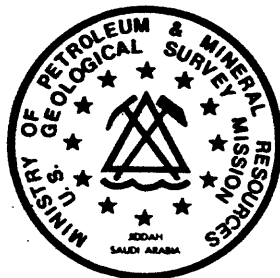


UNITED STATES DEPARTMENT OF THE INTERIOR  
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SAUDI ARABIAN PROJECT REPORT 238



**TITANIFEROUS MAGNETITE IN THE  
LAYERED INTRUSIVE COMPLEX  
AT LAKATHAH,  
KINGDOM OF SAUDI ARABIA**

By  
Conrad Martin, Ralph J. Roberts,  
and Douglas B. Stoesser

U. S. Geological Survey  
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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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ABSTRACT

The Lakathah layered intrusive complex about 90 km east of Qunfudhah contains significant resources of low-grade titanium-bearing rock. The complex is about 10 km in diameter and consists of three principal units: an outer syenite ring, an intermediate diorite-gabbro zone, and a central pyroxenite-hornblendite core. The principal mineralization zone is in the ultramafic core of the complex.

The titanium is mainly in titaniferous magnetite, but some is in ilmenite intergrown with magnetite and in the titanium-bearing hornblende, kaersutite. The titaniferous magnetite is in concordant lenses and veinlets and is disseminated throughout the host rock. The lenses and veins range from a few centimeters to 3 m in width and are as much as 50 m long. The layered disseminated bodies contain as much as 25 percent magnetite.

Exploratory drilling showed that an area 500 by 1000 m contains titaniferous rock averaging about 6.2 percent  $\text{TiO}_2$ . This mineralized zone contains about 175,000,000 tons per 100 m depth. Material of this grade is not commercial at this time, but may be a future resource. Alluvial deposits along the Red Sea near Al Qunfudhah should be tested for possible deposits of titaniferous sand.

## INTRODUCTION

In the course of mapping the Wadi Yiba quadrangle (lat 19°00' to 19°30'N., long 41°30' to 42°00'E.) in 1970, Bayley noted that an intrusive complex 2 km east of Lakathah contains pods of titaniferous magnetite over an area of several square kilometers. Accordingly, it was decided to map the area on a scale of 1:20,000 and explore the deposits by diamond drilling to determine their titanium potential. Four holes aggregating 998 m were drilled to an average depth of about 250 m in 1970-71. Four hundred and fifty chemical analyses were made of drill cores and specimens collected in the field. Martin spent a month in field work during the winter of 1970 and spring of 1971, studied thin sections and mineral separates, and prepared a preliminary report. Roberts carried out some additional field work in early 1972, and revised and completed the report in November 1975.

The Lakathah complex lies about 90 km east of the Red Sea town of Al Qunfudhah and directly east of the old village of Lakathah, now largely abandoned. The area is centered at about lat 19°08'N. and long 41°59'E. The desert road from Jiddah and Al Qunfudhah to Abha and Jizan, which here crosses the foothills of the Red Sea escarpment, passes by the area.

The area is rugged mountainous terrain and the Lakathah deposit is in a bowl-shaped valley, ringed by a high outer ridge and open to the west. The lowest point in the mapped area is at Wadi al Dhamu, 440 m above sea level, and the highest is Jabal al' Isha, at 1730 m. The mapped area is about 100 km<sup>2</sup> in extent, and only about 5 percent of this area is cultivated.

The report is part of the program of investigation of the mineral deposits of Saudi Arabia being conducted cooperatively by the Saudi Arabian Directorate General of Mineral Resources and the U.S. Geological Survey. Chemical analyses were made by Al Farouki, M. Dahlawi, M. Alharbi, M. Fourati, A. Mahjub, A. Masud, S. Osman and J. Jambi in the DGMR laboratory under the direction of M. Gonshor.

#### GEOLOGY

The Lakathah complex intrudes metavolcanic rocks that Bayley (1972) assigned to a suite of rocks east of the Ablah Formation. These rocks were subdivided by Bayley into two units, one of metadacite, quartz porphyry, and tuff, and the other of metamorphosed basaltic flows and volcaniclastic rocks. In the adjacent Hali quadrangle, Hadley (1975) included these rocks - interlayered amphibolite, hornblende schist, and garnet-hornblende-biotite gneiss - in the Sarbon Formation of the Ablah Group. The complex also cuts metatonalite of Bayley (1972) (biotite tonalite gneiss of Hadley (1975)). The outer ring of the complex extends into the western side of the An Nimas quadrangle (Greenwood, in press).

The Lakathah complex is here divided into three units (pl. 1): an outer ring of syenite, an intermediate zone of layered diorite-gabbro, and a central core of pyroxenite-hornblendite. Steeply dipping radial chloritic zones cut the core and intermediate zone. Dikelike albitite-zoisite bodies

and zones of saussuritic alteration also cut the complex. The units making up the complex are described below.

### Syenite

The outer ring of the complex consists of coarse-grained equigranular syenite. The outer diameter of the ring is 10 km and the ring is 0.8-5 km wide (pl. 1). Although the rock is not obviously layered, differential erosion of some zones in the southwestern part of the syenite suggests the presence of large-scale primary layering.

The syenite is made up mostly of alkali feldspar. In some places anorthoclase predominates, in others orthoclase(?), microcline, oligoclase, and perthite are dominant. Small amounts of pyroxene, biotite, hornblende, apatite, chlorite, sericite, quartz, titaniferous magnetite, and olivine are also present; these together rarely compose more than 10 percent of the rock. Greenwood and Brown (1973) classified the rock as a syenodiorite, but syenite seems to be a preferable term. A chemical analysis of the rock is given in table 1 (sample 61234).

Feldspar grains are commonly ovoid in shape and their longest axes tend to be aligned roughly parallel. Most grains show undulatory extinction. Grain boundaries are generally indistinct and are lobate or sutured. Inclusions of sericite, zoisite, and clinozoisite lie along crystallographic directions of the feldspars. Sericite occurs in narrow veins in the feldspars and fills interstices between the grains. The perthitic feldspars include micro-, crypto-, and orthoperthite.



Table 1. Approximate analyses of rocks and mineral separates, Lakathah complex.

Analyses by DGMR laboratory, Jiddah. Data are accurate to within  
+10 percent of amounts reported.

Sample Number	42788 Albite- zoisite	61234 Syenite	42831 Olivine gabbro	61239 Pyroxene	61240 Hornblende (kaersutite)	61241 Magnetite
SiO <sub>2</sub>	61.5	67.3	43.5	42.5	32.0 <sup>2/</sup>	3.0 <sup>3/</sup>
Al <sub>2</sub> O <sub>3</sub>	23.7	18.3	17.0	4.5	11.8	5.1 <sup>3/</sup>
Fe <sub>2</sub> O <sub>3</sub>	1.6	2.3	9.9	7.2	11.4	76.1
CaO	3.6	.35	16.5	23.0	14.4	2.4 <sup>3/</sup>
MgO	.12	.18	9.04	13.0	12.4	3.6
Na <sub>2</sub> O	9.23	5.48	1.46	2.20	2.62	.14
K <sub>2</sub> O	2.00	7.99	.21	.04	1.00	.05
TiO <sub>2</sub>	.14	.08	1.17	.34 <sup>1/</sup>	5.05	10.95
P <sub>2</sub> O <sub>5</sub>	.01	.03	.03	1.03	.02	.34
Sr	.30	.02	.03	.02	.15	-
Ig. loss	-	-	-	-	1.4	-

1/ The TiO<sub>2</sub> content is abnormally low compared to most pyroxenes listed by Deer, Howie and Zussman (1963, p. 114-124).

2/ The SiO<sub>2</sub> content is low compared to hornblendes from Alaska, Russia, and Japan cited by Taylor in Wyllie (1967, p. 102).

3/ The high contents of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and CaO, indicate the sample to be impure.

Pyroxene generally occurs in rounded and corroded grains bordered by chlorite and epidote. Because of pervasive alteration, the pyroxene could not be definitely identified, but the optical properties correspond most closely to those of augite or aegirine-augite. Small exsolved grains of magnetite or ilmenite within the pyroxene crystals are aligned parallel to the crystal borders. Larger rounded grains of magnetite are also found within the pyroxene and as interstitial blebs bordered by sphene.

Green biotite in felted masses and an altered olive-green, brittle(?) mica dusted with magnetite are generally present to the extent of a few percent. Apatite in subrounded grains and rods is ubiquitous in amounts commonly less than one percent. Chlorite is common as an alteration product of biotite and pyroxene. Quartz is very rare and is nested in carbonate aggregates.

The mafic minerals are not evenly dispersed throughout the rock mass but are found in aggregates in varying amounts in different parts of the body. They reflect in these small domains the mineral relationships and textures of the more definitely layered part of the complex.

The syenite grades into the intermediate unit of the complex through a transition zone of layered saussuritized sodic diorite 20 m to 50 m wide. This transitional zone locally contains pods and layers of coarse-grained rock composed of albite and sericite (paragonite?), with lesser amounts of

oligoclase and alkali feldspar. The feldspars contain abundant sericite microlites which obscure the feldspar grain boundaries. Zoisite, clinozoisite, and carbonate are accessory minerals.

#### Diorite-gabbro

The intermediate unit is an elliptical body of diorite-gabbro 3 by 5.6 km whose long axis trends about N.70°W.; it lies in the northwestern part of the syenite ( pl. 1). Two prongs of diorite-gabbro extend northward into the syenite. Lithologically the diorite-gabbro unit ranges from sodic diorite through ferro-diorite to olivine gabbro; pods of troctolite and gabbroic pyroxenite occur locally in the unit. A chemical analysis of olivine gabbro appears in Table 1 (sample 42831).

The diorite-gabbro is conspicuously layered. The layers commonly dip steeply outward to vertically at the periphery, and gradually flatten to about 30° near the center. The layers range from a few millimeters to tens of meters in thickness and are defined by variations in the relative proportions of plagioclase, pyroxene, and magnetite. The boundaries between layers may be diffuse or sharp, and mineralogic changes from one layer to another may be gradational or abrupt. Elongated grains of pyroxene and feldspar are arranged parallel to the layering and in places impart a platy or gneissic aspect to the rock. These features as well as textures observed in thin sections suggest that the diorite-gabbro is of cumulus origin.

Feldspars of the sodic diorite are oligoclase (about An<sub>24</sub>) and minor alkali feldspar, whereas feldspar of other gabbroic rocks is calcic plagioclase (up to An<sub>76</sub>). Most of the pyroxene

is pigeonite, but augite is also found. Orthopyroxene, mainly bronzite, is associated with olivine in some mafic gabbro, and these minerals together with calcic plagioclase make up the main cumulus phases in this rock. Apatite in subrounded grains and rods is also an early mineral. Magnetite and less calcic plagioclase are generally interstitial. Kaersutite, brown titanohornblende, is the last post-cumulus mineral and occurs interstitially between the magnetite and plagioclase and as patches replacing pyroxene. Large crystals of kaersutite, as much as 2 cm in greatest dimension, locally enclose all other minerals. The boundaries between magnetite and kaersutite are sharp; both minerals are fresh, and there appear to be no reaction effects.

Saussuritic alteration is pervasive and is generally concentrated at discrete centers whereas the minerals in the surrounding area remain fresh. The altered rock contains as much as 3 to 10 percent saussurite aggregates, and is often localized along flat-lying joints and late peripheral faults.

#### Pyroxenite-hornblendite

The core of the complex, about a kilometer in diameter, consists of dark-gray to black pyroxenite-hornblendite. Some parts of the core are made up of pyroxenite and gabbro, others of hornblendite and diorite, and a few pods of peridotite were cut in drill holes. Layering is obscure in most places, but where it can be seen it is steeply dipping.

The pyroxenite consists mainly of pigeonite, augite, and some olivine all of which are present as rounded cumulus grains.

Plagioclase, generally  $An_{60-70}$ , and rounded magnetite grains fill the intercumulus space. The pyroxene and olivine are in places altered to aggregates of talc, serpentine, and chlorite. Lens- or dike-like segregations of hornblende are enclosed in the pyroxenite, and remnants of pyroxenite are found locally in the hornblende.

The hornblende is composed dominantly of kaersutite accompanied by augite and plagioclase ( $An_{40-50}$ ). Where the rock has been recrystallized the plagioclase is about  $An_{25}$  and is bordered by feldspar rims of brown biotite that separate the plagioclase from enclosing augite and kaersutite. Brown biotite also occurs in interstices between pyroxene and amphibole grains. Cumulus grains of pyroxene, magnetite, apatite, and plagioclase are locally enclosed in large anhedral grains of kaersutite as much as 2 cm long. In places coarse kaersutite and plagioclase crystals form alternating layers, both parallel and normal to the enclosing walls. These aggregates resemble pegmatitic dikes and are thought to have formed from volatile-rich magmas late in the crystallization of the core rocks. Hornblende in Alaskan ultramafic rocks is considered by Kennedy (1955) to have been derived from  $H_2O$ -rich gas phases that reacted deuterically with earlier pyroxene and magnetite.

#### Saussurite zones

Zones of saussuritic alteration as much as 10 m wide cut the diorite-gabbro and pyroxenite-hornblende. In outcrop these zones commonly resemble resistant dikes; they show sharp boundaries with the enclosing rocks and exhibit contrasting colors and textures.

The saussurite zones are radially oriented, steeply dipping to vertical, and cut across the primary layering. They are made up of chlorite, zoisite, clinozoisite, albite-oligoclase, carbonate, quartz or chalcedony, and epidote. The proportion of these minerals varies in accordance with the original composition of the rocks from which they were derived. In saussuritized zones, commonly only the ghosts of the original minerals remain.

#### ORE DEPOSITS

The titanium-bearing minerals at Lakathah are found mainly in the pyroxenite-hornblendite core and associated rocks. Most of the titanium is in the titaniferous magnetite, but a significant amount is also in the kaersutite.

The titaniferous magnetite is in lenses, veins, and disseminated throughout the host rocks in amounts ranging from 5 to 25 percent. The lenses are commonly a half meter to 3 m wide and are as much as 50 m long; the lenses are estimated to make up about 50 percent of the rock volume. The magnetite is present as fine grains enclosed in other minerals, in cumulate interstices, and as coarsely crystalline masses.

An analysis of a magnetite mineral separate is given in table 1 (sample 61241). Other samples of magnetite contain as much as 16 percent  $TiO_2$ . Microprobe studies on the titaniferous magnetite by G. M. Steed of the Royal School of Mines, London (written commun., 1971) showed that part of the titanium is in solid solution and part is in ilmenite intergrowths. Steed also found traces of pyrrhotite, chalcopyrite, pyrite, and pentlandite in drill core samples.

Although titaniferous magnetite accounts for most of the titanium in the deposit, a significant amount also occurs in kaersutite. Analysis of a mineral separate of kaersutite gave 11.4 percent  $\text{Fe}_2\text{O}_3$  and 5.05 percent  $\text{TiO}_2$  (table 1, sample 61240). A sample of pyroxene, mostly pigeonite, contained 7.2 percent  $\text{Fe}_2\text{O}_3$  and 0.34 percent  $\text{TiO}_2$  (table 1, sample 61239). Platinum, lanthanum, and tin were sought in these samples but were not detected.

#### Exploration at Lakathah

Four drill holes aggregating 998 m were drilled during 1971 in the central zone at Lakathah. Figure 1 is a geologic cross section along these drill holes. About 450 samples were collected from the cores and were analyzed in the DGMR laboratory in Jiddah. Core recovery was virtually 100 percent in all drill holes. Logs of the drill holes are given in tables 2, 4, 6, and 8; analyses of cores appear in tables 3, 5, 7, and 9.

The titanium oxide content of the cores averaged 6.2 percent, and ranged to 10.1 percent over 2 to 3 m intersections. The iron content ranged from 5 to 35 percent.

The principal mineralized zone is about 500 m wide and 1000 m long. This block contains about 175 million tons for each 100 m depth; the titaniferous zones may extend to other parts of the central zone. At 6.2 percent  $\text{TiO}_2$  these deposits are probably too low in grade to be worked at present, but may be a future resource. In addition, a large volume of the Lakathah complex has been eroded and transported to the Red Sea at Al Qunfudhah, about 90 km to the southwest, and titanium-rich sands may exist on the sea margin.

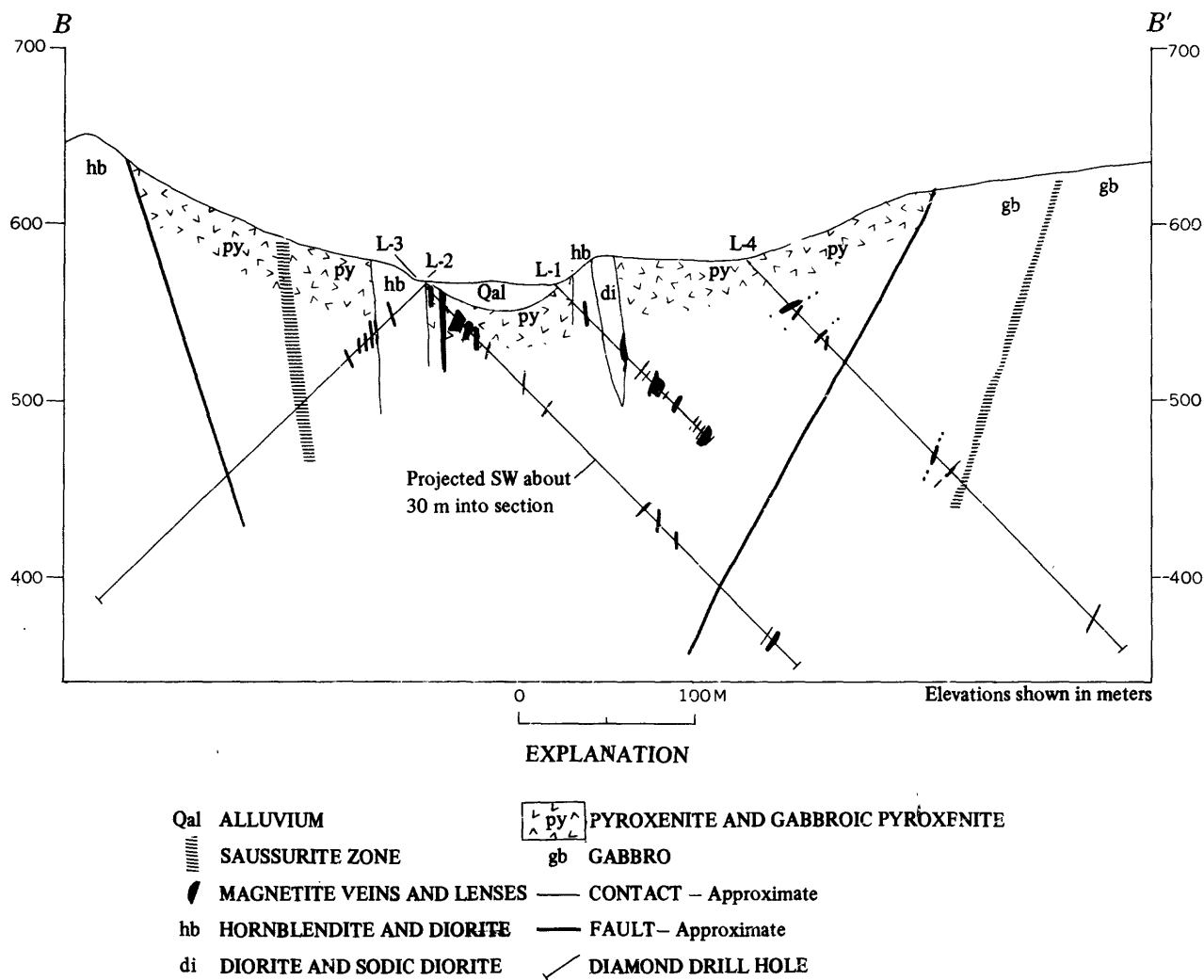


Figure 1.- Geologic cross section along diamond drill holes, Lakathah complex (pl. 1).



**Table 2. - Log of USGS drill hole L-1, Lakathah.**

Depth (meters)	Lithology	Percentage magnetite (estimated)
0-4	Detritus no core	
4-11	Pyroxenite-hornblendite and diorite; saussuritized and chloritized	10
11-21	Diorite-gabbro, fine-grained	15
21-25	Magnetite, olivine gabbro	40
25-30	Diorite, saussuritized; hornblendite	5
30-35	Peridotite and troctolite	10
35-52	Diorite, syenite, altered; local lenses of magnetite and hornblendite	5
52-64	Pyroxenite-hornblendite, peridotite; gabbroic at 63 m	20
64-71	Hornblendite-pyroxenite, troctolite at 60 m	20
71-75	Pyroxenite-magnetite	30
75-78	Hornblendite	20
78-84	Magnetite and peridotite	35
84-89	Hornblendite; diorite at 89 m	20
89-91	Pyroxenite and gabbro	25
91-93	Gabbro, fine-grained (dike?)	5
93-96	Magnetite and peridotitic gabbro at 93 m	50
96-106	Hornblendite and pyroxenite	20
106-112	Gabbro and pyroxenite	15
112-120	Pyroxenite and peridotite	35
120-123.5	Hornblendite-pyroxenite	5

Table 3. - Analyses of core samples from USGS drill hole L-1, Lakathah.  $\text{TiO}_2$  and iron were determined by atomic absorption in DGMR Laboratory in Jiddah, 1971. Check analyses were run by USGS laboratories in Washington, D.C.

Depth (meters)	Sample number	Percent		Check analyses USGS, Washington, D.C.	
		Fe	$\text{TiO}_2$	Fe	$\text{TiO}_2$
4.1-5.2	42581	14.4	8.0		
5.2-8.0	582	11.6	6.3	13.0	5.8
8.0-10.0	583	13.4	6.8		
10.5-11.7	584	27.4	8.3		
11.7-14	585	14.9	6.5		
14-16	586	18.6	3.5	18.3	5.8
16-18	587	16.1	7.3		
18-21	588	18.8	8.5		
21-23	589	30.6	8.7	30.4	8.4
23-24	590	24.8	7.2		
24-25	591	16.0	6.3		
25-26	592	12.9	5.4		
26-27.5	593	17.8	3.5	18.1	3.2
27.5-30	594	14.0	5.8		
30-32	595	15.5	5.1		
32-34	596	15.7	3.0		
34-36	597	14.8	3.0		
36-37.5	598	15.8	2.9		
37.5-40	599	9.9	3.1		
40-42	600	9.6	2.8		
42-44	601	10.8	2.4		
44-47	602	9.7	3.0		
47-49	603	8.2	3.2		
49-50	604	14.8	4.3		
50-52	605	8.1	2.5		
52-54	606	25.8	6.9	25.3	7.1
54-56	607	17.7	5.8		
56-58	608	17.2	5.7		
58-60	609	16.7	6.0		
60-62	610	15.6	5.5		
62-64	611	10.4	4.0		
64-66	612	16.3	6.0		
66-68	613	14.4	6.5		
68-71	614	18.9	6.5		
71-73	615	19.1	6.3		
73-74	616	20.1	7.2		
74-76	617	18.8	7.7		
76-78	618	16.6	7.7	16.7	6.5
78-81	619	20.5	6.1		
81-82	620	11.1	3.6		
82-83	621	21.0	5.9		
83-84	622	19.2	6.1		
84-86	623	16.8	5.7		
86-88	624	16.8	5.8		
88-90	625	16.2	5.7		
90-93	626	11.3	5.2		
93-96	627	23.0	6.2		
96-99	628	17.5	8.3	18.1	7.3
99-102	629	14.5	6.8		
102-104	630	15.2	6.3		

Table 3. - Analyses of core samples from USGS drill hole L-1, Lakathah,  $\text{TiO}_2$  and iron were determined by atomic absorption in DGMR Laboratory in Jiddah, 1971. Check analyses were run by USGS laboratories in Washington, D.C. (cont'd.)

Depth (meters)	Sample number	Percent		Check analyses USGS, Washington, D.C.	
		Fe	$\text{TiO}_2$	Fe	$\text{TiO}_2$
104-106	631	15.9	6.3		
106-109	632	21.5	6.7	21.9	6.5
109-112	633	17.3	5.2		
112-114	634	25.4	6.3	24.7	6.9
114-116	635	22.8	6.2		
116-118	636	21.0	6.0		
118-120	637	18.0	4.7	17.3	6.1
120-121.5	638	9.5	3.8		
121.5-122.5	639	13.1	4.8		
122.5-123.5	640	19.9	7.5		

Table 4. - Log of USGS drill hole L-2, Lakathah.

Depth (meters)	Lithology	Percent magnetite (estimated)
0-3	No core; fragments of diorite	- -
3-9	Hornblendite and pyroxenite; diorite at 6.5 m	20
9-16	Diorite, fine-grained	- 5
16-22	Hornblendite, green; pyroxenite	20
22-24	Diorite	- 5
24-40	Hornblendite-pyroxenite; diorite at 31 and 33 m; breccia with carbonate and zoisite	20
40-42	Magnetite, olivine, pyroxenite	30
42-47	Pyroxenite and hornblendite	5
47-50	Pyroxenite and magnetite	25
50-52	Pyroxenite, sodic diorite	5
52-60	Pyroxenite, gabbro	15
60-64	Pyroxenite, fine-grained; magnetite pods	25
64-69	Pyroxenite, saussuritized	20
69-75	Pyroxenite, fine-grained	15
75-82	Pyroxenite, fine-grained; gabbro	10
82-86	Pyroxenite, fine-grained; gabbro	10
86-94	Diorite-gabbro; hornblendite	5
94-101	Saussuritized gabbro	5
101-106	Pyroxenite, saussuritized	5
106-112	Diorite, saussuritized	5
112-117	Pyroxenite; gabbro; hornblendite with 20 percent apatite	15
117-119	Gabbro, medium- to coarse-grained	10
119-123	Pyroxenite, fine-grained; gabbroic lenses	15
123-125	Fault breccia with carbonate, chlorite, talc, and zoisite	5
125-129	Pyroxenite-hornblendite, gabbro	5
129-132	Gabbro, medium- to coarse-grained	10
132-140	Hornblendite-pyroxenite, coarse-grained	10
140-152	Gabbro, medium-grained; pyroxenite at 146 m and 149 m	10

Note: - less than

Table 4. - Log of USGS drill hole L-2, Lakathah. (cont'd.)

Depth (meters)	Lithology	Percent magnetite (estimated)
152-158	Pyroxenite, gabbroic, medium-to coarse-grained	10
158-170	Hornblendite-pyroxenite, gabbro	10
170-171	Saussuritized gabbro	10
171-180	Hornblendite; diorite; pyroxenite	5
180-183	Diorite, fine-grained	20
183-186	Pyroxenite-hornblendite, fine- to coarse-grained	5
186-188	Diorite, coarse-grained	20
188-205	<b>Hornblendite, fine- to coarse-grained, some apatite</b>	7
205-212	Diorite with apatite	not determined
212-226	Hornblendite; sodic diorite at 2.4 m; much apatite	10
226-230	Diorite, saussuritized	5
230-235	Hornblendite, coarse, altered	15
235-243	Diorite, saussuritized	- 5
243-251	Hornblendite, coarse-grained; breccia zone at 244-247 m	5
251-255	Hornblendite, fine- to coarse-grained	10
255-257	Pyroxenite-hornblendite, gabbro	5
257-258.8	Gabbro, altered	-5

Note: - less than

Table 5. - Analyses of core samples from USGS drill hole L-2, Lakathah. Titanium ( $\text{TiO}_2$ ) was determined by X-ray spectroscopy, titanium (Ti) by atomic absorption; iron by volumetric analysis; copper (Cu) and phosphorous ( $\text{P}_2\text{O}_5$ ) by colorimetric analysis; and nickel (Ni) by X-ray spectroscopy in DGMR Laboratory.

Depth (meters)	Sample Number	Percent					Ni
		Fe	$\text{TiO}_2$	Ti	Cu	$\text{P}_2\text{O}_5$	
2.4-4.0	42835	22.9	7.9	4.7			
4-6	836	14.5	6.2	3.7			
6-7	837	12.3	5.8	3.5			
7-9	838	17.8	7.3	4.4	.01	.34	.015
9-10	839	10.4	4.9	2.9			
10-12	840	11.2	5.3	3.2			
12-14	841	12.8	5.6	3.4			
14-16	842	11.9	5.0	3.0			
16-17	843	15.3	7.1	4.3			
17-19	844	16.9	7.0	4.2			
19-21	845	20.1	7.3	4.4			
21-22	846	18.6	7.4	4.4			
22-24	847	13.5	6.2	3.7			
24-26	848	15.8	6.6	3.9			
26-28	849	20.0	7.0	4.2			
28-30	850	17.6	6.7	4.0			
30-31	851	11.6	4.4	2.6			
31-33	852	15.2	6.6	4.0			
33-35	853	16.6	6.4	3.8	.01	.46	.005
35-37	854	17.2	7.0	4.2			
37-38	855	18.8	6.6	3.9			
38-40	856	18.3	6.7	4.0			
40-41	857	21.0	7.2	4.3			
41-43	858	19.0	6.8	4.1	.01	.69	.004
43-45	859	15.3	6.2	3.7			
45-47	860	19.3	7.8	4.7			
47-48	861	17.8	6.5	3.9			
48-50	862	17.2	6.3	4.1			
50-52	863	17.4	7.8	4.7			
52-54	864	21.4	8.2	4.9			
54-56	865	17.9	7.2	4.3			
56-58	866	19.3	5.5	3.3	.01	.27	.005
58-60	867	15.6	6.3	3.8			
60-62	868	19.8	7.2	4.3			
62-64	869	21.0	6.5	3.9			
64-66	870	18.9	6.3	3.8			
66-68	871	18.6	8.2	4.9			
68-70	872	17.3	6.4	3.8			
70-72	873	16.9	6.3	3.8			
72-74	874	19.1	7.0	4.2			
74-75	875	16.9	5.9	3.5			
75-77	876	15.1	6.2	3.7			
77-79	877	18.0	5.9	3.5			
79-80	878	16.5	5.9	3.6			
80-82	879	18.8	6.3	3.8			

Table 5. - Analyses of core samples from USGS drill hole L-2, Lakathah. Titanium (TiO<sub>2</sub>) was determined by X-ray spectroscopy, titanium (Ti) by atomic absorption; iron by volumetric analysis; copper (Cu) and phosphorous (P<sub>2</sub>O<sub>5</sub>) by colorimetric analysis; and nickel (Ni) by X-ray spectroscopy in DGMR Laboratory. (cont'd.)

Depth (meters)	Sample Number	Percent					
		Fe	TiO <sub>2</sub>	Ti	Cu	P <sub>2</sub> O <sub>5</sub>	Ni
82-84	880	15.9	6.2	3.7			
84-86	881	12.1	6.0	3.6			
86-88	882	14.1	5.8	3.5			
88-90	883	13.6	6.3	3.8			
90-92	884	14.5	5.4	3.2	.004	1.03	.003
92-94	885	15.2	6.1	3.7			
94-96	886	14.5	5.9	3.5			
100-101	887	15.1	5.9	3.5			
101-103	888	17.6	6.3	3.8			
103-112	889	18.0	5.6	3.9			
112-113	890	20.4	6.7	4.0			
113-115	891	22.0	7.7	4.6			
115-117	892	15.4	6.5	3.9			
117-119	893	18.4	7.0	4.2			
119-121	894	16.1	6.8	4.1	.005	.80	.0015
121-123	895	16.9	6.8	4.1			
123-125	896	12.8	5.5	3.3			
125-127	897	14.8	5.7	3.4			
127-129	898	14.9	6.0	3.9			
129-130	899	15.9	6.0	3.9			
130-132	900	15.9	6.8	4.1			
132-134	901	16.5	6.6	3.9			
134-136	902	14.1	6.3	3.8			
136-138	903	14.2	5.8	3.5			
138-140	904	14.9	6.3	3.8			
140-142	905	13.7	6.2	3.7			
142-144	906	12.6	5.5	3.3			
144-146	907	15.1	6.5	3.9			
146-148	908	12.3	5.7	3.4	.005	1.15	.0015
148-149	909	14.4	5.5	3.3			
149-151	910	14.3	5.8	3.5			
151-153	911	12.0	5.3	3.2			
153-155	912	13.1	5.7	3.4			
155-156	913	14.4	6.5	3.9			
156-158	914	10.5	6.0	3.6			
158-160	915	15.9	6.8	4.1			
160-162	916	11.7	6.8	4.1			
162-164	917	14.8	6.2	3.7			
164-166	918	14.9	7.5	4.5			
166-168	919	13.7	6.7	4.0			
168-170	920	14.0	6.5	3.9			
170-174	No data available						
174-176	921	12.9	6.3	3.8			
176-178	No data available						
178-180	922	11.9	5.7	3.4			
180-182	923	14.8	5.9	3.5	.0065	1.37	.003
182-184	924	12.4	6.6	3.8			

Table 5.-- Analyses of core samples from USGS drill hole L-2, Lakathah. Titanium (TiO<sub>2</sub>) was determined by X-ray spectroscopy, titanium (Ti) by atomic absorption; iron by volumetric analysis; copper (Cu) and phosphorous (P<sub>2</sub>O<sub>5</sub>) by colorimetric analysis; and nickel (Ni) by X-ray spectroscopy in DGMR Laboratory. (cont'd.)

Depth (meters)	Sample Number	Percent					Ni
		Fe	TiO <sub>2</sub>	Ti	Cu	P <sub>2</sub> O <sub>5</sub>	
184-186	925	14.9	6.0	3.6			
186-187	926	27.8	7.2	4.3			
187-189	927	15.5	5.5	3.3			
189-191	928	16.6	6.7	4.0			
191-193	929	12.0	6.3	3.8			
193-195	930	11.8	5.6	3.3			
195-197	931	11.3	6.2	3.7			
197-199	932	11.4	5.7	3.4			
199-201	933	15.8	6.2	3.7			
201-203	934	14.7	6.0	3.6			
203-205	935	15.6	6.1	3.7			
205-207	936	14.7	6.5	3.9			
207-209	937	17.0	6.5	3.9			
209-211	938	17.6	6.7	4.0	.003	.34	.001
211-214	939	17.4	6.8	4.1			
214-216	No data available						
216-218	940	13.3	5.1	3.0			
218-220	No data available						
220-222	941	15.1	5.5	3.3	.025	.50	.017
222-223	942	15.5	5.9	3.2			
223-230	No data available						
230-232	943	17.7	6.5	3.9			
232-234	944	17.0	6.3	3.8			
234-235	945	14.1	5.9	3.5			
235-243	No data available						
243-245	946	14.1	6.2	3.7			
245-247	947	14.8	6.3	3.8			
247-250	948	14.7	6.5	3.9			
250-252	No data available						
252-254	949	14.9	6.5	3.9			
254-256	950	13.2	7.0	4.2			
256-258.8	No sample.						



**Table 6. - Log of USGS drill hole L-3, Lakathah.**

<b>Depth (meters)</b>	<b>Lithology</b>	<b>Percent magnetite (estimated)</b>
0-5.6	Detritus, no core	—
5.6-10	Magnetite, olivine pyroxenite	50
10-15	Olivine gabbro-diorite	15
15-23	Pyroxenite, gabbro	30
23-29	Pyroxenite, diorite-gabbro, hornblendite	10
29-49	Magnetite, olivine pyroxenite, hornblendite	35
49-78	Pyroxenite, hornblendite, magnetite, and locally up to 2 percent pyrrhotite	15
78-82	Diorite-gabbro	5
82-86	Pyroxenite-hornblendite, magnetite	25
86-88	Diorite	5
88-99	Pyroxenite-hornblendite, diorite	15
99-104	Hornblendite, coarse-grained	5
104-112	Pyroxenite-hornblendite	10
112-120	Pyroxenite	20
120-128	Hornblendite, coarse-grained, pyroxenite	15
128-137	Pyroxenite-hornblendite, diorite at 136 m, massive magnetite at 137 m	15
137-140	Pyroxenite, fine-grained gabbro, locally mylonitized and altered	5
140-144	Gabbro, pyroxenite	10
144-148	Pyroxenite, hornblendite	10
148-159	Pyroxenite, gabbro	17
159-163	Hornblendite-pyroxenite, altered	5
163-173	Pyroxenite, locally mylonitized, some disseminated pyrrhotite	5
173-177	Pyroxenite, fine-grained	15
177-182	Hornblendite, coarse grained; diorite, altered	5
182-187	Pyroxenite, hornblendite pods	20
187-192	Diorite, fine-grained, altered to chlorite and oligoclase	5
192-197	Pyroxenite, fine- to medium-grained, cut by biotite-plagioclase veins	5
197-200	Hornblendite-pyroxenite	5
200-203	Gabbro, fine-grained	10

Table 6. - Log of USGS drill hole L-3, Lakathah (cont'd.)

Depth (meters)	Lithology	Percent magnetite (estimated)
203-211	Hornblendite-pyroxenite, altered; diorite, saussuritized; local magnetite pods	5
211-226	<b>Pyroxenite-hornblendite, local disseminated pyrrhotite up to 1 percent</b>	15
226-232	Gabbro, fine-grained, altered	12
232-240	Pyroxenite, altered to chlorite	5
240-245	Gabbro	15
245-255	Olivine pyroxenite, fine-grained, locally gabbroic; pods of magnetite	20
255-283	Gabbro, fine-grained; pyroxenite, mostly fine-grained.	15
<b>283-287</b>	Gabbro-pyroxenite and hornblendite at 287 m	20
287-292	Magnetite, pyroxenite with some pyrrhotite	40
292-297	Gabbro, medium-grained	10
297-300	Pyroxenite-hornblendite	20
300-307.5	Gabbro; pyroxenite at 305 and 307 m	15

Table 7.- Analyses of core samples from USGS drill hole L-3, Lakathah. Titanium (Ti) and iron (Fe) were determined by X-ray spectroscopy; titanium (TiO<sub>2</sub>) and iron (Fe(v)) by volumetric analysis; copper (Cu) and phosphorous (P<sub>2</sub>O<sub>5</sub>) by colorimetric enalysis; and nickel (ni) by X-ray spectroscopy in DGMR laboratory, 1971.

Depth (meters)	Sample number	Fe	Fe(v)	Ti	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	Cu	Ni
5.5-7.0	42956	24.5	25.8	5.0	8.3			
7-9	957	35.2		5.0	8.3			
9-11	958	22.5		3.6	6.0			
11-13	959	18.3		3.5	5.9			
13-15	960	14.1		3.1	5.1			
15-17	961	15.9		3.1	5.2			
17-19	962	21.3		3.2	5.3			
19-21	963	28.9		5.6	9.4			
21-23	964	21.7		4.0	6.7			
23-26	965	21.6		4.1	6.9	.17	.005	.04
26-28	966	17.9		3.2	5.3			
28-29	967	20.2		3.2	5.4			
29-31	968	32.3		5.7	9.5			
31-33	969	31.7		5.3	8.9			
33-35	970	34.7		6.1	10.1			
35-37	971	30.6		5.9	9.8			
37-39	972	26.5		4.8	8.1			
39-41	973	22.8		4.6	7.7			
41-43	974	26.5		4.4	7.4			
43-45	975	16.5	15.2	3.9	6.5			
45-47	976	22.2		4.7	7.8			
47-49	977	31.3		6.0	10.0	.17	.006	.03
49-51	978	13.2		3.4	5.7			
51-53	979	18.9		4.2	7.0			
53-55	980	21.6	22.1	4.6	7.7			
55-57	981	19.6		4.4	7.4			
57-59	982	26.6		4.7	7.9			
59-61	983	19.8		4.0	6.6			
61-63	984	19.7		4.3	7.2			
63-65	985	21.0		4.3	7.1	.09	.008	.02
65-67	986	17.8		4.0	6.6			
67-69	987	16.2		3.8	6.3			
69-72	988	16.0		3.8	6.3			
72-74	989	16.5		3.7	6.1			
74-76	990	14.9	15.6	3.4	5.2			
76-78	991	20.3		2.9	4.9			
78-82	992	22.5		2.1	3.5			
82-84	993	18.7		4.7	7.8			
84-87	994	20.4		4.5	7.5	.046	.01	.05
87-88	995	12.8	13.7	3.4	5.4			
88-90	996	16.1		3.7	6.2			
90-92	997	15.5		3.4	6.2			
92-94	998	16.4		4.2	7.0			
94-96	999	15.9		4.3	7.2			
96-98	61000	16.9		4.0	6.6			

Table 7. - Analyses of core samples from USGS drill hole L-3 Lakathah, Titanium (Ti) and iron (Fe) were determined by X-ray spectroscopy; titanium (TiO<sub>2</sub>) and iron (Fe(v)) by volumetric analysis; copper (Cu) and phosphorous (P<sub>2</sub>O<sub>5</sub>) by colorimetric analysis; and nickel (Ni) by X-ray spectroscopy in DGMR laboratory, 1971. (cont'd.)

Depth (meters)	Sample number	Fe	Fe(v)	Ti	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	Cu	Ni
98-100	61001	18.0	18.2	4.5	7.5			
100-102	02	18.0		3.7	6.1			
102-104	03	16.3		4.2	7.0	.27	.01	N.D.
104-106	04	16.9		3.9	6.5			
106-108	05	16.1	16.9	3.7	6.2			
108-110	06	16.6		4.1	6.8			
110-112	07	16.3		4.2	7.0			
112-114	08	22.7		4.1	6.8			
114-116	09	16.9		3.9	6.5			
116-118	10	17.2	18.0	4.0	6.6			
118-120	11	14.2		4.0	6.6			
120-122	12	14.1		3.7	6.2			
122-124	13	15.6		5.0	8.3			
124-126	14	15.6		4.2	7.0			
126-128	15	14.5	15.1	4.2	7.0			
128-130	16	18.4		4.1	6.8			
130-132	17	17.2		4.1	6.8	.69	.01	≈.008
132-134	18	16.5		4.4	7.3			
134-136	19	17.2		3.7	6.1			
136-137	20	32.3	29.0	5.3	8.8			
137-140	21	15.7		3.7	6.1			
140-142	22	19.1		4.2	7.0			
142-144	23	15.6		4.3	7.2			
144-146	24	16.7		4.2	7.0			
146-148	25	16.8	17.0	4.1	6.9			
148-150	26	19.1		4.1	6.8			
150-152	27	17.4		4.0	6.6			
152-154	28	16.1		4.0	6.6			
154-156	29	16.1		4.0	6.6			
156-159	30	16.0	15.7	4.2	7.0			
159-162	31	14.6		3.9	6.5	1.37	.008	N.D.
162-163	32	15.9		3.8	6.3			
163-165	33	16.5		4.2	7.0			
165-167	34	16.5		3.7	6.2			
167-169	35	18.3	15.8	4.1	6.8			
169-171	36	16.0		3.7	6.1			
171-172	37	15.5		3.7	6.1			
172-174	38	19.4		4.0	6.6	.18	.01	N.D.
174-176	39	17.2		4.1	6.8			
176-179	40	14.3	12.1	3.7	6.2			
179-181	41	14.3		3.8	6.3			
181-183	42	17.3		4.4	7.1			
183-185	43	18.0		4.2	6.9			
185-187	44	15.8		4.2	6.9			
187-190	45	13.5	12.9	3.5	5.8			
190-192	46	11.9		3.4	5.7			
192-194	47	16.9		4.2	6.9			
194-196	48	16.5		4.2	7.1			
196-198	49	18.3		3.9	6.5			
198-200	50	16.1	16.2	3.9	6.5			

Table 7. - Analyses of core samples from USGS drill hole L-3 Lakathah, Titanium (Ti) and iron (Fe) were determined by X-ray spectroscopy; titanium (TiO<sub>2</sub>) and iron (Fe(v)) by volumetric analysis; copper (Cu) and phosphorous (P<sub>2</sub>O<sub>5</sub>) by colorimetric analysis; and nickel (Ni) by X-ray spectroscopy in DGMR laboratory, 1971. (cont'd.)

Depth (meters)	Sample number	Fe	Fe(v)	Ti	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	Cu	Ni
200-203	61051	15.8		3.9	6.5			
203-206	52	20.8		4.1	6.8			
206-208	53	15.0		3.3	5.4			
208-210	54	17.6		4.1	6.8			
210-212	55	20.5	22.1	4.1	6.8			
212-214	56	22.9		4.5	7.5	.09	.013	N.D.
214-216	57	18.8		3.9	6.4			
216-218	58	20.5		3.9	6.5			
218-220	59	16.1		3.7	6.1			
220-222	60	16.0	17.7	3.9	6.5			
222-224	61	18.4		4.3	7.1			
224-226	62	21.0		4.2	7.1	.34	.01	≈.024
226-228	63	16.8		3.6	5.9			
228-231	64	1.45		3.2	5.3			
231-234	65	15.6	14.7	3.3	5.5			
234-237	66	12.0		3.1	5.1			
237-239	67	17.4		3.8	6.3			
239-241	68	18.6		4.5	7.5			
241-244	69	16.7		3.9	6.4			
244-246	70	12.3	13.8	3.3	5.4			
246-248	71	18.6		3.5	5.8			
248-249	72	12.9		2.9	4.8			
249-251	73	17.6		3.6	6.0			
251-253	74	19.5		4.3	7.1			
253-255	75	22.7	24.7	4.7	7.8			
255-257	76	18.7		2.9	4.8			
257-260	77	17.6		3.9	6.4			
260-262	78	17.6		4.0	6.6			
262-264	79	20.8		4.5	7.4			
264-266	80	18.5	16.4	3.6	5.8			
266-268	81	16.3		3.3	5.4			
268-270	82	16.5		2.8	4.7	.18	.006	.018
270-272	83	19.1		3.5	5.8			
272-274	84	18.0		4.2	7.1			
274-276	85	20.5	21.2	3.9	6.5			
276-278	86	18.7		3.1	5.1			
278-280	87	22.0		4.2	6.9			
280-282	88	19.6		3.8	6.3			
282-284	89	17.2		3.8	6.3			
284-286	90	18.0	17.0	3.9	6.4			
286-288	91	19.1		4.0	6.7			
288-290	92	26.4		4.1	6.8	.23	.025	N.D.
290-292	93	24.9		4.0	6.6			
292-294	94	18.3		3.1	5.2			
294-297	95	16.3	17.7	3.6	5.9			
297-299	96	16.5		3.2	5.3			
299-301	97	15.7		3.5	5.8			
301-303	98	14.1		3.7	6.1			
303-305	99	13.9		3.3	5.4			
305-307.5	100	16.8	17.2	4.0	6.7			

Table 8. - Log of USGS drill hole L-4, Lakathah.

Depth (meters)	Lithology	Percent magnetite (estimated)
0-6	Detritus, no core	--
6-9	Pyroxenite	15
9-13	Diorite-gabbro	10
13-16	Pyroxenite-hornblendite	5
16-32	Diorite-gabbro, fine- to-medium grained	15
32-35	Pyroxenite	20
35-37	<b>Magnetite, pyroxenite, peridotite</b>	40
37-40	Diorite-gabbro, altered; sodic diorite at 41 m	5
40-42	Magnetite; olivine pyroxenite	60
42-55	Gabbro, local olivine, pyroxenite	7
55-64	<b>Magnetite up to 50 percent; olivine pyroxenite and gabbro</b>	25
64-68	Gabbro (troctolite)	25
68-70	<b>Gabbro, fine- to medium-grained</b>	5
70-73	Diorite, sodic; pyroxenite-hornblendite, sparse chalcopyrite	5
73-75	Pyroxenite, some chalcopyrite and pyrrhotite	10
75-87	Gabbro, sodic diorite at 83.5 m	15
87-90	Olivine gabbro and troctolite	20
90-102	<b>Gabbro; pyroxenite with 20 percent magnetite at 100 m</b>	5
102-105	<b>Pyroxenite with 30 percent biotite, 20 percent plagioclase</b>	2
105-110	Gabbro, medium-grained	10
110-114	Gabbro-diorite	15
114-125	Diorite, fine-grained	5
125-130	Diorite	10
130-133	Diorite, saussuritized	10
133-136	Pyroxenite, some olivine	20
136-142	Gabbro, fine-grained	20
142-146	Pyroxenite, massive magnetite at 143 m	25
146-151	Gabbro, fine-grained, saussuritized	15
151-153	Pyroxenite, fine-grained	5

Table 8. - Log of USGS drill hole L-4, Lakathah (cont'd.)

Depth (meters)	Lithology	Percent magnetite (estimated)
153-155	Magnetite; olivine pyroxenite	50
155-162	Gabbro, medium-grained	5
162-166	Gabbro; pyroxenite	5
166-168	Magnetite; olivine pyroxenite	45
168-174	Gabbro-pyroxenite, alternating	15
174-178	Gabbro, saussuritized	5
178-184	Diorite; pyroxenite-hornblende	10
184-198	Gabbro, fine-to medium-grained	10
198-204	Pyroxenite, fine-grained	25
204-207	Gabbro, coarse-grained	5
207-210	Pyroxenite-hornblendite	5
210-216	Pyroxenite, fine-grained; gabbro at 213 m	20
216-240	Gabbro-diorite; some pyroxenite	15
240-253	Gabbro, medium-to fine-grained; up to 50 percent magnetite at 245 m and 252 m	10
253-258	Pyroxenite, fine-grained, altered	20
258-265	Gabbro, fine-grained	0
265-276	Diorite-gabbro, pyroxenite	5
276-282	Gabbro, fine-grained	0
282-285	Magnetite-pyroxenite, fine-grained	35
285-307.9	Gabbro; pyroxenite; troctolite at 302 m	10

Table 9. - Analyses of core samples from USGS drill hole L-4, Lakathah. Titanium (Ti) iron (Fe) and nickel (Ni) were determined by X-ray spectroscopy; titanium (TiO<sub>2</sub>) and iron (Fe(v)) in some samples were analyzed volumetrically; and copper (Cu) and phosphorous (P<sub>2</sub>O<sub>5</sub>) were determined by colorimetric analysis. Analyses by DGMR laboratory 1971.

Depth (meters)	Sample number	Fe	Fe(v)	Ti	TiO <sub>2</sub>	Cu	P <sub>2</sub> O <sub>5</sub>	Ni
6.1-9	61101	20.9		3.6	5.9			
9-12	102	15.8		3.1	5.1			
12-14	103	16.5		3.6	5.9			
14-16	104	14.8		3.1	5.1			
16-18	105	15.4	15.3	2.9	4.8			
18-21	106	13.4		3.1	5.1			
21-23	107	16.9		3.9	6.4			
23-25	108	16.0		3.6	5.9			
25-27	109	17.6		3.6	5.9	.003	1.03	≈.008
27-29	110	18.8	20.5	3.6	5.9			
29-31	111	17.4		2.9	4.8			
31-32	112	14.7		3.0	5.0			
32-34	113	17.4		3.3	5.5			
34-36	114	24.0		4.4	7.4			
36-38	115	14.4	16.5	3.2	5.3			
38-40	116	14.9		2.5	4.2			
40-42	117	24.6		3.9	6.4	.0065	.09	≈.008
42-45	118	13.9		2.9	4.8			
45-47	119	15.2		3.7	6.1			
47-50	120	15.0	14.2	2.7	4.5			
50-52	121	16.0		3.5	5.8			
52-54	122	14.3		2.7	4.5			
54-56	123	15.3		2.7	4.5			
56-58	124	23.1		4.2	7.1			
58-60	125	13.0	12.3	2.7	4.5			
60-62	126	19.4		3.8	6.3			
62-64	127	24.3		3.8	6.3			
64-66	128	22.1		3.7	6.1			
66-68	129	25.9		3.8	6.3			
68-71	130	19.1	17.6	3.3	5.4	.006	.16	N.D.
71-73	131	12.3		2.7	4.5			
73-76	132	14.5		2.9	4.8			
76-78	133	13.3		2.3	3.8			
78-81	134	13.8		3.2	5.3			
81-84	135	12.5	12.9	3.2	5.3			
84-87	136	14.3		3.6	5.9			
87-90	137	20.0		4.2	7.1			
90-93	138	15.6		3.2	5.3			
93-95	139	15.6		3.2	5.3			
95-98	140	15.4	17.5	3.7	6.1			
98-100	141	15.3		3.6	5.9			
100-102	142	15.6		3.2	5.3			
102-105	143	11.8		2.7	4.5			
105-107	144	17.2		3.0	4.9	.008	.23	≈.016
107-110	145	13.6	13.3	3.3	5.5			



Table 9. - Analyses of core samples from USGS drill hole L-4, Lakathah. Titanium (Ti) iron (Fe) and nickel (Ni) were determined by X-ray spectroscopy; titanium (TiO<sub>2</sub>) and iron (Fe(v)) in some samples were analyzed volumetrically; and copper (Cu) and phosphorous (P<sub>2</sub>O<sub>5</sub>) were determined by colorimetric analysis. Analyses by DGMR laboratory 1971. (cont'd.)

Depth (meters)	Sample number	Fe	Fe(v)	Ti	TiO <sub>2</sub>	Cu	P <sub>2</sub> O <sub>5</sub>	Ni
110-112	61146	15.5		3.7	6.1			
112-114	147	14.9		3.3	5.4			
114-117	148	15.2		2.8	4.7			
117-120	149	16.5		2.8	4.7			
120-123	150	15.6	14.8	3.2	5.3			
123-126	151	14.7		3.1	5.1			
126-128	152	14.2		2.6	4.3			
128-130	153	16.0		2.7	4.5			
130-132	154	17.5		2.7	4.5			
132-134	155	19.4	17.9	3.5	5.8			
134-136	156	19.3		3.4	5.7			
136-138	157	17.8		3.5	5.8	.003	1.15	N.D.
138-140	158	16.3		3.8	6.3			
140-142	159	19.4		3.1	5.1			
142-144	160	20.1	19.1	3.4	5.7			
144-146	161	15.5		3.2	5.3			
146-149	162	16.7		3.3	5.5			
149-151	163	16.0		3.2	5.3			
151-153	164	16.9		3.2	5.3			
153-155	165	29.6	28.5	4.9	8.2			
155-157	166	17.9		3.3	5.5			
157-160	167	15.7		3.3	5.5			
160-162	168	16.7		3.3	5.5			
162-164	169	16.1		3.3	5.4			
164-166	170	16.0	15.6	3.2	5.3			
166-168	171	24.6		4.1	6.8	.006	.21	~.004
168-169	172	16.1		3.5	5.9			
169-172	173	16.6		3.2	5.3			
172-174	174	17.1		3.1	5.1			
174-176	175	15.4	15.1	3.0	5.0			
176-178	176	15.8		3.0	5.0			
178-181	177	18.0		2.9	4.8			
181-183	178	14.3		3.2	5.3			
183-186	179	15.0		3.5	5.8			
186-188	180	16.1	16.8	3.2	5.3			
188-191	181	17.2		3.2	5.3			
191-193	182	18.0		3.5	5.8			
193-196	183	14.7		3.2	5.3			
196-199	184	12.7		3.0	5.0			
199-201	185	16.5	17.5	3.5	5.8	.003	.68	N.D.
201-204	186	18.6		4.4	7.3			
204-207	187	12.2		3.2	5.3			
207-210	188	12.9		3.2	5.3			
210-213	189	15.7		3.5	5.8			
213-216	190	16.3	16.6	3.8	6.3			

Table 9. - Analyses of core samples from USGS drill hole L-4, Lakathah. Titanium (Ti) iron (Fe) and nickel (No) were determined by X-ray spectroscopy; titanium (TiO<sub>2</sub>) and iron (Fe(v)) in some samples were analyzed volumetrically; and copper (Cu) and phosphorous (P<sub>2</sub>O<sub>5</sub>) were determined by colorimetric analysis. Analyses by DGMR laboratory 1971. (cont'd.)

Depth (meters)	Sample number	Fe	Fe(v)	Ti	TiO <sub>2</sub>	Cu	P <sub>2</sub> O <sub>5</sub>	Ni
216-219	61191	16.2		3.4	5.6			
219-222	192	16.1		3.3	5.4			
222-225	193	16.1		3.6	5.9			
225-228	194	13.9		3.1	5.2			
228-230	195	16.5	16.3	3.1	5.1	.006	.21	≈.012
230-232	196	14.6		3.1	5.2			
232-235	197	13.9		3.2	5.3			
235-237	198	13.1		3.7	6.2			
237-239	199	13.9		3.7	6.2			
239-242	200	18.2	17.8	3.6	5.9			
242-244	201	17.6		3.8	6.3			
244-246	202	22.4		3.7	6.2			
246-249	203	17.8		3.6	5.9			
249-251	204	14.0		3.6	6.0			
251-253	205	18.4	19.9	3.9	6.4			
253-255	206	20.1		4.0	6.6			
255-257	207	15.8		3.7	6.2			
257-259	208	18.9		3.4	5.7			
259-262	209	14.5		3.0	5.0	.004	.45	≈ .008
262-265	210	14.3	14.7	3.1	5.2			
265-268	211	13.3		3.6	6.0			
268-271	212	14.0		3.4	5.6			
271-274	213	13.2		3.6	6.0			
274-277	214	12.8		3.3	5.5			
277-279	215	16.5	17.5	4.0	6.6			
279-282	216	12.1		3.3	5.5			
282-284	217	18.5		4.0	6.6			
284-286	218	17.2		3.7	6.2			
286-288	219	15.4		3.7	6.1			
288-290	220	15.6	16.6	3.9	6.4			
290-292	221	15.8		4.1	6.8			
292-294	222	17.2		3.7	6.1			
294-296	223	17.3		3.6	6.0	.006	.17	≈.01
296-299	224	14.5		3.7	6.2			
299-301.5	225	14.1	12.0	3.7	6.2			
301.5-304	226	13.6		3.8	6.3			
304-307	227	15.1		3.8	6.3			
307-307.9	228	15.2		3.8	6.3			

### Origin of the Lakathah complex

The distribution of rock types of the layered Lakathah complex appears to have originated through a complicated multi-cyclical sequence of events involving crystal settling, crystal flotation, convection currents, and multiple intrusions. Comparison with Walton's (1951) findings at Blashke Island, Alaska, suggests that the components of the complex were emplaced at high temperatures. The lack of chilled margins at the contacts of the complex indicates that the wall rocks were also at high temperatures.

Martin considers that the complex was formed by magmatic crystal differentiation; crystallization was from the periphery inward, forming first the syenite ring, then the diorite-gabbro intermediate ring, and lastly the core. As a result, lighter elements moved outward and heavier elements were concentrated in the central core, similar to the segregation of minerals that gives rise to extended orbicular structures. The outer part is thought to have cooled first and the core last; volatiles were retained into late stages of crystallization, resulting in the formation of coarse-grained mineral aggregates such as the albitite-zoisite lenses, hornblendite bodies, pods and veins of magnetite and ilmenite, and saussuritic alteration zones.

Based on the layering, the cumulate textures, and apparent order of crystallization, Roberts and Stoesser prefer to interpret the ultramafic core and intermediate unit as a layered intrusion formed by gravity stratification of a cooling basaltic magma, and sheathed by the cogenetic syenite. The apparent

order of precipitation of the main cumulus phases is olivine, pyroxene, magnetite, and plagioclase. In the core unit olivine and pyroxene were the primary cumulus phases, although the concentration of magnetite in the core unit suggests that it was also in part a cumulus phase. In the core unit plagioclase is strictly a late stage intercumulus mineral. The boundary between the ultramafic core and the diorite-gabbro intermediate unit marks the appearance of plagioclase as a primary phase on the liquidus of the residual magma. The kaersutite entered either as the last intercumulus phase or was strictly a secondary mineral formed by deuteric alteration of the cumulus rock. The syenite does not appear to fit into the differentiation sequence which formed the layered rocks of the inner two units. The syenite surely is cogenetic with the layered intrusion portion of the complex and so possibly formed by partial melting in the lower part of the crust.

In a normal layered intrusion the ultramafic unit would be the basal layer and the gabbroic layer would overlie it. Figure 1 shows that the present geometry of these units is such that, if our interpretation is correct, they could not have formed in situ. To explain the observed spatial relations Roberts and Stoesser propose that the original layered intrusion along with the associated syenitic anatectic melt rose as a domal diapir, thus emplacing the lower ultramafic unit in the core of the diapir and the gabbroic unit on the flanks.

Crosscutting bodies of albitite-zoisite, hornblende,  
magnetite and ilmenite could have formed at any time during  
the intrusive cycle. Accumulated vesicles in the late-stage  
magmas account for saussuritization of the rocks and formation  
of late veinlike bodies of hornblende, mica and sodic  
plagioclase similar to those described by Upton (1967) from  
alkali pyroxenites in Africa.

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## APPENDIX I

### Location and other data on diamond drill holes, Lakathah complex

Drill hole # 1	South side of main wadi; 2.1 m north of base of rock bank in wadi; 6.2 m east of first tree; 40.5 m east of second tree.
Bearing	S.33°E. @ -45° Total Depth = 123.3 m lat 19°08.1'N., long 41°59.15'E. Elevation of collar 565.8 m.
Drill hole # 2	North side of main wadi against bank; 18.5 m southwest of small gulch; about 84 m N.18°W. of drill hole # 1.
Bearing	N.33°W. @ -44° Total Depth 258.8 m Elevation of collar 566.6 m
Drill hole # 3	North side of main wadi against bank; 25 m N.67°E. of drill hole # 2; 6.5 m NE of gulch; 92 m N.2°W. of drill hole # 1.
Bearing	S.30°E. @ -45° Total Depth = 307.5 m Elevation of collar 568.2 m
Drill hole # 4	In small tributary wadi above and south of main wadi, about 109 m S.31°E. of drill hole # 1.
Bearing	S.43°E. @ -45° Total Depth - 307.9 m Elevation of collar 579.0 m