DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Mineralogy of the microgranite at Jabal Tawlah,

Kingdom of Saudi Arabia

by

Mortimer H. Staatz[1] and Isabelle K. Brownfield[1]

Open-File Report 86-106

Report prepared for Ministry of Petroleum and Mineral Resources,
Deputy Ministry for Mineral Resources, Saudi Arabia

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

1/ U.S. Geological Survey, Denver, CO

1986

CONTENTS

ILLUSTRATIONS

TABLES

MINERALOGY OF THE MICROGRANITE AT JABAL TAWLAH, KINGDOM OF SAUDI ARABIA

by

Mortimer H. Staatz[1/] and Isabelle K. Brownfield[1/]

ABSTRACT

A study of the mineralogy of the microgranite at Jabal Tawlah was made principally to identify those minerals containing rare-earth elements, niobium, zirconium, tantalum, thorium, and uranium. The mineralized microgranite forms a sill, and samples are from both surface and drill holes. Rare-earth minerals are fairly common in the heavy mineral separates. Those identified in various separates are gagarinite, yttrofluorite, xenotime, and fergusonite. All are yttrium-group, rare-earth minerals. World-wide, gagarinite is a very uncommon mineral, and previously has been reported only from Umm al Birak in Saudi Arabia; the USSR; Norway; and the USA. At Jabal Tawlah, niobium and, to a much lesser extent, tantalum, have been found in columbite-tantalite and fergusonite. Zirconium occurs in zircon, which is the most common accessory mineral in the microgranite, and is found in almost every sample. Thorium is found in thorite. No uranium or tin minerals were noted in any of the separates. Autoradiographs show the distribution and size of the radioactive minerals.

Microprobe studies were made of six different minerals, ranging from one to 12 grains each. Studies of the rare-earth-mineral gagarinite indicated that the yttrium content varies from 22.3 to 32.3 percent. Other rare-earth minerals in this sample are principally yttrium-group lanthanides. Gagarinite contains only traces of niobium. The other rare-earth minerals xenotime and fergusonite were analysed for yttrium. Xenotime contained from 36 to 41 percent yttrium, and fergusonite contained 18 percent. The niobium content of columbite-tantalite was about 56 percent, and of fergusonite about 29 percent. Zircon principally is made of zirconium and silicon. Elemental substitution in this mineral is principally by hafnium, although in some grains there is minor substitution by yttrium, thorium, and uranium. The high zinc content of ilmenite at the surface suggests that sphalerite was formerly present.

Microcline occurs in grains several mm across, and other minerals generally are in much smaller grains. Most accessory minerals have diameters ranging from about 0.04 to 0.30 mm.

1/ U.S. Geological Survey, Denver, CO

INTRODUCTION

This report is a detailed study of a radioactive, mineralized microgranite intrusive at Jabal Tawlah (MODS 1635), at lat 28°14'28" N., long 35°23'30" E., in the Precambrian shield of Saudi Arabia, about 25 km north-northeast of Ash Sharma, in the Midyan district of northwest Hijaz (fig. 1). Microgranite forms most of Jabal Tawlah, a short, steep-sided ridge that lies along the north-northeast side of Wadi Tawlah. It is intruded into intermediate and mafic volcanic rocks, and forms an irregular, partly transgressive sill, the upper part of which shows lateral spreading to form a cap on the ridge (Drysdall, 1979; Douch and Drysdall, 1980). The sill has a length of about 320 m, is 60 m thick, and has a strike of 120°. The dip of the microgranite contact with volcanic rocks ranges from 45° to 80°. Xenoliths of basalt rock are common near the eastern end of the microgranite sill, and dikes of microgranite are in the basaltic rocks adjacent to the main intrusive body.

Three inclined drill holes have shown that the sill is continuous to at least 100 m below the present surface, but at greater depths it forms narrow dikes (Douch and Drysdall, 1982, p. 13-15). The analytical results of nine composite surface samples showed that the amounts of Zr, Y, Nb, and Zn in all samples was greater that 2000 parts per million (ppm) and that Ce, La, Th, U, Ta, and Sn also occurred in anomalously high amounts (Douch and Drysdall, 1982, table 2). Similar results were obtained on assays from three diamond drill holes (Douch and Drysdall, 1980, p. 13-15).

The purpose of the present study is to identify the mineral or minerals in which these potentially valuable elements may occur. Sources may consist of primary minerals in which the potentially valuable metal is a major part of that mineral, or they may be secondary minerals where the metal of interest substitutes for the primary element. An example of this latter type of substitution commonly occurs in thorite ($ThSiO_4$), where rare-earth elements may replace as much as 20 percent of that mineral (Staatz and others, 1976, p. 577). The present study was made primarily to aid possible future work on mineral dressing and metallurgical separation. The emphasis is on those minerals of economic importance, especially those containing yttrium, other rare-earth elements, niobium, tantalum, zinc, zirconium, uranium, and tin.

Samples used in this study came from five small core samples and one composite surface sample sent by A. R. Drysdall, and five surface samples and two bulk core samples collected by Staatz and Drysdall during a visit to the area in November, 1983 (table 1). The seven samples collected in 1983 were selected on the basis of their radioactivity, on the assumption that much of the radioactivity is due to thorium and, as thorium and rare-earth elements commonly occur in the same minerals, that these samples would be potential sites for the minerals sought for study. The assumption appears to be correct, as four primary rare-earth minerals were found in these samples. All but one of the surface samples, and three of the largest core samples, were used to provide mineral separations. Thin sections were made from core and surface samples, and some of the thin sections were used to make autoradiographs. Isolated grains from the mineral separations, and individual grains in thin sections, were used both in microprobe and scanning electron studies.

The heavy minerals found in the various samples studied are highly variable in mineralogy and grade. Minerals common in one sample may be absent or scant in the next. Hence, a more detailed sampling of both the surface and the drill core of the Jabal Tawlah microgranite would probably increase the number of minerals known, and give more detailed knowledge of their distribution.

The work on which this report was based was performed in accordance with a cooperative agreement between the U.S. Geological Survey and the Ministry of Petroleum and Mineral Resources.

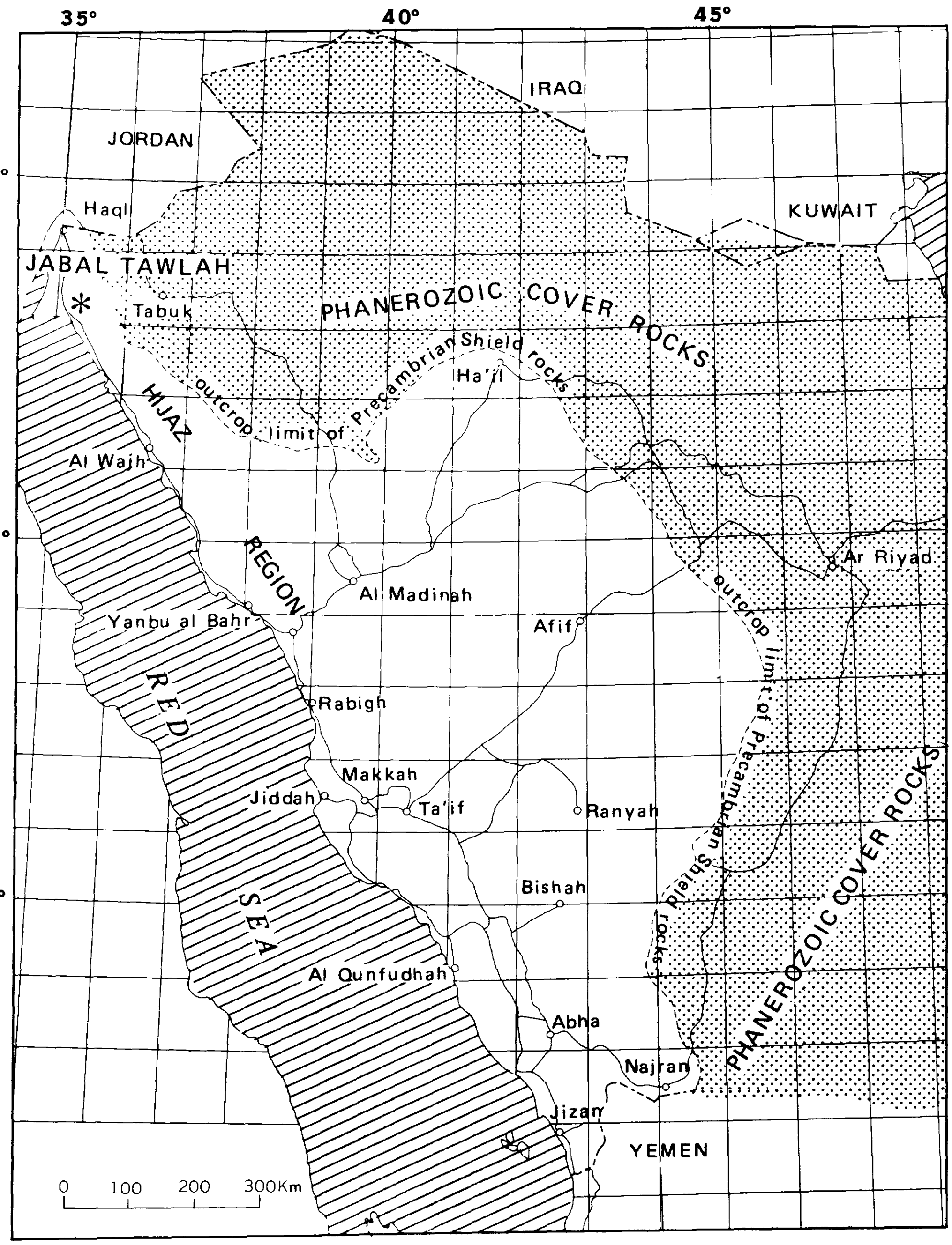

Figure 1.--*Location of Jabal Tawlah*

Table 1.--Location of samples used in the Jabal Tawlah study

Sample no.	Type of sample	Location	Remarks
311089	Drill core	Hole JT-2; depth 25.3 - 28.5 m	Only one piece of core from this interval
311096	do.	Hole JT-2; depth 46.3 - 49.45 m	do.
311103	do.	Hole JT-2; depth 68.4 - 71.4 m	do.
311106	do.	Hole JT-2; depth 77.3 - 80.3 m	do.
311143	do.	Hole JT-3; depth 36.0 - 39.0 m	do.
311157	do.	Hole JT-3; depth 78.0 - 81.0 m	do.
311159	do.	Hole JT-3; depth 84.50 - 87.50	do.
337000	Composite surface	Scattered over intrusive	
JT-1	Surface	Crest of ridge near west-northwest end	Rock veined with brown iron-oxide-bearing quartz veins
JT-2	do.	9 m below crest of ridge on its north side near the west-northwest end	Anomalously radioactive area
JT-3	do.	In microgranite just above contact with basalt on north side of ridge, approximately 100 m south-southeast from the west-northwest end of the sill	
JT-4	do.	North side of sill one of several granite dikes that parallel its eastern end	Much of sample includes volcanic wallrocks. One of the most radioactive areas
JT-5	do.	South side of sill near its eastern end	Average appearing granite for this part of the area
JT-8	Drill core	Hole JT-1; depth 63.9 - 72.3 m	Scattered pieces along this interval; most radioactive part of this drill hole
JT-9	do.	Hole JT-3; depth 78 - 87 m	do.

MINERAL-SEPARATION STUDIES

The minerals in six bulk samples and three drill core samples were separated and identified using the following methods: The samples were ground and sieved through a -20 mesh screen. The +100-20 mesh fraction was saved and material larger than +20 mesh was reground to a -20 mesh size. The sized fraction was washed to remove dust particles which make separation and identification difficult. The washed material was divided into a light and a heavy fraction using methylene iodide in a large separatory funnel. The light fraction made up about 80 to 95 percent of the various samples. The heavy fraction was spread out thinly on paper, and a magnetic fraction was separated using a hand magnet. The magnetic fraction was small in all fractions, and much of the material consisted of scrap iron from the grinders. The largest magnetic fractions were found in samples of the drill core, where the rock is not intensely oxidized. The remainder of the heavy fraction was then divided into four parts, on the basis of magnetic properties, by use of a Franz Isodynamic Separator. Each of the six fractions of the original sample was then examined under a binocular microscope, and the minerals were recorded. Any mineral not readily recognized was picked out of the sample and identified by X-ray diffraction pattern. Several of the diffraction patterns had few distinctive peaks but a broad, gentle sine curve. This type of pattern is commonly indicative of metamict minerals. Minerals with this type of pattern were repicked and heated in an oven to 1000°C for an hour to restore the mineral crystallinity. It was then re-X-rayed. Many of the heavy minerals were very fine grained, and individual pieces in the separates might consist of multiple grains of several different minerals. These composite grains were picked so that one particular mineral would predominate over the others. This would generally accent the diffraction peaks of that particular mineral. Multiple selections of the composite grains aided in identifying all the component parts. Some minerals in composite grains may not be identified if the particular mineral does not make up a large enough part of such a grain to make distinct X-ray diffraction peaks.

Minerals identified in the six surface and three drill-core samples are listed in table 2. The principal minerals in samples of the microgranite are plagioclase, microcline, and quartz. Mafic silicates are not common, but of these biotite and(or) phlogopite are the most common. Visual separation of the micas is difficult, and identification is based on differences in X-ray diffraction patterns. Although both patterns are similar, most biotites have a 2θ peak at about 18.0 degrees, and phlogopite does not. Zircon is found in all samples, and generally is the most abundant accessory mineral. It occurs in scattered, tiny, white, gray, or flesh-colored bipyramidal crystals. Rare-earth elements are fairly common in samples from Jabal Tawlah (Douch and Drysdall, 1980, p. 16), and rare-earth minerals were found in seven of the nine samples examined. The four rare-earth minerals are gagarinite [Na Ca Y)F,Cl$)_6$], yttrofluorite [(Ca,Y) $(F,O)_2$], xenotime [YPO_4], and fergusonite [(Y, Er, Ce, Fe) (Nb, Ta, Ti)O_4]. All are yttrium-rich minerals. Gagarinite was found in two samples (JT-1) and JT-4), where it occurs as a white, granular mineral. Although these grains appear monomineralic, they commonly consist of a mixture of similar-appearing white minerals; gagarinite, yttrofluorite, and plagioclase. The gagarinite and yttrofluorite differ chemically principally in the presence of sodium in the gagarinite. Gagarinite is an extremely rare mineral. It was first described from riebeckite-bearing albitized granitic massifs in Kazakhstan, where it is replaced by yttrofluorite, synchisite [(Ce. La) Ca $(CO_3)_2$], and tengerite [Ca Y_3 $(CO_3)_4(6H_2O)$ $3H_2O$] (Stepanov and Severov, 1961). This mineral has also been reported in miarolic cavities in an aegirine- and riebeckite-bearing granite from the Oslo region, Norway (Raade and Haug, 1980), in a riebeckite granite at Washington Pass, Washington, U.S.A, and in a riebeckite granite at Umm al Birak, Kingdom of Saudi Arabia (Staatz and Brownfield, 1985). The X-ray pattern, and data obtained from the microprobe, are an excellent fit with the published data for this mineral.

Table 2.--Minerals identified in mineral separates from Jabal Tawlah

[*Identified by X-ray]

Sample no.	Mineralogy - relative amount Large	Medium	Small	Rare
JT-1	Microcline quartz,* plagioclase*	Limonite zircon,* fergusonite*	Hematite,* yttrofluorite* gagarinite*	Calcite, magnetite
JT-2	Microcline, plagioclase*	Ilmenite,* yttrofluorite*	Hematite, siderite,* zircon,* sericite	Calcite, limonite
JT-3	Microcline, plagioclase*	Quartz,* columbite-tantalite,* xenotime*	Hematite,* goethite,* zircon	Calcite, magnetite, thorite
JT-4	Microcline, plagioclase,*	Zircon,* biotite	Hematite, ilmenite,* quartz,* yttrofluorite,* xenotime* gagarinite*	Calcite, magnetite, thorite
JT-5	Microcline, plagioclase*	Quartz,* phlogopite,* zircon*	Hematite, xenotime*	Calcite, magnetite, MnO mineral, limonite, thorite
JT-8 Drill core hole #1	Microcline, quartz, plagioclase*	Zircon,* sphalerite*	Limonite, phlogopite ilmenite, thorite,* yttrofluorite*	Magnetite, pyrite, galena
JT-9 Drill core hole #3	White feldspar, (plagioclase*)	Phlogopite,* ilmenite,* zircon*	Pyrite, fluorite, quartz,* siderite,* xenotime,* thorite*	Galena
311157	Microcline, quartz*	Fluorite, siderite,* zircon,* ilmenite*	Biotite* chlorite, hematite, columbite-tantalite*	Magnetite, chrysocolla (?), galena, thorite
337000	Quartz,* plagioclase,* microcline	Zircon*	Sericite,* fluorite	Magnetite, pyrite

Yttrofluorite was found in four of the samples. It is a white, granular mineral. Pale-purple fluorite also occurs in a number of samples. These two minerals are similar both chemically and structurally. Yttrium substitutes for calcium in varying amounts and forms an isomorphous series ranging from fluorite through yttrium to yttrofluorite (Adams and Sharp, 1972, p. C65-C68). The increase of yttrium in this sequence also brings an increase in specific gravity, refractive index, and cell size. Pure CaF_2 floats easily in methylene iodide, but yttrofluorite readily sinks. The X-ray diffraction pattern of both fluorite and yttrofluorite are similar in number of peaks, their spacing, and their relative heights. They differ, however, in their position. The increase in cell size shifts the entire pattern to the right. Using the diffraction pattern obtained for yttrofluorite in sample JT-2, the cell size was found to be about 5.53 angstroms. A comparison with a plot of cell size versus yttrium content, published by Adams and Sharp (1972, p. C67) indicates that the yttrofluorite contains about 15 percent yttrium. Xenotime is another common yttrium mineral in the microgranites. It occurs as tiny, white, gray, or pale-brown tetragonal bipyramids. It may be more wide-spread than noted in table 2, as the small size, color, and crystal shape make it difficult to distinguish from similar-appearing zircon crystals. Fergusonite was found only in sample JT-1, where it occurs as small, brown, shiny crystals intermixed with plagioclase, gagarinite, quartz, and zircon. The fergusonite was found to be partially metamict, therefore it was necessary to heat the mineral in order to obtain a satisfactory pattern. This resulted in a pattern that belonged to Lima De Faria's F_I phase (de Faria, 1964, p. 38), which he believed to be the original fergusonite structure. Some rare-earth minerals may also occur in thorite.

Two primary niobium minerals were identified in samples: fergusonite and columbite-tantalite. Both are fine grained, and were found in separate samples. Most of the thorium found in the microgranite probably occurs in dark-reddish-brown, shiny thorite. This mineral was identified in six of the samples although in minor amounts. The sulfides sphalerite, pyrite, and galena were found principally in the drill core. Sphalerite is fairly abundant in some samples. The sulfides may have been oxidized and leached at the surface. Hematite and limonite are common minerals in rare-earth mineral deposits in granites, as at Jabal Tawlah, but the presence at Jabal Tawlah of equal amounts of ilmenite is not common elsewhere.

Other minerals noted in the samples are siderite, magnetite, calcite, a manganese oxide mineral, and chysocolla. Although magnetite and calcite are found in most samples, they are rare in all of them.

AUTORADIOGRAPHS

The distribution and the size of various radioactive minerals can be determined by making an autoradiograph. This is done by cutting and polishing a rock surface or by using an uncovered thin section. The polished surface is placed on a film and, as time passes, light spots are produced on the film by radiation from any radioactive mineral that may be present. The system applied in this work is called a radioluxograph, and uses a zinc-sulfide phosphor screen placed between the rock and the film. This method, which was described by Dooley (1958), enhances the brightness of the spots and shortens the amount of time needed to make a good exposure.

Fifteen autoradiographs were made, six of which are shown in figure 2. All samples were exposed for 18 hours. Radiation from either uranium or thorium minerals will cause bright spots on the autoradiographs. The brightness of various spots is not only a function of the total radioactivity, but also the distance between the radioactive mineral and the exposed surface, and the amount of exposure time. Where the amount

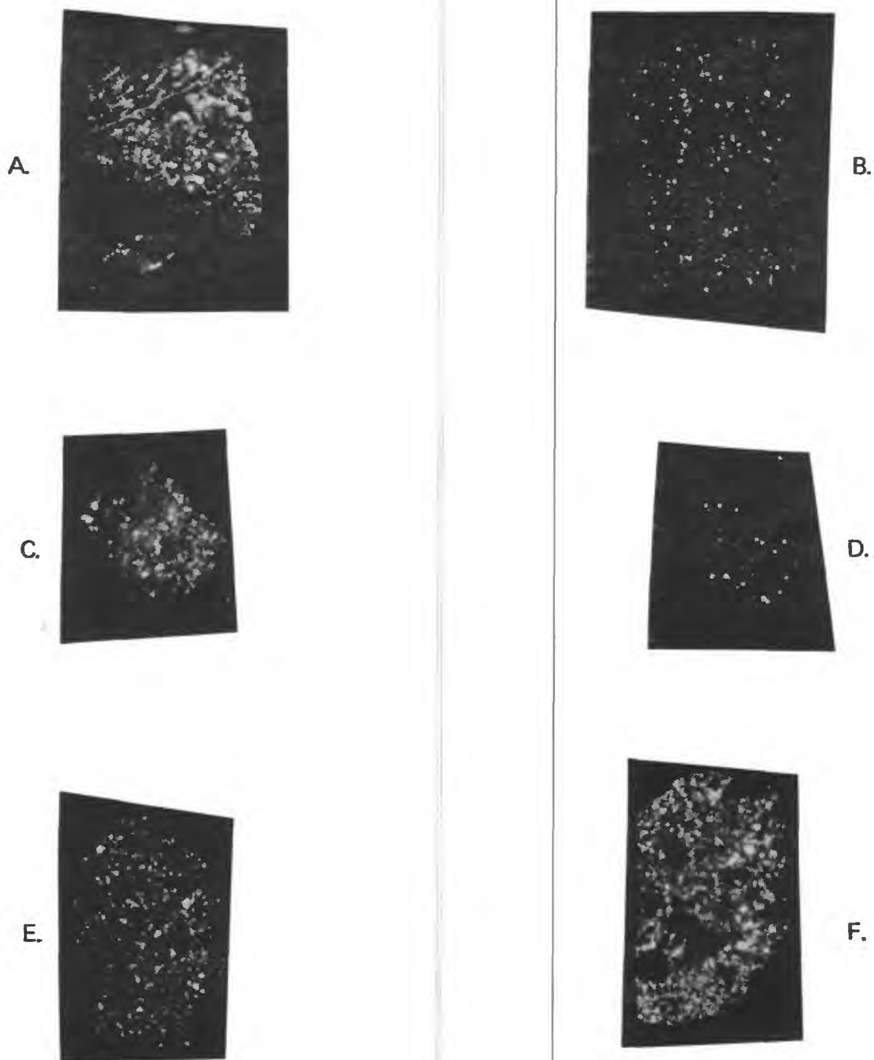

Figure 2.--*Autoradiographs of Jabal Tawlah rock samples. Light spots indicate radioactive minerals. Exposure time for all samples is 18 hours.* **A**, *sample no. 311040;* **B**, *sample no. 311038;* **C**, *sample no. 337000;* **D**, *sample no. 311157;* **E**, *sample no. JT-2; and* **F**, *sample no. JT-4.*

of uranium or thorium in a mineral is quite small, the radiation may barely register at the time-setting used. The six samples chosen were those showing the most radiation. One of the samples (not shown) did not emit radiation, and several were only slightly radioactive. The location of the more weakly radioactive minerals can be enhanced by increasing the time of exposure. Some minerals, such as limonite, apparently absorb into their structure small amounts of thorium or uranium. The small amounts in these minerals take longer exposure time than given the samples in this study. Samples with the most and brightest points are JT-4, 337000, and 311040. Thorite has been noted in the heavy mineral separates from these samples, and the larger bright spots in these two autoradiographs are probably due to this mineral. Points of lesser intensity may be areas where uranium and(or) thorium do not form primary minerals, but proxy for other elements. This commonly happens in some rare-earth minerals, where thorium proxies for some of the rare-earth elements. Distribution of the radioactive minerals in each autoradiograph is fairly uniform. However, large differences occur between samples from different localities, as the microgranite may vary from rock having fairly abundant radioactive minerals to one having almost none.

An approximation of the size of the various radioactive minerals can be be determined from the autoradiographs. The apparent size of the radioactive mineral may be larger that the actual size. This may be due to either one image being produced by two adjacent radioactive minerals or, the mineral crystal is unusually radioactive, the apparent size may be increased by a bright halo that extends beyond the actual mineral. The size of the halo is dependant on the size of the radioactive mineral, its total radioactivity, and the amount of exposure time used in making the autoradiograph.

INDIVIDUAL-GRAIN STUDIES

Individual grains of several minerals were investigated in order to determine the presence of minor elements. Many elements, especially those having similar atomic radii, substitute for other elements in various minerals. Thus, thorium commonly substitutes for rare-earth elements in monazite, and niobium commonly substitutes for titanium in rutile or brookite. In addition, apparently monomineralic grains may contain tiny inclusions of various other minerals. To understand the types of substitution in the microgranite at Jabal Tawlah, various minerals from the heavy mineral separates were polished and examined by one of three systems. One is the scanning electron microscope (SEM), with an attached energy dispersive system (EDS) of X-ray fluorescence that can determine semiquantitative ratios of elements. The second system is the EDS attached to the microprobe; this obtains semiquantitative results that are accurate to within 10 percent of the obtained figure. The third system is the electron microprobe that is quantitative. Analyses are much easier and more quickly obtained using either semiquantitative system. The quantitative system, the electron microprobe, takes about a day to set up a new data set, and another day to run, but the semiquantative data can be set up and run in less than an hour. This study combined the semiquantitative and the quantitative methods, using a semiquantative system for preliminary examination of all minerals, with elimination of certain minerals as possible sources of certain elements, and to determine approximate contents of some specific elements in some minerals. The choice of the semiquantitative method was determined by the availability of an instrument at a specific time. The quantitative method was used in the study of zircon, gagarinite, and fergusonite.

Zircon is the most common accessory mineral of potential economic interest. The mineral is found in small grains in all samples, and in most samples is the most abundant accessory mineral. Zircon from six different samples was analysed quantitatively by the electron microprobe (table 3) using from one to three grains from each sample locality. Totals for all analyses were near 100 percent, indicating that analyses were made for all important elements, and that the reliability of the analyses was good. Hafnium is the most important non-primary element, and the HfO_2 content of 12 analyses ranged from 1.08 to 3.82 percent of the various zircons. Zircon commonly contains anomalous amounts of thorium and uranium. Results from the zircons from Jabal Tawlah were erratic. Eight of the samples contained from 0.09 to 1.44 percent ThO_2, and from 0.14 to 0.28 percent UO_2. The remaining four samples contained very little of either oxide. Rare-earth elements also occur in the zircon, and yttrium is the most important. The Y_2O_3 content of the zircons was found to be highly variable, ranging from 0.00 to 0.66 percent of the total mineral. Other rare-earth elements may be present, but none were indicated on EDS.

Several rare-earth minerals are present in the Jabal Tawlah microgranite, and gagarinite is one of the most interesting. This mineral was identified in samples JT-1 and JT-4. Separate analyses were made of four grains in JT-1, and of eight grains in JT-4 (table 4). The formula of this mineral [Na Ca Y $(F,Cl)_6$] indicates that it can be either a fluoride or a chloride, but analyses in this study show that the Jabal Tawlah gagarinite has very little chloride. In JT-4, the gagarinite is intergrown with yttrofluorite and plagioclase (fig. 3, A). The total of all elements analysed ranges from 82.37 to 93.21 percent. Missing elements are mainly the yttrium-group rare-earth elements erbium and ytterbium, as demonstrated by the EDS.

The rare earth elements are commonly segregated in nature into yttrium-group and cerium-group rare-earth elements. The former comprises yttrium and the heavier lanthanides, those having atomic numbers from 64 to 71. The cerium-group rare-earth elements are the lighter lanthanides, those having atomic numbers from 57 to 63.

Gagarinite is principally a yttrium-group mineral, and cerium-group rare-earth minerals are not common, as can be seen from the cerium content of the 12 gagarinite analyses, which range from 0.00 to 1.19 percent of the total mineral. Valid readings for erbium and ytterbium are difficult to obtain when dysprosium is present, because the spectra of these elements overlap and they cannot accurately be separated for quantitative analysis. One of the gagarinite grains contained as much as 0.17 percent thorium but, in most grains, this element was absent. The gagarinite does not contain niobium, even where adjacent to a niobium-bearing mineral (for example, in JT-1) and where the gagarinite is intergrown with fergusonite.

A.

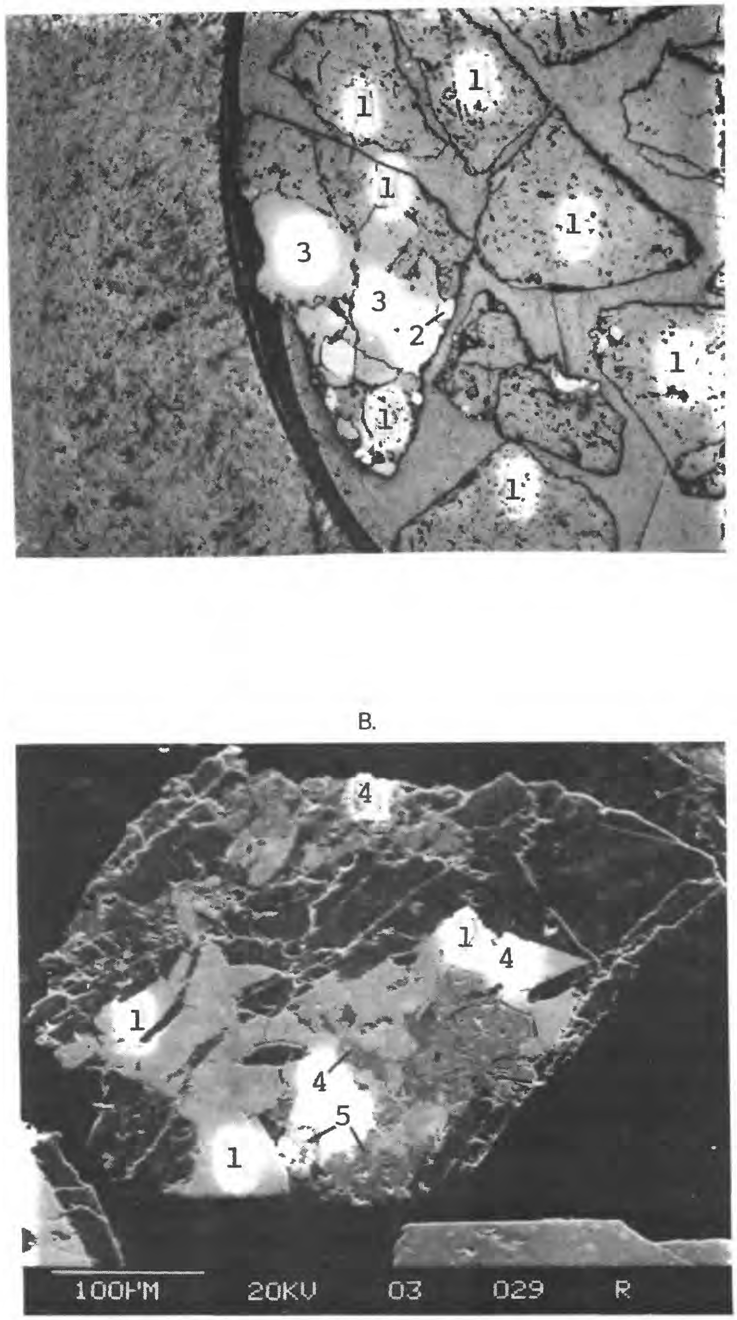

Figure 3.--*Photographs of mineral grains from heavy mineral separates.* **A**. *Gagarinite (1) sample JT-4. In grain to left is intergrown with yttrofluorite (2) and plagioclase (3). Picture is a photomicrograph. Large grain to left is 0.05 mm across.* **B**. *Compound grain made up of fergusonite (1), plagioclase (2), quartz (3), zircon (4), and ilmenite (5). Picture taken with a scanning electron microscope. Line at base is 100 microns long.*

Table 3.--Electron microprobe analysis of zircon, in percent, from Jabal Tawlah

Sample No.	Individual grains tested in same samples	ZrO_2	SiO_2	HfO_2	ThO_2	UO_2	Y_2O_3	Total
311103	a	68.31	32.31	1.08	.11	.16	.66	102.63
311143	a	63.47	32.52	1.64	.26	.19	.49	98.57
do.	b	63.71	32.24	3.17	.12	.19	.00	99.43
311157	a	64.21	30.13	2.09	.26	.15	.55	97.39
do.	b	66.72	31.82	2.22	1.44	.28	.38	102.86
311159	a	63.77	32.50	2.03	.00	.00	.06	98.36
do.	b	61.69	31.69	3.82	.00	.00	.02	97.22
337000	a	63.16	32.44	2.89	.00	.00	.02	98.51
do.	b	62.12	32.02	2.12	.08	.00	.32	96.66
JT9	a	61.60	32.30	2.15	.42	.16	.20	96.83
do.	b	62.74	32.20	2.23	.09	.14	.11	97.51
do.	c	61.99	32.50	2.35	.28	.15	.03	97.30

Table 4.--Partial microprobe analysis of gagarinite, in percent, from Jabal Tawlah

Sample No.	Specimen No.	Ca	Na	Y	Dy	Ce	F	Cl	Nb	Th	Total
JT1	a	12.22	2.68	32.25	2.66	0.03	43.20	0.00	0.00	0.17	93.21
JT1	b	11.26	2.70	31.71	2.63	.02	42.63	.00	.02	.00	90.97
JT1	c	11.78	2.72	31.23	2.61	.00	43.06	.00	.00	.00	91.40
JT1	d	11.84	2.68	31.85	2.63	.02	43.82	.00	.00	.02	92.86
JT4	a	6.56	5.91	29.62	5.38	.10	42.00	.06	.00	.00	89.63
JT4	b	14.26	1.97	22.26	2.18	1.19	42.06	.07	.00	.10	84.09
JT4	c	11.11	3.10	28.11	3.66	.39	42.33	.00	.00	.00	88.70
JT4	d	9.24	3.55	28.66	3.50	1.03	41.67	.00	.00	.00	87.65
JT4	e	6.17	3.76	25.61	8.47	.01	38.27	.00	.06	.02	82.37
JT4	f	9.56	3.31	29.00	3.32	.27	43.97	.01	.00	.11	89.55
JT4	g	6.54	4.17	29.85	4.85	.21	42.01	.00	.00	.00	87.63
JT4	h	10.40	3.15	26.42	3.56	.42	42.95	.00	.02	.00	86.92

A partial quantitative analysis was made on the major constituents in one grain of fergusonite associated with microcline and gagarinite in sample JT-1. Grains of fergusonite intergrown with plagioclase are illustrated in figure 3, B. The grain analysed contained 41.41 percent Nb_2O_5; 23.30 percent Y_2O_3; 5.94 percent Dy_2O_3; and 0.61 percent ThO_2. Examination of this grain with the SEM indicates that it also contains small amounts of erbium, ytterbium, and tantalum.

Three other minerals were semiquantitatively analysed using the EDS system (table 5). They are xenotime, columbite-tantalite, and ilmenite. Xenotime is an important yttrium-group rare-earth mineral that contains the most Y_2O_3 of any mineral in the Jabal Tawlah microgranite. Alternatively, the niobium-rich columbite-tantalite separated from the same sample contains no detectable yttrium-group rare-earth minerals. The limit of detection is between one and two percent, however, for the semiquantitative, EDS method used to produce table 5. The third mineral, ilmenite, was tested primarily for niobium. The elements, Ti and Nb, have similar atomic radii, and commonly substitute for one another. No Nb was found within the limit of detection. More than 5 percent zinc was found in the ilmenite. Zinc probably replaces titanium in the ilmenite, because they have a similar atomic radius. Sphalerite was found in a sample from the drill core, and 5 percent zinc is found in ilmenite, but no sphalerite was seen in the surface samples. It probably was present at the surface, but was subsequently oxidized and leached out of the near-surface rocks.

GRAIN-SIZE STUDIES

The microgranite at Jabal Tawlah has a variable grain size, even among the common leucocratic minerals. The sizes of the various minerals in this granite were measured with a micrometer ocular on thin sections. The largest grains are those of microcline, which tend to form equant grains. This mineral ranges in size from about 0.25 by 0.30 mm to 2.5 by 3.0 mm. Quartz grains are smaller and many have dimensions of about 0.04 by 0.045 mm to 0.32 by 0.32 mm. Identifiable grains of other minerals are uncommon; the two rare-earth minerals noted in thin sections are xenotime and yttrofluorite. The xenotime also occurs in small bipyramids. It ranges in size from about 0.25 by 0.25 mm. Quartz, although common in some samples, is almost absent in others. Plagioclase is commonly found in clots of small grains that are about 0.30 by 0.35 mm in cross-section. In long dimension, the plagioclase may be as much as 0.70 mm. Accessory and various possible ore minerals tend to form smaller crystals. Ilmenite, which makes up most of the opaques in the thin sections studied, occurs in aggregates of anhedral grains. Individual grains within these aggregates range from about 0.12 by 0.12 mm to 1.5 by 2.2 mm. Zircon in the granite tends to form small, squat bipyramids that range in size from about 0.05 by 0.07 mm to 0.22 by 0.45 mm. Yttrofluorite is found principally in narrow veinlets cutting across the microgranite. Individual grains in these veinlets range from 0.10 by 0.10 mm to 0.20 by 0.25 mm. The only other accessory minerals identified in these thin sections are siderite and sphalerite. The few small grains of siderite observed range from 0.04 by 0.05 mm to 0.07 by 0.09 mm. The sphalerite grains vary in size from 0.09 by 0.11 mm to 0.18 by 0.22 mm.

Table 5.--Semiquantitative microprobe analyses, in percent, of various minerals at Jabal Tawlah

[n.d. = not determined]

Mineral	Sample No.	Specimen No.	Y_2O_3	Dy_2O_3	Er_2O_3	Yb_2O_3	P_2O_5	FeO	MnO	Nb_2O_5	Ta_2O_5	TiO_2	ZnO
Xenotime	JT-3	a	46	4.2	6.1	11	32	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
do.	JT-3	b	50	3.5	5.6	8.5	33	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
do.	JT-3	c	52	5.4	6.5	10	26	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Columbite-tantalite	JT-3	d	n.d.	n.d.	n.d.	n.d.	n.d.	15	2.4	79	2.4	1.5	n.d.
do.	JT-3	e	n.d.	n.d.	n.d.	n.d.	n.d.	11	5.6	79	2.8	2.0	n.d.
do.	311157	a	n.d.	n.d.	n.d.	n.d.	n.d.	15	5.8	80	n.d.	n.d.	n.d.
Ilmenite	JT-2	a	n.d.	n.d.	n.d.	n.d.	n.d.	43	1.2	n.d.	n.d.	51	5.6

DATA STORAGE

Petrographic descriptions, sample locations, thin sections, and results of chemical analyses are stored in Data-File USGS-DF-04-4 (Staatz and Brownfield, 1984) in the Jeddah office of the U.S. Geological Survey Saudi Arabian Mission.

MODS entry number 1635 has been updated to include this report.

REFERENCES CITED

Adams, J. W., and Sharp, W. N., 1972, Thalenite and allanite derived from yttrofluorite in the White Cloud pegmatite, South Platte area, Colorado: U.S. Geological Survey Professional Paper 800-C, p. C63-C69.

Dooley, J. R., Jr., 1958, The radioluxograph: a fast, simple type of autoradiograph: Second United Nations International Conference of Peaceful Uses of Atomic Energy, v. 3, p. 550-553.

Douch, C. J., and Drysdall, A.R., 1980, The geology and resource potential of the Jabal Tawlah radioactive microgranite, N.W. Hijaz, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Open-File Report DGMR 694, 34p.

Drysdall, A. R., 1979, Petrogenesis of two peralkaline microgranites from the N.W. Hijaz; some considerations relative to further prospecting: Saudi Arabian Directorate General of Mineral Resources Open-File Report DGMR 705, 51 p.

----------, 1982, Jabal Tawlah prospect (28/35C): revised estimate of resource potential: Saudi Arabian Directorate General of Mineral Resources Open-File Report DGMR-OF-02-8, 15 p.

Lima de Faria, J., 1964, Identification of metamict minerals by X-ray powder photographs: Lisbon, Junta de Investigacoes do Ultramar, Estudos, Ensaios e Documentos, No. 112. 130 p.

Raade, Gunnar, and Haug, Jan, 1980, Rare fluorides from a soda granite in the Oslo region, Norway: Mineralogical Record, v. 4, no. 5, p. 83-91.

Staatz, M. H., Adams, J. W., and Wahlberg, J. S., 1976, Brown, yellow, orange, and greenish-black thorites from the Seerie pegmatite, Colorado: U.S. Geological Survey Journal of Research, v. 4, no, 5, p. 757-582.

Staatz, M. H., and Brownfield, I. K., 1984, Mineralogy of the microgranite at Umm al Birak, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Open-File Report USGS-OF-04-59, 14 p. Also, 1986, U.S. Geological Survey Open-File Report 86-106.

Stepanov, A. V., and Severov, E. A., 1961, Gagarinite, a new rare-earth mineral: Doklady Akad. Nauk.,S.S.S.R., v. 141, p. 954-957.