INAUGURAL LECTURE : PROF. JOS LURIE, 19 SEPTEMBER, 2001

FROM PILANESBERG TO LOVOZERO

INTRODUCTION

The Pilanesberg, besides being a great game park, providing golfing and gambling venues is, above all, one of the world's outstanding geological wonders. A satellite image of the northeastern part of the North West Province shows the prominent and perfectly circular complex. It is an eroded alkaline volcano that formed 1 200 million years ago and now presents its structure of concentric rings (cones in section) clearly (Fig. 1). It consists of rare rocks and minerals and lies geographically at the contact of the granite and norite phases of the Bushveld Complex which itself is a geological wonder.

Figure 1: Satellite image of the Pilanesberg

I investigated the geology, geochemistry and structure of the complex over a six-year period. This research was largely done in solitude as the erstwhile farmers of the area had been bought out and the planned settlement of people had not yet taken place (this plan was later supplanted by the establishment of the game park). During my researches I became very aware of the similar alkaline complex, Lovozero, in Russian which at this point had already been subjected to investigation by 64 geologists (I was only the third geologist to investigate the Pilanesberg in detail). It was also clear that the Russians were the leaders in rare earth metallurgy but, because of the political situation at the time, direct contact was not possible and I made use of the Israeli Programme for Scientific Translations (IPST) for, as it were, somewhat dated information of Russian research. Nevertheless, I started a comparison of the two complexes.

After the appearance of my thesis I conducted groups of geological scientists from various institutions on request, including: University of Arizona, Free University of Berlin, the Anglo American Corporation and a Geocongress party. Fifteen mining engineers from the US also paid a visit. Later I led an International Congress for Applied Mineralogy (ICAM) earth science party including a group of Russian professors. Incidentally, my wife Brenda accompanied and did the camp catering for the excursion. Professor Alexei Bulach (an alkaline rock specialist) of Leningrad literally leaped up and down with excitement to see Pilanesberg lujavrite virtually identical to that in Lovozero.

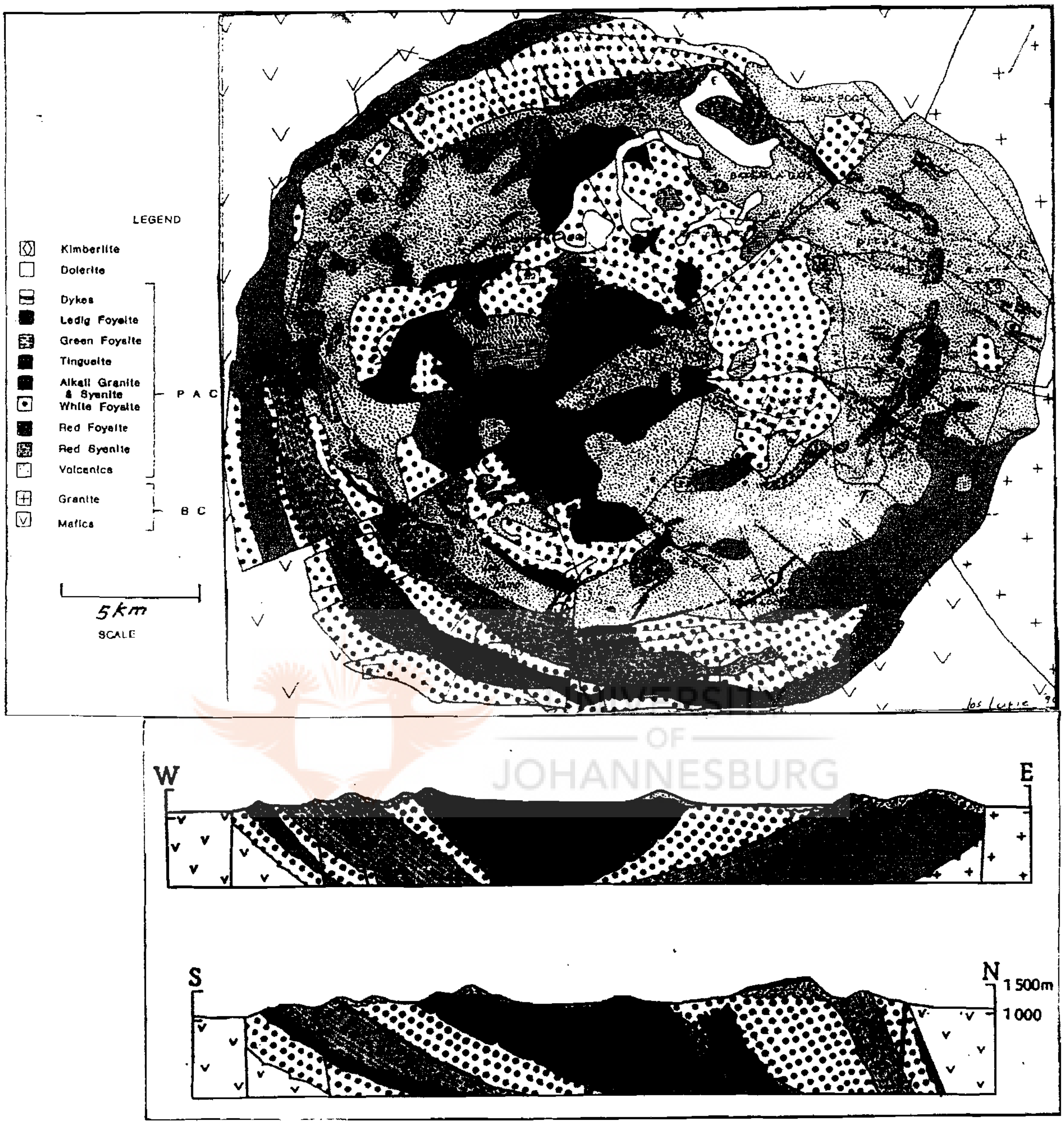
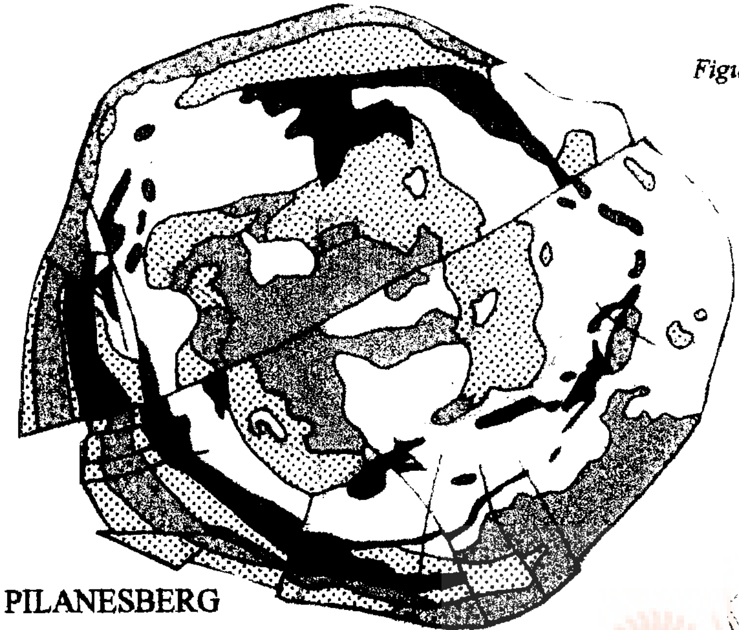


Figure 2 : Pilanesberg surface geology and east-west and north-south cross-sections through the complex

ST PETERSBURG AND UNIVERSITY

I was invited by the University of St Petersburg to do a study tour of the alkaline complexes north of the Arctic Circle. This was not to be a tourist round with luxury facilities but a raw encounter with aspects of Russian geoscience and social intercourse mainly north of the Arctic circle. Diet staples were barley porridge, cabbage soup and sour bread with an occasional helping of stringy meat. My guide was Dr Alexandr Ivanovich Serebritsky a

Figure 3: The three akali complexes



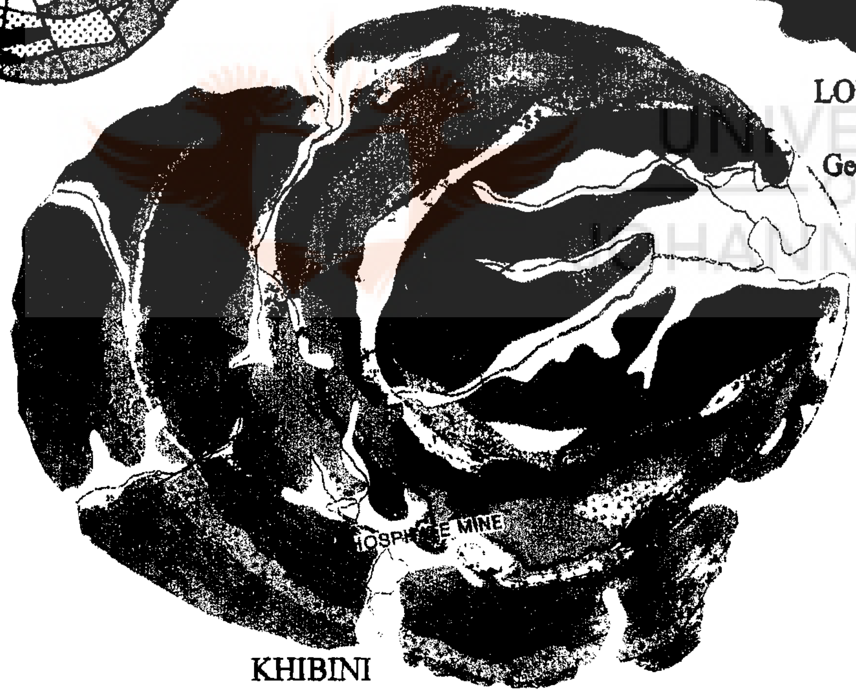
PILANESBERG

Geology of the Pilanesberg
see Figure 2

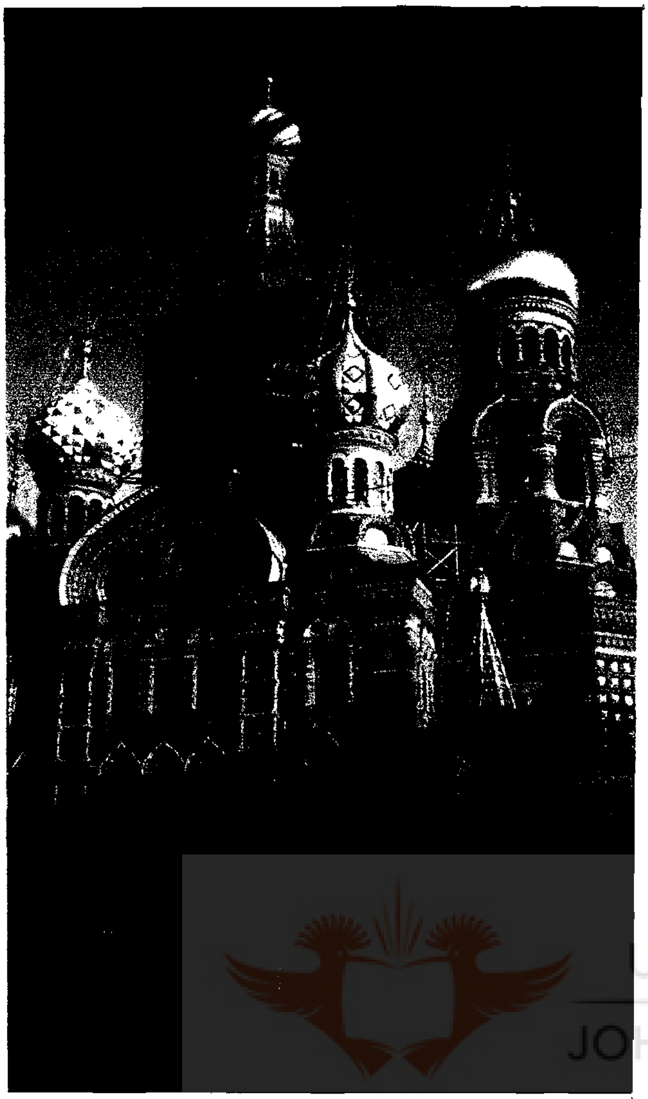
Core and outer zones nepheline
Syenites (greens), central area:
ijolites, urtites, lujavrites
(Reds and yellows

LOVOZERO

Geology:
The important ore bearers: lujavrite, foyaites, urtites, rythmically repeated (greens)



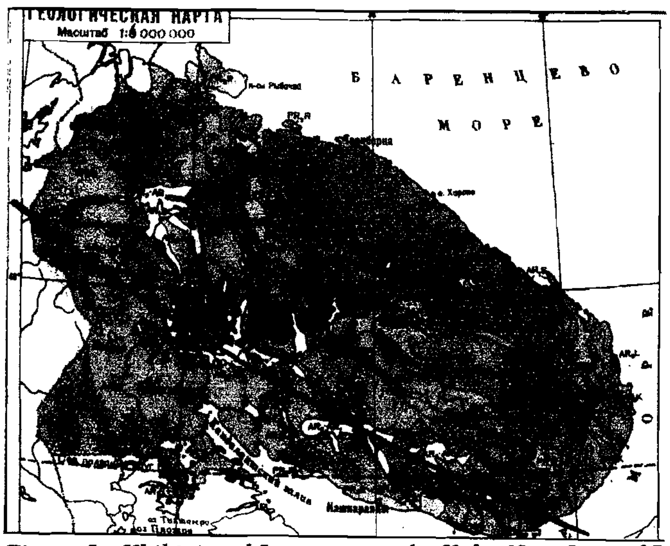
KHIBINI



I travelled to Vienna, thence to St Petersburg, Murmansk, back to St Petersburg, to Moscow, to Vienna and back to Johannesburg. I stayed in St Petersburg at the so-called Academic Hotel (really a slum where a shower bath required heavy negotiation) while a visa problem was sorted out. It was located a stone's throw from the famous Hermitage museum which had been the Tsar's Winter Palace with a column of Alexander I in front. I was entertained at Prof Bulach's apartment where I saw magnificent urns of jadeite (sodium aluminium iron silicate) and charoite (sodium calcium barium strontium silicate). Russia has a superabundance of semi-precious and ornamental stones. St Petersburg is a beautiful canaled city and among many sights I saw : the byzantine cathedral of the resurrection of Christ and the Palace of Prince Yussapov where Rasputin was murdered in 1916.The University is located on the Neva River which is lined with huge blocks of Karelian granite. The Institute of Mines was established in 1773 is one of the oldest technical institutes while the University was founded only in 1819. One of the long buildings houses earth sciences and on the first floor a gallery almost the length of the building is lined with book cabinets alternating with alcoves in which are displayed marble busts of past savants of the University such as Mendeleev (the father of modern chemistry), Euler (possibly the greatest mathematician of all time), Fersman (geology), Pavlov (psychology) and Pushkin (Poetry). I gave a one-hour lecture on the geochemistry of the Pilanesberg followed by three-quarters of an hour of questions indicating the deep interest in the complex.

Figure 4 : Cathedral of the Resurrection of Christ

We travelled by hydrofoil up the Gulf of Finland past the naval fortress of Kronstadt to Petrodvorets Peter the Great's recreations area where the Grand Palace, Peter's laquer-panelled study and numerous ornate pavilions were to be seen.



KOLA PENINSULA

The railway line from St Petersburg to Kola passes along the Finnish border through Karelia. A terrain of birch and conifer forests, wetlands and tundra was traversed for 1200km to Apatity on the foot of the Khibini massif with liberal amounts of remnant winter snow. Structures such as Lovozero, Khibini, and Lovozero represent ancient volcanoes that have been eroded. The KhibinI complex is 1 400 square kilometres at surface and consists of treeless tundra. The highest point, Chasnachorr, is 1191 m above seal level.

Figure 5 : Khibini and Lovozero on the Kola. Note Line of Pemafrost (blue), Arctic circle (dashed black)

Figure 6: Khibini massif

We spent three nights at Dr Uri Kirnatski's apartment at Apatity and he and *gaspazha* Zirnatski were most hospitable. Apatity is the 2nd largest city on the kola (after Murmansk) and was establish in 1966 and named after the phosphate mineral apatite For the first time I experienced midnight sun or "white nights" as the Russians call it. The mosquitos were incredibly persistent and about the size of dragonflies. I gave a lecture at the Academy of Sciences attended by members of the eleven earth science research institutes.

We planned to climb Chasnachorr but the weather did not permit - the average annual temperature is -4°and Apatity has 190 days of Snow storms with winds up to 150kph. Regarding the geology of Khibini: it has a zonal asymmetric structure. In common with Pilanesberg and Lovozero, rocks are enriched in alkalis, especially sodium, and impoverished in silica.

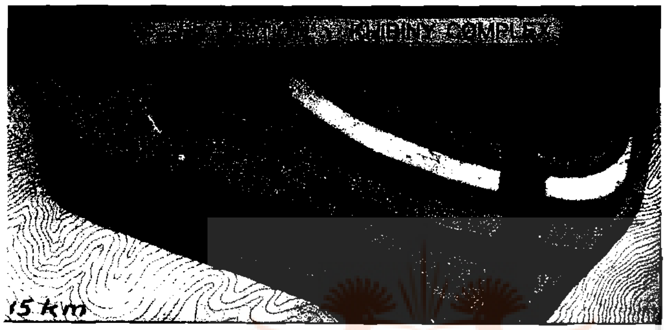


Figure 7: Cross section through Khibini Complex

The core and outer zones are of nepheline syenite (essentially alkali feldspar and nepheline, a feldspar-like mineral with lower silica), and the central areas of ijolites and urtites (both essentially aegirine -sodium iron silicate and nepheline - sodium aluminium silicate but in different proportions) and lujavrites (flow structured nepheline syenite with aegirine and eudyalite). The complex is about 365 million years old and over 400 minerals occur in it and Lovozero collectively - 70 were discovered here for the first time. Much seismic work and deep drilling enable the Russians the present a convincing model of the form of the complex.

The deepest drillhole in the world is `15 000 m deep at Pechenga to the northwest. Comparison with the Pilanesberg shape and structure is interesting.

KIROVSK is a mining town on the southwest margin is named after Sergei Kirov, a reform-minded leader, assassinated after being critical of some of Stalin's policies. The phosphate mine produces 130 million tons of ore per year (Palabora in South Africa produces about 3 million tons). The plant produces a 96% apatite concentrand potah and alumina are extracted. The museum at Kirovsk displays core of the hole at Pechengs these are granite and schist.

LOVOZERO

We travelled by bus and train to Revda on the noerthwest foot of the massif. Many of the rock-types and minerals of Lovozero and Khibin are extremely similar to those of the Pilanesberg : for instance the very rare zirconium silicate mineral, eudialyte is found in the rocks of both (also found in other smaller alkaline complexes) . On Lovozero I traversed a very large area of lujavrite outcrop with good concentrations of eudialyte representing many millions of ore tons (100 mllion tons have been assesed). Dr Igor Musatov, Director of both the niobium mine and concentrator, asked me to use my influence (!!) With some South African firm to set up a joint venture for extracting zirconium - the Russians, he said, had developed the necessary technology. Peter Gush, Deputy chairman of the Anghlo American Corporation showed some interest, but the economics looked a bit dubious. He did, however, fund Ivan Serebritsky to come out to do research on the Pilanesberg volcanics.

There are, however, striking differences such as in age, size and form:

Complex	Age (ma)	Surface Size (km²)	Form
Khibini	365	1 140	Oval
Lovozero	600	640	Pear-shaped
Pilanesberg	1 200	530	Circular

Figure 7 : Structural map of the Pilanesberg Complex

My researches indicated further significant differences. Some of these are::

- Considerable post-emplacement fracturing and subsidence has occurred in the case of the Pilanesberg while the others are relatively undisturbed.

In the Pilanesberg, besides extensive faulting, the superincumbent volcanics are dipping centripally as large faulted blocks indicating a collapse structure or *caldera.* On the eastern side where the remnant lavas have considerable thickness the faults between blocks are occupied by syenite dykes. The dips of intrusives indicate that what was the vertical axis of the cone now leans over to the southeast. The cone has split in two and the southwestern half has rotated through an angle of 30°.

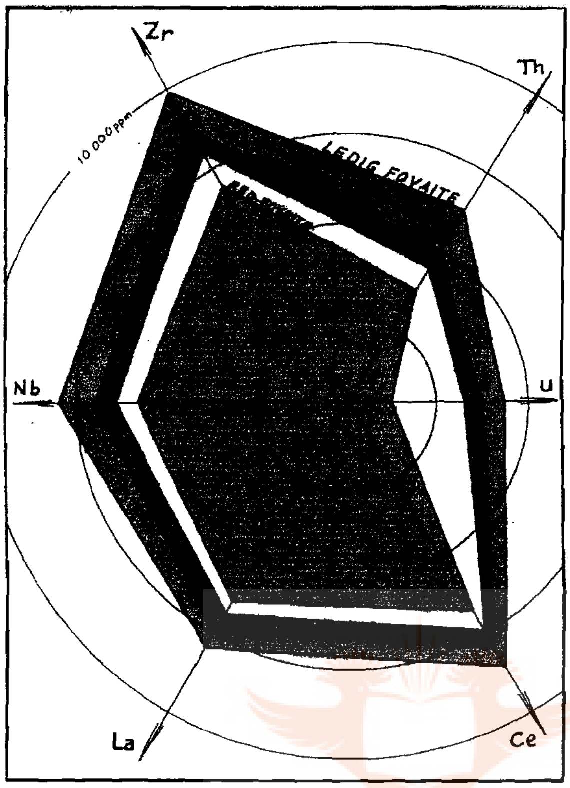


Figure 8: Trace element concentration trend

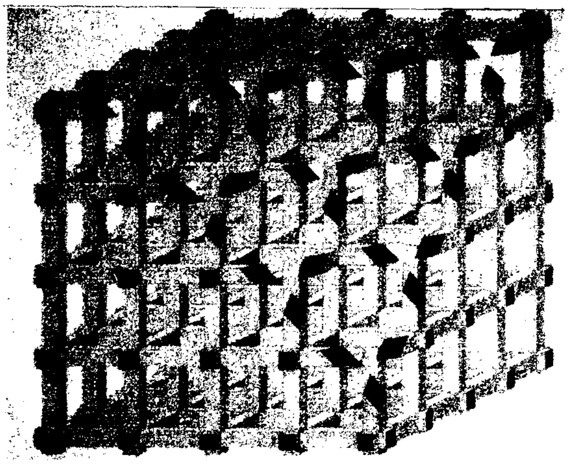


Figure 9 : Structure of Pilanesberg fluorite

- In the case of certain trace elements, namely, those that are known to be concentrated in alkali rocks, there is a single concentration trend of these, while in the Kola complexes a host of rythmic repetitive trends are apparent resulting in the formation of the highly attractive banded rock, kakortokite and over a hundred zones of ore horizons in the niobium mine. In the Pilanesberg the oldest rock (red foyaite) with the lowest concentration of these elements is located in the geographic centre and, remarkably, progressively younger rocks with ever higher concentrations of these elements occur outwards (see figure 7).
- My map of the Pilanesberg (see figure 2) reveals that approximately 45% of the complex is underlain by surface volcanics; *in* the Kola complexes superincumbent volcanics are absent having been removed by erosion. This despite the fact that these complexes are considerably younger than the Pilanesberg (see table above).
- Fluorine in the Pilanesberg at 0,45% is considerably higher than the Kola complexes. Every rock type in the Pilanesberg contains fluorite, generally in very small amount. It was also found cementing a volcanic conglomerate. A unique form of the mineral occurs in two localities about 12 km apart one of which is in a defunct fluorite mine, the other discovered by myself. The fluorite, a low temperature mineral, occurs as small rods oriented in the three directions of the cube forming large skeleton crystals. Relatively high temperature minerals such as feldspars and aeginine fill the spaces between the rods.
- Apatite is so concentrated in part of Khibini that it supports the largest phosphate mine in the world while the mineral occurs merely as a minor accessory mineral in the Pilanesberg.
- Loporite, a cerium sodium niobium oxide, provides the basis for a large niobium mine but I did not locate it in the Pilanesberg at all. Nevertheless I calculated the content of niobium in the complex as 0,043% which is about 18 X Clarke for igneous rocks. Generally my calculated values values are based on the analysis of 49 composite samples comprising about 1 500 inividual samples covering all the outcrop areas.

A tuff body on the eastern side of the complex constitutes an orebody of 20 million tons with 0,37% Nb_2O_5, plus 0,12 kg/ton U_3O_8. The Nb appears to play a substitution role in ilmenite a titanium iron oxide.

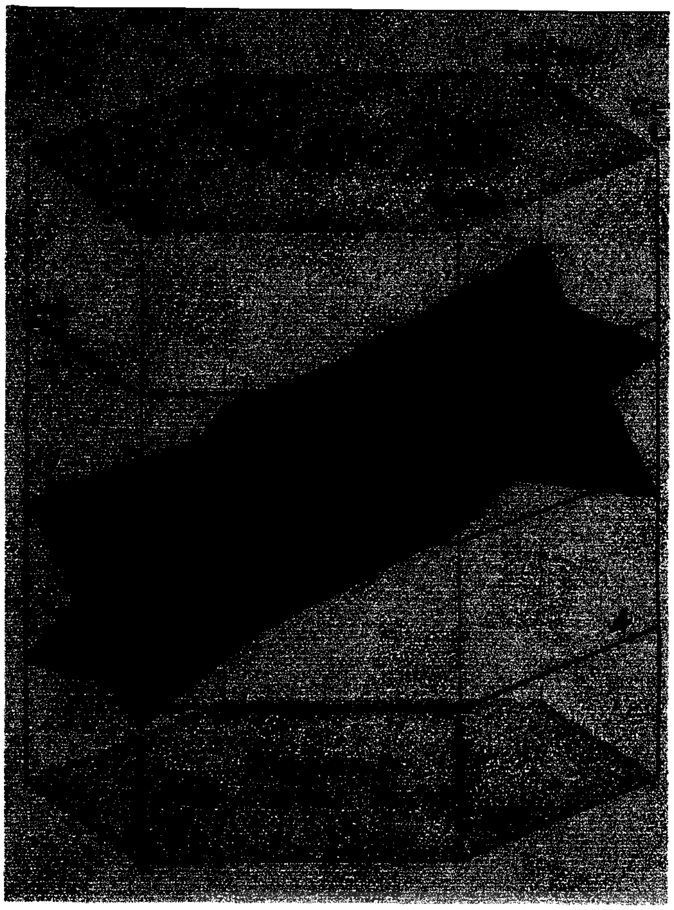


Figure 10 : Trace elements : Pilanesberg/Lovozero

●A mineral I discovered in the Pilanesberg, britholite, a cerium calcium phospho-silicate is not found in the Kola complexes. At the time it was known in only a few localities in the world. It occurs in two localities of different geological environment in the Pilanesberg and on Thabayadiotsa contains 57% rare earth oxides and 1.56% thoria.

The light rare earths are about three times as concentrated as in Lovozero. At one locality (Thabayadiotsa) I could demonstrate a mineable tonnage of 1,5 million at 7,5% rare earth oxides plus thoria. An interesting comparison could be made between Pilanesberg and Lovozero in respect of the enrichment of the rare elements typical of alkaline rocks: yttrium, uranium, thorium, zirconium, hafnium, niobium, tantalum, cerium and lanthanum. U, Th, Ce, La are higher in the Pilanesberg , while Y, Zr, Hf, Nb, Ta are higher in Lovozero.

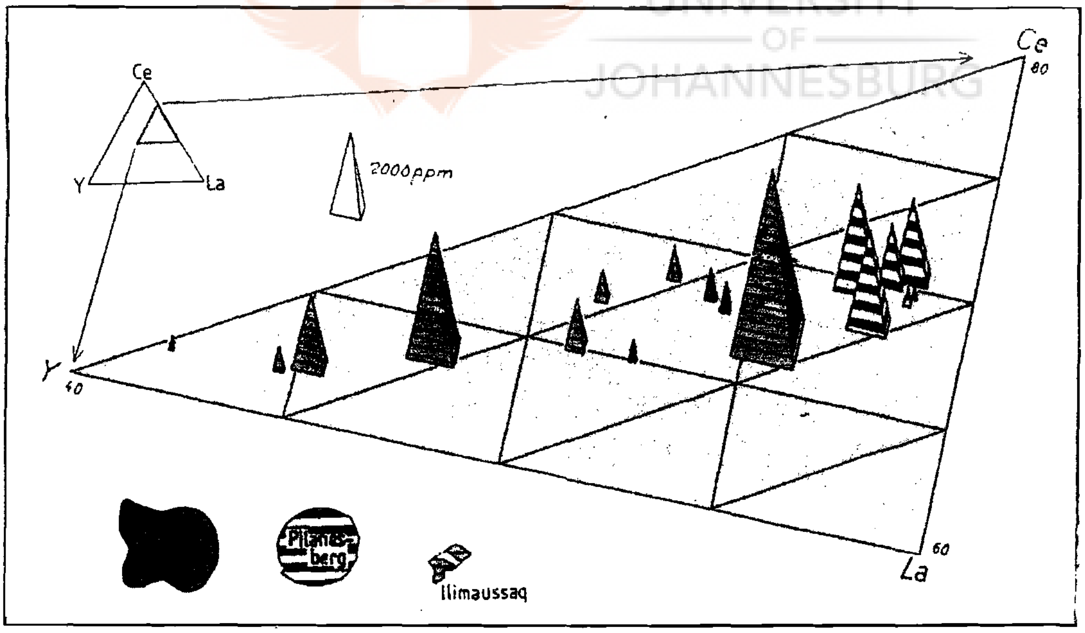


Figure 11: Comparison of rare earth elements in major rock units of Lovozero (red), Pilanesberg (green) and Ilimausaq (Blue) alkali complexes

Ilimausaq is a small complex in Greenland investigated by South African geologist John Ferguson. I developed this type of diagram for showing four variables. In this case the volumes of obelisks are proportional to the total concentration the elements, cerium, lanthanum and yttrium. Besides indicating the concentration of RE in individual major rock units of each complex, an indication is given of age order and the degree of differentiation (residual composition change with crystallisation).

ASCENT OF LOVOZERO

The climb involved 8 km through some remnant snowfields and about 400 m vertical ascent. As previously indicated we traversed considerable distances of eudyalite rich lujavrite. When the weather cleared there were magnificentl views. I was was accompanied by Ivan Serebritsky and Dr Uri Zirnatsky. Near the top, in a pass we encountered a memorial to a young Russian who had been overtaken by a snow storm and had perished.

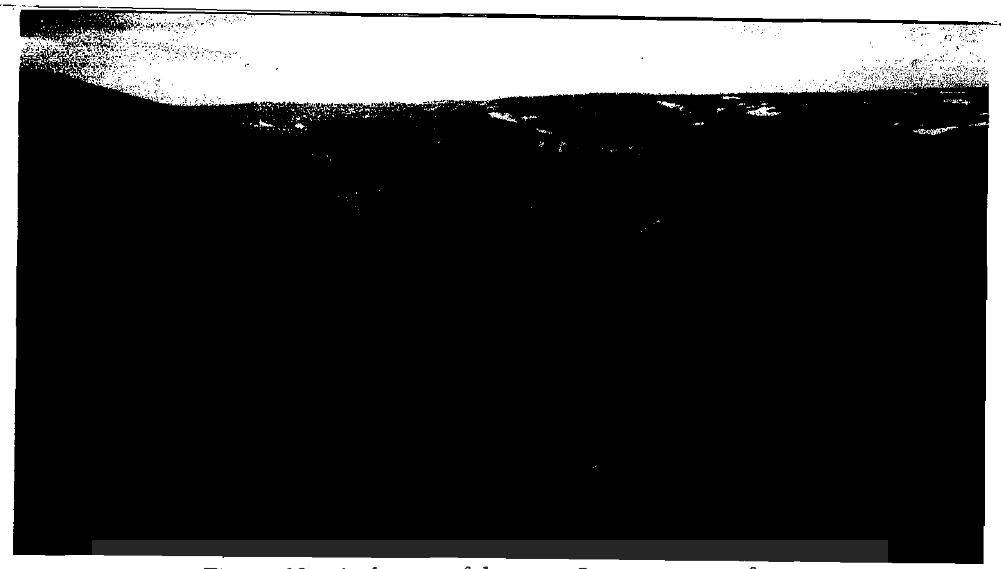


Figure 12 : At the top of the pass, Lovozero massif

MINING & CONCENTRATION

In the niobium mine two orebodies are accessed via three inclined shafts. 3 000 tons per day of ore is moved by conveyor belt into the plant. There is no discrimination at the work face and we accompanied Tanya, chief geologist, underground. Russian miners here do not wear socks underground but fold a square of cloth very cunningly around each foot - I could not master the technique and Ivan Serebritsky did mine for me. What was very interesting to me was the sampling method which involved using geiger counters to measure the radioactivity. The loporite contains constantly 0.75% thoria. I had established a geochemical correlation between niobium and thorium of 0.72. Also I had used a portable scintilometer to do a radiometric survey of the entire Pilanesberg complex and had thus picked all the anomalies. It has been estimated that there are more than 1500 pegmatites in the Lovozero Complex and the highlight of the underground visit with Tanya was clambering over a waste barrier "sealing off" the most spectacular pegmatite. Huge crystals (up to 2 m) of white feldspar, purple ussingite (sodium aluminium silicate), brown arfvedsonite (hydrous sodium magnesium aluminium silicate), green aegirine (sodium iron silicate), red eudialyte, and black steenstrupine (rare earth manganese hydrous silicate) and ramsayite (sodium titanium silicate). Because of the rythmic crystallisation, mentioned before, there are altogether more than a hundred ore horizons. The ore is crushed, graded, classified and concentrated using gravity, electrostatic and electromagnetic separation techniques. The plant output is 12 000 tons per month of 95% loporite concentrate with about 10% niobium and tantalum oxides.

FINALLY

The visit to Kola ended with an unscheduled visit to Murmansk the largest city in the Arctic (causing tremendous logistic and bureaucratic problems). It has an ice-free port which was used by World War II convoys. Archangel well to the south in the White sea could not be used because its port becomes frozen in the winter. The harbour at Murmansk extends 30 km up the estuary and its area could probably accommodate six Rotterdams (the biggest cargo-handling port in the world).