DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Mineralogy of drill cores from Jabal Sa'id

Kingdom of Saudi Arabia

by

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Open-File Report 85-12

Prepared for the Ministry of Petroleum and Mineral Resources, Deputy Ministry for Mineral Resources, Jiddah, Kingdom of 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 80225

1985

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MINERALOGY OF DRILL CORES FROM JABAL SA'ID, KINGDOM OF SAUDI ARABIA

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ABSTRACT

The mineralogy of three drill cores from the apogranite at Jabal Sa'id was determined principally to identify those minerals containing rare earths, niobium, tantalum, thorium, zirconium, and tin. Heavy mineral studies of two other drill cores indicate that the deposit is enriched in rare earths. The principal rare earth minerals are bastnaesite and doverite; other rare earth minerals include monazite and synchisite. Niobium occurs in pyrochlore; zirconium is present in zircon. Thorium is found principally in thorite and secondarily in thorianite. Autoradiographs show the distribution and relative sizes of several radioactive minerals.

Microprobe studies of grains of eight different minerals indicated that significant elemental substitution took place in most of them. The rare earth metals cerium and lanthanum occur in significant amounts in pyrochlore; yttrium is abundant in doverite and is also present in bastnaesite, thorite, and zircon. Niobium substitutes for titanium in anatase and brookite, and some tantalum occurs with the niobium in pyrochlore. Minor amounts of thorium are found in bastnaesite, doverite, and zircon. Small amounts of uranium mostly occur with the thorium in thorite. Tin minerals were not found in any of the samples, but small and variable amounts of this element occur in bastnaesite, doverite, hematite, and zircon.

The potential ore minerals in the apogranite commonly occur along the grain boundaries of the larger quartz and feldspar. Most of the ore minerals have diameters in the range 0.020 to 0.20 mm.

INTRODUCTION

Mineral studies of the mineralized alkalic apogranite from Jabal Sa'id have been performed primarily to aid in possible future work on mineral dressing and metallurgical separation; therefore, emphasis is on those minerals of possible economic importance, particularly on those containing rare earths, niobium, tantalum, zirconium, uranium, and tin. The apogranite is a late phase of an arfvedsonite granite; it forms a sheet with exposed dimensions of 1500 x 150 m along the southern margin of the

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arfvedsonite granite (Turkistany and Ramsay, 1982). Five drill holes, ranging in depth from 98 to 123 m, were drilled in the spring of 1982 and logged by Damien Hackett (written commun., 1982). Samples from these holes were analyzed for Nb, Ta, Sn, La, Ce, Th, and U. The present mineralogic study was on splits of the cores obtained from these holes (table 1). Two types of samples were studied. One type of sample consisted of small pieces of core taken from two intervals in the first three holes. The other type was bulk, samples of the core taken at eight intervals in the first two holes. The bulk samples were used for making mineral separations. Core samples were used principally for thin sections, scanning electron microscope studies, autoradiographs, and microprobe studies. Some of the core samples were also used for mineral separations, where either the analytical data or thin sections indicated a mineral of interest.

The deposit is principally enriched in rare earths; rare earth deposits tend to be highly variable in grade and mineralogy. Thus, minerals common in one sample may be absent or quite scarce in another sample a short distance away. For this reason we do not feel that there was a sufficient number of samples, especially bulk samples, to provide a complete list of the minerals in this deposit.

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.

MINERAL SEPARATION STUDIES

The minerals in the bulk samples and select pieces of core were separated and identified in the following manner. The sample was ground and sieved through a -20 mesh screen. The +100 mesh -20 mesh fraction was saved and any oversize material was reground to a -20 mesh. The size fraction was washed to remove dust particles, which cling to the grains and which make identification difficult. The cleaned and sized material was divided into heavy and light fractions by use of methylene iodide in a separatory funnel. The light fraction made up more than 90 percent of all samples. The heavy fraction was spread out, and a magnetic fraction was separated from it using a hand magnet. This magnetic fraction was very small in all the samples from Jabal Sa'id and consisted primarily of scrap iron from the grinders and small amounts of magnetite. The rest of the heavy fraction was then divided, by use of a Frantz Isodynamic Separator, into four parts on the basis of magnetic properties. Each of the six fractions of the original sample was examined under a binocular microspcope, and the minerals in each fraction recorded. Any mineral not readily identifiable was picked out of the sample and identified by its powder X-ray diffraction pattern. In a few minerals where the unknown was too sparse to give a discrete powder X-ray

Table 1.--Drill hole numbers and depths of core samples from Jabal Sa'id

Sample no.	Type of sample	Drill hole no.	Depth of sample (meters)
336847	Bulk	JSA1	20-22
336848	do.	do.	26-28
336849	do.	do.	4-6
336850	do.	JSA2	30-31
336851	do.	do.	8-10
336852	do.	do.	66-68
336853	do.	do.	86-88
336854	do.	do.	36-37
336825	Individual piece	JSA1	20.5
336826	do.	do.	70.5
336827	do.	do.	43.0
336828	do.	do.	49.0
336829	do.	do.	41.0
336830	do.	do.	64.0
336831	do.	JSA2	12.8
336832	do.	do.	13.5
336833	do.	do.	15.0
336834	do.	do.	85.0
336835	do.	do.	18.0
336837	do.	do.	26.0
336838	do.	do.	31.0
336839	do.	do.	66.0
336840	do.	do.	67.0
336841	do.	do.	68.0
336842	Individual piece	JSA3	48.0
336843	do.	do.	62.0
336844	do.	do.	130.0
336845	do.	do.	135.0
336846	do.	do.	139.0

pattern, tiny single crystals were ground and mounted in a Gandolfi camera and an X-ray diffraction pattern was made using a six-hour exposure on film.

Some minerals, however, may be present in a sample and may not be identified. This can be due to the grain size of the mineral being less than 100 mesh and going into the fines or to occurrence of the mineral in composite grains with other minerals. In the latter case, if enough of these composite grains are present, X-ray patterns may reveal the mineral identity. The mineral may be brittle and disappear entirely into the fines or it can be disguised by iron or manganese oxides. Generally, however, if present in several samples, the mineral may be identified.

Minerals identified in eight bulk and four core samples from Jabal Sa'id are listed in table 2. The host rock for the mineralization, as previously noted, is an apogranite, and thus quartz and two feldspars are the principal minerals. In the samples studied, dark-red, granular and specular hematite are common. Hematite might be formed as a result of alteration of such minerals as amphiboles or pyroxenes, and(or) it might be of primary origin. Rare earth minerals are common and were noted in all but one sample. Four primary rare earth minerals were identified: bastnaesite ((Ce, La) (CO_3) F), doverite ((Y, Ce) Ca, $CO_3)_2$ F), monazite ((Ce, La, Nd, Th) PO_4), and synchysite ((Ce, La) Ca $(CO_3)_2F$). Most of the rare earths, however, occur in bastnaesite and doverite. Bastnaesite is the principal cerium (or light rare-earth) group mineral. Some rare earths also are found in thorite and zircon. The principal niobium mineral is pyrochlore, which was found in four samples. This mineral generally occurs in tiny yellow crystals, although in some samples it forms brown to yellow granular masses. Thorium is found chiefly in thorite, which is probably more common than indicated in table 1, as its color and texture can commonly be confused with that of hematite. A true representation can be derived from the autoradiographs, which show the sites and general radioactivity of various radioactive minerals. Most of the bright spots are due to thorite, although a few are due to thorianite grains. Zirconium is found in zircon in 10 of the 12 samples examined; it is a fairly ubiquitous accessory in much of the apogranite. Other minerals noted in the samples are: sericite, magnetite, calcite, anatase, biotite, brookite, clay, flourite, limonite, pyrite, rutile, siderite, sphalerite, and sphene. Light green aggregates of scaly sericite are fairly common in many samples. Magnetite and calcite are found in many samples, but are rare in all of them. The rest of these minerals are found in only a few samples and are generally not common in any of them.

Table 2.--Minerals identified in heavy mineral separates from Jabal Sa'id
(*Identified by X-ray diffractions)

Sample no.	Mineralogy - relative amounts: Large	Medium	Small	Rare
	Bulk samples			
336847	quartz* pink feldspar sericite	red granular hematite* bastnaesite* zircon*	specularite limonite brookite*	magnetite sphene?*
336848	quartz* white feldspar	red granular hematite zircon* pyrochlore*	rutile* anatase*	magnetite calcite
336849	quartz* sericite	red granular hematite* bastnaesite*	brookite* zircon* thorite* thorianite-uraninite*	specularite purple fluorite
336850	quartz* pink feldspar (microcline)	red granular hematite* bastnaesite* doverite*	specularite zircon*	calcite brookite*
336851	quartz* pink feldspar	sericite red granular hematite bastnaesite* zircon*	specularite	magnetite calcite thorite* brookite*
336852	pink feldspar quartz*	red granular hematite* zircon*	bastnaesite*	magnetite calcite pyrochlore*
336853	quartz* pink feldspar (microcline)	red granular hematite* sericite* doverite zircon*		calcite magnetite
336854	quartz* pink potassium feldspar*	sericite red granular hematite zircon*	bastnaesite* doverite*	magnetite thorite anatase* rutile*
JS-1	quartz* white feldspar	hematite* thorite*	doverite*	calcite magnetite
JS-2	quartz* pink feldspar	hematite* pyrochlore* bastnaesite* doverite*	thorite*	calcite magnetite anatase*
JS-3	pink feldspar quartz*	hematite thorite*	sericite brookite* zircon* pyrocholore*	magnetite calcite
JS-4	quartz* pink feldspar	hematite* pyrochlore* doverite*	brookite*	calcite
	Core samples			
336826	quartz* white feldspar (microcline)	red granular hematite doverite* bastnaesite* monazite*	biotite	magnetite pyrite
336834	quartz	white feldspar* (potassium feldspar) red granular hematite sericite	zircon* bastnaesite* clay mineral*	biotite magnetite pyrochlore*
336843	pink potassium feldspar quartz	red granular hematite* specularite* zircon*	sericite pyrochlore*	magnetite pyrite
336844	pink potassium feldspar quartz*	sericite white plagioclase siderite*	synchesite* rutile*	calcite magnetite spalerite*

AUTORADIOGRAPHS

The distribution as well as the size of various radioactive minerals can be determined by making an autoradiograph. This is done by cutting and polishing a surface on the rock and placing it on a film so that the radiation from various radioactive minerals produces light spots on the developed film. The system which we use is called a radioluxograph, which 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 the image. Eighteen autoradiographs were made, six of which are shown in figure 1. All samples were exposed for at least 18 hours. The radiation from both uranium and thorium minerals will cause bright spots on an autoradiograph; some samples containing small amounts of uranium and thorium may barely register during this exposure time.

Thorium and uranium contents of 212 samples taken along the five drill holes were given on the drill logs by Damien Hackett (written commun., 1982). The thorium to uranium ratio of these samples ranges from 0.5 to 46 and averages 6.3. The thorium to uranium ratio of the five samples shown in figure 1 ranged from 3.4 to 9.6 and averages 5.9. Although thorium tends to be more abundant, the radioactivity due to uranium is equivalent to 5.7 times that created by an equal amount of thorium. Thus, the radioactivity of uranium is stronger than its general meager content would indicate, and in these samples about equals that of thorium.

Figure 1 shows the distribution of thorium and uranium minerals in samples of the apogranite. Within each specimen, the autoradiographs show that the radioactive minerals have a fairly uniform distribution except where relatively large quartz or feldspar crystals show up as circular black blobs. Many of the feldspar and quartz crystals have been fractured and impregnated by radioactive minerals, so that not nearly as many dark areas (lacking radioactive minerals) occur as might otherwise be expected. The brightness of various spots is not only a function of the total radioactivity, but also how close the radioactive minerals are to the exposed surface and the amount of time exposed. Sample 336834 (fig. 1*E*) does not have as much uranium and thorium as the other samples shown (fig. 1*A*-*D*); the autoradiograph made of sample 336834 for 18 hours, like those of the other samples, shows a much dimmer pattern of radioactivity. This pattern was greatly enhanced, however, by exposing this sample for 66 hours (fig. 1*E*).

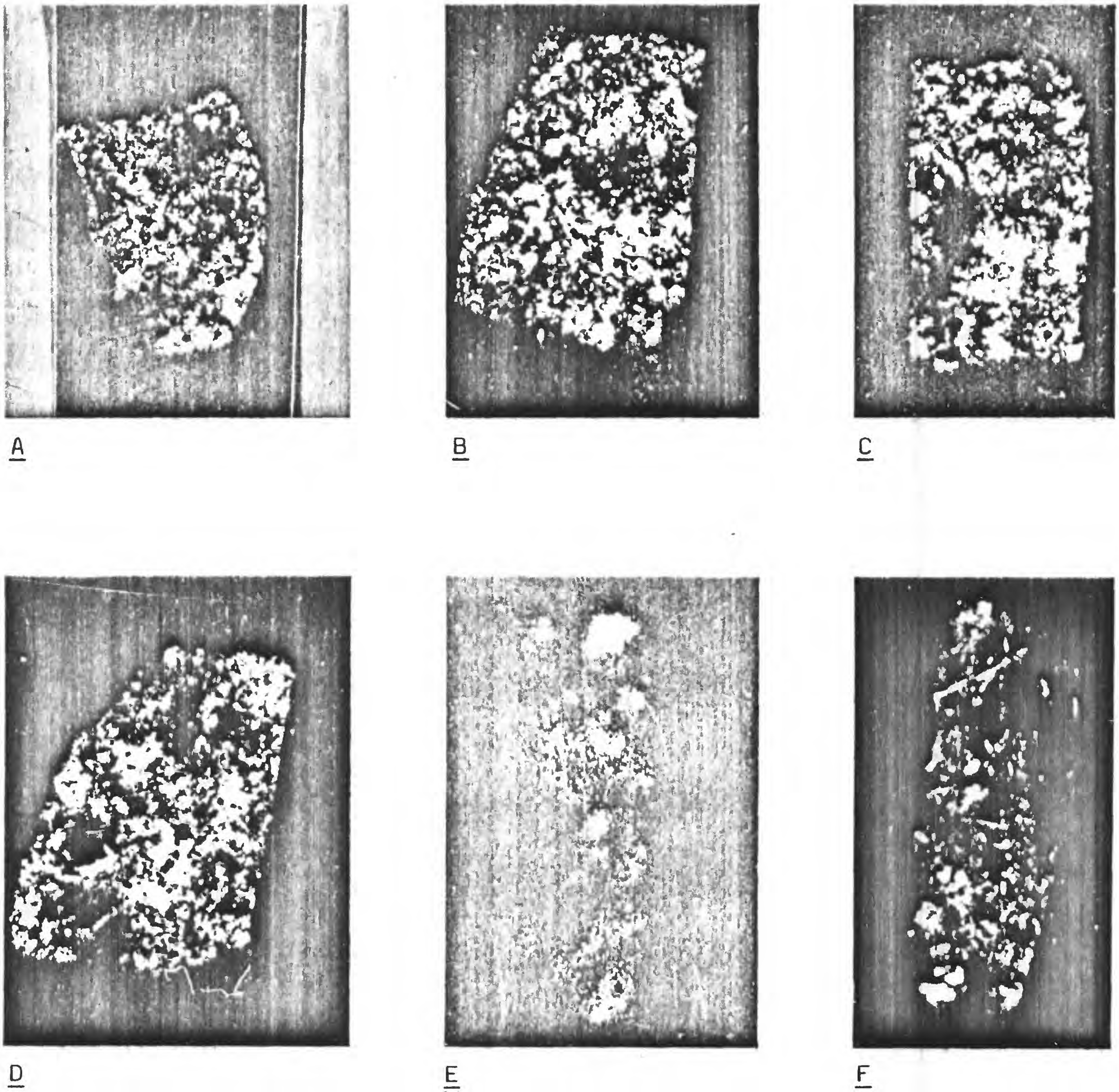


Figure 1.--Autoradiographs of Jabal Sa'id drill core specimens. Light spots show radioactive minerals. A, Core sample no. 336826; B, Core sample no. 336827; C, Core sample No. 336829; D, Core sample no. 336832; E, Core sample no. 336834; and F, Core sample no. 336834. Exposure time 66 hours for sample no. 336834 in F, and 18 hours for other autoradiographs, A-E.

In addition to showing the general distribution of the radioactive minerals, an approximation of the size of the various radioactive minerals can be obtained from the autoradiographs. The apparent size of the radioactive mineral, however, tends to be larger than the actual size. This may be due to the image of two adjacent radioactive minerals merging and also to radiation creating a bright halo beyond the actual limits of the mineral. The size of this halo is dependent on a number of variables, which include total radioactivity of the mineral and the amount of exposure time used in making the autoradiograph. Autoradiographs thus give a qualitative idea of the amount, distribution, and size of the radioactive minerals.

MICROPROBE STUDIES

Many elements, especially those having similar atomic radii, substitute for one another in various minerals. Thus niobium commonly substitutes for titanium, and titanium minerals, such as rutile and brookite, may contain significant amounts of niobium. Thorium, having a similar atomic radius to that of various rare earths will substitute for those elements in minerals such as monazite. The reverse is also true, and the rare earths will substitute for thorium in thorite. To understand what substitution takes place and its importance in the apogranite from Jabal Sa'id, microprobe studies were made of various pieces of core using a six spectrometer American Research Laboratories electron microprobe.

Examination of rocks with the microprobe is slow and only small areas can be examined at one time. The scanning electron microscope (SEM) with its X-ray energy dispersive spectrometer (EDS), on the other hand, can be used to examine a much larger area in a shorter period of time. Unfortunately, only semiquantitative analyses can be made with the SEM. We combined both methods and used the SEM for preliminary examination of all samples. It helped locate and define the minerals of interest. Then the various minerals were examined and specific grains were analyzed by the electron microprobe.

Analyses of eight minerals were made for nine elements of particular economic interest: La, Ce, Y, Nb, Ta, Th, U, Zr, and Sn. As the element contents commonly vary within individual grains and from grain to grain, multiple analyses were made of each mineral. Grains of zircon, for example, were analyzed from six different core samples. In addition, from one to five different grains were analyzed in each core sample. A total of 48 mineral grains were examined, and the results are given in table 3.

Table 3.--Electron microprobe partial analysis of various minerals in core samples from Jabal Sa'id
[- = less than the value indicated]

Mineral	Sample no.	Individual grains tested in the same sample	Oxide content (weight percent)								
			La_2O_3	Ce_2O_3	Y_2O_3	Nb_2O_5	Ta_2O_5	ThO_2	UO_2	ZrO_2	SnO_2
Anatase	336848	a	-0.001	0.023	0.06	1.72	-0.001	-0.001	-0.001	-0.09	-0.001
do.	do.	b	-.001	-.001	-.001	2.75	-.001	.10	.043	.12	-.001
Bastnaesite	336850	a	6.75	15.23	11.70	-.001	-.001	1.51	-.001	.085	.197
do.	do.	b	7.08	18.22	12.29	.020	.009	.16	-.001	-.001	.176
do.	do.	c	12.61	28.43	4.65	.001	.11	-.001	.08	-.001	.167
Brookite	336847	a	.16	-.001	-.001	4.02	.10	-.001	.10	-.001	-.001
do.	do.	b	-.001	.18	-.001	3.50	-.001	-.001	-.001	-.001	.15
do.	336849	a	-.001	.11	-.001	5.21	-.001	-.001	-.001	-.001	-.001
do.	do.	b	-.001	.17	.12	2.58	-.001	.03	-.001	.06	.015
do.	do.	c	-.001	.001	-.001	1.84	-.001	.17	-.001	-.001	-.001
Doverite	336850	a	1.81	4.08	21.71	-.001	.367	.320	.071	-.001	.087
do.	do.	b	.07	.54	31.08	-.001	.743	.68	-.001	-.001	-.001
Hematite	336850	a	-.001	-.001	-.001	.36	-.001	.075	-.001	-.001	.342
do.	do.	b	-.001	-.001	-.001	-.13	-.001	.035	-.001	-.001	-.001
do.	336852	a	.043	.018	.099	.17	-.001	.26	.36	.11	-.001

Table 3.--Electron microprobe partial analysis of various minerals in core samples--Continued

Mineral	Sample no.	Individual grains tested in the same sample	Oxide content (weight percent)								
			La_2O_3	Ce_2O_3	Y_2O_3	Nb_2O_5	Ta_2O_5	ThO_2	UO_2	ZrO_2	SnO_2
do.	do.	b	-0.001	0.028	0.042	0.13	-0.001	-0.001	0.19	0.037	0.001
do.	336854	a	-.001	.037	.058	.060	-.001	.020	.023	-.001	-.001
do.	do.	b	-.001	-.001	-.001	.13	-.001	.054	.163	.015	-.001
do.	do.	c	.009	-.001	-.001	.16	-.001	.010	.054	.015	-.001
Hematite	336853	a	.064	.12	-.001	.14	-.001	.030	.082	.15	.01
do.	do.	b	.021	-.001	-.001	1.21	.093	-.001	.015	-.001	-.001
do.	do.	c	.136	.023	-.001	.68	-.001	.074	.058	.033	-.001
Pyrochlore	336848	a	2.46	6.08	1.21	56.99	2.92	.22	1.85	.32	-.001
do.	do.	b	2.20	5.36	1.88	53.38	2.65	.035	1.82	.46	-.001
do.	do.	c	.26	.51	15.32	.28	-.001	49.38	2.25	8.26	-.001
do.	do.	d	.14	-.001	10.57	.19	-.001	54.46	2.14	-.001	-.001
do.	do.	e	-.001	.072	8.49	-.001	-.001	46.45	2.29	.066	-.001
Zircon	336847	a	-.001	-.001	2.50	-.001	-.001	0.50	.40	48.44	-.001
do.	do.	b	-.001	-.001	3.26	-.001	-.001	1.07	.61	45.59	-.001

Table 3.--Electron microprobe partial analysis of various minerals in core samples--Continued

Mineral	Sample no.	Individual grains tested in the same sample	Oxide content (weight percent)								
			La_2O_3	Ce_2O_3	Y_2O_3	Nb_2O_5	Ta_2O_5	ThO_2	UO_2	ZrO_2	SnO_2
do.	336850	a	0.012	-0.001	1.88	-0.001	-0.001	-0.001	0.32	48.14	-0.001
do.	do.	b	-.001	.005	1.47	-.001	-.001	-.001	.19	42.91	.068
do.	do.	c	.23	.21	.16	-.001	-.001	-.001	.22	50.99	.307
do.	do.	d	.14	-.001	2.48	-.001	-.001	.099	.092	44.95	.181
Zircon	336851	a	-.001	.001	1.93	-.001	-.001	-.001	.18	48.74	.13
do.	do.	b	-.001	.162	2.00	-.001	-.001	.24	.082	48.41	.59
do.	do.	c	-.001	-.001	1.31	-.001	-.001	-.001	.20	47.95	.050
do.	336852	a	-.001	.17	1.83	-.001	-.001	-.001	-.001	56.84	.016
do.	do.	b	-.001	.12	3.63	-.001	-.001	-.001	-.001	55.50	-.001
do.	do.	c	.059	.14	2.61	-.001	-.001	.083	-.001	56.27	.13
do.	336853	a	-.001	.074	1.60	-.001	-.001	.21	-.001	57.83	-.001
do.	do.	b	-.001	.058	1.00	-.001	-.001	.17	.29	50.05	.070
do.	336854	a	-.001	.20	4.26	-.001	-.001	-.001	.18	56.23	-.001
do.	do.	c	.12	-.001	4.81	-.001	-.001	.077	.58	55.39	.015

Rare earths occur in major amounts, as would be expected, in bastnaesite and doverite. Bastanesite is generally a cerium group rare earth mineral. The bastnaesite from Jabal Sa'id differs from the norm in having relatively high amounts of Y_2O_3 (4.6-11.3 weight percent). Doverite is a yttrium group rare earth mineral and the Y_2O_3 content of the grains examined were considerably higher than both the Ce_2O_3 and La_2O_3 contents. Doverite is sometimes referred to as Y-synchisite and available data indicate that a solid solution sequence occurs between cerium-rich synchisite and yttrium-rich doverite. The two end members are not isostructural as their X-ray diffraction patterns exhibit a shifting in position of many peaks. Significant amounts of rare earths are also found in several other minerals. Thorite grains were found to contain from 6.5 to 13.3 weight percent Y_2O_3, the amounts of Ce_2O_3 and La_2O_3 were relatively low. Seventeen grams of zircon contained between 0.16 and 4.81 weight percent Y_2O_3, with an average Y_2O_3 content of 2.37. Pyrochlore could be a source of secondary rare earths as well as niobium. Total Ce_2O_3, La_2O_3, and Y_2O_3 contents of three grains ranged from 9.44 to 10.16 weight percent; most appears to be in the cerium group (Ce_2O_3+La_2O_3).

Niobium occurs principally in the niobium mineral pyrochlore. Niobium commonly substitutes for titanium, and grains of the titanium minerals, anatase and brookite, contain from 1.7 to 5.2 weight percent Nb_2O_5. Small and highly variable amounts of niobium occur in thorite. Some grains do not appear to contain any niobium; others may contain as much as a couple of percent.

Tantalum, although occurring in anomalous amounts is not an important element in the samples from Jabal Sa'id. Most of the tantalum occurs with the niobium in pyrochlore.

Thorium occurs mainly in thorite, but also occurs in thorianite, plus minor amounts occur in bastnaesite (up to 1.5 weight percent), doverite, and zircon.

Uranium is of relatively minor importance in the apogranite of Jabal Sa'id. No minerals in which uranium is major constituent were found during this study. The principal uranium-bearing mineral is thorite, which contains some 1.76 to 6.00 weight percent UO_2. Pyrochlore may contain between 1 and 2 weight percent UO_2 and zircon may contain from 0.001 to 0.61 weight percent UO_2.

Zirconium occurs principally in zircon, which is relatively abundant in the apogranite. The 17 grains of this mineral analyzed contained between 42.91 and 57.83 weight percent ZrO_2. Small and highly variable amounts of this oxide also occur in thorite. The ZrO_2 content of six grains of thorite ranged from 0.001 to 8.26 weight percent. Small amounts of ZrO_2 are also found in pyrochlore.

Tin is another anomalous element which is probably not economically very important at Jabal Sa'id. No minerals in which tin is a principal constituent were found during this study. In the heavy mineral grains examined (table 3), small and variable amounts of SnO_2 amounts were found in bastnaesite, doverite, hematite, and zircon.

GRAIN SIZE STUDIES

The apogranite is a medium-grained rock and the quartz and feldspar grains commonly are between 1 and 4 mm across. The ore minerals are much smaller than the felsic minerals and are commonly found along the grain boundaries of the quartz and feldspar crystals. The diameter of various possible ore minerals was measured with a micrometer ocular on thin sections (table 4). Considerable range in size was noted between individual grains of the same minerals in the same thin section. Most minerals fell in the range 0.020 to 0.20 mm or 60 to 725 mesh. Zircon has a long dimension (along the C axis) that may be as much as 20 times that of its cross sectional measurement (diameter); to free this mineral from its matrix, it would be necessary to grind it as small as its diameter. The zircon in the drill core was probably an accessory mineral in the original apogranite. The other potential ore minerals were formed during a later mineralization (Turkistany and Ramsay, 1982, p. 86). A SEM photomicrograph shows one of the larger pyrochlore crystals (fig. 2A), which was freed by grinding during our mineral separation process and which measures 0.24 mm in diameter.

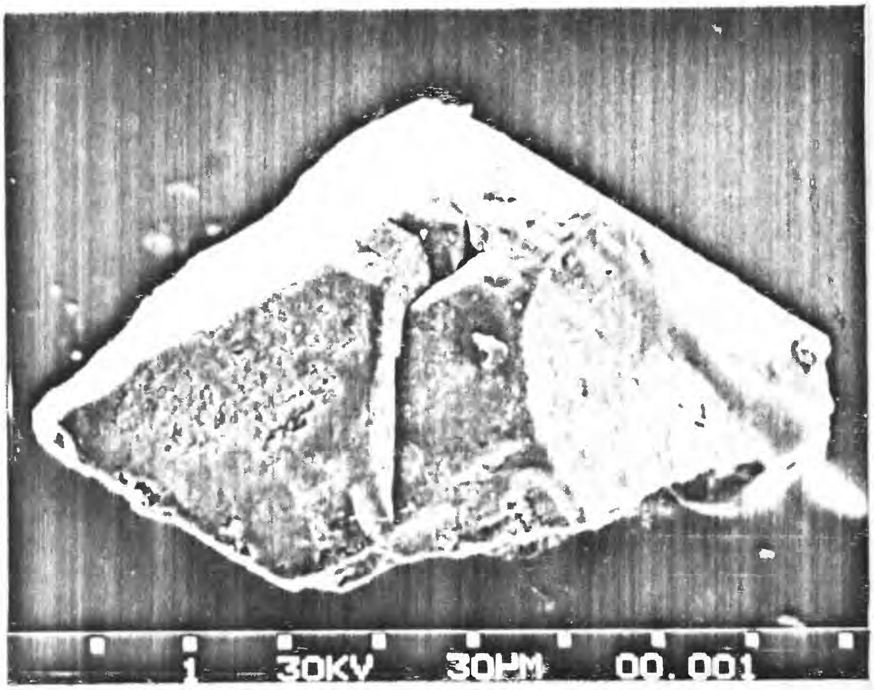
Although individual grains of the various ore minerals fall into the ranges shown in table 4, ore mineral grains commonly contain impurities in the form of tiny inclusions. These inclusions are quite small but are readily visible using the SEM. Figure 2B shows a crystal of bastnaesite, wich contains many small, six-sided inclusions of quartz from 0.005 to 0.025 mm.

DATA STORAGE

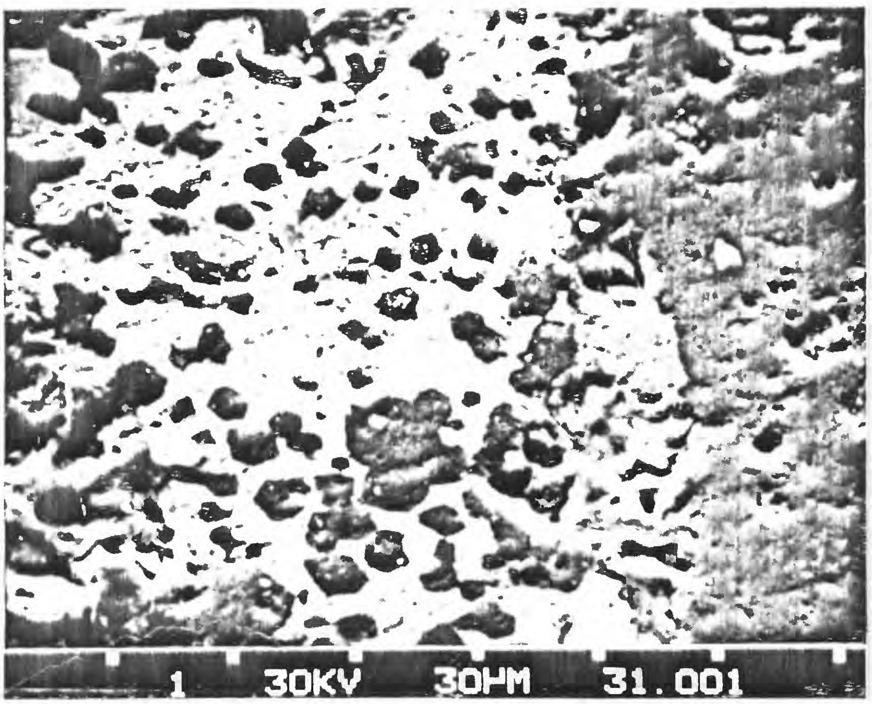
Data-file USGS-DF-04-04 (Staatz and Brownfield, 1984) has been established for the storage of data used in this report. No MODS entries have been made.

Table 4.--Grain sizes of accessory minerals in apogranite samples from Jabal Sa'id

Sample no.	Mineral	Size range (mm)			Remarks
336826	Doverite	0.008	-	0.13	Many in 0.015 to 0.040 mm size range
336827	Monazite	.016	-	.09	
336829	Doverite	.024	-	.13	
336832	Bastnaesite	.024	-	.19	
	Thorite	.032	-	.16	
336834	Zircon	.05	-	.11	Diameter
	Zircon	1.0	-	2.2	Length
	Monazite	.07	-	.58	
	Pyrochlore	.10	-	.24	
336839	Doverite	.016	-	.079	
336843	Pyrochlore	.032	-	.25	



A



B,

Figure 2.--Mineral grains photographed by the scanning electron microscope. Distance between dots at base of photographs is 30 microns. A, Pyrochlore crystal; B, Bastanaesite crystal (light) containing hexagonal quartz inclusions (dark).

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