37	101	367	4	10	12	112	40	323	4.40	2.50
MF.2	59	51	2	6	38	433	0	37	4	27	37	268	-	-
MF.3	118	47	5	5	119	474	3	15	7	34	225	254	5.50	0.90
MF.4	252	260	4	98	102	462	4	4	12	288	28	247	-	-
MF.5	269	189	3	84	97	483	2	3	11	199	26	265	-	-
MF.6	207	232	2	106	113	463	2	7	10	360	30	300	-	-
MF.7	157	136	0	64	90	496	2	8	16	205	52	294	-	-
Mean	190.3	148.7	2.4	57.1	94.3	454	2.4	12	10.3	175	62.6	278.7	-	-
SD	75.79	75.40	1.59	38.85	24.67	39.93	1.29	10.85	3.57	116.02	66.82	25.54	-	-
CV%	39.9	50.5	66.2	68.0	26.1	8.8	53.7	90.4	34.6	66.3	106.7	9.1	-	-

	K/Rb	K/Ba	Ba/Rb	Ba/Sr	Rb/Sr	Na/K	Nbx10^3/Zr
Mean	-	-	0.42	19	45.4	-	337.9
MF.1	99	135	0.73	22.5	31.4	0.51	312.7
MF.3	96	388.9	0.24	16.8	67.7	0.14	468.5

TABLE VII : Comparison of Means (A) and Element Ratios (B) of Groups IV and V Granites (Sekukuniland), Bobbejaankop Granite (Potgietersrus), and Granite at Mutue Fides.

(A)	Ba	Ce	Co	La	Nb	Rb	Sc	Sn	Sr	Y	Zn	Zr
Groups IV and V	145	423	4.4	147	38	302	2	4.8	17	149	42	265
Bobbejaankop	220	256	2	118	83	408	3	122	7	146	26	328
Bobbejaankop (Lease)	211	185	1.5	73.5	111	485	5.25	328	10	145	14.5	376
Bobbejaankop (Main)	238	275	2.3	133	51	385	2.75	63	6	161	31	303
Mutue Fides	190	148	2.4	56	94	454	2	12	10	175	62	279

(B)	K/Rb	K/Ba	Ba/Rb	Ba/Sr	Rb/Sr	Nbx10^3/Zr
Groups IV and V	-	-	0.48	8.5	18	143
Bobbejaankop	98	183	0.5	33	58.3	253
Bobbejaankop (Lease)	88	192.7	0.4	21.1	48.5	372
Bobbejaankop (Main)	106	171.4	0.6	39.7	63.1	206
Mutue Fides	99	135	0.4	19	37.8	336

* *Bobbejaankop mean includes both the Lease and Main varieties of the Bobbejaankop granite, which are also shown separately.*

(c) Moloto

A section across the Moloto granite outcrops is shown in Figure 5. The coarse-grained granite is generally poorly exposed, and is covered by a veneer of Karroo sedimentary rocks. The granite is composed of pinkish feldspar grains, with subordinate amounts of greenish-grey feldspar. In addition to quartz, there are also large books of chloritized biotite. Irregularly-shaped stringers of more aplitic granite are sometimes present. This rock-type passes into a pink porphyritic granite which has an aplitic groundmass. The phenocrysts are rounded grains of clear quartz and euhedral laths of feldspar. Red equigranular granite that contains variable proportions of chloritized biotite was seen near prospecting trenches at Enkeldoorn. The granite loses its red colour when traced away from areas of mineralization. Aplitic dykes and pegmatitic stringers, some of which are mairolitic, are common. Their presence is associated with a deepening of the reddish colour of the granite. This granite contains more chloritized biotite when it grades into a granophyric granite which, in the section shown in Figure 5, was not found to grade directly into granophyre. Instead, equigranular granite immediately underlies granophyre. At the western side of the section, a broad zone of medium-to-fine-grained granite, that apparently grades from the coarse-grained granite through reddish porphyritic granite, lies beneath the granophyre.

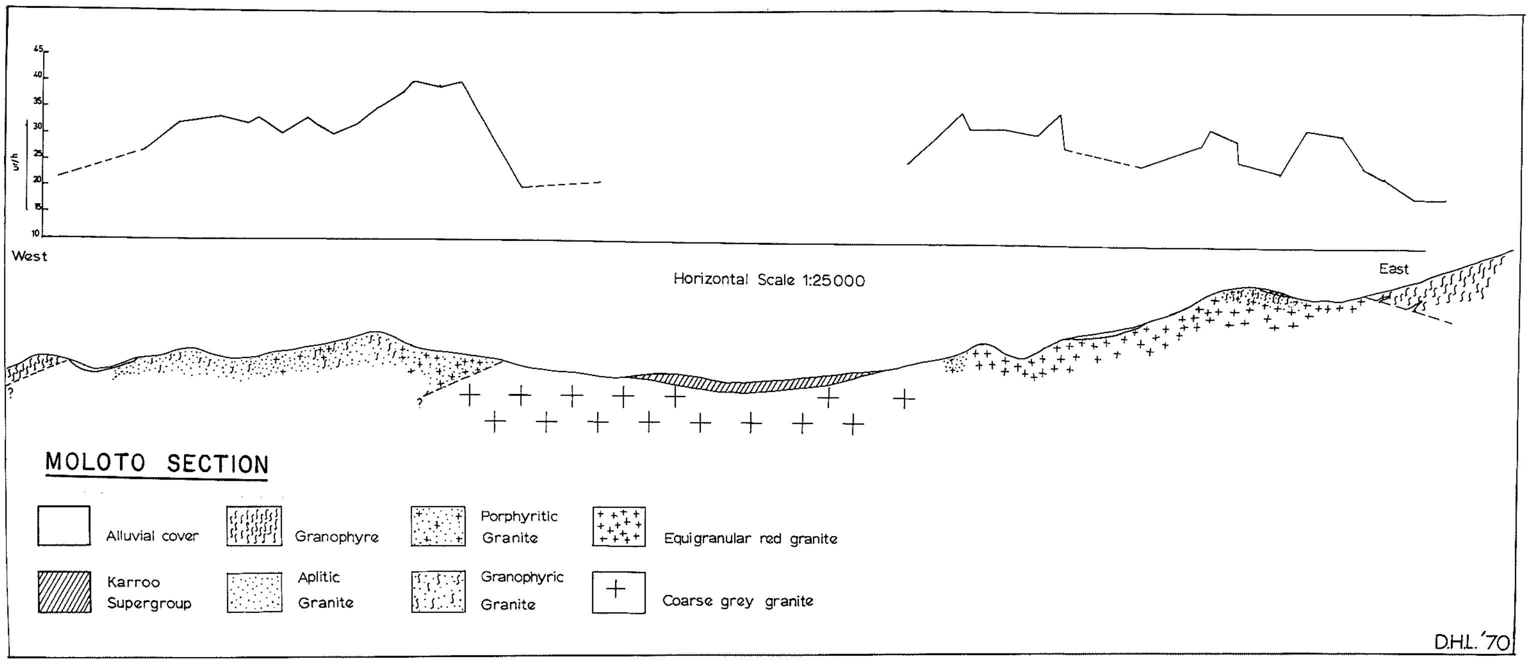

Figure 5 : Section across the granite outcrop at Moloto, showing lithologic variations and gamma-flux density.

The section in Figure 5 shows the level of radioactivity recorded over the various granites. The reddish marginal granites have a higher radioactivity count than the coarse-grained varieties. Aplitic dykelets cause local peaks in the radioactivity in both the grey, coarse-grained granite and the reddish, equigranular, porphyritic or granophyric granites. The counts fall sharply once the transition to granophyre takes place.

Eight samples of granite were selected for X-ray diffraction study of their contained potassium feldspar, the structural states of which are summarized below:

	Sample No. and Lithology	Structural State	Obliquity Value
74.	Coarse-grained pink granite	V	0.731
77.	Coarse-grained red granite	V	0.804
80.	Mairolitic feldspar pegmatite	V	0.854
81.	Equigranular pink granite	III/V	0.801
82.	Equigranular pink granite	III/V	0.706
83.	Finer-grained variant of 82	V	0.756
88.	Aplitic granite	V	0.735
92.	Red granophyre	IV	0.608

The samples reflect higher structural states in the coarse-grained granite than have been recorded at Potgietersrus, although it was noted there that stratigraphically higher levels in the granites had higher structural states. It may be that the Moloto granite has not been eroded sufficiently deeply to expose granites carrying feldspars with lower structural states.

Eleven samples of granite from Moloto have been analyzed and the results are presented in Table VIII.

Two samples have very high concentrations of barium which is accompanied by a high content of the light lanthanides, Ce and La. The analysis of one of these samples for K_2O and Na_2O reflects a very high content of these alkalis, suggesting a syenitic affinity. The remaining granites have a mean concentration of 691 ppm Ba, that is close to that recorded for the stratiform granites in the Potgietersrus area. The content of Nb, Sc, and Rb is similar in Sekukuniland and at Potgietersrus. Similarly, if samples ED.1 and ED.2 are ignored, the remaining granites in the Moloto area have concentrations of La and Ce comparable to those in the other two areas. Sr- and Y-contents are similar to those at Potgietersrus, whereas Zn- and Zr-contents are similar to those in Sekukuniland (Table IX).

The stratiform granites in the Potgietersrus area differ from those on the Sekukuni plateau and at Endeldoorn by virtue of a lower mean concentration of Co and higher contents of Zn and Zr. The higher Sr-content in the Sekukuni granites results in their having a mean Ba/Sr ratio lower than those for Enkeldoorn and Potgietersrus. The mean content of Sn at Enkeldoorn approaches that of the Potgietersrus granites, but the coefficient of variance is lower. Minor deposits of tin have been worked at Enkeldoorn. This lends some support to the contention that viable tin deposits will only be found where the granite is itself stanniferous. It may be that the lack of a sufficiently pronounced dome in the roof of the granite at Endeldoorn militated against significant concentration of tin. The absence of such a structure could be expected to lead to a more even distribution of tin in the roof of the granite, that is now reflected by the low coefficient of variance.

(d) Dennilton

Bushveld granite is in contact with members of the Transvaal Supergroup approximately 1 km north of Dennilton. A flat, sandy plain, apparently underlain by coarse-grained granite (>70 mm^2), extends for 6 km south of this contact. Thereafter, in a southerly direction, the granites, granophyres, and felsites build a series of broken hills, with a good outcrop that rise steadily in elevation to the highveld peneplain. The lithologic variations in the granite were measured along or near the main Groblersdal-Bronkhorstspruit road from Maloek-zyn-Kop southwards to the granophyre. The stratigraphic column constructed from this survey is shown in Figure 6, together with a graph of the radioactivity count.

Aplitic granite veinlets, from 4 cm to 15 m wide, and arranged in a sub-parallel manner as irregularly-shaped lenses, dykes or sheets, are developed throughout the granites in the measured section. Pegmatitic stringers are present, but are not abundant. The development of red or pinkish granites in the lower part of the succession is associated with faults and quartz-veining. The mafic minerals are typically chloritized in these zones. Similarly, chloritic alteration is more common in the red granites and granophyric granites at the top of the succession.

TABLE VIII : Analytical Data for the Enkeldoorn Granites of the Moloto Area, with Means, Standard Deviations, and Element Ratios

	Ba	Ce	Co	La	Nb	Rb	Sc	Sn	Sr	Y	Zn	Zr	K_2O%	Na_2O%
ED. 1	3397	736	7	283	28	245	2	7	32	79	101	315	-	-
ED. 2	3403	632	5	268	28	238	1	2	39	82	70	343	9.70	5.90
ED. 3	720	204	3	60	24	281	2	4	47	71	25	303	-	-
ED. 4	707	348	7	112	36	232	2	7	43	110	75	420	-	-
ED. 5	690	288	5	94	26	211	2	5	41	105	61	368	-	-
ED. 6	680	304	5	104	30	233	2	10	30	77	66	328	5.00	2.85
ED. 7	637	343	6	110	30	222	2	2	41	98	65	325	-	-
ED. 8	678	217	7	62	28	290	2	7	32	88	29	333	-	-
ED. 9	750	527	3	182	30	300	4	14	25	99	22	372	-	-
ED.10	574	230	4	67	21	230	2	7	24	78	50	277	-	-
ED.11	787	246	4	75	21	235	4	10	24	81	120	377	-	-
Mean	1184	370	5	129	27	247	2	6.8	34	88	62	342	-	-
SD	1046.0	172.0	1.4	76.5	4.2	28.1	0.9	3.4	7.8	12.3	29.1	38.0	-	-
Excluding ED.1 and ED.2														
Mean	691	301	4.9	97	27	248	2	7.3	34	90	57	345	-	-
SD	58.4	94.1	1.4	33.2	4.6	30.9	0.8	3.4	8.5	13.0	28.9	41.0	-	-

	K/Rb	K/Ba	Ba/Rb	Ba/Sr	Rb/Sr	Na/K	Nbx10^3/Zr
Enkeldoorn Mean	-	-	4.79	34.8	7.26	-	78.9
Enkeldoorn Mean (excluding ED.1 and ED.2)	-	-	2.78	20.3	7.3	-	78.2
ED. 2	338	23.6	14.3	87.2	6.1	0.54	81.6
ED. 6	173	61.0	2.9	22.6	7.7	0.51	91.4

TABLE IX : Comparison of Means, Coefficients of Variance, and Element Ratios of Granites from Sekukuniland, Enkeldoorn (excluding Samples ED.1 and ED.2), Potgietersrus, and Mutue Fides

	Sekukuniland		Enkeldoorn		Potgietersrus S		Potgietersrus B		Mutue Fides	
	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%
Ba	789	57	691	8	896	36	220	41	190	40
Ce	238	40	301	31	269	20	256	25	149	50.5
Co	4.6	46	5	29	2	66	2	54	2	66
La	74	47	97	34	100	37	118	67	57	68
Nb	22	30	27	17	24	29	83	32	94	26
Rb	207	31	248	12	225	15	408	16	454	9
Sc	3	90	2	41	3	52	3	68	2	54
Sn	3.5	50	7.3	46	8.5	85	122	255	12	90
Sr	65	52	34	25	39	146	7	29	10	35
Y	88	34	90	14	97	35	146	19	175	66
Zn	63.5	29	57	50	91	41	26	62	63	107
Zr	380	30	345	12	433	12	328	15	288	9
K/Rb	170*	-	173**	-	181	-	98	-	99***	-
K/Ba	49.2*	-	61**	-	45.4	-	183	-	135***	-
Ba/Rb	3.8	-	2.8	-	3.9	-	0.5	-	0.4	-
Ba/Sr	12.1	-	20.3	-	23.0	-	33	-	19.0	-
Rb/Sr	3.2	-	7.3	-	5.7	-	58.3	-	45.4	-
Na/K	0.63*	-	0.51**	-	0.55	-	0.53	-	o.51***	-
$Nbx10^3/Zr$	57.9	-	78.9	-	55.4	-	253	-	337.9	

Potgietersrus S = Stratiform granites

Potgietersrus B = Bobejaankop granite

* *Data Source = Column 2, Table IV*

** *Data Source = Sample ED.6*

*** *Data Source = Sample MF.1*

The data for Sekukuniland are based only on the new analyses presented in this paper.

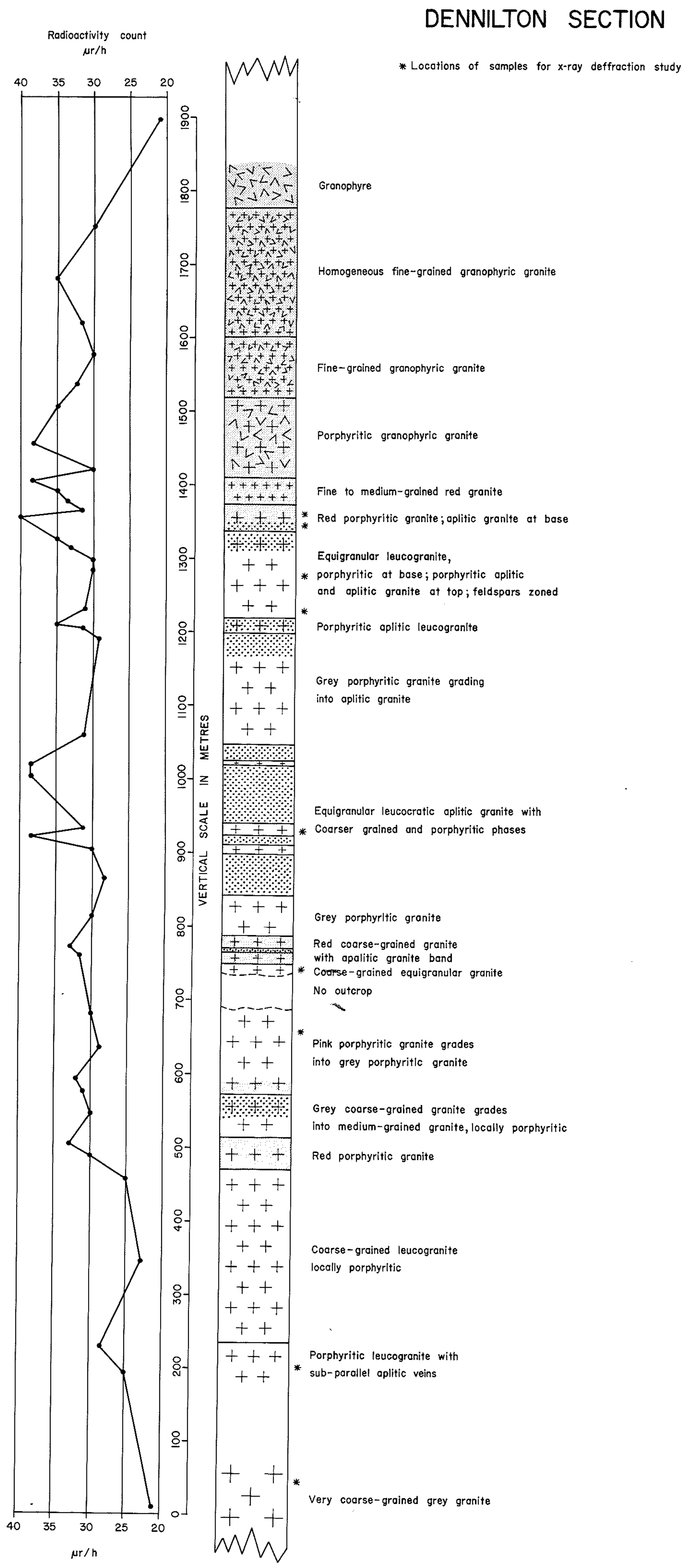

Figure 6 : *Stratigraphic column through the granites from Maloek-zyn-Kop south to the granophyre, Dennilton area, showing the profile of gamma-flux density.*

Nine samples of granite where collected for X-ray diffraction study of the structural state of their constituent alkali feldspar.

	Sample No. and Lithology	Structural State	Obliquity Value
13.	Coarse-grained leucogranite	III	-
14.	Coarse-grained leucogranite	III	-
21.	Porphyritic granite (grey)	III/V	-
22.	Coarse-grained granite (red)	V	0.842
27.	Coarse-grained granite	III	-
29.	Medium-grained leucogranite	III/V	0.707
32.	Equigranular leucogranite	V	0.794
34.	Equigranular leucogranite	V	0.755
36.	Red porphyritic granite	V	0.822
37.	Red porphyritic granite	V	0.719

The upward progression to feldspars with a more-ordered state, that is found in other areas, is also apparent in the Dennilton section.

(e) Sustersstroom

The area examined lies between the main Groblersdal-Bronkhorstspruit road, in the north, and the Wilge River, in the south, where the Waterberg Supergroup rests on the Bushveld granite. On both the east and west sides of the broad valley that drains towards the Wilge River, felsites build the higher ground. Outcrops, however, are poor in the west.

The central area of the valley is underlain by coarse-grained, porphyritic granite, building prominent tors, and having a radioactivity count averaging 40 μr/h. In the northern part of the area, on the farm Leeuwfontein 228 JS, coarse-grained granite gives way to a porphyritic granite with a medium-grained groundmass. This is succeeded, in turn, by a thin development of slightly granophyric, fine-to-medium-grained granite that is overlain by felsite. Elsewhere in the same area, coarse-grained granite, locally porphyritic, intrudes felsite.

Some 4 km north of the Wilge River, the felsites on the east side of the area are underlain by a fine-grained, granophyric granite that forms a thin layer. Mairolitic red granite, with abundant rosettes of tourmaline, builds the low hills below the felsite and granophyric granite, extending over an area of approximately 1 km^2. Coarse-grained granite underlies the lower ground. Radioactivity counts in this area and southwards towards the Wilge River reach 45 μr/h along the contact with the felsites. This contrasts with the situation further to the north, where coarse-grained granite is in contact with the felsites. In this case, the count falls to below 30 μr/h.

(f) Naboomspruit

The section measured extends from the Karroo cover, northwest of Naboomspruit, towards Die Oog (Figure 7). The low hills immediately adjacent to the Karroo cover are underlain by a grey, very coarse-grained, porphyritic granite that contains reversely-mantled feldspars. With minor textural variants, this granite extends to the base of the intercalated band of so-called leptites. The large potassium feldspar crystals are usually rounded in shape, but more euhedral forms are not uncommon. Plagioclase mantles the ovoid orthoclase, the reverse mantles apparently being preferentially developed in specific bands within the granite. Jointing is prominent in the granite, some of the joints being filled by quartz, while others are strongly ferruginized. Finer-grained aplitic granite forms small patches, rarely exceeding 1 metre in diameter, within the coarse granite. Boudin-like masses of meta-quartzite, aligned approximately parallel to the strike of the leptites, appear in the granite approximately 2 km from the main leptite intercalation. Locally, the granite becomes more equigranular, in which case it has a reddish hue. The mafic minerals are chloritized in all varieties of granite.

The so-called leptites, dipping gently northwestwards, crop out approximately mid-way between the eastern and western limits of the granite outcrop. The leptites display bedding and

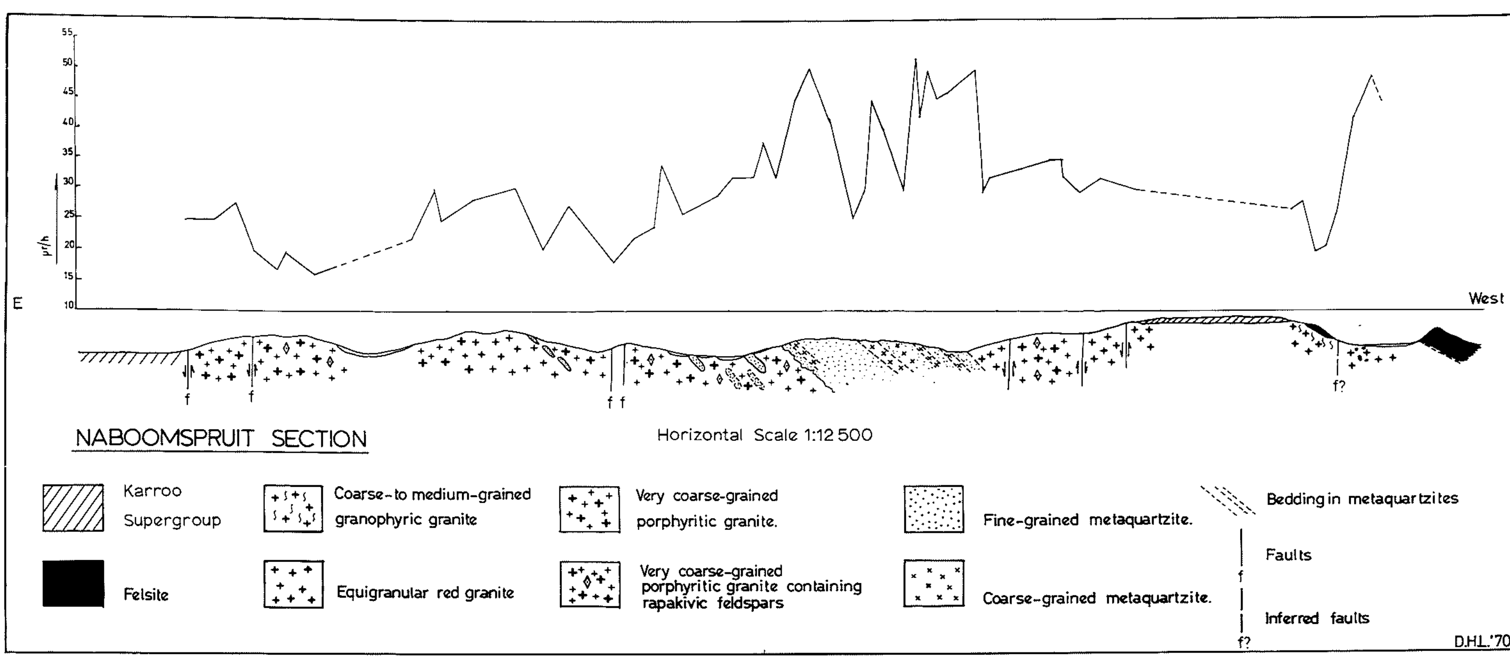

Figure 7 : *Section across granite outcrop northwest of Naboomspruit, showing lithologic varieties and gamma-flux density.*

cross-bedding, the former being apparent on weathered surfaces. The leptites are highly feldspathic, the feldspar often having a red colour, but more siliceous bands are also present. The grain-size varies within wide limits, the coarsest leptites being medium-grained. The leptites are intruded by granite along bedding and joint planes. The presence of economically viable deposits of fluorspar within the leptites makes the elucidation of their true nature important. Watson (1965) considered that there is considerable step-faulting within the leptites, accounting for their outcrop width.

The granite overlying the leptites is generally equigranular, and is composed of red feldspar, quartz, and chloritized mafic minerals. Coarse-grained granite, similar to that found below the leptites, crops out between two parallel faults. Thereafter, the equigranular granite continues to the outlier of Karroo sandstone. When the granite reappears, it is finer in grain-size and has granophyric intergrowths. Small areas of felsite occupy higher ground in this area. Outcrops are poor until the felsite ridges are reached. Outcrops of equigranular granite are found in this zone, apparently including small xenoliths of felsite. The felsites are typically massive and devoid of internal macroscopic structure, although a thick, coarse agglomerate crops out to the south of the area traversed. The massive felsites are dark chocolate-brown or deep green in colour.

The radioactivity count (Figure 7) shows that there is a gentle increase in the count-rate from the coarse-grained granites towards the felsites, with a sharp rise immediately below the felsites. Superimposed on this trend is the increase recorded over the leptites with their associated fluorspar mineralization.

(g) Zwartkloof

The sequence of lithological varieties of the granite on the farms Zwartkloof 470 KR and Baviaansberg 442 KR is shown diagrammatically in Figure 8. The usual gradation upwards into finer-grained, red, granophyric granites is again demonstrated. No true granophyre intervenes between the granophyric granite and the felsite. The radioactivity count shows a significant increase in the higher part of the granite, before falling rapidly over the felsites. Counts are particularly high over the fluorspar-bearing granites, the levels being comparable to those in the Naboomspruit section.

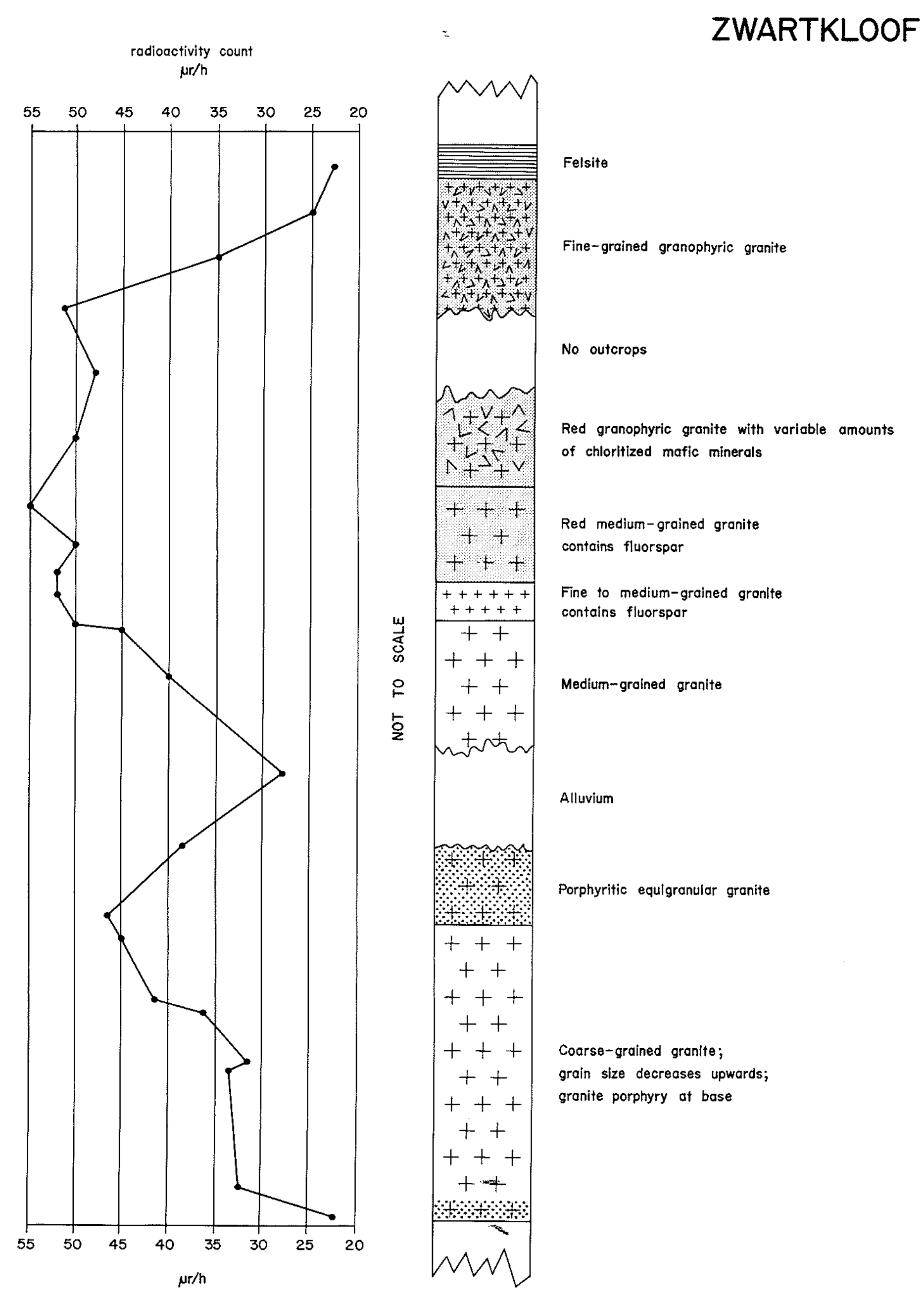

Figure 8 : *Diagrammatic section through the granites on the farms Zwartkloof 470 KR and Baviaansberg 442 KR, west of Warmbaths, showing lithologic variations and gamma-flux density.*

(h) Cyferfontein

The granites were examined on the farms Cyferfontein 434 KR, Kareefontein 432 KR, and Witfontein 430 KR. Coarse-grained granites grade upwards into medium-grained varieties that range from leucocratic to mesocratic. As the felsites are approached, the granites become finer-grained and red in colour. Aplitic granites, locally porphyritic, underlie the felsite. These rocks are granular and sometimes have vugs, pegmatitic quartz, and occasional books of biotite up to 5 cm long. Locally, the aplitic granites have a banded appearance, due to the alternation of 2,5-cm layers of coarse and fine grain. The aplitic granites are grey in colour, but lack of outcrops precludes tracing the aplitic granites to the contact with the felsites.

No true granophyric granite or granophyre was found in this area, underlying the felsites. Radioactivity counts are low, reaching a maximum of 40 µr/h in the topmost aplitic granites.

CONCLUSIONS

The reconnaissance nature of the survey precludes drawing firm conclusions at this stage. However, the trace-element geochemistry indicates that, despite the apparent consistency of the major-element chemistry, subtle differences do exist. If this investigation is to be extended, it should be done on a systematic basis in order to test whether different areas of the Bushveld granite have a distinctive geochemistry. This would be of value in testing whether the background Sn-content of the Potgietersrus granites is unique. It would help to indicate whether the Bushveld granites were intruded in a series of discrete bodies, each having its own geochemical fingerprint.

The presently available data indicate that the Potgietersrus granite is distinguished from the Moloto and Sekukuniland granites by virtue of a higher content of Co and lower and less variable concentrations of Sn in the latter granites. The Sr-content of the Sekukuni granites is higher than that in the other areas. There is some evidence from the element ratios to suggest that the Sekukuni granites are slightly less fractionated, but it is doubtful if this difference can wholly explain the less stanniferous nature of the Sekukuni granite.

The granites in the Moloto area have a mean Sn-content approaching that of the Potgieterstus stratiform granite, but the lower coefficient of variance suggests a more uniform distribution of this element, due possibly to a lack of a suitable domical roof structures in which the tin could be concentrated.

Notably high concentrations of the light lanthanides are reported from Moloto and Sekukuniland, the former apparently containing rock-types that approach potassic syenite in character.

ACKNOWLEDGEMENTS

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REFERENCES

Hall, A.L. (1932). The Bushveld Igneous Complex of the central Transvaal. Geol. Surv. S. Afr., Mem. 28, 554 pp.

Kaye, M.M., Nicolaysen, L.O., Willis, J.P., and Ahrens, L.H. (1965). The abundance of Li, Na, K, Rb, Tl, Ca, Sr, Ba, and Pb in some granitic rocks of the Precambrian of South Africa. (Unpublished manuscript).

Liebenberg, C.J. (1961). The trace elements of rocks of the Bushveld Igneous Complex. Pub. No. 13, Univ. of Pretoria, 75 pp.

Turekian, K.K., and Wedepohl, K.H. (1961). Distribution of the elements in some major units of the Earth's crust. Geol. Soc. Amer., Bull., 72, p. 175-192.

Watson, M.D. (1967). Die vloeispaatvoorkomste op Buffelsfontein 347 en omstreke, noordwes van Naboomspruit Transvaal. Unpublished M.Sc. Thesis, Univ. of Pretoria.

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