DEPARTMENT OF THE INTERIOR
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Reconnaissance geochemical exploration of plutons of syenite and shonkinite, Southern Asir, Kingdom of Saudi Arabia

by

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RECONNAISSANCE GEOCHEMICAL

EXPLORATION OF PLUTONS OF SYENITE AND SHONKINITE,

SOUTHERN ASIR, KINGDOM OF SAUDI ARABIA

by

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ABSTRACT

Reconnaissance geochemical exploration for rare metals in plutons of syenite and shonkinite disclosed generally less than 20 ppm Nb in rocks, wadi sediments, and concentrates. The sparsity of Nb is accompanied by low values for La, Sn, W, Y, and Zr and relatively high but insignificant values for Be and Mo. Base and precious metals are either below their respective limits of determination in the various sample media or are present at background levels commensurate with average crustal abundances in felsic rocks. Pegmatite dikes associated with the syenite plutons are rare and lack vermiculite. The present investigation disclosed no possible ore deposits in the plutons covered by the field work.

Known kyanite-topaz-natroalunite rocks in the vicinity of the surveyed areas should be examined for possible deposits of Cu, Mo, or Au associated with high-alumina hydrothermal deposits.

INTRODUCTION

The three areas covered by geochemical reconnaissance are situated to the southeast of Abha (fig. 1) in the Red Sea Escarpment. The syenite plutons at Jabal Fayfa and Jabal Bani Malik (locality 1, fig. 1) are in a surveyed area of about 300 sq km. The Syenite pluton between Wadi Rudum and Wadi Bishah is about 25 km to the southeast of Suq al Ithnayn and occupies a surveyed area of 100 sq km (locality 2, fig. 1), and the shonkinite pluton at Jabal Atwid (locality 3, fig. 1) is within a surveyed area of about 70 sq km. Each of the plutons forms a buttress of high relief, subcircular in plan, attaining altitudes of 2,300 m at Jabal Atwid from bases as low as 270 m at the foot of Jabal Fayfa. Drainage systems radiate outward from the centers of the plutons in wadis developed on surfaces of steep relief.

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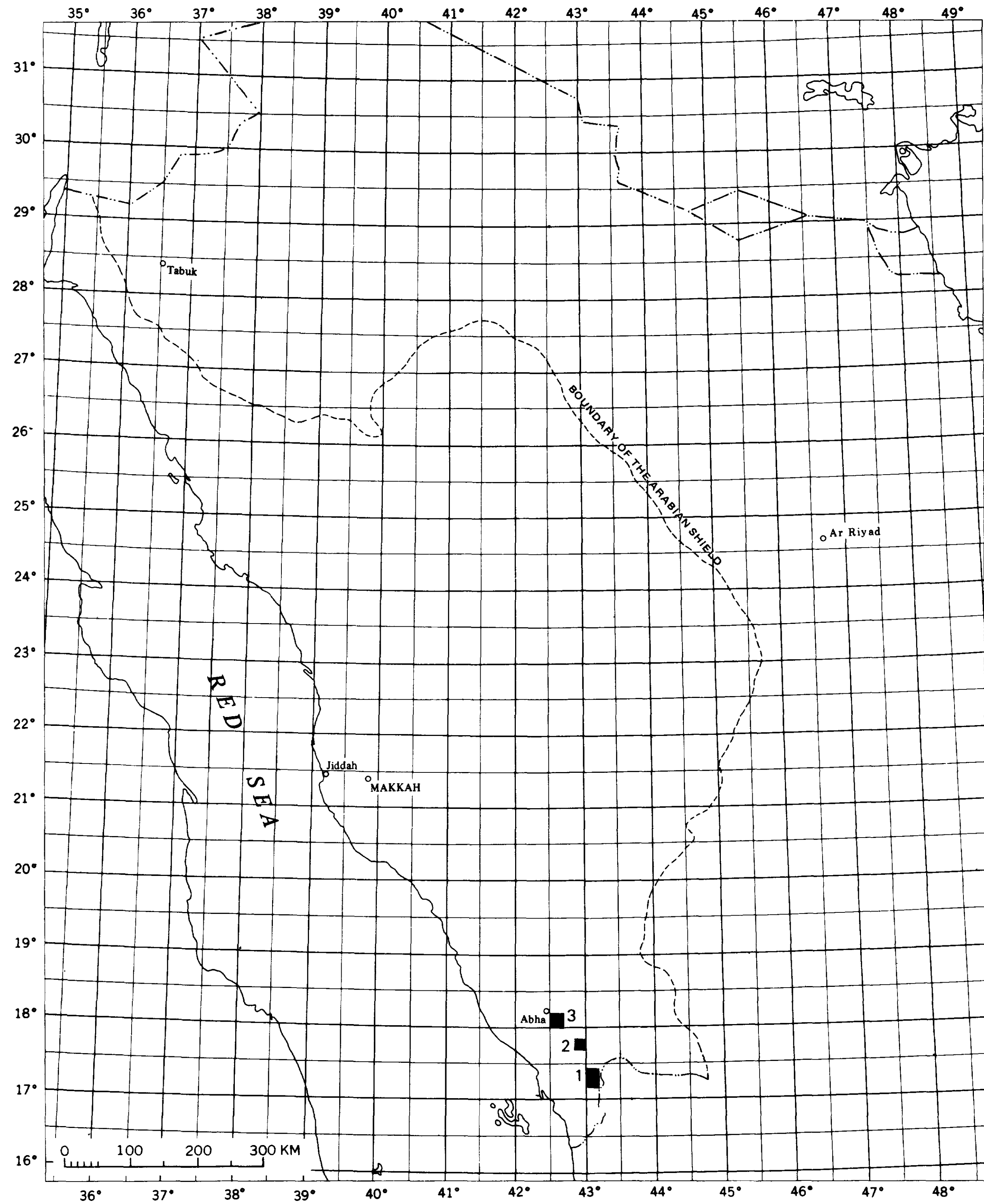


Figure 1.--Index map showing areas covered by reconnaissance geochemical exploration of syenite plutons at Jabal Fayfa and Jabal Bani Malik (1), syenite pluton between Wadi Rudum and Wadi Bishah (2), and shonkinite pluton at Jabal Atwid (3).

Previous geologic work in the three areas consists of 1:500,000-scale mapping by Brown and Jackson (1959) and 1:100,000-scale mapping of the area containing the shonkinite pluton (Coleman, 1973) and the syenite plutons (Fairer, 1981; 1982).

This report is the result of laboratory and helicopter-supported field work conducted during February and March 1980. The work was performed in accordance with a work agreement between the U.S. Geological Survey (USGS) and the Saudi Arabian Ministry of Petroleum and Mineral Resources.

The writers wish to acknowledge the support received in this investigation from the Deputy Ministry for Mineral Resources, Kingdom of Saudi Arabia, and the staff of the U.S. Geological Survey Saudi Arabian Mission. Appreciation is also expressed for the assistance received from Mohammed Jambi and Hassan Mousa, DGMR, for spectrographic analyses made at the DGMR/USGS Chemical Laboratory in Jiddah, and to G. H. Abubakar, USGS, Jiddah, for sedimentalogical preparations. Helpful suggestions were made by R. G. Schmidt, USGS, Reston, Virginia, concerning exploration of high-alumina hydrothermal deposits, and by Theodore Botinelly, USGS, Denver, Colorado, about the distribution of particles of ore minerals in overwhelmingly large amounts of barren material.

PROCEDURES

Through the use of a helicopter from a camp near Suq al Ithnayn, 40 km to the southeast of Abha (Brown and Jackson 1959), each area was sampled and six geochemical sample media were taken at each site: rock, -10+32-mesh wadi sediment, -32+80-mesh wadi sediment, -80-mesh wadi sediment, raw concentrate, and nonmagnetic concentrate. The total number of samples from each area was: (1) Jabal Fayfa and Jabal Bani Malik, 372; syenite pluton to the southeast of Suq al Ithnayn and between Wadi Rudum and Wadi Bishah, 153; and shonkinite pluton at Jabal Atwid, 116. The apparent sample density, based on the size of the area and the number of localities sampled, was 1 sample per 5 sq km in the Jabal Fayfa-Jabal Bani Malik area 1 sample per 4 sq km in the syenite pluton to the southeast of Suq al Ithnayn and 1 sample per 3.5 sq km in the Jabal Atwid area.

Scintillometer measurements of the relative radioactivity of the exposed rocks were made at each locality where samples were taken.

Concentrates were prepared from standard 10 kg samples of wadi sediment by panning in camp. In Jiddah, the raw concentrate as recovered from the pan was divided by microsplitter into two parts, one of which was further processed to remove highly magnetic minerals with a hand magnet and to separate minerals of low density by the use of the heavy liquid acetylene tetrabromide (density 2.96). The magnetic fraction was archived for additional study at USGS, Denver, USA.

Samples of wadi sediment weighing about 500g each were sieved to four size fractions: -10-mesh, -10+32-mesh, -32+80-mesh, and -80-mesh. Splits of the three finer sizes of sediment were used for spectrographic analyses.

The samples of rocks, wadi sediment exclusive of the -10-mesh material, raw concentrate, and nonmagnetic concentrate from each locality were analyzed for thirty elements by semiquantitative spectrographic procedures at the DGMR-USGS Chemical Laboratory in Jiddah using a modification of the method of Grimes and Marranzino (1968). The upper and lower limits of reporting for the 30 elements are given in table 1. Numerical values substituted for technically censored data in some statistical operations are also shown. The abbreviations N, L, and G are alphabetic conventions used in laboratory reports for:

N = Not detected at the lower limit of determination, or at value shown.

L = Detected, but below the lower limit of determination, or below value shown.

G = Greater than upper limit of determination, or greater than value shown.

The mineralogical compositions of 33 nonmagnetic concentrates from the three areas were determined in the mineralogical laboratory of USGS, Jiddah, by Mir A. Hussain and Mohammed I. Naqvi using X-ray diffraction methods. The nonmagnetic concentrates were divided at amperages of 0.2, 0.3, 0.5, 0.6, 0.7, 0.8, 1.0, 1.2, 1.5, 1.7 at 15° slope on the Frantz Isodynamic Separator, pulverized, and analyzed. Minerals represented by the strongest peaks were classed as major components of the concentrates; minerals exhibiting intermediate peak strengths were classed as minor components; and identifiable minerals with the weakest peaks were classed as trace components of the concentrates. Further identification of hand-picked individual minerals grains was performed by J. J. Matzko and M. I. Naqvi using optical and X-ray methods to confirm determinations made

Table 1.--Upper and lower limits of determination for 30 elements by emission spectrographic methods, and values substituted for technically censored data in some statistical operations.

Element	Limits of determination		Substitute values		
	Lower	Upper	N	L	G
		In Percent			
Fe	0.05	20	0.01	0.02	30
Mg	.02	10	.005	.01	15
Ca	.05	20	.01	.02	30
Ti	.002	1	.0005	.001	1.5
		In parts per million			
Mn	10	5,000	2	5	7,000
Ag	.5	5,000	.1	.2	7,000
As	200	10,000	50	100	15,000
Au	10	500	2	5	700
B	10	2,000	2	5	3,000
Ba	20	5,000	5	10	7,000
Be	1	1,000	.2	.5	1,500
Bi	10	1,000	2	5	1,500
Cd	20	500	5	10	700
Co	5	5,000	1	2	7,000
Cr	10	5,000	2	5	7,000
Cu	5	20,000	1	2	30,000
La	20	1,000	5	10	1,500
Mo	5	2,000	1	2	3,000
Nb	20	2,000	5	10	3,000
Ni	5	5,000	1	2	7,000
Pb	10	20,000	2	5	30,000
Sb	100	10,000	20	50	15,000
Sc	5	100	1	2	150
Sn	10	1,000	2	5	1,500
Sr	100	5,000	20	50	7,000
V	10	10,000	2	5	15,000
W	50	1,000	10	20	1,500
Y	10	2,000	2	5	3,000
Zn	200	10,000	50	100	15,000
Zr	10	1,000	2	5	1,500

from the powders. To be identified even as a trace component, a mineral must represent about 5 percent of the concentrate. A rigorous quantitative relation to the actual abundances of these minerals in the nonmagnetic concentrates is, therefore, not afforded by these data, and mineral species present in quantities less than 5 percent of the concentrate were generally not identified.

Results of the spectrographic and mineralogical analyses of the various sample media are interpreted with the aid of the field observations and by reference to prior work to form an appraisal of the mineral potential of the three areas.

GEOLOGIC SETTING

A small province of late Precambrian, posttectonic, alkalic intrusive rocks is exposed in the Red Sea Escarpment to the south of Abha, Kingdom of Saudi Arabia (fig. 1). The most common of these rocks syenite, which grades into nepheline-bearing shonkinite (Coleman, 1973; Fairer, 1982) and quartz monzonite (Fairer, 1981), is in Jabal Fayfa, Jabal Bani Malik, and a pluton about 25 km to the southeast of Suq al Ithnayn between Wadi Rudum and Wadi Bishah. The shonkinite is best exposed in a pluton at Jabal Atwid. Several small bodies of syenite and shonkinite have also been reported in the area, but the four main plutons, which may be enriched in alkalic rocks (Rankama and Sahama, 1950, p. 180; Parker and Adams, 1973, p. 446-447) are the most obvious of these igneous masses to explore for rare metals such as Be, La, Mo, Nb, Y, and Zr. Summaries of the geologic setting of the main plutons follow from the reports of Coleman (1973) and Fairer (1981; 1982).

Syenite plutons

Jabal Fayfa and Jabal Bani Malik

The posttectonic plutons of syenite in Jabal Fayfa and Jabal Bani Malik (fig. 2) are complexly reintruded discordant bodies in metamorphosed Precambrian sedimentary and mafic volcanic rocks of the Sabya Formation and Baish Formation. The extraordinarily numerous faults mapped by Fairer (1981) in these two plutons are not shown on figure 2 to provide room for radioactivity measurements recorded during the present investigation. Quartz is present in the syenite, and the ratios of quartz to plagioclase to orthoclase are quite variable (Fairer, 1981, table 3), but the principal mafic constituents of the rock--hornblende, biotite, and allanite--are more constant in their relative distributions, as are the main accessory minerals apatite and zircon. As is shown in the section on "Mineralogy of the Concentrates," hornblende survives less commonly in the heavy minerals of the concentrates than other amphiboles such as hastingsite and kaersutite. This may be the result of the widespread alteration of the hornblende to actinolite, iddingsite, titanite, and iron-oxide minerals (Fairer, 1981, p. 10). Allanite is also unreported in the concentrates. The apatite, zircon, epidote, and titanite observed in thin sections of the syenite are common in the concentrates. None of the complex Nb-, Ta-, and Zr-bearing minerals characteristic of the agpaitic syenites were observed either in thin section or concentrates. The presence of common hornblende, biotite, apatite, titanite, and zircon in thin sections, and hastingsite, augite, and the other minerals in the concentrates, is interpreted to show that these are common (miaskitic) syenites.

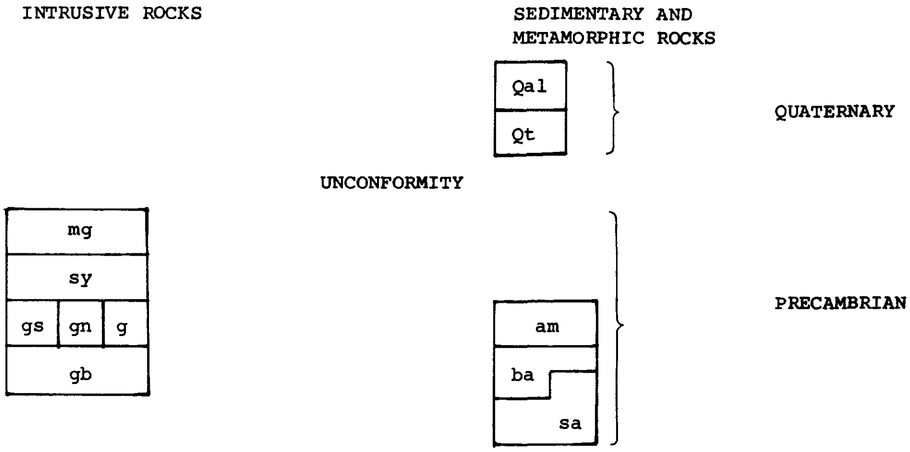
Pluton to the southeast of Suq al Ithnayn between Wadi Rudum and Wadi Bishah

The syenite pluton between Wadi Rudum and Wadi Bishah (fig. 3) intrudes the Precambrian Sabya Formation and the Khamis Mushayt Complex. Amphibolite is locally developed along the contact between the syenite and the Sabya Formation, as it is a Jabal Bani Malik (fig. 2). In the area of figure 3 the Sabya Formation consists mainly of metamorphosed pelitic sediments with local actinolite schist and metabasalt. The Khamis Mushayt Complex in the area is made up mainly of massive to gneissic granitic rock locally grading into migmatite and including some amphibolite. The pluton consists of syenite that grades into shonkinite and is intruded by late-stage granite, aplite, and muscovite-bearing pegmatite.

The principle components of this body of syenite are orthoclase, clinopyroxene, hornblende, biotite, and quartz (Fairer, 1982, p. 9). Concentrates panned from alluvium derived from the syenite lack complex minerals containing Nb, Ta, and Zr, and consist largely of mafic amphiboles, apatite, titanite, and zircon, which confirm the similarity of this pluton with those at Jabal Fayfa and Jabal Bani Malik and show that the rock is a common (miaskitic) syenite.

EXPLANATION

CORRELATION OF MAP UNITS
(Adapted from Fairer, 1981)



DESCRIPTION OF MAP UNITS

Qal	ALLUVIUM--Unconsolidated, poorly sorted silt, sand, and gravel in beds of wadis
Qt	TERRACE DEPOSIT--Unconsolidated sand and gravel covered in part by loess
mg	BIOTITE-QUARTZ MONZONITE--Light-gray, coarse-grained, posttectonic plugs
sy	SYENITE--Dark- to medium-gray, coarse-grained, posttectonic plutons
gs	SYNTECTONIC GRANITIC ROCKS--Light- to dark-gray, massive to layered
gn	GNEISS--Biotite, quartz, amphibole, plagioclase, and orthoclase gneiss
g	GRANITE--Granitic rocks ranging in composition from quartz diorite to quartz monzonite
gb	METAGABBRO--Hypabyssal sills and pods in Sabya Formation, greenschist facies
am	AMPHIBOLITE--Amphibole-orthoclase-quartz amphibolite in gneiss and schist
ba	BAISH FORMATION--Greenstone and green schist, sparse chert, marble, and metagraywacke
sa	SABYA FORMATION UNDIVIDED--Quartz-biotite schist, quartz-sericite schist, phyllite, black slate, marble, quartzite, and greenschist

SYMBOLS

——— - - -	CONTACT--dashed where approximately located; fault contacts common
—◆— —▼—	STRIKE AND DIP OF FOLIATION--vertical or inclined in syenite
•180	RADIOACTIVITY--in counts per second; locality shown by dot or by symbol for strike and dip
• 156399	NONMAGNETIC CONCENTRATE--used for mineralogical analyses

Figure 2.--Generalized geologic map showing the syenite plutons at Jabal Fayfa and Jabal Bani Malik, relative radioactivity of rocks, and sources of concentrates used for mineralogical analyses. Adapted from G. M. Fairer, 1981, Jabal Fayfa quadrangle, sheet 17/43 C.

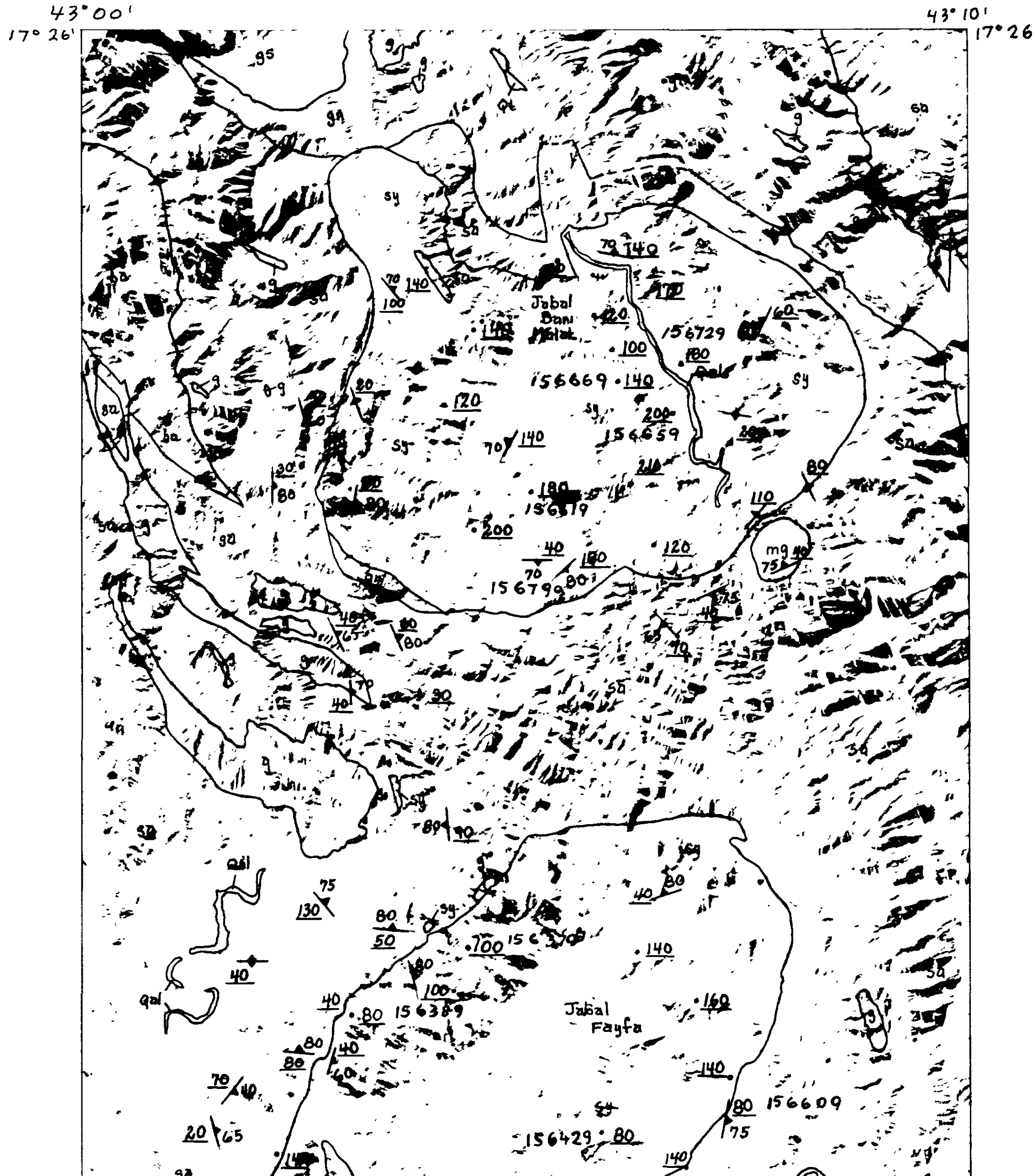
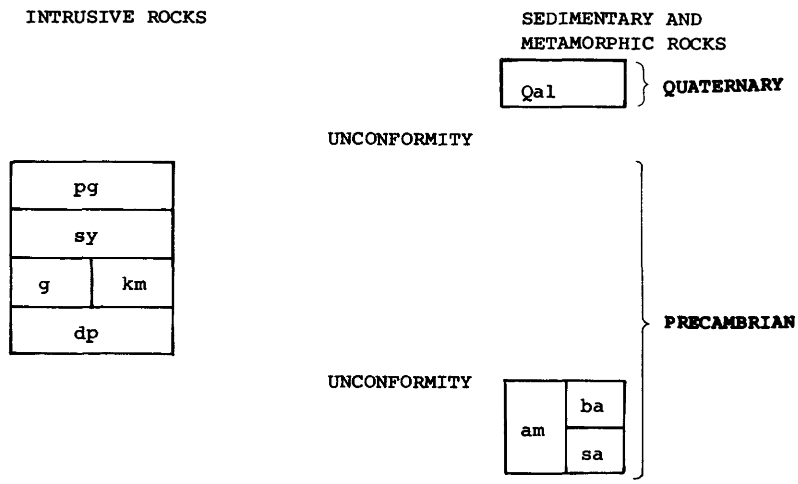


Figure 2.--Generalized geologic map showing the syenite plutons at Jabal Fayfa and Jabal Bani Malik, relative radioactivity of rocks, and sources of concentrates used for mineralogical analyses. Adapted from G. M. Fairer, 1981, Jabal Fayfa quadrangle, sheet 17/43 C.--Continued.

EXPLANATION

CORRELATION OF MAP UNITS
(Adapted from Fairer, 1982)



DESCRIPTION OF MAP UNITS

Qal — ALLUVIUM--Unconsolidated, poorly sorted silt, sand, and gravel in beds of wadis

pg — PEGMATITE--Coarse-grained, pale-pink to white pegmatite, many septa of wall rocks

sy — SYENITE--Medium- to coarse-grained, white, pink, and dark gray; generally sharp contacts

g — GRANITE--Medium-grained, light gray, syntectonic to posttectonic

km — KHAMIS MUSHAYT COMPLEX--Gneissic to structureless, light-gray to white granitic rock

dp — DIORITE--Fine-grained, dark-gray, brown-weathering, pyritiferous diorite

am — AMPHIBOLITE--Greenish-black to black amphibolite adjacent to intrusive syenite

ba — BAISH GROUP--Baealtic greenstone and greenschist, sparse marble and chert

sa — SABYA FORMATION UNDIVIDED--Quartz-sericite schist, biotite-quartz-sericite schist, quartzite

SYMBOLS

——— - - — CONTACT OF GEOLOGIC UNITS--dotted where covered

•110 — RATE OF COUNT ON SCINTILLOMETER--locality shown by dot

•153559 — NONMAGNETIC CONCENTRATE--used for mineralogical analyses

Figure 3.--Reconnaissance geologic map showing the syenite pluton between Wadi Rudum and Wadi Bishah, relative radioactivity of rocks, and sources of concentrates used for mineralogical analyses. Adapted from G. M. Fairer, 1982, Wadi Baysh quadrangle, sheet 17/42 B.

Figure 3.--Reconnaissance geologic map showing the syenite pluton between Wadi Rudum and Wadi Bishah, relative radioactivity of rocks, and sources of concentrates used for mineralogical analyses. Adapted from G. M. Fairer, 1982, Wadi Baysh quadrangle, sheet 17/42 B.--Continued

Shonkinite pluton at Jabal Atwid

The pluton of shonkinite at Jabal Atwid (fig. 4) intrudes a sequence of Precambrian metamorphosed sedimentary and volcanic rocks described by Coleman (1973) as including parts or equivalents of the Hali, Baish, and Bahah Groups. As shown on figure 4, the unit of metamorphic rocks is undivided. The posttectonic shonkinite of Precambrian age is reported to consist mainly of orthoclase, olivine, and clinopyroxene with minor nepheline. This composition is well reflected in the suite of heavy minerals panned from wadi sediment derived from the rock. Clinopyroxene is represented by diopside, augite, and acmite, and the olivine group is present as both fayalite and fosterite. Phlogopite, amphiboles, apatite, and titanite are also present in the concentrates. Thorite, baddelyite, and monazite are present in concentrates from the shonkinite, but they were not detected in the areas underlain by syenite. Niobium- and Ta-bearing minerals were not identified.

Previous evaluations of mineral potential

Previous accounts of the regional geology of the areas covered by this investigation show that the potential for economic mineral resources is low. Results of present work confirm those assessments for the four plutons of syenite and shonkinite, but outside the areas covered here, the identification by Fairer (1982, p. 18; 1983, map) of outcrops of kyanite-topaz-natroalunite rocks in the lower Escarpment and Tihama may hold as yet unexplored metallogenic significance. Elsewhere, some alumina-rich hydrothermal deposits are associated with large Cu- Mo- Au deposits (Nakovnik, 1968; Sillitoe, 1973; Laznicka, 1976; Lawrence, 1978; Schmidt, 1982).

In the Jabal Fayfa and Jabal Bani Malik areas, no indications of mineralization have been reported (Fairer, 1981, p. 16) nor was evidence for mineralization observed in the Wadi Rudum-Wadi Bishah area (Fairer, 1982,) or at Jabal Atwid (Coleman, 1973,). However, near the southwestern corner of the Wadi Baysh Quadrangle, sheet 17/42 B, and about 45 km to the southwest of the syenite pluton between Wadi Rudum and Wadi Bishah, Fairer (1982, p. 18) discovered an outcrop of kyanite, topaz, and natroalunite that was evaluated to be too small to provide an economically exploitable source for kyanite. This is one of several similar deposits recognized by Fairer (1983, map) in the lower Escarpment and Tihama. Farther northward, near Wadi ad Arj about 200 km southeast of Jiddah, kyanite quartzite was described by Gaskill (1970, p. 12-19). The high-alumina assemblages described by Fairer, certainly, and the kyanite quartzite at Wadi ad Arj, possibly, deserve further examination to determine if they are examples of the type of hydrothermal system characterized by extensive alteration to high-alumina minerals and with which economic deposits of one or more of Au, Cu, Mo, Sn, Bi, As, Pb, and Ag may be associated.

In a summary of the characteristics of these high-alumina deposits as a guide to future exploration, R. G. Schmidt, USGS, (written commun., April 19, 1983) noted that the mineral suite varies within a deposit and between deposits but includes kyanite, topaz, alunite, kaolinite, pyrophyllite, andalusite, chloritoid, diaspore, corundum, and zunyite. The bulk composition of the original rock is profoundly changed, most primary textures are destroyed, TiO_2 is converted to rutile, and F is common. These deposits are generally associated with volcanic activity and may tend to favor transitions from andesite to rhyolite. Quartz-like rock associated with these deposits is commonly a hydrothermal alteration product of diverse protoliths. Recognition of these quartzite-like quartz granofels is regarded by Schmidt as important in economic evaluations. The diversity among these deposits requires extensive field and laboratory work to classify and to evaluate them, but a reconnaissance of the alumina-rich rocks located by Fairer (1982; 1983) would serve to determine if detailed examinations are justified.

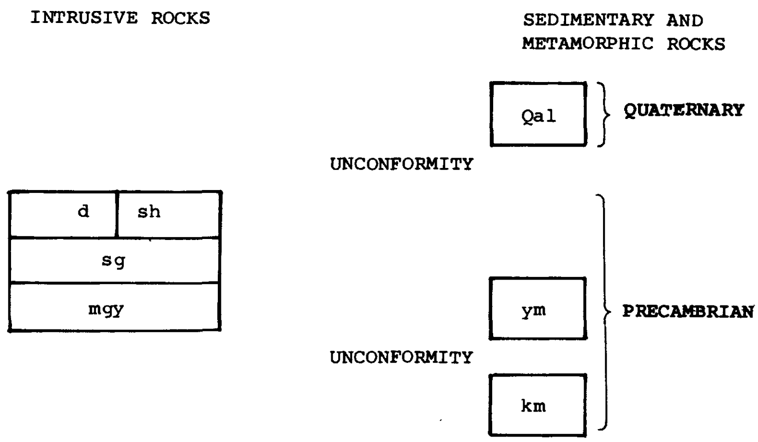
Radioactivity of the rocks

The total-count radioactivity of the rocks was measured by scintillometer on exposures at each station where geochemical samples were taken (fig. 2-4; table 2). Only slight differences obtain in the average values for the radioactivity of the syenite and shonkinite plutons, but wide variations exist in the average radioactivity of the metamorphic rocks into which the plutons are intruded or which form roof pendants and inclusions in the plutons.

In general, the intrusive bodies of syenite and shonkinite appear to have little effect on the characteristic radioactivity of the units of metamorphic rocks. Even the large mass of granitic pegmatite to the south of the syenite pluton between Wadi Rudum and Wadi Bishah (fig. 3) has no effect on the radioactivity of its wall rocks. The value measured on the pegmatite is 150 and that on the Baish Formation at the contact is a normal 20.

EXPLANATION

CORRELATION OF MAP UNITS
(Adapted from Coleman, 1973)



DESCRIPTION OF MAP UNITS

Qal — ALLUVIUM--Unconsolidated, poorly sorted silt, sand, and gravel in beds of wadis

d — DIORITE--Fine- to medium-grained, dark greenish gray diorite and quartz diorite

sh — SHONKINITE--Medium- to coarse-grained, dark-gray

sg — QUARTZ MONZONITE--Fine- to medium-grained, light-gray quartz monzonite and granite

ym — YOUNG METAMORPHIC ROCKS--Variably metamorphosed pelitic schist, marble, and matabasalt

mgy — GABBRO AND YOUNG METAMORPHIC ROCKS--Intrusive gabbro; metamorphic rocks dominant

km — KHAMIS MUSHAYT GNEISS--Granitic orthogneiss, paragneiss, migmatite, amphibolite, and pegmatite

SYMBOLS

——— CONTACT of geologic units

STRIKE AND DIP OF FOLIATION--vertical or inclined

• 110 RADIOACTIVITY--in counts per second; locality shown by dot or by symbol for strike and dip

•156169 NONMAGNETIC CONCENTRATE--used for mineralogical analyses

X 1169 SPOT ELEVATION--in meters

Figure 4.--Reconnaissance geologic map showing the shonkinite pluton at Jabal Atwid, relative radioactivity of rocks, and sources of concentrates used for mineralogical analyses. Adapted from R. G. Coleman, 1973, Khamis Mushayt quadrangle, sheet 18/42 D.

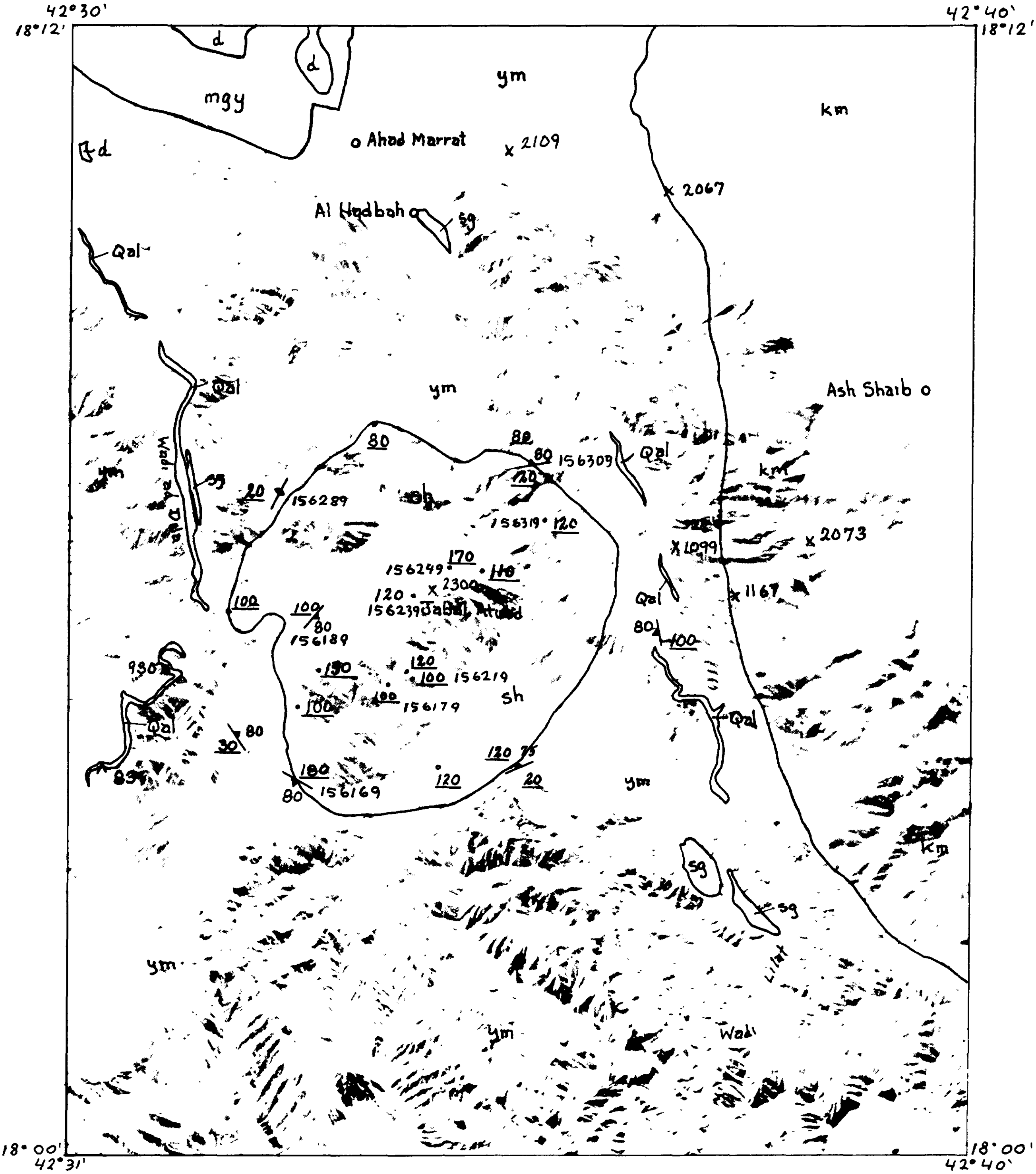


Figure 4.--Reconnaissance geologic map showing the shonkinite pluton at Jabal Atwid, relative radioactivity of rocks, and sources of concentrates used for mineralogical analyses. Adapted from R. G. Coleman, 1973, Khamis Mushayt quadrangle, sheet 18/42 D.--Continued

Table 2.--Scintillometer measurements of total-count radioactivity for bedrock in the study area.

Rock	Number of measurements	Average radioactivity (counts per second)
Intrusives		
Syenite plutons		
Jabal Fayfa	11	115
Jabal Bani Malik	20	135
Southeast of Suq al Ithnayn	10	90
Shonkinite pluton		
Jabal Atwid	13	115
Metamorphic rocks		
Undivided		
Wall rocks at Jabal Ativid	5	50
Inclusion in shonkinite at Jabal Atwid	1	100
Khamis Mushayt Complex		
Wall rocks southeast of Suq al Ithnayn	11	85
Baish Formation		
Wall rocks southeast of Suq al Ithnayn	3	25
Inclusion in syenite of Suq al Ithnayn	1	35
Sabya Formation		
Wall rocks in area of Jabal Fayfa and Jabal Bani Malik	22	60
Inclusions in syenite at Jabal Fayfa	4	65
Inclusions in syenite at Jabal Bani Malik	5	50

The data from the scintillometer measurements indicate that highly radioactive minerals such as thorite and monazite, observed in concentrates from the shonkinite, are uncommon on these plutons.

Weathering

Three of the four plutons form prominent, steep-sided, subcircular peaks that rise from low-gradient bases, but the syenite pluton to the southeast of Suq al Ithnayn is in an area of less steep relief. Agricultural terraces are common and native vegetation is relatively abundant on Jabal Fayfa, Jabal Bani Malik, and Jabal Atwid, but not on the body of syenite to the southeast of Suq al Ithnayn. On the three prominent peaks the upper reaches of the wadis descend steeply through a series of rock shoots and falls, variably entrenched and choked by boulders, flattening in the lower reaches to broad, boulder-strewn wadis. Most exposed rock above the main breaks in slope at the bases of the mountains is unweathered, but on the lower slopes, where gradients are relatively gentle and erosion is less vigorous, the exposed surfaces of the rocks locally are either deeply weathered to saprolite or thickly mantled with gruss. Severe erosion on the steep slopes proceeds more rapidly than chemical weathering with the result that the exposed rock is fresh. Where erosion is less active, chemical weathering produces mantles of saprolite, some of which are sufficiently large and deep to permit fields to be carved therefrom by earth-moving machinery, such as are used to build roads, to create new tracts for agriculture. On the syenite pluton to the southeast of Suq al Ithnayn, saprolite is locally present on flat upper surfaces.

Grain size of wadi sediments

Sieving to four size-fractions of the samples of wadi sediment taken for chemical analysis indicates the distribution of sand-size material in the wadis, but owing to the huge volume of boulders and cobbles in the alluvium, particularly in the upper reaches of the wadis, the resulting data only classifies the interstitial debris. No measure of the percentages of boulders and cobbles was made, because they were not the material taken for analysis.

Wadi sand from the medium- to coarse-grained syenite plutons tends to be finer grained than sand derived from the schistose and gneissic wall rocks, but at Jabal Atwid the wadi sand from shonkinite and from schistose wall rocks has essentially equal size distributions.

Table 3.--Size distributions of wadi sediment samples from the study area.

Area	Number of samples	Size distribution (percent) -10-mesh	-10+32-mesh	-32+80-mesh	-80-mesh
Jabal Fayfa					
Syenite	14	28.6	42.7	20.1	8.6
Wall rocks	13	43.7	33.5	17.3	5.5
Jabal Bani Malik					
Syenite	22	37.0	34.4	21.3	7.3
Wall rocks	12	59.8	24.7	10.4	5.1
Pluton to the southeast of Suq al Ithnayn					
Syenite	8	43.9	37.2	16.3	2.6
Wall rocks	18	52.0	31.0	13.5	3.5
Jabal Ativid					
Shonkinite	15	39.1	36.7	16.8	7.4
Wall rocks	4	38.6	35.8	17.7	7.9

Grain size of the wadi sediments has been shown to affect the results of chemical analyses of both the raw sand and of concentrates prepared therefrom (Theobold and Allcott, 1973; duBray, 1981; Overstreet and others, 1983, unpub. data) because the size distribution reflects the variable factors of source, transport, and deposition. The gross similarity of grain-size distributions in the samples from these areas assures that differences in the chemical composition of the wadi sediments and concentrates reflect real differences in the source areas.

MINERALOGY OF THE CONCENTRATES

Nonmagnetic concentrates

The mineralogical composition of the nonmagnetic fraction of the concentrates panned from wadi sediment from the areas of the plutons of syenite and shonkinite is given in table 4. Most minerals in these concentrates are pyroxenes, olivine, amphiboles, garnet, epidote, and mica. Small amounts of feldspar and quartz are present. Rare-metal-bearing minerals, exclusive of zircon, are extremely scarce. None has economic importance. Chemical formulas for minerals discussed below are given in the Appendix.

Rare-metal-bearing minerals

The rare-metal-bearing minerals except zircon are restricted to single concentrates. A trace of cassiterite was detected in sample 156379 from the northwestern flank of the syenite pluton at Jabal Fayfa (fig. 2; table 4). Trace amounts of monazite are present in sample 156219 from the south-central part of the shonkinite pluton at Jabal Atwid, and traces of baddeleyite and thorite were found in sample 156169 from the southwestern side on the shonkinite pluton (fig. 4; table 4). Zircon is present in many concentrates (table 4).

Cassiterite is evidently very sparse in sample 156379, because in the spectrographic analysis of the nonmagnetic concentrate only 15 ppm Sn was detected, a value which is within background for Sn in nonmagnetic concentrates.

The sparseness of monazite in sample 156219 is reflected by the background value of 100 ppm La in the nonmagnetic concentrate.

Table 4.--Mineralogical composition of nonmagnetic concentrates from areas underlain by syenite and shonkinite plutons.

Sample Number	Major minerals	Minor minerals	Trace minerals
		Syenite plutons at Jabal Fayfa and Jabal Bani Malik	
156379	Hematite, ilmenite, augite, titanite, zircon	Tirodite, spessartine, fluorapatite	Cassiterite
153389	Ilmenite, hastingsite, titanite, zircon	Spessartine, fluorapatite	Hematite, epidote, mukhinite
156399	Ilmenite, hastingsite, titanite, zircon	Augite, spessartine, fluorapatite	Hematite, mukhinite
156429	Ilmenite, augite, hastingsite, kaersutite, zircon, fluorapatite	Augite	Hematite, mukhinite, spessartine, titanite
156579	Ilmenite, hastingsite, augite, titanite, zircon, fluorapatite	Hematite, mukhinite	———
156609	Hematite, hastingsite, zircon, titanite	Ilmenite, augite, mukhinite, fluorapatite	Spessartine
156659	Hastingsite, titanite, fluorapatite, zircon	———	———
156669	Hematite, hastingsite, mukhinite, titanite, zircon	Augite, spessartine, fluorapatite	———
156709	Hastingsite, hornblende, zircon, titanite	Epidote, almandine, fluorapatite	Ilmenite, quartz
156729	Hastingsite, fluorapatite	Ilmenite, epidote, albite, zircon	Almandine, titanite, quartz
156799	Hastingsite, titanite, zircon, fluorapatite	Epidote, spessartine, ilmenite	Hematite, mukhinite
156819	Hematite, hastingsite, titanite, zircon, fluorapatite	Spessartine	Ilmenite, epidote, mukhinite
156859	Hematite, ilmenite, zircon, tirodite	Spessartine, epidote	Titanite
156879	Hastingsite, titanite, zircon, fluorapatite	Hematite, ilmenite, spessartine, epidote	Quartz, kaersutite

Table 4.--Mineralogical composition of nonmagnetic concentrates from areas underlain by syenite and shonkinite plutons.--Continued

Sample Number	Major minerals	Minor minerals	Trace minerals
		Syenite pluton between Wadi Rudum and Wadi Bishah	
153559	Ilmenite, tirodite, titanite	Fluorapatite	————
153569	Ilmenite, tirodite, titanite, fluorapatite	Zircon	
153579	Ilmenite, tirodite, fluorapatite, titanite	————	Magnetite
153589	Tirodite, hastingsite, flourapatite, titanite	Ilmenite	————
153629	Ilmenite, titanite, fluorapatite	Tirodite	Magnetite
153639	Ilmenite, titanite, flourapatite	————	————
153649	Ilmenite, fluorapatite	Tirodite, titanite	————
153729	Tirodite, fluorapatite	Ilmenite, titanite, zircon	Hematite magnetite
		Shonkinite pluton at Jabal Atwid	
156169	Hornblende, phlogopite, fluorapatite	Fosterite	Thorite, baddeleyite
156179	Diopside	Titanite	Richterite
156189	Hornblende, hypersthene	Ilmenite, tremolite	Siderophyllite
156219	Diopside	Phlogopite	Fassaite, epidote, monazite
156239	Diopside, fluorapatite	Kaersutite	Fayalite
156249	Diopside, acmite, apatite	Magnetite, tirodite	Biotite, titanite
156259	Diopside, acmite, apatite, tirodite	Augite, titanite	Magnetite, ilmenite, biotite
156269	Titanite	————	————
156289	Tirodite, fosterite, fluorapatite	Titanite, magnetite	Ilmenite, muscovite
156309	Diopside, tirodite, acmite, apatite	Augite, titanite	Magnetite
156319	Richterite, fluorapatite	Kaersutite	————

Baddeleyite may be somewhat more abundant than the other rare-element-bearing minerals exclusive of zircon, because the nonmagnetic concentrate in which it was detected contains the positive anomalous amount of 1,000 ppm Zr but lacks zircon at the lower limit of detection by X-ray diffraction. However, that does not mean that zircon is not present in the concentrate. The interesting aspect of both baddeleyite and zircon from alkalic rocks is that they tend to contain less Hf than zircon from granites. Both Zr and Hf are used as metals in nuclear reactors, but for different purposes arising from the different nuclear properties of the two metals (Klemic and others, 1973, p. 714). Zirconium metal must be freed of Hf for this use.

Pyroxene and olivine groups

Minerals of the pyroxene group identified in the nonmagnetic concentrates are hypersthene, acmite, augite, diopside and fassaite. None is present in concentrates derived from the pluton of syenite southeast of Suq al Ithnayn. Augite is both a major and a minor mineral in concentrates from the syenite plutons at Jabal Fayfa and Jabal Bani Malik, but the other members of the group are absent. All five varieties of pyroxene are represented in the concentrates from the shonkinite (table 4). Diopside is the most common.

Fayalite and fosterite end members of the olivine group, are present in several concentrates from the area of the shonkinite pluton (table 4), but they are absent from concentrates having sources in the syenite bodies.

Amphibole, garnet, epidote, and mica groups

Amphiboles identified in the concentrates include hastingsite, hornblende, kaersutite, richterite, tirodite, and tremolite. Hastingsite is the major amphibole in concentrates from the plutons of syenite at Jabal Fayfa and Jabal Bani Malik (table 4) and is present in one sample from the syenite pluton to the southeast of Suq al Ithnayn, but the mineral is absent from shonkinite-derived concentrates. Hornblende and kaersutite are present in one or two samples each from the syenite at Jabal Fayfa and Jabal Bani Malik and from the shonkinite at Jabal Atwid, but neither mineral is present in concentrates from the body of syenite exposed to the southeast of Suq al Ithnayn. Richterite and tremolite were identified only in a few concentrates from the area of the shonkinite. Tirodite is widely present in concentrates from the syenite pluton southeast of Suq al Ithnayn, and is somewhat less common in the concentrates from Jabal Fayfa, Jabal Bani Malik, and Jabal Atwid.

Almandine and spessartine garnets are reported only in concentrates from the area of Jabal Fayfa and Jabal Bani Malik. Spessartine is far more common than almandine. Most spessartine-bearing concentrates are from the syenite plutons (fig. 4, table 4). Of the two locations yielding almandine, one is in syenite and one is in the wall rocks.

Epidote and mukhinite, members of the epidote group, are present in concentrates from the Jabal Fayfa and Jabal Bani Malik areas and absent from concentrates from the pluton of syenite southeast of Suq al Ithnayn; epidote alone is present in one concentrate from the Jabal Atwid area (table 4). Allanite, the rare-earth-bearing form of epidote, was absent from the concentrates in the areas of the syenite plutons at Jabal Fayfa and Jabal Bani Malik, whereas allanite was sufficiently conspicuous and constantly present in thin sections of the syenite to permit it to be classed as one of the mafic minerals of the rock (Fairer, 1981, p. 10). An argument might be made that the notable instability of allanite under conditions of weathering (Watson, 1917) caused it to be lost from the heavy-mineral suite of sediments derived from the syenite, but this interpretation does not fit the lack of weathering in the upper parts of Jabal Fayfa and Jabal Bani Malik which are the source areas for the concentrates. None of the mukhinite-bearing concentrates is anomalously enriched in V or in Y; thus, the trace elements in the nonmagnetic concentrates are not a confirmation of the presence of either mukhinite or allanite. However, values for V are in the high background range (200-500 ppm), whereas values for Y are in the low background range of 20-70 ppm, which suggests that mukhinite could be more common than allanite in these concentrates.

The mica group of minerals is represented in table 4 by biotite, muscovite, phlogopite, and siderophyllite, all of which are reported only for concentrates from the shonkinite pluton.

Other minerals

Other minerals identified in the nonmagnetic concentrates are albite, quartz, magnetite, apatite, fluorapatite, hematite, ilmenite, and titanite. The presence of albite and quartz in concentrates from which these minerals have been removed by separation in heavy liquids is caused by polymineralic intergrowths in which sufficient quantities of higher-density minerals are intergrown with the quartz and albite to cause them to sink in the heavy liquids and to be recovered with the other high-density minerals.

Albite and quartz appear only as minor or trace minerals in a few concentrates (table 4). Owing to this sparsity, they do not constitute significant contaminants in the results of the spectrographic analyses of the cleaned concentrates.

Minor and trace amounts of magnetite persist into some nonmagnetic concentrates after cleaning with a hand magnet owing to the intergrowth of some grains of magnetite with nonmagnetic minerals. The response of these mixed grains is nonmagnetic. X-ray diffraction analyses of the magnetite removed with the hand magnet showed hematite and ilmenite as the commonest minerals to be intergrown with the magnetite (Theodore Botinelly, USGS, written commun., June 8, 1981). Where the amounts of hematite and ilmenite are sufficiently great to override the ferromagnetic response of the magnetite, then the magnetite persisted into the nonmagnetic concentrates. Other minerals intergrown with magnetite in the nonmagnetic concentrates were identified under the binocular microspcope by Overstreet to be quartz, feldspar, pyroxene, amphibole, biotite, and garnet. The amounts of magnetite in the nonmagnetic concentrates are too small to modify significantly the results of spectrographic analyses.

Fluorapatite, also identified in table 4 as apatite, is, with hematite and titanite, among the major mineralogical components of the nonmagnetic concentrates from all the plutons. Ilmenite is a major component of the concentrates from the syenite plutons but not from the shonkinite pluton at Jabal Atwid.

Concentration ratios

The concentration effected by panning can be expressed as the ratio of the weight of the concentrate to the 10-kg weight of the standard sample of wadi sediment used for panning. The weight of the concentrate determines the ratio.

Table 5.--The concentration ratios for nonmagnetic concentrates from the study area.

Source of concentrates	Average weight (g)	Ratio
Jabal Fayfa		
Syenite	41.0	243
Wall rocks	101.1	99
Jabal Bani Malik		
Syenite	41.1	243
Wall rocks	20.8	481
Pluton southeast of Suq al Ithnayn		
Syenite	245.2	41
Wall rocks	34.3	292
Jabal Atwid		
Shonkinite	188.8	53
Wall rocks	181.8	55

The magnetic fractions removed from the raw concentrates when the nonmagnetic concentrates were prepared are quite small compared with the nonmagnetic fractions; thus, the magnetic concentrates show higher concentration ratios than the nonmagnetic concentrates.

Table 6.--The concentration ratios for magnetic concentrates from the study area.

Source of concentrates	Average weight (g)	Ratio
Jabal Fayfa		
Syenite	9.2	1,086
Wall rocks	3.8	2,632
Jabal Bani Malik		
Syenite	9.4	1,064
Wall rocks	1.1	9,091
Pluton southeast of Suq al Ithnayn		
Syenite	80.1	125
Wall rocks	5.7	1,754
Jabal Atwid		
Shonkinite	77.6	129
Wall rocks	63.0	159

The average concentration ratios for all types of concentrates and all rock units are shown in table 7.

Table 7.--Average concentration ratios for heavy-mineral concentrates in the study area.

Type of concentrate	Average concentration ratios by area
	Jabal Fayfa
Raw	94
Magnetic	1,515
Nonmagnetic	143
	Jabal Bani Malik
Raw	59
Magnetic	1,545
Nonmagnetic	295
	Area southeast of Suq al Ithnayn
Raw	59
Magnetic	350
Nonmagnetic	101
	Jabal Atwid
Raw	28
Magnetic	134
Nonmagnetic	53

All the source rocks contain only small amounts of magnetite.

DISTRIBUTION OF SELECTED ELEMENTS

The maximum, minimum, and mean values for the 30 elements determined spectrographically on the six varieties of geochemical sample media in the areas underlain by the plutons of syenite and shonkinite are given in tables 8-10 where substitute values for the technically censored data are entered according to the usage outlined in table 1. Full analytical data for these media at each site shown on figures 2-4 are stored in the USGS/DMMR RASS (Rock Analysis Storage System) computer system, Jiddah, by DMMR sample numbers 153550-153798 (syenite pluton to the southeast of Suq al Ithnayn), 156160-156348 (shonkinite pluton at Jabal Atwid), and 156370-156978 (syenite plutons at Jabal Fayfa and Jabal Bani Malik). A guide to accessing these data is given by Overstreet and others (1983, unpub. data).

Values and frequency of determination

The mean values for the samples of rocks and the sieved wadi sediment, except the finest size, are quite similar and reflect the dominance of unweathered materials in these media. The mean tenors of Fe and Mn in the finest-grained fraction of wadi sediment rise in comparison with those of the rocks and coarse-grained sediment, which reflects an access of the products of weathering, and the rise in Fe and Mn is accompanied by rises in the mean abundances of other elements (tables 8-10). The highest values for many elements are obtained in the concentrates. These variations reflect the different geochemical phases represented by the media: samples of rock show the chemical conditions at the site; the detrital material reflects the composition of the mix of rocks in the distributive province upstream; and the concentrates indicate the chemical composition of the mafic constituents of the rocks.

The mean and maximum values for Nb are less than crustal abundance (Beus and Grigorian, 1975, table 3) in all samples of rocks from the areas of the three syenite plutons and the shonkinite pluton (tables 8-10). Other elements with mean values less than crustal abundance include Mn in all rocks, Ca in the plutons at Jabal Fayfa and Jabal Bani Malik; B, Be, La, Ni, Y, and Zr in the syenite pluton to the southeast of Suq al Ithnayn; and Ti in the shonkinite pluton at Jabal Atwid. Elements with maximum values equal to or less than crustal abundance are Be and Pb in the syenite to the southeast of Suq al Ithnayn and Ti, Mn, and Y in the shonkinite. The mean values of Pb and V are about equal to crustal abundance in all samples of rocks. In the syenite plutons, Fe, Mg, Ti, Cu, and Sr are equal to crustal abundance; in the plutons at Jabal Fayfa and Jabal Bani Malik, B, Co, Ni, and Zr are equal to crustal abundance, as are Ca and Sc in the syenite to the southeast of Suq al Ithnayn. Boron, Be, Sc, and Y have mean values in the shonkinite pluton equal to crustal abundances. Mean values exceeding crustal abundances are shown for Ba and Cr in all plutons, and for Be, La, Sc, and Y in the syenite plutons at Jabal Fayfa and Jabal Bani Malik. The mean value of Co exceeds crustal abundance in the syenite pluton to the southeast of Suq al Ithnayn and in the shonkinite pluton. Other elements with mean values exceeding crustal abundances in the shonkinite are Fe, Mg, Ca, Cu, La, Ni, Sr, and Zr.

The frequency of determination of each element by sample medium is shown in tables 11-13 where a modification of the classification proposed by Lovering (1972, p. 55) is adopted.

Characteristic elements

The characteristic elements Fe, Mg, Ca, Ti, Mn, Cr, and Zr are present in every sample of each medium from all areas (tables 11-13). Their presence in determinable quantities in all samples is interpreted to reflect the influence of the pyroxenes, amphiboles, titanite, ilmenite, and zircon (table 4) on the chemical composition of all media. Other characteristic elements present in all media from each area, but undetermined in some media are shown in table 14.

The tendency for the frequency of determination of Ba and Sr to decline in nonmagnetic concentrates from the syenite plutons and for Pb and Sr to decline in frequency of determination in nonmagnetic concentrates from the shonkinite is interpreted to indicate that these elements are in part camouflaged in feldspars. The ion Sr^{2+} may substitute for Ca^{2+} in plagioclase and K^{+} in potassium feldspar, where Ba^{2+} and Pb^{2+} may also substitute for K^{+} (Rankama and Sahama, 1950, p. 471).

The rise in the frequency of determination of Co, Cu, Ni, and V from samples of rocks to samples of wadi sediments and concentrates is thought to reflect the broad compositional mix of the sedimentary materials in comparison with the narrow representation of the rock samples as well as the great increase in pyroxenes, amphiboles, titanite, and ilmenite in the concentrates in which minerals these elements are camouflaged.

The frequency of determination of Pb and Sc reflects the composition of source rocks: these elements are more frequently reported in samples from the shonkinite pluton than from the syenite plutons.

Factors influencing the frequency of determination of Y include both source areas and media. The syenite plutons at Jabal Fayfa and Jabal Bani Malik are lesser sources for Y-bearing samples than the other plutons, and the samples of rocks and coarse-grained sediments are less likely sources than the fine-grained sediments and concentrates.

Table 8.--Values for 30 elements determined by semiquantitative spectrographic methods on six varieties of geochemical sample media from the area underlain by syenite plutons at Jabal Fayfa and Jabal Bani Malik.

E. JABAL FAYFA AND JABAL BANI MALIK PLUTONS

1. ROCKS

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	0.30	0.03	0.07	0.03	20.00	0.10	50.00	2.00	5.00	20.00
MAXIMUM	10.00	7.00	10.00	1.50	5000.00	0.10	50.00	2.00	50.00	3000.00
MEAN	4.25	2.43	3.03	0.62	745.57	0.10	50.00	2.00	6.97	979.84
STD.DEV.	2.25	1.67	2.08	0.32	712.81	0.00	0.00	0.00	6.97	786.92

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	1.00	70.00	2.00	5.00	1.00	5.00	1.00
MAXIMUM	3.00	2.00	5.00	50.00	700.00	200.00	50.00	15.00	5.00	200.00
MEAN	1.10	2.00	5.00	11.23	252.30	50.80	20.57	1.46	5.00	56.02
STD.DEV.	0.83	0.00	0.00	8.43	155.21	40.39	11.35	2.49	0.00	48.54

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	1.00	2.00	20.00	5.00	10.00	2.00	50.00	20.00
MAXIMUM	30.00	20.00	50.00	2.00	1500.00	500.00	10.00	50.00	50.00	700.00
MEAN	11.26	20.00	12.85	2.00	444.10	147.87	10.00	16.57	50.00	140.00
STD.DEV.	7.87	0.00	9.53	0.00	343.15	114.85	0.00	9.86	0.00	117.86

2. <10+32-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	1.50	1.00	0.50	0.15	200.00	0.10	50.00	2.00	5.00	50.00
MAXIMUM	10.00	5.00	5.00	1.50	3000.00	0.10	50.00	2.00	15.00	3000.00
MEAN	5.17	2.61	3.48	0.55	703.28	0.10	50.00	2.00	5.49	1136.89
STD.DEV.	1.88	1.05	1.35	0.27	477.34	0.00	0.00	0.00	1.96	781.96

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	2.00	150.00	10.00	5.00	1.00	5.00	15.00
MAXIMUM	2.00	2.00	5.00	20.00	700.00	200.00	50.00	15.00	5.00	200.00
MEAN	0.78	2.00	5.00	9.59	277.05	48.85	13.36	1.56	5.00	58.20
STD.DEV.	0.56	0.00	0.00	4.73	119.96	40.49	8.67	2.05	0.00	31.43

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	2.00	2.00	50.00	30.00	10.00	5.00	50.00	30.00
MAXIMUM	50.00	20.00	30.00	2.00	1500.00	200.00	10.00	50.00	50.00	300.00
MEAN	8.98	20.00	12.08	2.00	655.74	129.51	10.00	14.51	50.00	87.21
STD.DEV.	8.20	0.00	6.89	0.00	440.95	52.74	0.00	7.50	0.00	52.67

3. <32+80-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	3.00	1.50	0.70	0.15	300.00	0.10	50.00	2.00	5.00	50.00
MAXIMUM	10.00	5.00	5.00	1.50	5000.00	0.10	50.00	2.00	10.00	2000.00
MEAN	6.48	3.18	3.93	0.75	1027.87	0.10	50.00	2.00	5.16	886.89
STD.DEV.	1.63	1.15	1.20	0.32	711.99	0.00	0.00	0.00	0.89	649.39

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	5.00	100.00	10.00	5.00	1.00	5.00	10.00
MAXIMUM	3.00	2.00	5.00	50.00	700.00	150.00	50.00	20.00	5.00	300.00
MEAN	0.95	2.00	5.00	14.46	311.48	57.38	16.64	2.62	5.00	77.13
STD.DEV.	0.70	0.00	0.00	7.88	128.80	36.58	12.67	4.40	0.00	46.35

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	2.00	2.00	50.00	30.00	10.00	5.00	50.00	10.00
MAXIMUM	50.00	20.00	50.00	2.00	1500.00	300.00	10.00	50.00	50.00	1500.00
MEAN	10.05	20.00	16.92	2.00	582.79	175.57	10.00	19.67	50.00	257.21
STD.DEV.	10.16	0.00	9.07	0.00	380.56	64.67	0.00	10.32	0.00	319.27

Table 8.--Values for 30 elements determined by semiquantitative spectrographic methods on six varieties of geochemical sample media from the area underlain by syenite plutons at Jabal Fayfa and Jabal Bani Malik.--Continued

4. <80-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	3.00	1.50	1.00	0.20	300.00	0.10	50.00	2.00	5.00	70.00
MAXIMUM	10.00	5.00	7.00	1.50	2000.00	0.10	50.00	2.00	15.00	1500.00
MEAN	6.44	3.16	4.13	0.97	934.43	0.10	50.00	2.00	5.74	570.82
STD.DEV.	1.30	1.22	1.37	0.36	289.65	0.00	0.00	0.00	2.19	407.54

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	5.00	150.00	10.00	5.00	1.00	5.00	20.00
MAXIMUM	5.00	2.00	5.00	30.00	700.00	150.00	70.00	7.00	5.00	200.00
MEAN	1.11	2.00	5.00	12.93	322.95	60.57	24.43	1.28	5.00	80.16
STD.DEV.	1.09	0.00	0.00	4.99	133.85	30.41	20.86	1.18	0.00	44.96

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	1.00	2.00	100.00	50.00	10.00	5.00	50.00	50.00
MAXIMUM	50.00	20.00	30.00	2.00	1000.00	300.00	10.00	30.00	50.00	1500.00
MEAN	10.75	20.00	15.89	2.00	454.92	184.75	10.00	23.03	50.00	516.23
STD.DEV.	10.73	0.00	7.77	0.00	292.49	54.73	0.00	6.23	0.00	462.23

5. RAW CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	5.00	0.70	1.50	0.50	500.00	0.10	50.00	2.00	5.00	30.00
MAXIMUM	30.00	5.00	7.00	1.50	7000.00	0.10	50.00	2.00	30.00	1000.00
MEAN	10.62	2.77	4.30	1.15	1593.44	0.10	50.00	2.00	6.07	252.46
STD.DEV.	5.81	1.35	1.42	0.35	1256.18	0.00	0.00	0.00	3.85	203.48

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	10.00	150.00	10.00	5.00	1.00	5.00	15.00
MAXIMUM	20.00	2.00	5.00	200.00	5000.00	150.00	70.00	20.00	5.00	300.00
MEAN	2.63	2.00	5.00	38.69	641.80	69.26	25.08	1.95	5.00	88.93
STD.DEV.	3.54	0.00	0.00	37.93	701.12	28.94	20.23	3.32	0.00	51.51

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	1.00	2.00	50.00	70.00	10.00	15.00	50.00	50.00
MAXIMUM	200.00	20.00	50.00	30.00	1000.00	700.00	10.00	100.00	50.00	1500.00
MEAN	22.05	20.00	14.77	5.41	393.44	327.21	10.00	33.85	50.00	861.97
STD.DEV.	30.62	0.00	13.98	5.97	283.49	162.76	0.00	16.00	0.00	607.19

6. NONMAGNETIC CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	5.00	1.00	3.00	0.70	500.00	0.10	50.00	2.00	5.00	5.00
MAXIMUM	30.00	7.00	15.00	1.50	7000.00	0.10	50.00	2.00	70.00	200.00
MEAN	11.36	3.75	5.84	1.29	2365.57	0.10	50.00	2.00	6.39	70.41
STD.DEV.	5.41	1.54	2.28	0.29	1782.69	0.00	0.00	0.00	8.45	40.05

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	7.00	100.00	15.00	5.00	1.00	5.00	15.00
MAXIMUM	10.00	2.00	5.00	300.00	1500.00	200.00	100.00	30.00	5.00	150.00
MEAN	2.41	2.00	5.00	55.36	599.18	82.87	32.62	1.62	5.00	71.07
STD.DEV.	2.42	0.00	0.00	60.42	290.21	49.02	31.40	3.84	0.00	31.04

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	1.00	2.00	20.00	100.00	10.00	20.00	50.00	30.00
MAXIMUM	500.00	20.00	70.00	50.00	200.00	700.00	10.00	100.00	50.00	1500.00
MEAN	35.92	20.00	16.49	7.25	34.59	316.39	10.00	45.57	50.00	873.11
STD.DEV.	67.25	0.00	15.73	8.95	39.61	150.88	0.00	21.84	0.00	617.86

Table 9.--Values for 30 elements determined by semiquantitative spectrographic methods on six varieties of geochemical sample media from the area underlain by syenite pluton to the southeast of Suq al Ithnayn.

D. SYENITE PLUTON (SE OF SUQ AL ITHNAYN)

1. ROCKS

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	0.50	0.10	0.70	0.03	100.00	0.10	50.00	2.00	5.00	20.00
MAXIMUM	10.00	7.00	10.00	1.50	3000.00	0.10	50.00	2.00	5.00	2000.00
MEAN	4.70	2.62	4.49	0.74	878.00	0.10	50.00	2.00	5.00	830.00
STD.DEV.	2.78	2.09	2.82	0.51	675.44	0.00	0.00	0.00	0.00	659.51

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	1.00	70.00	7.00	5.00	1.00	5.00	1.00
MAXIMUM	2.00	2.00	5.00	50.00	700.00	70.00	50.00	1.00	5.00	100.00
MEAN	0.87	2.00	5.00	16.44	252.80	32.96	15.00	1.00	5.00	33.64
STD.DEV.	0.66	0.00	0.00	15.18	171.43	22.93	10.58	0.00	0.00	31.99

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	1.00	2.00	150.00	10.00	10.00	2.00	50.00	10.00
MAXIMUM	20.00	20.00	50.00	2.00	700.00	500.00	10.00	50.00	50.00	300.00
MEAN	9.28	20.00	15.24	2.00	482.00	188.80	10.00	14.00	50.00	103.60
STD.DEV.	5.90	0.00	16.02	0.00	215.35	162.68	0.00	11.17	0.00	68.33

2. <10+32-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	1.00	0.50	2.00	0.10	100.00	0.10	50.00	2.00	2.00	100.00
MAXIMUM	7.00	5.00	7.00	1.50	1500.00	0.10	50.00	2.00	5.00	2000.00
MEAN	4.74	2.42	4.16	0.69	706.00	0.10	50.00	2.00	4.40	810.00
STD.DEV.	1.91	1.41	1.43	0.40	305.39	0.00	0.00	0.00	1.20	550.27

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	2.00	10.00	2.00	5.00	1.00	5.00	10.00
MAXIMUM	2.00	2.00	5.00	30.00	700.00	150.00	30.00	1.00	5.00	100.00
MEAN	0.42	2.00	5.00	13.12	220.40	42.16	12.40	1.00	5.00	36.20
STD.DEV.	0.52	0.00	0.00	5.56	120.12	32.64	7.23	0.00	0.00	18.88

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	2.00	2.00	100.00	30.00	10.00	5.00	50.00	30.00
MAXIMUM	20.00	20.00	30.00	2.00	1500.00	300.00	10.00	30.00	50.00	500.00
MEAN	4.60	20.00	14.64	2.00	548.00	150.40	10.00	14.40	50.00	97.60
STD.DEV.	4.72	0.00	7.19	0.00	283.01	78.31	0.00	5.54	0.00	97.95

3. <32+80-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	3.00	1.50	3.00	0.50	300.00	0.10	50.00	2.00	2.00	70.00
MAXIMUM	10.00	5.00	7.00	1.50	2000.00	0.10	50.00	2.00	5.00	1500.00
MEAN	7.12	3.34	4.92	1.00	1060.00	0.10	50.00	2.00	4.28	594.80
STD.DEV.	2.07	1.32	1.06	0.41	474.97	0.00	0.00	0.00	1.28	378.17

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	10.00	10.00	10.00	5.00	1.00	5.00	30.00
MAXIMUM	2.00	2.00	5.00	50.00	700.00	150.00	50.00	1.00	5.00	100.00
MEAN	0.30	2.00	5.00	21.80	302.40	67.00	15.40	1.00	5.00	54.80
STD.DEV.	0.38	0.00	0.00	9.47	176.23	31.11	11.99	0.00	0.00	18.79

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	7.00	2.00	100.00	100.00	10.00	10.00	50.00	30.00
MAXIMUM	15.00	20.00	50.00	2.00	1000.00	500.00	10.00	50.00	50.00	1000.00
MEAN	4.20	20.00	19.88	2.00	464.00	216.00	10.00	20.80	50.00	182.40
STD.DEV.	3.71	0.00	8.41	0.00	251.21	112.89	0.00	8.45	0.00	240.24

Table 9.--Values for 30 elements determined by semiquantitative spectrographic methods on six varieties of geochemical sample media from the area underlain by syenite pluton to the southeast of Suq al Ithnayn.--Continued

4. <80-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	1.00	2.00	3.00	0.20	500.00	0.10	50.00	2.00	2.00	100.00
MAXIMUM	10.00	5.00	7.00	1.50	2000.00	0.10	50.00	2.00	20.00	1000.00
MEAN	7.04	3.64	4.92	1.06	1108.00	0.10	50.00	2.00	5.68	412.00
STD.DEV.	1.97	1.05	1.06	0.36	399.92	0.00	0.00	0.00	4.32	213.67

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	2.00	10.00	30.00	5.00	1.00	5.00	10.00
MAXIMUM	1.00	2.00	5.00	50.00	700.00	100.00	70.00	1.00	5.00	150.00
MEAN	0.26	2.00	5.00	19.28	305.20	72.00	21.80	1.00	5.00	60.80
STD.DEV.	0.22	0.00	0.00	8.63	207.25	20.98	14.48	0.00	0.00	23.99

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	2.00	2.00	100.00	50.00	10.00	5.00	50.00	70.00
MAXIMUM	10.00	20.00	30.00	2.00	700.00	500.00	10.00	70.00	50.00	1000.00
MEAN	3.60	20.00	20.68	2.00	338.00	230.00	10.00	29.00	50.00	285.20
STD.DEV.	2.33	0.00	7.45	0.00	190.93	117.47	0.00	12.33	0.00	266.35

5. RAW CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	7.00	1.50	2.00	1.00	300.00	0.10	50.00	2.00	2.00	50.00
MAXIMUM	15.00	7.00	7.00	1.50	3000.00	0.10	50.00	2.00	2.00	300.00
MEAN	12.04	4.64	4.88	1.32	1992.00	0.10	50.00	2.00	2.00	152.00
STD.DEV.	2.99	1.59	1.58	0.24	652.33	0.00	0.00	0.00	0.00	47.92

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	15.00	150.00	15.00	5.00	1.00	5.00	50.00
MAXIMUM	3.00	2.00	5.00	70.00	700.00	100.00	70.00	1.00	30.00	100.00
MEAN	0.58	2.00	5.00	44.40	438.00	81.00	15.20	1.00	11.60	72.80
STD.DEV.	0.72	0.00	0.00	21.69	188.30	25.22	14.86	0.00	9.02	15.37

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	15.00	2.00	20.00	200.00	10.00	20.00	50.00	70.00
MAXIMUM	200.00	20.00	50.00	2.00	500.00	700.00	10.00	100.00	50.00	1000.00
MEAN	9.92	20.00	35.00	2.00	218.40	456.00	10.00	43.60	50.00	470.40
STD.DEV.	38.80	0.00	12.96	0.00	135.46	106.13	0.00	19.16	0.00	298.01

6. NONMAGNETIC CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	7.00	0.70	2.00	0.70	1000.00	0.10	50.00	2.00	2.00	5.00
MAXIMUM	30.00	10.00	10.00	1.50	5000.00	0.10	50.00	2.00	5.00	300.00
MEAN	14.38	3.95	4.75	1.47	2291.67	0.10	50.00	2.00	3.38	59.79
STD.DEV.	7.03	2.33	1.96	0.16	852.90	0.00	0.00	0.00	1.49	56.67

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	15.00	200.00	30.00	5.00	1.00	5.00	1.00
MAXIMUM	0.20	2.00	5.00	300.00	700.00	150.00	30.00	1.00	5.00	100.00
MEAN	0.20	2.00	5.00	78.33	350.00	76.25	7.08	1.00	5.00	44.42
STD.DEV.	0.00	0.00	0.00	88.70	147.20	22.70	5.76	0.00	0.00	26.24

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	1.00	2.00	20.00	150.00	10.00	10.00	50.00	20.00
MAXIMUM	2.00	20.00	50.00	2.00	100.00	700.00	10.00	100.00	50.00	1500.00
MEAN	2.00	20.00	14.71	2.00	35.00	443.75	10.00	39.79	50.00	421.25
STD.DEV.	0.00	0.00	14.88	0.00	26.93	185.58	0.00	25.92	0.00	378.74

Table 10.--Values for 30 elements determined by semiquantitative spectrographic methods on six varieties of geochemical sample media from the area underlain by the shonkinite pluton at Jabal Atwid.

C. JABAL ASWAD PLUTON

1. ROCKS

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	7.00	1.50	0.70	0.30	150.00	0.10	50.00	2.00	5.00	10.00
MAXIMUM	15.00	7.00	20.00	1.00	1500.00	0.10	50.00	2.00	30.00	3000.00
MEAN	8.05	4.29	6.06	0.65	850.00	0.10	50.00	2.00	13.42	1458.95
STD.DEV.	2.04	1.70	3.97	0.20	280.51	0.00	0.00	0.00	8.28	779.61

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	1.00	150.00	15.00	5.00	1.00	5.00	1.00
MAXIMUM	5.00	2.00	5.00	70.00	700.00	150.00	150.00	7.00	10.00	300.00
MEAN	1.76	2.00	5.00	27.79	410.53	71.84	66.84	2.11	6.05	123.95
STD.DEV.	1.81	0.00	0.00	20.78	201.69	31.34	45.86	1.65	2.04	93.59

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	1.00	2.00	100.00	70.00	10.00	2.00	50.00	30.00
MAXIMUM	30.00	20.00	70.00	2.00	1500.00	300.00	10.00	30.00	50.00	700.00
MEAN	15.37	20.00	20.58	2.00	784.21	157.37	10.00	28.00	50.00	228.95
STD.DEV.	6.56	0.00	15.23	0.00	343.76	61.46	0.00	6.52	0.00	181.83

2. <10+32-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	3.00	2.00	3.00	0.50	500.00	0.10	50.00	2.00	5.00	500.00
MAXIMUM	7.00	10.00	7.00	1.00	1000.00	0.10	50.00	2.00	30.00	2000.00
MEAN	5.84	4.42	3.84	0.60	684.21	0.10	50.00	2.00	10.26	1563.16
STD.DEV.	1.18	2.14	1.35	0.13	163.07	0.00	0.00	0.00	6.58	490.12

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.50	2.00	5.00	10.00	150.00	10.00	10.00	1.00	5.00	50.00
MAXIMUM	3.00	2.00	5.00	50.00	1000.00	100.00	30.00	1.00	5.00	300.00
MEAN	1.13	2.00	5.00	18.68	492.11	38.68	22.11	1.00	5.00	111.58
STD.DEV.	0.76	0.00	0.00	9.30	290.31	24.43	6.14	0.00	0.00	61.92

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	10.00	20.00	5.00	2.00	300.00	100.00	10.00	5.00	50.00	50.00
MAXIMUM	20.00	20.00	50.00	2.00	1500.00	200.00	10.00	30.00	50.00	200.00
MEAN	14.21	20.00	15.42	2.00	968.42	139.47	10.00	13.68	50.00	112.11
STD.DEV.	3.35	0.00	10.77	0.00	379.82	41.61	0.00	5.34	0.00	44.91

3. <32+80-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	7.00	3.00	5.00	0.70	1000.00	0.10	50.00	2.00	5.00	300.00
MAXIMUM	15.00	10.00	10.00	1.50	1500.00	0.10	50.00	2.00	15.00	1500.00
MEAN	8.32	6.74	5.47	0.93	1236.84	0.10	50.00	2.00	6.84	1057.89
STD.DEV.	2.54	1.80	1.23	0.19	249.65	0.00	0.00	0.00	3.70	382.95

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.50	2.00	5.00	20.00	300.00	20.00	10.00	1.00	5.00	70.00
MAXIMUM	3.00	2.00	5.00	50.00	1500.00	100.00	50.00	1.00	5.00	500.00
MEAN	1.58	2.00	5.00	30.00	763.16	58.95	26.32	1.00	5.00	161.58
STD.DEV.	1.04	0.00	0.00	11.24	247.54	23.15	10.86	0.00	0.00	83.93

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	5.00	20.00	15.00	2.00	300.00	150.00	10.00	15.00	50.00	70.00
MAXIMUM	15.00	20.00	50.00	2.00	1000.00	500.00	10.00	30.00	50.00	700.00
MEAN	11.05	20.00	25.00	2.00	663.16	265.79	10.00	21.05	50.00	238.95
STD.DEV.	2.61	0.00	8.27	0.00	184.14	98.75	0.00	4.16	0.00	160.59

Table 10.--Values for 30 elements determined by semiquantitative spectrographic methods on six varieties of geochemical sample media from the area underlain by the shonkinite pluton at Jabal Atwid.--Continued

4. <80-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	3.00	2.00	3.00	0.30	700.00	0.10	50.00	2.00	5.00	200.00
MAXIMUM	15.00	10.00	10.00	1.50	2000.00	0.10	50.00	2.00	20.00	1000.00
MEAN	7.79	5.79	5.58	0.76	1178.95	0.10	50.00	2.00	7.37	657.89
STD.DEV.	2.53	2.04	1.43	0.23	330.20	0.00	0.00	0.00	4.40	232.41

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	10.00	200.00	30.00	5.00	1.00	5.00	70.00
MAXIMUM	3.00	2.00	5.00	50.00	1500.00	100.00	150.00	1.00	5.00	150.00
MEAN	1.59	2.00	5.00	25.53	689.47	71.05	51.84	1.00	5.00	124.21
STD.DEV.	1.09	0.00	0.00	10.50	290.00	18.32	33.69	0.00	0.00	31.68

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	5.00	20.00	10.00	2.00	200.00	70.00	10.00	10.00	50.00	70.00
MAXIMUM	20.00	20.00	30.00	2.00	700.00	500.00	10.00	50.00	50.00	300.00
MEAN	12.11	20.00	21.05	2.00	484.21	245.79	10.00	28.95	50.00	187.89
STD.DEV.	4.08	0.00	6.61	0.00	146.05	109.32	0.00	9.12	0.00	72.23

5. RAW CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	5.00	2.00	2.00	0.30	300.00	0.10	50.00	2.00	5.00	100.00
MAXIMUM	10.00	5.00	5.00	1.00	1500.00	0.10	50.00	2.00	5.00	500.00
MEAN	7.42	2.68	3.74	0.59	805.26	0.10	50.00	2.00	5.00	234.21
STD.DEV.	1.93	1.08	1.12	0.20	248.10	0.00	0.00	0.00	0.00	93.26

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	10.00	700.00	10.00	10.00	1.00	5.00	20.00
MAXIMUM	2.00	2.00	5.00	20.00	2000.00	50.00	50.00	1.00	5.00	200.00
MEAN	0.95	2.00	5.00	15.79	1168.42	19.21	23.16	1.00	5.00	102.63
STD.DEV.	0.61	0.00	0.00	2.93	458.89	9.36	9.76	0.00	0.00	47.67

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	20.00	5.00	2.00	100.00	100.00	10.00	10.00	50.00	30.00
MAXIMUM	20.00	20.00	15.00	2.00	500.00	300.00	10.00	20.00	50.00	1000.00
MEAN	5.11	20.00	10.89	2.00	268.42	173.68	10.00	15.26	50.00	158.42
STD.DEV.	4.99	0.00	3.73	0.00	120.54	57.05	0.00	3.43	0.00	206.94

6. NONMAGNETIC CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	5.00	3.00	5.00	0.30	1000.00	0.10	50.00	2.00	5.00	50.00
MAXIMUM	10.00	7.00	15.00	1.50	3000.00	0.10	50.00	2.00	5.00	1000.00
MEAN	8.16	5.63	10.95	0.91	1657.89	0.10	50.00	2.00	5.00	140.00
STD.DEV.	1.63	1.13	3.39	0.33	430.81	0.00	0.00	0.00	0.00	205.81

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MINIMUM	0.20	2.00	5.00	15.00	300.00	15.00	10.00	1.00	5.00	50.00
MAXIMUM	7.00	2.00	5.00	50.00	1500.00	100.00	150.00	1.00	5.00	200.00
MEAN	2.65	2.00	5.00	25.26	663.16	35.53	64.74	1.00	5.00	85.26
STD.DEV.	2.11	0.00	0.00	11.97	262.00	23.11	34.54	0.00	0.00	35.00

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MINIMUM	2.00	50.00	15.00	2.00	50.00	150.00	10.00	15.00	50.00	50.00
MAXIMUM	20.00	150.00	50.00	2.00	500.00	300.00	10.00	70.00	50.00	1500.00
MEAN	7.21	55.26	30.79	2.00	252.63	181.58	10.00	35.00	50.00	466.84
STD.DEV.	5.90	22.33	7.65	0.00	109.39	37.03	0.00	13.86	0.00	344.05

Table 11.--Frequency of determination of elements in various geochemical sample media from areas underlain by syenite plutons at Jabal Fayfa and Jabal Bani Malik.

Classificaton of element	Percent of samples	Elements detected in each sample medium and number of samples: Rocks (67)	<10+32-mesh sediment (61)	<32+80-mesh sediment (61)	<80-mesh sediment (61)	Raw concentrate (61)	Nonmagnetic concentrate (61)
Characteristic	90-100	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, Sc, Sr, V, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Sc, Sr, V, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Sc, Sr, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Sc, Sr, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, V, Y, Zr
Abundant	50-89	Be, Co, La, Ni, Pb, Y	Y	Be	Be, La, Pb	Be, La, Pb Sc	Be, La, Pb Sc
Common	10-49	B	Be, La, Mo, Pb	La, Mo, Pb	B	B, Mo, Sn	Sn, Sr
Scarce	2-9	Mo	B	B	Mo	-----	B, Mo
Rare	<2	-----	-----	-----	-----	-----	-----
Undetermined[1]	0	Ag, As, Au, Bi, Cd, Nb, Sb, Sn, W, Zn	Ag, As, Au, Bi, Cd, Nb, Sb, Sn, W, Zn	Ag, As, Au, Bi, Cd, Nb, Sb, Sn, W, Zn	Ag, As, Au, Bi, Cd, Nb, Sb, Sn, W Zn	Ag, As, Au, Bi, Cd, Nb, Sb, W, Zn	Ag, As, Au, Bi, Cd, Nb, Sb, W, Zn

[1]Values reported as detected but below the limit of determination (L), or as not detected at the lower limit of determination (N).

Table 12.--Frequency of determination of elements in various geochemical sample media from the area of the syenite pluton southeast of Suq al Ithnayn between Wadi Rudum and Wadi Bishah.

Classification of element	Percent of samples	Elements detected in each sample medium and number of samples					
		Rocks (26)	<10+32-mesh sediment (26)	<32+80-mesh sediment (26)	<80-mesh sediment (26)	Raw concentrate (26)	Nonmagnetic concentrate (26)
Characteristic	90-100	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, Sr, V, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Sc, Sr, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Sc, Sr, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Sc, Sr, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Sc, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Co, Cr, Cu, Ni, V, Y, Zr
Abundant	50-89	Be, Co, Ni Pb, Sc, Y	La	-----	La	Sr	Ba, Sc
Common	10-49	La	Be, Pb	La, Pb	B	Be, La, Nb	La, Sr
Scarce	2-9	-----	-----	Be	Be,Pb	Pb	Be
Rare	<2	-----	-----	-----	-----	-----	-----
Undetermined[1]	0	Ag, As, Au, B, Bi, Cd, Mo, Nb, Sb, Sn, W, Zn	Ag, As, Au, B, Bi, Cd, Mo, Nb, Sb, Sn, W, Zn	Ag, As, Au, B, Bi, Cd, Mo, Nb, Sb, Sn, W, Zn	Ag, As, Au, Bi, Cd, Mo, Nb, Sb, Sn, W, Zn	Ag, As, Au, B, Bi, Cd, Mo, Sb, Sn, W, Zn	Ag, As, Au, B, Bi, Cd, Mo, Nb, Pb, Sb, Sn, W, Zn

[1] Values reported as detected but below the limit of determination (L), or as not detected at the lower limit of determination (N).

Table 13.--Frequency of determination of elements in various geochemical sample media from the area of the shonkinite pluton at Jabal Atwid.

Classification of elements	Percent of elements	Elements detected in each sample medium and number of samples					
		Rocks (21)	<10+32-mesh sediment(19)	<32+80-mesh sediment(19)	<80-mesh sediment(19)	Raw concentrate(19)	Nonmagnetic concentrate(19)
Characteristic	90-100	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, Sc, Sr, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Pb, Sc, Sr, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Pb, Sc, Sr, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Pb, Sc, Sr, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Sc, Sr, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Sc, Sr, V, Y, Zr
Abundant	50-89	B, Co, La, Ni, Pb	Be, La	Be, La	Be, La	Be, La	Be, La
Common	10-49	Be, Mo	B	B	B	Pb	Pb
Scarce	2-9	-----	-----	-----	-----	-----	Sb
Rare	<2	-----	-----	-----	-----	-----	-----
Undetermined[1]	0	Ag, As, Au, Bi, Cd, Nb, Sb, Sn, W, Zn	Ag, As, Au, Bi, Cd, Mo, Nb, Sb, Sn, W, Zn	Ag, As, Au, Bi, Cd, Mo, Nb, Sb, Sn, W, Zn	Ag, As, Au, Bi, Cd, Mo, Nb, Sb, Sn, W, Zn	Ag, As, Au, B, Bi, Cd, Mo, Nb, Sb, Sn, W, Zn	Ag, As, Au B, Bi, Cd, Mo, Nb, Sn, W, Zn

[1]Values reported as detected but below the limit of determination (L), or as not detected at the lower limit of determination (N).

Table 14.--Sample media characteristic elements and percentage of samples in which elements were determined in less than all samples.

Rock	Wadi sediments			Concentrates	
	<10+32-mesh	<32+80-mesh	<80-mesh	Raw	Nonmagnetic
Syenite plutons at Jabal Fayfa and Jabal Bani Malik					
Co, 69; Cu, 97; Ni, 85; Sc, 91; Sr, 97; V, 97 Y, 87	Co, 98; Sc, 97; Sr, 98;	Sc, 98; Sr, 98; Y, 97;	Sc, 92; Y, 98	Sc, 61; Sr, 97	Ba, 93; Sc, 57; Sr, 13
Syenite pluton southeast of Suq al Ithnayn					
Co, 65; Ni, 85; Sc, 58; Y, 62	Cu, 96	----	Sc, 96	Sr, 88	Ba, 88; Ni, 92; Sc, 54; Sr, 12
Shonkinite pluton at Jabal Atwid					
Ba, 90; Co, 86; Cu, 95; Ni, 86; Pb, 86; Sc, 95 Y, 95	Y, 95	Pb, 95	Pb, 95	Pb, 21	Pb, 32 Sr, 95

Abundant elements

The abundant elements in the samples of rocks from the syenite plutons--Be, Co, La, Ni, Pb, and Y--are partitioned in their frequency of determination in the other media by the kinds of sample material used for analysis (table 11-12). The frequency of determination of Co, Ni, and Y rises in the samples of sediments and concentrates, whereas the frequency of determination of Be, La and Pb declines in the sedimentary materials. For the abundant elements in rock samples from the shonkinite--B, Co, La, Ni, and Pb (table 13)--Co and Ni rise in frequency of determination in sedimentary materials, whereas B and Pb decline. The decrease of B to the undetermined category in the concentrates is a particularly clear example of an unfavorable medium for an element and may relate to the loss of tourmaline during panning. Beryllium rises from a common element in the rocks from the shonkinite pluton to an abundant element in the sieved samples of wadi sediment and the concentrates. Together with La, the category of Be remains unchanged as abundant through the other media. The actual percentage of determinations is, of course, variable within the category, and the percentage of determinations of Be rises from 53 in the -10+32-mesh fraction of wadi sediment to a high of 74 in the nonmagnetic concentrates. Evidently Be in the shonkinite is in a mineral or minerals that, in contrast to beryl, have sufficiently high density to accumulate in concentrates.

Common, scarce, and rare elements

The common, scarce, and rare categories of frequency of determination are sparsely populated, and include the only Nb-, Sb- and Sn-bearing samples (tables 11-13). No element was reported in the rare category for any medium in any of the areas. The common and scarce elements are principally B, Be, La, Mo and Pb in samples from the syenite plutons, and B, Be, Mo and Pb in samples from the shonkinite pluton. Tin is a common element in both raw and nonmagnetic concentrates from the southern border of the syenite pluton at Jabal Fayfa, and Nb is a common element in raw concentrates from the eastern half of the syenite pluton to the southeast of Suq al Ithnayn. Lack of Nb in the nonmagnetic concentrates from these localities is interpreted to indicate that Nb is in a magnetic mineral that was removed during the processing of the nonmagnetic concentrates.

The frequency of determination of B, Be, La, Mo, and Pb is highly variable from abundant to undetermined in the various media from the different source rocks. This variability suggests that these elements may be camouflaged in common minerals, for example, Be in pyroxene and amphibole, La in apatite, Mo in femic minerals, and Pb in feldspar or apatite, or they may be present as major elements in erratically distributed accessory minerals, such as B in tourmaline, Be in beryl or chrysoberyl, La in monazite, or Mo in molybdenite. Although chrysoberyl was not detected mineralogically (table 4) the fact that chrysoberyl may be derived from olivine (Rankama and Sahama, 1950, p. 445) may account for the position of Be among the abundant elements in terms of frequency of determination in samples from the shonkinite pluton (table 13), which is olivine-bearing (table 4). Furthermore, the presence of Be in the nonmagnetic concentrates from all plutons suggests the possibility of another as yet unidentified Be-bearing mineral with a density greater than the 2.69 of beryl.

Tin also may be mainly camouflaged because only a trace of cassiterite was found in one concentrate (table 4).

The appearance of Sb in one sample may be an example of the random presence of an appropriate mineral in the split of the concentrate (table 13) used for analysis where the Sb-bearing mineral is a sparse small particle in an overwhelmingly large amount of Sb-free material (Clifton and others, 1969; Harris, 1982). Some numerical data on this problem have been prepared by Theodore Botinelly, USGS (written commun., 1979) to show the relation of the abundance of common ore metals, expressed as parts per million in a nonmagnetic concentrate, to the weight percent and volume percent of the respective ore minerals, using an estimated density of 3.00 for the nonmagnetic concentrate. A nonmagnetic concentrate weighing 10 mg, of 80 mesh size (0.177mm), and with a density of 3.00, contains approximately 10,000 particles (11,480), assuming maximum spheres; therefore, 1 percent would equal 100 particles in 10,000 and 0.01 percent would equal 1 particle in 10,000. The relative diameter and relative volume of larger and smaller spheres are shown in table 15.

Table 15.--The relative diameter and relative volume of larger and smaller spheres (Botinelly, 1979, written commun.).

Mesh	Opening (mm) U.S. Standard	Relative diameter	Relative volume
20	0.840	4.75	107.0
50	.297	1.7	4.7
70	.210	1.2	1.7
80	.177	1.0	1.0
100	.149	0.8	0.6
200	.074	.4	.07

By panning 10 pounds (4536 g) of alluvial sediment to 100 g of concentrate, and considering the lower limits of spectrographic determination as the minimum original content, then the contents of commonly determined elements would be as shown in table 16. Because recovery of heavy minerals in the 100g concentrate may be as little as 1/3 or 1/2 of the amount present in the alluvium, the original content of these elements may be two or three times the amount shown.

Table 16.--The contents of commonly determined elements in ten pounds of alluvial sediment.

Element	Lower limit of determination	Original content	
	(ppm)	(ppm)	(ppb)
Ag	0.5	0.01	10
Be	1	.02	20
Co, Cu, Mo, Ni, Sc,	5	.10	100
Au, Bi, Cr, Pb, Sn, V, Y, Zr	10	.20	200
Ba, Cd, La, Nb, Ti	20	.45	450
W	50	1.1	1,000
Sb, Sr	100	2.2	2,000
As, Mg, Zn	200	4.4	4,500

The relation of parts per million of an element to the required weight percent and volume percent of the main ore mineral in a nonmagnetic concentrate having the above characteristics are shown in table 17.

Table 17.--The relation of parts per million of an element to the required weight percent and volume percent of the main ore mineral in a nonmagnetic concentrate.

Galena, PbS, density 7.59:

Pb (ppm)	Weight percent	Volume percent
20,000	2.31	0.91
15,000	1.73	.68
10,000	1.15	.45
7,000	0.81	.32
5,000	.58	.23
3,000	.35	.14
2,000	.23	.09

Cassiterite, Sn02, density 6.995:

Sn (ppm)	Weight percent	Volume percent
20,000	2.54	1.09
15,000	1.90	0.81
10,000	1.27	.54
7,000	0.89	.38
5,000	.63	.27
3,000	.38	.16
2,000	.25	.11

Scheelite, CaW04, density 6.12:

W (ppm)	Weight percent	Volume percent
20,000	3.13	1.53
15,000	2.35	1.15
10,000	1.57	0.77
7,000	1.10	.54
5,000	0.78	.38
3,000	.48	.23
2,000	.31	.15

Zircon, ZrSi04, density 4.67:

Zr (ppm)	Weight percent	Volume percent
20,000	4.02	2.58
15,000	3.01	1.93
10,000	2.01	1.29
7,000	1.41	0.91
5,000	1.00	.64
3,000	0.60	.39
2,000	.40	.29

Barite, BaS04, density 4.48:

Ba (ppm)	Weight percent	Volume percent
20,000	3.40	2.27
15,000	2.55	1.71
10,000	1.70	1.14
7,000	1.19	0.80
5,000	0.85	.57
3,000	.51	.34
2,000	.34	.23

The significant factor is that 1 particle in 10,000 is equal to 0.01 percent (100 ppm) of the concentrate. Where low values for an element combine with sparsity of a main source mineral for an element, very large errors can occur based on the presence or absence of grains of the mineral in the part of the sample taken for analysis. For example, if stibnite, Sb_2S_3 with a density of 4.52-4.62, were the source of the antimony in the single nonmagnetic concentrate in which the element was detected, then the reported abundance of 150 ppm Sb would equal 0.018 volume percent of the source in 100g of concentrate proportionately reduced to the 10 mg taken from the concentrate for spectrographic analysis.

Undetermined elements

Elements below their respective lower limits of determination in all samples from each medium in every area surveyed are Ag, As, Au, Bi, Cd, W, and Zn (tables 11-13). Other elements that were undetermined in one or more media from one area, but were sufficiently abundant in other media to be determined in that area or in other areas are B, Mo, Nb, Pb, Sb, and Sn. Some of these elements, such as Nb in raw concentrates from the syenite pluton to the southeast of Suq al Ithnayn, Sb in the nonmagnetic concentrates from the shonkinite pluton, and Sn in raw and nonmagnetic concentrates from the syenite plutons at Jabal Fayfa and Jaba Bani Malik, appear in no other media in no other localities; hence, their abundance in the rocks is so low that enhancement techniques are required to raise them above their lower limits of determination. The frequency of determination of other elements may be such that some samples in all media from all areas except one medium from one area contain the element. For example, Pb was undetermined in all nonmagnetic concentrates from the syenite pluton to the southeast of Suq al Ithnayn; hence, the element most likely is camouflaged in low-density minerals in that area. Molybdenum is an example of an element nearly specific to the syenite plutons at Jabal Fayfa and Jabal Bani Malik, where it is variably present in all media. All samples from the syenite pluton to the southeast of Suq al Ithnayn lack the element as do all samples except three specimens of rock from the pluton of shonkinite at Jabal Atwid. However, none of these anomalously present elements in the undetermined category (tables 11-13) reaches abundances that signal the possible presence of ore deposits.

Influence of weathering

Owing to the prevalence of fresh rock in the sampled areas, no detectable variation of the chemical composition of rocks and wadi sediments from the plutons of syenite and shonkinite can be attributed to the effects of chemical weathering. Where weathering influences the composition of rocks and -80-mesh wadi sediment, as at Jabal Lababa in the Tihama (Overstreet and others, 1983), Fe^{3+}, Mn^{4+}, Ti, Be, V, Y, and Zr were found to be concentrated in the weathered rocks and -80-mesh sediment over their abundances in the unweathered rocks, and Cu, Ni, Pb, and Sr were depleted. Differences between the compositions of fresh rocks and of weathered rocks and -80-mesh wadi sediment from the areas underlain by plutons of syenite and of shonkinite can be attributed to normal variation in sampling and in analysis (table 18). The mean values for the different sample media from a given area are seldom greater than one laboratory reporting interval. Even this scant variation, however, is in the direction of concentration of Fe and Zr in the Jabal Fayfa, Jabal Bani Malik, and Jabal Atwid areas, of the concentration of Mn and V in all areas, and of the concentration of Be, Ti, and Y in one or more of the weathered materials from one or more of the areas. Depletion, however, is only indicated for Pb and Sr in weathering products at Jabal Atwid. These influences are negligible. Any chemical changes caused by the weathering of these sample media are too slight to be a factor in appraising positive anomalous values in these areas.

Positive anomalous values

Threshold anomalous values for the 30 elements determined in the areas underlain by plutons of syenite at Jabal Fayfa, Jabal Bani Malik, and between Wadi Rudum and Wadi Bishah to the southeast of Suq al Ithnayn are given in tables 19 and 20. Threshold anomalous values for these elements in the various sample media from the area underlain by the pluton of shonkinite at Jabal Atwid are listed in table 21. The threshold values in tables 19-21 are calculated on the basis of the mean value plus two standard deviations, using the data in tables 8-10. Many of the threshold anomalous values thus identified are also the maximum value for the element in a particular medium. None of the anomalous values signals a possible mineral deposit, but the principal positive geochemical anomalies are reviewed below.

Table 18.--Comparison of chemical composition of fresh and weathered rocks and -80-mesh wadi sediment from syenite and shonkinite plutons.

[Mean values; number of determinations in mean shown in parentheses.]

Elements	Syenite plutons at Jabal Fayfa and Jabal Bani Malik			Syenite pluton to the southeast of Suq al Ithnayn			Shonkinite pluton at Jabal Atwid		
	Rock		<80-mesh	Rock		<80-mesh	Rock		<80-mesh
	Fresh	Weathered	sediment	Fresh	Weathered	sediment	Fresh	Weathered	sediment
	(17)	(9)	(28)	(7)	(3)	(10)	(14)	(2)	(12)
	In percent								
Fe	5	5	7	5	5	7	7	7	7
Mg	3	3	3	3	3	3	5	2	5
Ca	3	3	5	7	3	5	5	2	5
Ti	0.7	0.7	0.5	1	0.7	1.5	0.5	0.5	0.7
	In parts per million								
Mn	700	500	1,000	1,000	1,000	1,500	1,000	1,000	1,500
B	L(10)	L(10)	L(10)	L(10)	L(10)	10	20	10	10
Ba	1,500	1,500	1,000	1,000	2,000	500	2,000	2,000	700
Be	1.5	2	2	L(1)	1	L(1)	2	2	2
Co	15	15	15	20	7	30	30	30	30
Cr	300	300	200	300	500	500	300	700	700
Cu	50	30	50	30	50	70	70	50	70
La	30	30	30	20	30	30	70	150	50
Ni	100	100	100	50	20	70	100	300	100
Pb	15	20	15	L(10)	15	L(10)	70	10	10
Sc	10	10	10	15	10	20	15	15	20
Sr	700	700	700	500	700	500	1,000	1,000	500
V	100	100	200	200	100	300	150	70	300
Y	10	10	10	15	15	30	30	30	30
Zr	150	200	700	70	150	300	300	200	200

Table 19.--Threshold anomalous values for 30 elements in six types of geochemical sample media from the syenite plutons at Jabal Fayfa and Jabal Bani Malik.

[Anomalous values are taken as the mean plus two standard deviations from the data in table 8.]

C. JABAL FAYFA AND JABAL BANI MALIK PLUTONS

1. ROCKS

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	8.76	5.77	7.19	1.25	2171.19	0.10	50.00	2.00	20.91	2553.68
	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	2.76	2.00	5.00	28.09	562.71	131.58	43.27	6.45	5.00	153.10
	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	27.01	20.00	31.92	2.00	1130.39	377.56	10.00	36.29	50.00	375.73

2. <10+32-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	8.94	4.71	6.18	1.09	1657.97	0.10	50.00	2.00	9.42	2700.81
	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	1.91	2.00	5.00	19.05	516.98	129.84	30.70	5.66	5.00	121.05
	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	25.39	20.00	25.86	2.00	1537.63	234.99	10.00	29.52	50.00	192.55

3. <32+80-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	9.73	5.47	6.33	1.39	2451.05	0.10	50.00	2.00	6.94	2185.67
	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	2.35	2.00	5.00	30.23	569.08	130.54	41.97	11.41	5.00	169.82
	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	30.36	20.00	35.05	2.00	1343.91	304.91	10.00	40.31	50.00	895.76

4. <80-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	9.04	5.59	6.87	1.70	1513.73	0.10	50.00	2.00	10.11	1385.90
	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	3.29	2.00	5.00	22.91	590.65	121.39	66.16	3.63	5.00	170.08
	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	32.21	20.00	31.43	2.00	1039.90	294.22	10.00	35.48	50.00	1440.70

5. RAW CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	22.25	5.47	7.15	1.84	4105.00	0.10	50.00	2.00	13.77	659.43
	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	9.71	2.00	5.00	114.54	2044.05	127.14	65.55	8.58	5.00	191.96
	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	83.28	20.00	42.72	17.35	960.42	652.74	10.00	65.86	50.00	2076.34

6. NONMAGNETIC CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	22.19	6.82	10.39	1.87	5930.96	0.10	50.00	2.00	23.30	150.52
	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	7.26	2.00	5.00	176.20	1179.60	180.91	95.42	9.30	5.00	133.14
	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	170.43	20.00	47.94	25.16	113.81	618.15	10.00	89.26	50.00	2108.83

Table 20.--Threshold anomalous values for 30 elements in six types of geochemical sample media from the syenite pluton between Wadi Rudum and Wadi Bishah to the southeast of Suq al Ithnayn.

[Anomalous values are taken as the mean plus two standard deviations from the data in table 9.]

D. SYENITE PLUTON (SE OF SUQ AL ITHNAYN)

1. ROCKS

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	10.26	6.79	10.12	1.76	2228.80	0.10	50.00	2.00	5.00	2149.02

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	2.19	2.00	5.00	46.80	595.66	78.81	36.17	1.00	5.00	97.62

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	21.09	20.00	47.27	2.00	912.70	514.16	10.00	36.34	50.00	240.26

2. <10+32-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	8.57	5.24	7.03	1.49	1316.78	0.10	50.00	2.00	6.80	1910.55

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	1.45	2.00	5.00	24.24	460.63	107.45	26.86	1.00	5.00	73.97

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	14.03	20.00	29.03	2.00	1114.02	307.01	10.00	25.47	50.00	293.50

3. <32+80-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	11.25	5.97	7.03	1.81	2009.95	0.10	50.00	2.00	6.84	1351.13

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	1.06	2.00	5.00	40.75	654.87	129.23	39.39	1.00	5.00	92.37

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	11.62	20.00	36.70	2.00	966.41	441.78	10.00	37.69	50.00	662.88

4. <80-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	10.98	5.75	7.03	1.77	1907.84	0.10	50.00	2.00	14.33	839.35

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	0.70	2.00	5.00	36.54	719.70	113.95	50.77	1.00	5.00	108.77

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	8.26	20.00	35.58	2.00	719.87	464.95	10.00	53.66	50.00	817.91

5. RAW CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	18.01	7.82	8.05	1.80	3296.66	0.10	50.00	2.00	2.00	247.83

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	2.01	2.00	5.00	87.79	814.60	131.44	44.93	1.00	29.65	103.53

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	87.52	20.00	60.92	2.00	489.32	668.26	10.00	81.92	50.00	1066.43

6. NONMAGNETIC CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	28.43	8.61	8.68	1.79	3997.46	0.10	50.00	2.00	6.36	173.13

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	0.20	2.00	5.00	255.74	644.39	121.64	18.60	1.00	5.00	96.90

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	2.00	20.00	44.47	2.00	88.85	814.91	10.00	91.63	50.00	1178.73

The most suitable geochemical sample medium for use in interpreting the positive anomalies represents a balance among threshold value, spread in values reported for an element (standard deviations in tables 8-10), maximum reported values (tables 8-10), and the frequency with which the element was determined in a given medium (tables 11-13). Using these criteria, samples of rocks are the preferred medium for Be in the syenite pluton to the southeast of Suq al Ithnayn, but at Jabal Fayfa and Jabal Bani Malik the preferred medium for Be is the raw concentrate, and at Jabal Atwid it is the nonmagnetic concentrate. Samples of rock are also the preferred medium for Mo at Jabal Atwid. The -80-mesh fraction of wadi sediment is the preferred medium for La and Y in the syenite pluton to the southeast of Suq al Ithnayn, but in the other areas the nonmagnetic concentrates serve better for La and Y. The preferred medium for Mo at Jabal Fayfa and Jabal Bani Malik and for Nb in the pluton to the southeast of Suq al Ithnayn is the raw concentrate. Nonmagnetic concentrates are the preferred medium for Sn in the plutons at Jabal Fayfa and Jabal Bani Malik, for Sb in the shonkinite pluton at Jabal Atwid, and for Zr in all areas. These differences among the media for a given element may reflect variation in the principal host minerals among the plutons.

Principal positive geochemical anomalies

Beryllium, niobium and tin

Beryllium was identified in all areas (fig. 5-7), but Nb was detected only in the pluton of syenite to the southeast of Suq al Ithnayn (fig. 6), and Sn appears only in the syenite plutons at Jabal Fayfa and Jabal Bani Malik (fig. 5).

Jabal Fayfa and Jabal Bani Malik--The peripheral arrangement of symbols at Jabal Fayfa (fig. 5) is caused by access to sampling sites. Most sites are in the lower reaches of wadis rising in the central part of the syenite pluton and flowing southeastward on that flank of Jabal Fayfa and flowing northwestward on the opposite flank. A somewhat similar but less pronounced pattern affects the distribution of sampling sites in the pluton at Jabal Bani Malik, but there the distribution is also affected by the prominent fault valley in the east-central part of the pluton. The central parts of the plutons as well as the flanks upstream from the sampling sites are geochemically sampled. Owing to the lengths upwadi from the sample sites in Jabal Fayfa the anomalous values found for the metals cannot be attributed to marginal phases of the pluton, but they must include the core as well.

EXPLANATION

SYMBOLS USED FOR ROCK UNITS

sy	SYENITE
Olm	OTHER IGNEOUS AND METAMORPHIC ROCKS
———	CONTACT of rock units

SYMBOLS FOR MINOR ELEMENTS IN
GEOCHEMICAL SAMPLE MEDIA

RAW CONCENTRATES

BERYLLIUM (ppm)
- ● N(1)-L(1)
- ○ 1-2 background
- ○ 3-7 values
- ● 10-20, anomalous values

MOLYBDENUM (ppm)
- △ 5-7, background values
- △ 10-20, anomalous values

NONMAGNETIC CONCENTRATES

TIN (ppm)
- □ 10-15, background values
- □ 20-50, anomalous values

Figure 5.--Map showing the distribution of beryllium, tin, and molybdenum in the syenite plutons at Jabal Fayfa and Jabal Bani Malik.

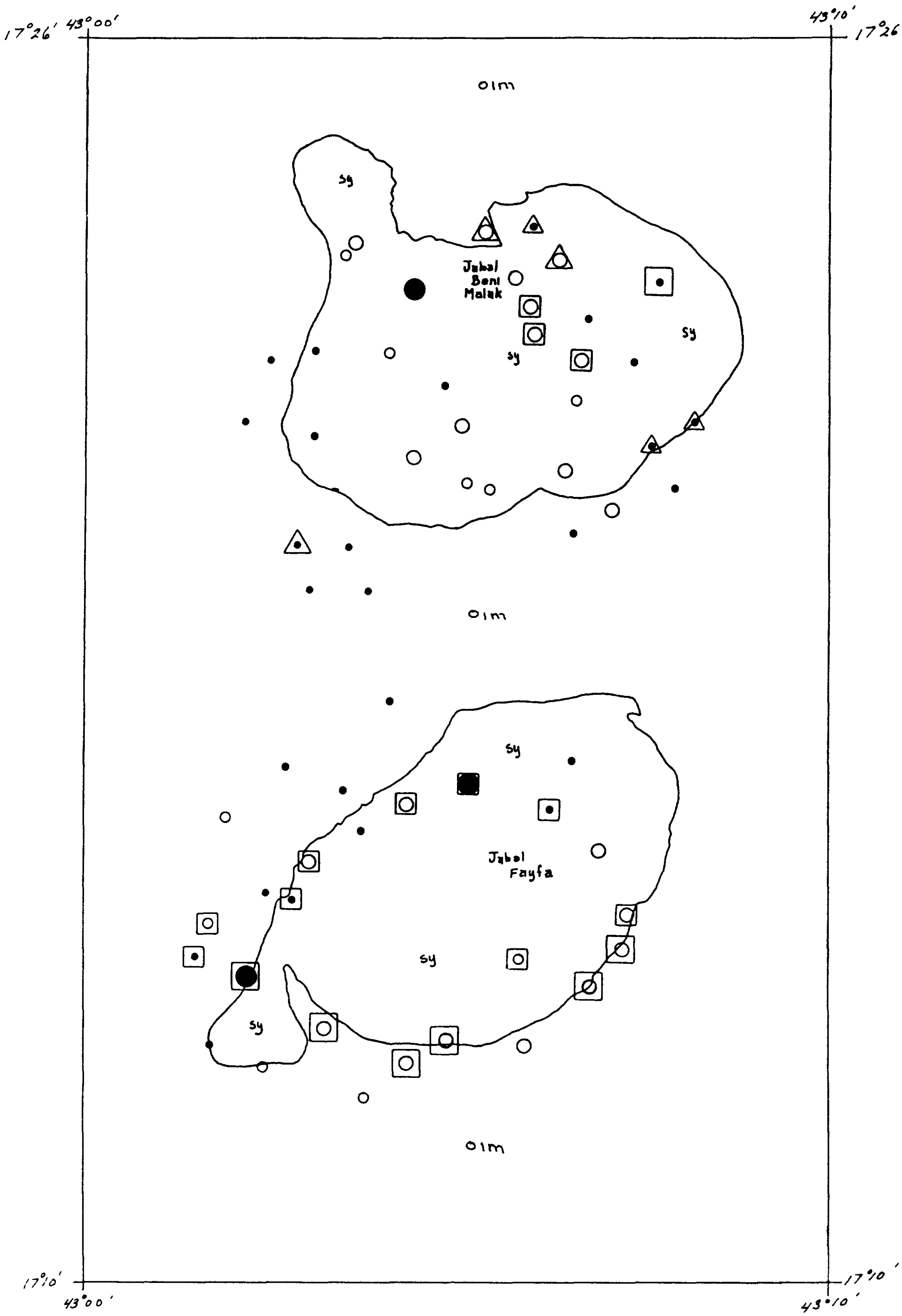


Figure 5.--Map showing the distribution of beryllium, tin, and molybdenum in the syenite plutons at Jabal Fayfa and Jabal Bani Malik.--Continued

EXPLANATION

SYMBOLS USED FOR ROCK UNITS

sy	SYENITE
pg	PEGMATITE AND GRANITE
01m	OTHER IGNEOUS AND METAMORPHIC ROCKS
———	CONTACT of rock units

SYMBOLS FOR MINOR ELEMENTS IN GEOCHEMICAL SAMPLE MEDIA

ROCKS

BERYLLIUM (ppm)

- • N(1)-L(1) background values
- ○ 1 background values
- ● 2, anomalous value

RAW CONCENTRATES

△ NIOBIUM (ppm)
20-30, anomalous values

Figure 6.--Map showing the distribution of beryllium and niobium in the syenite pluton to the southeast of Suq al Ithnayn.

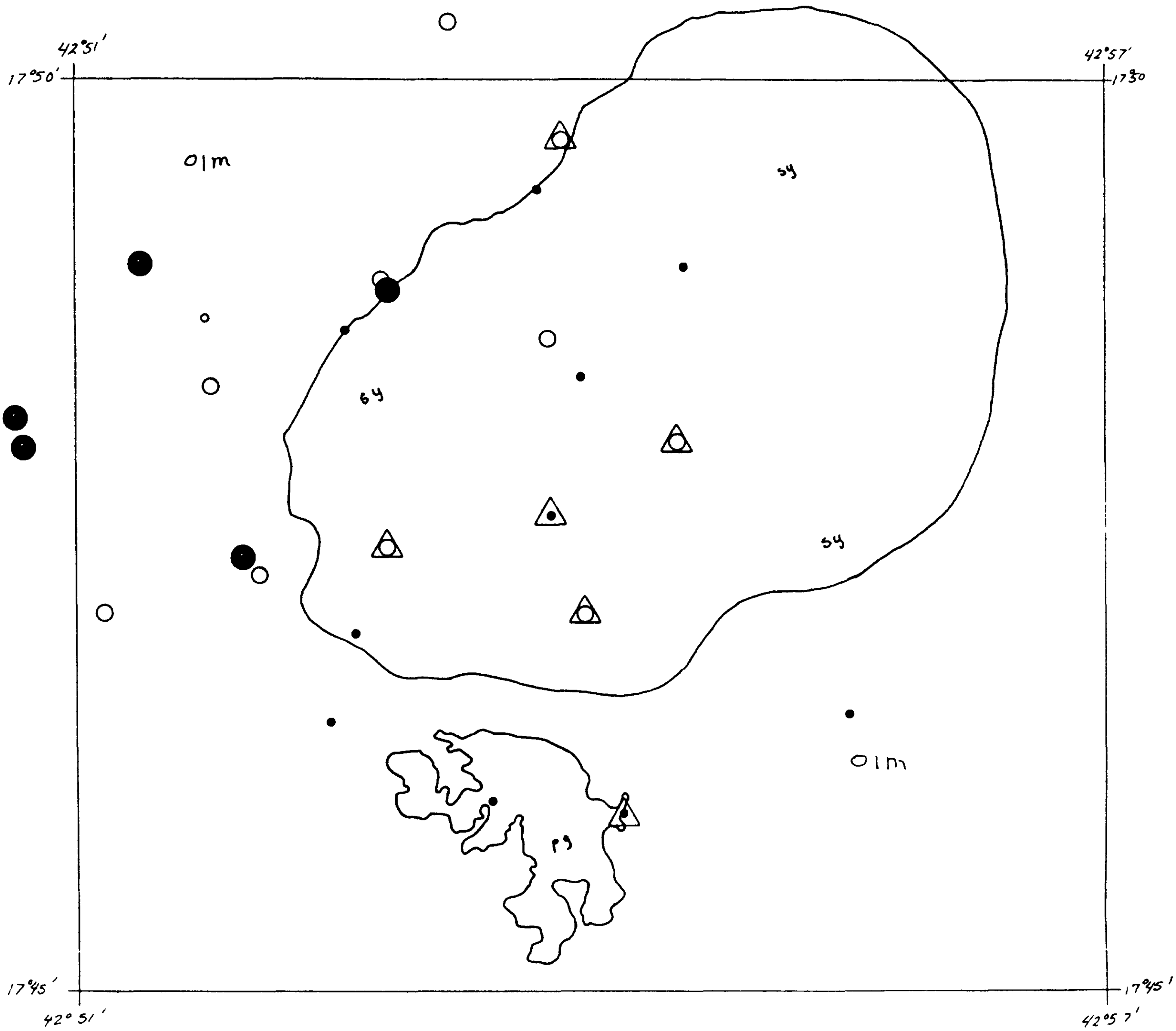


Figure 6.--Map showing the distribution of beryllium and niobium in the syenite pluton to the southeast of Suq al Ithnayn.--Continued

Two anomalous values for Be were found in raw concentrates from Jabal Fayfa (fig. 5): one (20 ppm Be) in the north and the other (10 ppm Be) in the south. One anomaly (15 ppm Be) was detected at Jabal Bani Malik (fig. 5). All are from areas of massive syenite. The Be could be in either independent Be-bearing mineral of low density such as beryl or of high density such as chrysoberyl, or the Be could be camouflaged in feldspar, pyroxene, or amphibole. Because nonmagnetic concentrates from the same sites also contain Be, the probable sources are high-density minerals. Further mineralogical examination of the concentrates with anomalous amounts of Be are needed to identify the source and to determine if it is a high-unit-value mineral such as gem-quality beryl or chrysoberyl.

Anomalous values for Nb are lacking in all geochemical sample media from the areas of the syenite plutons at Jabal Fayfa and Jabal Bani Malik.

The low-value positive anomalies for Sn in nonmagnetic concentrates are 20-30 ppm in the southern and eastern parts of Jabal Fayfa and 50 ppm in the northeastern part of Jabal Bani Malik. They are proof that Sn is not enriched in the plutons of syenite in this area.

<u>Syenite pluton to the southeast of Suq al Ithnayn</u>--The positive anomalous value of 2 ppm Be for rock samples from the areas of the syenite pluton between Wadi Rudum and wadi Bishah to the southeast of Suq al Ithnayn is in the lower part of the range in crustal abundance of Be (Griffitts, 1973, p. 88), which demonstrates the sparsity of the element in rocks underlying the area covered by figure 6. Most of these exceedingly low positive anomalies are in samples of metamorphic rocks to the west of the pluton. For industrial purposes the pluton of syenite is devoid of Be.

Low background values for Be were also obtained from specimens of granitic pegmatite to the south of the syenite (fig. 6).

The only Nb detected in these areas in the southern Asir (fig. 1) is in raw concentrates from and near the pluton of syenite (fig. 6). Even in these concentrates the values are only 20-30 ppm. The source may be a magnetic mineral, because Nb decreases to less than 20 ppm in the nonmagnetic concentrates (table 9), but it has no industrial significance. The syenite pluton is essentially devoid of Nb.

<u>Jabal Atwid</u>--The two anomalous values for Be in nonmagnetic concentrates from the shonkinite pluton at Jabal Atwid (fig. 7), 7 ppm each, suggest some mineral of greater density than beryl is the source of the Be, because the amount of the element is greater in this medium than in any

other sample media from the pluton (table 13). However, in all media the quantities of Be are too scant; the pluton is not an industrial source for Be.

Molybdenum and antimony

High background and low positive-anomalous values for Mo were detected in raw concentrates from the eastern part of the syenite pluton at Jabal Bani Malik (fig. 5) where they are situated mainly along or adjacent to the trace of a regional northwest-trending fault (Fairer, 1981). Low anomalous quantities of Mo are present in rock samples from the shonkinite pluton at Jabal Atwid (fig. 7). In the Jabal Bani Malik area Mo is present in low anomalous amounts in every geochemical sample medium (table 19), but at Jabal Atwid only the samples of rocks contain detectable amounts of the element (table 21).

The abundances of Mo in the various sample media at Jabal Bani Malik are too low to signal positively the presence of mineralization. Low positive correlation coefficients of Mo with Co (0.55), Cu (0.68) and Pb (0.80) in the raw concentrates may indicate the sparse presence of sulfide minerals containing a little Mo along the fault. Low negative correlation coefficients of Mo with Fe (-0.02), Mg (-0.19), and Ca (-0.03) suggest that femic minerals such as the pyroxenes and amphiboles, which are common constituents of the concentrates, are not the sources of the Mo. The presence of low positive anomalies for Mo along the trace of a regional fault in the pluton, but they lack positive anomalies for Ba, Co, Cu, Ni, Pb, and Sr in most samples having anomalous amounts of Mo, and the absence of W and Zn at their lower limits of determination, are interpreted to indicate that the trace of the fault through the syenite pluton is not the locus of mineralization.

At Jabal Atwid the single anomalous value for Sb in nonmagnetic concentrates is also at the site where a sample of rock has a low positive anomaly (5 ppm) for Mo. Inasmuch of this value for Mo is at its threshold of spectrographic determination, neither the Mo nor the Sb can be regarded as significant geochemical anomalies.

Lanthanum, yttrium, and zirconium

Neither the maximum abundances nor the anomalous concentrations of La and Y (tables 8-10 and 19-21) are indications of local enrichment of these elements in the plutons of syenite or shonkinite. Indeed, their abundances in these plutons are well below those observed in granitic rocks in the southern Asir (Overstreet and others, 1983 unpub. data). Zirconium also is much less abundant in the syenite and shonkinite than in granitic rocks in the Asir.

EXPLANATION

SYMBOLS USED FOR ROCK UNITS

sh	SHONKINITE
mr	METAMORPHIC ROCKS
———	CONTACT of rock units

SYMBOLS FOR MINOR ELEMENTS IN
GEOCHEMICAL SAMPLE MEDIA

NONMAGNETIC CONCENTRATES

BERYLLIUM (ppm)
- ● N(1)-L(1)
- ○ 1-2 background
- ○ 3-5 values
- ● 7, anomalous value

ANTIMONY (ppm)
150, anomalous value

ROCKS

MOLYBDENUM (ppm)
△ 5-7, anomalous values

Figure 7.--Map showing the distribution of beryllium, molybdenum, and antimony in the shonkinite pluton at Jabal Atwid.

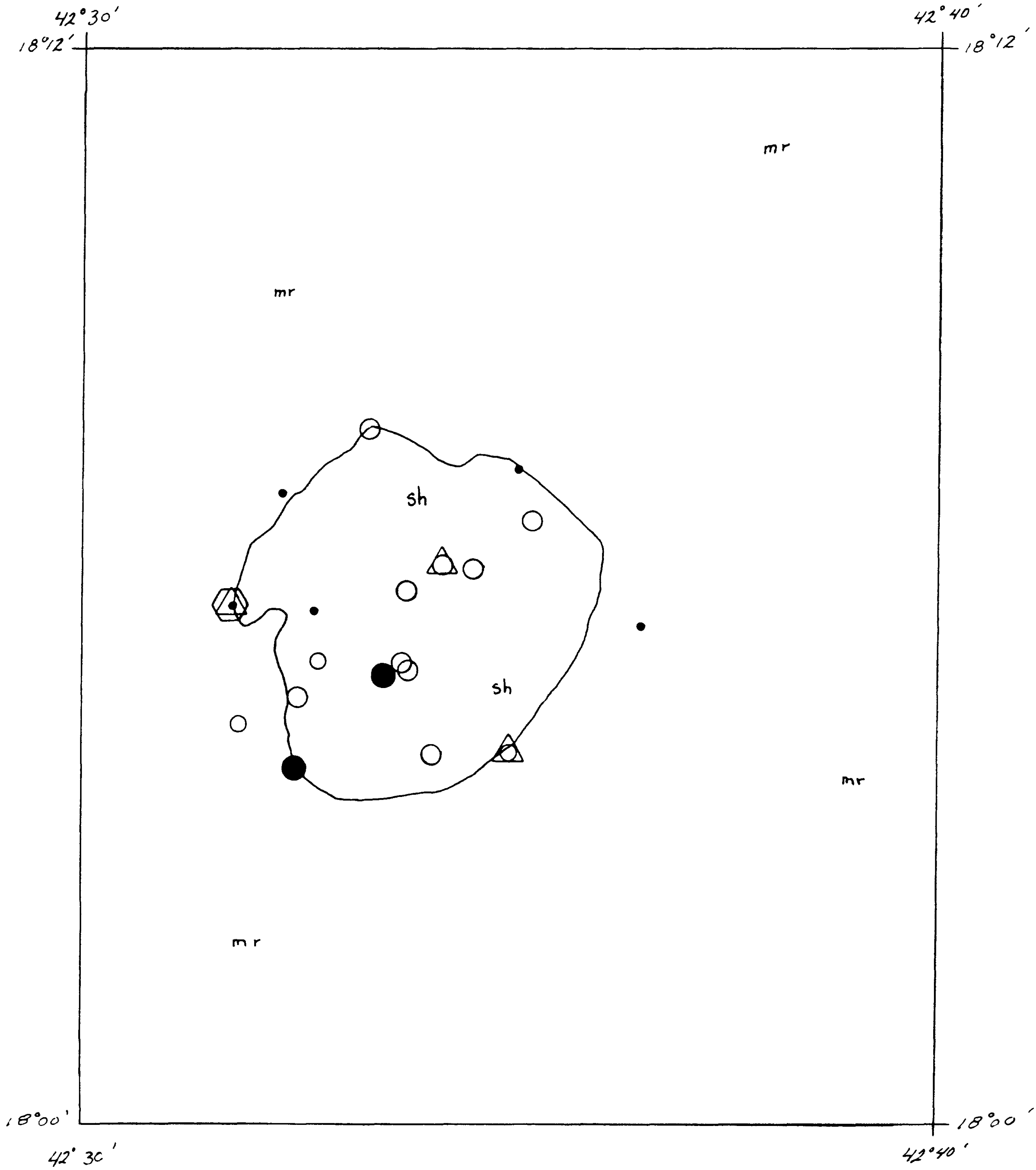


Figure 7.--Map showing the distribution of beryllium, molybdenum, and antimony in the shonkinite pluton at Jabal Atwid.--Continued

Table 21.--Threshold anomalous values for 30 elements in six types of geochemical sample media from the shonkinite pluton of Jabal Atwid.

[Anomalous values are taken as the mean plus two standard deviations from the data in table 10.]

C. JABAL ASWAD PLUTON

1. ROCKS

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	12.13	7.68	14.00	1.05	1411.01	0.10	50.00	2.00	29.98	3018.18

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	5.39	2.00	5.00	69.35	813.91	134.52	158.56	5.41	10.13	311.12

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	28.48	20.00	51.03	2.00	1471.73	280.29	10.00	41.04	50.00	592.61

2. <10+32-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	8.21	8.69	6.54	0.87	1010.36	0.10	50.00	2.00	23.43	2543.41

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	2.65	2.00	5.00	37.28	1072.72	87.55	34.38	1.00	5.00	235.42

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	20.91	20.00	36.96	2.00	1728.07	222.69	10.00	24.37	50.00	201.92

3. <32+80-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	13.39	10.34	7.93	1.32	1736.15	0.10	50.00	2.00	14.25	1823.79

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	3.66	2.00	5.00	52.48	1258.23	105.24	48.04	1.00	5.00	329.45

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	16.26	20.00	41.54	2.00	1031.43	463.28	10.00	29.37	50.00	560.12

4. <80-MESH WADI SAND

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	12.84	9.87	8.43	1.23	1839.34	0.10	50.00	2.00	16.18	1122.72

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	3.77	2.00	5.00	46.53	1269.47	107.70	119.21	1.00	5.00	187.56

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	20.26	20.00	34.26	2.00	776.30	464.43	10.00	47.18	50.00	332.35

5. RAW CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	11.28	4.84	5.97	0.99	1301.45	0.10	50.00	2.00	5.00	420.74

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	2.18	2.00	5.00	21.65	2086.21	37.92	42.68	1.00	5.00	197.96

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	15.09	20.00	18.35	2.00	509.49	287.79	10.00	22.13	50.00	572.30

6. NONMAGNETIC CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MEAN+2SD	11.42	7.90	17.74	1.57	2519.51	0.10	50.00	2.00	5.00	551.62

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	6.86	2.00	5.00	49.21	1187.15	81.74	133.83	1.00	5.00	155.26

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	19.01	99.92	46.10	2.00	471.42	255.64	10.00	62.72	50.00	1154.94

Other elements

The sparsity of the base and precious metals, the ferroalloy elements, and such geochemical indicator elements of possible hydrothermal mineralization as As, Be, Ba, Bi, Cd, Sb, and Sr are consistent with an interpretation that exploitable deposits of these metals are lacking in the plutons of syenite and shonkinite.

APPRAISAL AND RECOMMENDATIONS

Elements sought by geochemical exploration

Niobium and its possible pathfinder elements Be, La, Sn, Y, and Zr are not enriched in the plutons of syenite and shonkinite; thus, further work for ore deposits of these elements is not recommended. Further mineralogical study of the raw and the nonmagnetic concentrates from Jabal Fayfa, Jabal Bani Malik, and Jabal Atwid should be given a low priority to determine if gem-quality beryl or chrysoberyl is present.

The sparsity of Nb, a pathfinder element for Ta, indicates that Ta is probably absent in exploitable amount, but analyses for Ta were not made.

The distribution of Mo along the trace of the regional fault at Jabal Bani Malik indicates possible low-grade hydrothermal activity associated with the fault, but no mineralization was seen. In further long-term regional geochemical surveys of the 1:250,000-scale quadrangles, this fault and similar structures should be tested for possible hydrothermal mineralization.

Vermiculite

The wall zones of syenite pegmatites, and the contacts between syenite pegmatite and pyroxenite, in other areas of the world are commercial sources for vermiculite, an expandable micaceous mineral used industrially in light-weight aggregate, thermal insulation, and soil conditioners (Olson, 1952, p. 20; Overstreet and Bell, 1965, p. 42; Bush, 1973, p. 348-351). Vermiculite has a similar crystal structure to biotite and most commonly forms through hydrothermal alteration of biotite. In the series from biotite to vermiculite, varieties consisting of 10-50 percent vermiculite are called hydrobiotite (Bush, 1973, p. 349). Very few syenite pegmatites were observed in the areas of the syenite and shonkinite plutons, although granitic pegmatite is present. Several quartz-bearing pegmatite dikes up to 15 m wide and 0.8 km long were observed in the central and southwestern part of the syenite pluton to the southeast of

Suq al Ithnayn, but the mica in the dikes is biotite and hydrobiotite. Vermiculite was not observed in these plutons and pegmatite dikes. Owing to the general sparsity of pegmatite and the lack of pyroxenite, vermiculite is not likely to be present in exploitable deposits. Further search in these areas is not indicated.

Possible high-alumina deposits outside the areas surveyed

The possibility that the kyanite-topaz-natroalunite rocks identified by Fairer (1982 ; 1983,) outside the areas covered by the present geochemical exploration may be part of large hydrothermal systems with which Cu, Mo, or Au might be associated requires at least a preliminary field study to determine if they are associated with metallization. It is recommended that these deposits be assigned a high priority for investigation. Kyanite quartzite at Wadi ad Arj (Gaskill, 1970, p. 12-19) should be reexamined in the same program as the deposits of kyanite-topaz-natroalunite rocks.

DATA STORAGE

All geochemical data relevant to this report are included in tables 4 through 21. Field data and other work materials are archived in data-file USGS-DF-04-17 (Overstreet and others, 1984).

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APPENDIX

cassiterite	SnO_2
monazite	$(Ce, La, Nd, Th)PO_4$
baddeleyite	ZrO_2
thorite	$ThSiO_4$
hypersthene	$(Mg, Fe)_2 Si_2O_6$
acmite	$Na Fe Si_2O_6$
augite	$(Ca, Na) (Mg, Fe, Al, Ti) (Si, Al)_2O_6$
diopside	$Ca Mg Si_2O_6$
fassaite	$Ca (Mg, Fe, Al) (Si, Al)_2O_6$
fayalite	$Fe SiO_4$
fosterite	Mg_2SiO_4
hastingsite	$NaCa_2(Fe, Mg)_4 Fe Si_6Al_2O_{22} (OH)_2$
hornblende	$Ca_2(Fe, Mg)_4 Al(Si_7Al)O_{22}(OH, F)_2$
kaersutite	$NaCa_2(Mg, Fe)_4 Ti (Si_6Al_2)O_{22} (OH)_2$
richterite	$Na_2Ca (Mg, Fe)_5 Si_8O_{22} (OH)_2$
tirodite	$Mn (Mg, Fe)_5Si_8O_{22}(OH)_2$
tremolite	$Ca_2 (Mg, Fe)_5Si_8O_{22}(OH)_2$
almandine	$Fe_3Al^2 (SiO_4)_3$
spessartine	$Mn_3 Al_2(SiO_4)_3$
epidote	$Ca_2 (Al, Fe)_3(SiO_4)_3(OH)$
mukhinite	$Ca_2Al_2V(SiO_4)_3(OH)$
allanite	$(Ce, Ca, Y)_2 (Al, Fe)_3 (SiO_4)_3(OH)$
biotite	$K(Mg, Fe)_3 (Al, Fe) Si_3O_{10}(OH, F)_2$
muscovite	$K Al_2Si_3O_{10}(OH)_2$
phlogopite	$K Mg_3Si_3AlO_{10}(F, OH)_2$
siderophyllite	$K Fe Al (Al_2Si_2)O_{10} (F_1OH)_2$
albite	$Na Al Si_3O_8$
apatite	$Ca_5(PO_4)_3F$
ilmenite	$FeTiO_3$
titanite	$CaTiSiO_5$