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Reconnaissance geochemical exploration of the plutons of quartz monzonite and granite in the Jabal Lababa and Ar Rayth areas, southern Asir, Kingdom of Saudi Arabia

by

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RECONNAISSANCE GEOCHEMICAL EXPLORATION OF THE PLUTONS OF QUARTZ MONZONITE AND GRANITE IN THE JABAL LABABA AND AR RAYTH AREAS, SOUTHERN ASIR, KINGDOM OF SAUDI ARABIA

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ABSTRACT

Geochemical reconnaissance for rare metals in plutons of albite-muscovite granite and quartz monzonite in the vicinity of Jabal Lababa disclosed positive geochemical anomalies for beryllium, tantalum, thorium, lanthanum, niobium, tin, yttrium, and zirconium. The low anomalous values for the rare metals in rocks and the short mechanical dispersion trains, seldom exceeding 4 km in length, of rare-metal-bearing heavy minerals, are interpreted to indicate that primary deposits of these metals are lacking, and any placers would be small and low in tenor.

Small positive anomalies for barium were detected at scattered localities in the metasediments adjacent to the plutons in the Jabal Lababa area. Positive anomalies for the precious metals are lacking, and the low values observed for base metals do not indicate the presence of sulfide deposits. The abundant quartz lag gravel in the eastern part of the area is unmineralized. Small books of muscovite are present in some pegmatite, but is of non-commercial volume and quality.

A subcircular structure at the coast of the Red Sea near the mouth of Wadi Nahb should be tested to determine if it is a buried salt dome.

Three nonmagnetic high-density concentrates containing 1,000 to 15,000 ppm lead were found on the granitic pluton near Ar Rayth. The source of the lead is not galena, and high values for lead appear to be characteristic of the pluton but do not indicate an ore deposit.

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INTRODUCTION

Purpose of investigation and previous work

Albite-muscovite granite and quartz monzonite in the Jabal Lababa area had been described as accompanied by abundant pegmatite and vein quartz, but the chance for the discovery of minable deposits of muscovite or feldspar in the pegmatite was regarded as negligible (Ratte and Andreasen, 1974). However, the presence of muscovite in the granite, and the local abundance of pegmatite and quartz veins, gave an appearance of late aqueous magmatic phases with the attendant possibility for deposits of elements characteristic of felsic plutonic rocks, particularly beryllium, molybdenum, niobium, rare-earth elements, tin, tantalum, tungsten, and zirconium. Therefore, a geochemical reconnaissance of the Jabal Lababa area for these rare metals was defined as a subproject under the project, Prospecting in Acid Plutonic Rocks (U.S. Geological Survey Saudi Arabian Mission, 1979, p. 11).

Expansion of the objectives of the subproject was recommended by G. M. Fairer (written commun., 1980) to include geochemical reconnaissance for tin in the circular pluton of peralkaline granite (Brown and Jackson, 1959; Fairer, 1983) exposed to the southeast of Ar Rayth (fig. 1). Features of this pluton were thought by Fairer (oral commun., 1980) to resemble other tin-bearing bodies of granite in the eastern and southern Arabian Shield (Thiele and Schulze, 1978).

Areas covered by geochemical exploration

The two areas covered by geochemical exploration are in southwestern Saudi Arabia (fig. 1). The Jabal Lababa area covers about 375 km^2 of the coastal plain. Jabal Lababa, having an altitude of 678 m (Brown and Jackson, 1959), is the highest point in the area. Elsewhere, altitudes are generally about 150 m or less on a gently southwestward sloping sand- and gravel-covered plain drained by Wadi Nahb, Wadi Aramram, Wadi Jawayr, and Wadi Jandalah. The southern limits of the area reach within 10 km of the community of Ad Darb.

The Ar Rayth area is about 88 km^2 centered on a circular granitic pluton 5 km to the southeast of the Ar Rayth. Peaks reach nearly 2,300 m in altitude 10 km to the east of the pluton, but in the vicinity of the pluton, altitudes are 500 to 700 m. In the valley of Wadi Shahdan, the main drainage leading westward from the pluton, altitudes decrease to less than 300 m within a few kilometers of the western edge of the pluton. Terraced farming is practiced along the gentle valley walls and high pediment surfaces on the rounded hills formed by the weathering and erosion of the pluton. The Ar Rayth area appears to be less arid than the region around Jabal Lababa.

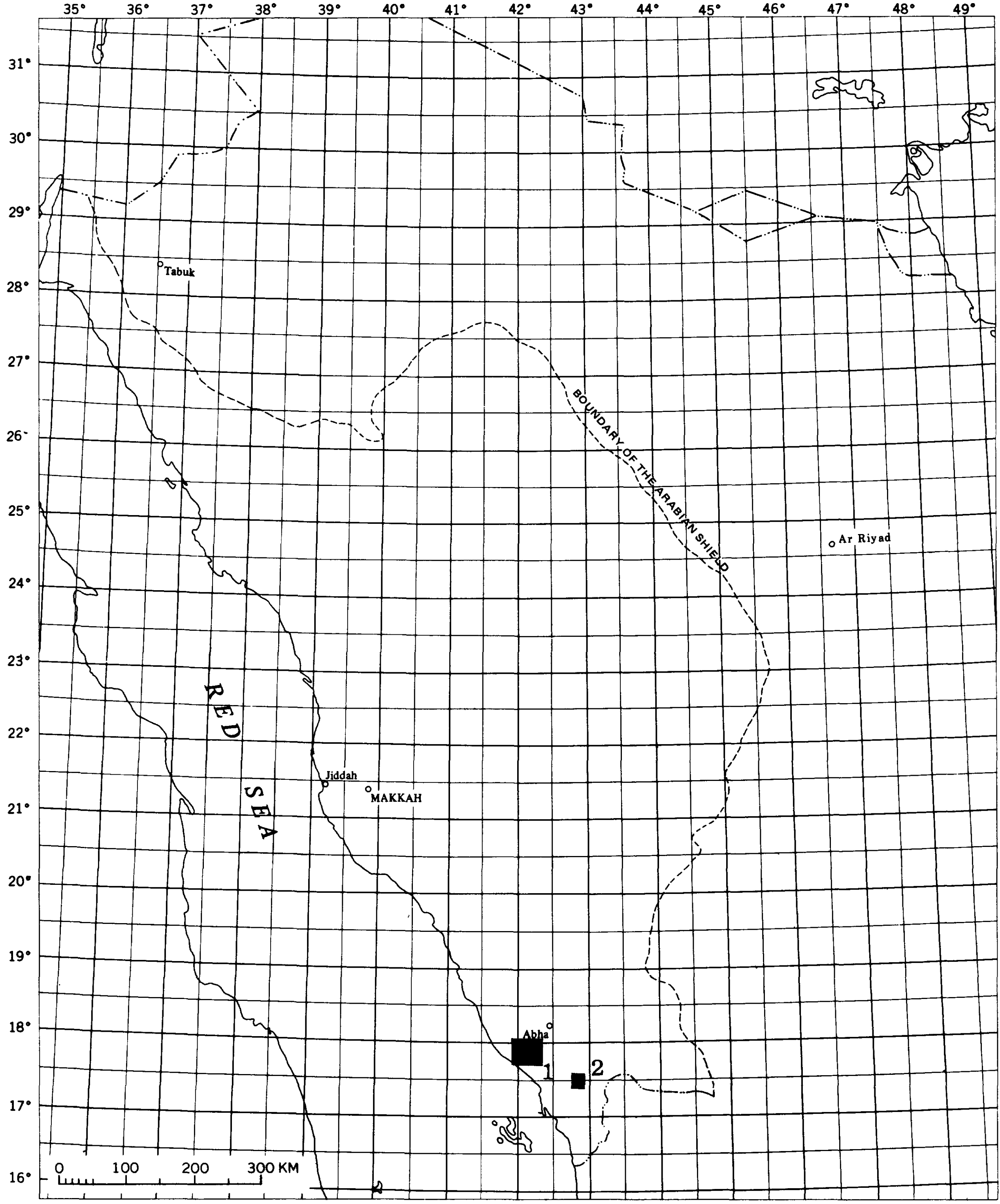


Figure 1.--Index map showing the locations of area studied by geochemical reconnaissance near Jabal Lababa (1) and Ar Rayth (2).

Acknowledgements

The senior writer wishes to acknowledge the support received from his associates during the present investigation and to express his appreciation to the officers of the Deputy Ministry for Mineral Resources, Kingdom of Saudi Arabia, and of the U.S. Geological Survey (USGS) Saudi Arabian Mission for the opportunity to undertake the work. In addition to the analytical work performed by the authors, other spectrographic analyses were contributed by Hassan Mousa, DGMR, and mineralogical analyses employing X-ray diffraction and scanning electron microscopy were performed by I. M. Naqvi, USGS, Jiddah, for which the writers are particularly grateful.

PROCEDURES

During February and March 1980, 860 samples were collected for geochemical analysis from 141 localities in the Jabal Lababa area and 345 samples were taken from 55 sites in the Ar Rayth area. Geologic maps (Brown and Jackson, 1959; Ratte and Andreasen, 1974; Fairer, 1983) and aerial photographs were used to record sample stations. The distribution of the stations was based on the systems of wadis to permit most stations to be placed within 2 km of the head of the wadi, but selected samples were taken at greater distances down-wadi to permit evaluation of the lengths of the mechanical dispersion trains of the rare metals. Distributive provinces were up to 3 km^2 for most stations, and as much as 25 km^2 for the down-wadi sites. Apparent sampling density based on the sizes of the two areas and the number of localities sampled in 2.7 km^2 at Jabal Lababa and 1.6 km^2 at Ar Rayth.

Scintillometer measurements of the radioactivity of the exposed rocks were made at each station where samples were collected for geochemical analysis.

Each station was the source of three kinds of samples: rocks, wadi sediment, and panned concentrates. Further division of the wadi sediment was made by sieving to four sizes: >10-mesh, <10 +32-mesh, <32 +80-mesh, and <80-mesh. The concentrates were divided into two fractions: (1) the raw concentrate as it came from the pan, and (2) a split from the raw concentrate, called the nonmagnetic concentrate, of high-density, non-magnetic minerals, prepared by removing highly magnetic minerals with a hand magnet and the low-density minerals with heavy liquid (acetylene tetrabromide, density 2.96). Panning was done in the field. Sieving of the wadi sediment and separation of the nonmagnetic concentrates were done in Jiddah at the petrographic laboratories of the USGS.

Samples of rocks, sieve fractions of wadi sediments exclusive of the >10-mesh material, the raw concentrates, and the nonmagnetic concentrates from each station were analyzed by semiquantitative spectrographic procedures at the

DGMR-USGS chemical laboratories using a modification of the method of Grimes and Marranzino (1968). Thirty elements were determined with precision and accuracy satisfactory for the purposes of reconnaissance geochemical exploration (Motooka and Grimes, 1976; Myers and others, 1976; Allcott and Lakin, 1974, 1978). However, when results of the analyses reflect abundances that are above or below the limits of analytical determination for particular elements (such results are termed technically censored data), these results are reported by the laboratory as alphabetic conventions:

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 upper and lower limits of reporting for the 30 elements are given in table 1 as well as numerical values substituted for the technically censored data. The substitute values are used in some statistical operations.

The mineralogical composition of 17 nonmagnetic concentrates from the Jabal Lababa area and 6 from the Ar Rayth area were determined at the mineralogical laboratory of USGS, Jiddah, with supplemental examination in USGS laboratories in Reston, Virginia, and Denver, Colorado. In the Jiddah laboratory 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, and 1.7 at 15° slope on the Frantz Isodynamic separator, pulverized, and analyzed by X-ray diffraction. Minerals represented by the strongest peaks were classed as major components of the concentrates, and identifiable minerals with the weakest peaks were classed as trace components. Between these categories of peak strengths is a group exhibiting intermediate strength classed as minor components. To be identified even as a trace component the mineral species represents at least 5 percent of the concentrate. Thus, a rigorous quantitative relation to actual abundances of the minerals is not afforded by the data, and many mineral species present as small percentages were not identified by the procedure. Individual grains from seven niobium-rich concentrates were hand-picked under the binocular microscope for study by petrographic microscope and by X-ray diffraction to determine the mineralogical sources of that element. Supplemental analyses were made of hand-picked minerals from two concentrates by scanning electron microscope and Kevex energy dispersive spectrometer for source minerals of niobium, tantalum, and thorium.

The results of the spectrographic and mineralogic analyses of the various geochemical sample media were interpreted with the aid of the reconnaissance geologic maps to reach an evaluation of potential primary and placer deposits of the

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

rare metals. Other possible mineral resources were also evaluated on a basis of the geology and geochemistry. The various geochemical sample media were appraised for suitability in the wide variety of geologic, geomorphic, and agriculturally affected settings in the coastal plain and adjacent highland where rainfall is greater than on the interior plateau of the Arabian Peninsula.

RESULTS IN THE JABAL LABABA AREA

Geologic setting

The geologic setting of the Jabal Lababa area is shown on a reconnaissance geologic map (fig. 2) based on published reports (Brown and Jackson, 1959; Ratte and Andreasen, 1974), a manuscript geologic map by G. M. Fairer (written commun., 1980), and present field work. The main addition of figure 2 to earlier geologic maps is to show surficial features that impinge on the results of geochemical exploration through possible modification of local representation of the alluvial sample media by the presence of allochthonous detrital materials.

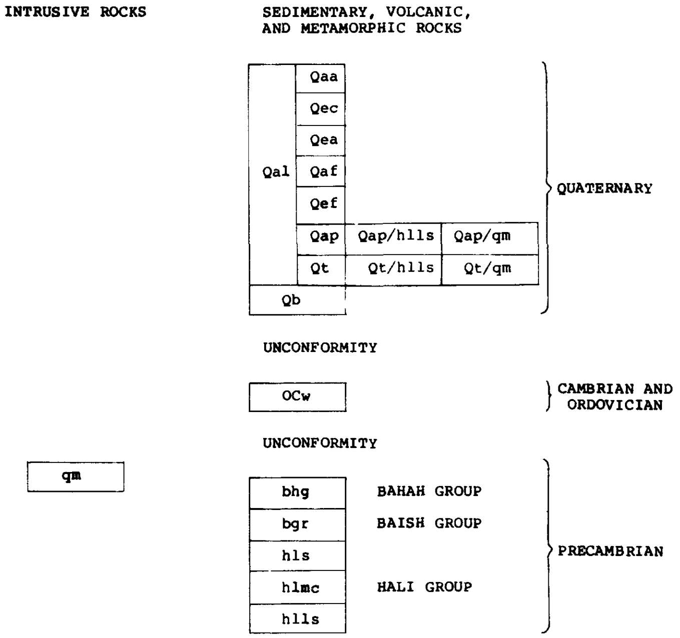
Rock types and structure

The oldest rocks are three units of Precambrian metasedimentary and metavolcanic rocks identified by Ratte and Andreasen (1974, p. 3-4) as (from oldest to youngest) the Hali Group, the Baish Group, and the Bahah Group. Only the Hali Group of Ratte and Andreasen is represented in the part of the area covered by geochemical exploration (fig. 2). It consists of an upper part composed of calcareous schist, phyllite, and quartzite and two interbedded sequences of brown-weathered marble, and a lower part composed of schist and phyllite that is gneissic near contacts of the intrusive granitoid plutons. The lower part of the Hali Group of Ratte and Andreasen in the area of figure 2 consists mainly of biotite-quartz schist and biotite-muscovite-quartz schist, but many minor lithologic varieties are present that give the unit a strongly layered aspect and include quartzite, biotite-hornblende schist, sericite-chlorite schist, and chlorite schist. Graphite is common in the muscovitic and sericitic schists and garnet is present in some of the biotitic schists. Within a few kilometers of the contacts of the plutons, the schists tend to be raised in grade by contact metamorphism to biotite gneiss, biotite-muscovite gneiss, biotite-hornblende gneiss, and hornblende gneiss.

The three plutons of Precambrian quartz monzonite are separated by septa of gneiss and schist, but at depth these bodies probably coalesce into a single intrusive mass (Ratte and Andreasen, 1974). The most massive phases of the quartz monzonite are in the high-relief parts of the western and eastern plutons. Outward from these massive cores the

EXPLANATION

CORRELATION OF MAP UNITS



Contact--Dashed where approximately located; dotted where concealed

Fault--Showing relative horizontal movement; dashed where approximately located; dotted where concealed

Strike and dip of foliation or schistosity
- Inclined
- Vertical

Bearing and plunge of lineation

Buried circular structure--Concealed by aeolian sand; may be volcanic cone

.75 Relative radioactivity of geologic units--Rate of counts on scintillometer shown by dot or by symbol for strike and dip of foliation or schistosity

DESCRIPTION OF MAP UNITS

(modified from Brown and Jackson, 1959: Ratte and Andreasen, 1974: Fairer, G.M., written commun., 1980)

SEDIMENTARY, VOLCANIC, AND METAMORPHIC ROCKS

Qal	Undivided wadi alluvium, pediment and terrace sand and gravel, and aeolian sand
Qaa	Alluvial sand, silt, and gravel in intermittently active wadi channels
Qec	Aeolian sand under cultivation
Qea	Aeolian sand in active dunes
Qaf	Alluvial sand, silt, and gravel in floodplains adjacent to wadi channel
Qef	Aeolian sand in vegetation-fixed dunes
Qap/hlls Qap/qm	Outwash sand and gravel on pediment and terrace surfaces, sheetwash and alluvial fan deposits
Qt/hlls Qt/qm	Terrace gravel, local strong desert varnish
Qb	Olivine basalt
OCw	Wakid Sandstone--reddish-brown, tan, and white crossbedded sandstone with pebble layers and conglomerate
bhg	Bahah Group--undivided; mostly graywacke and slate
bgr	Baish Group--mostly greenstone and(or) amphibolite
	Hail Group--Upper part
hls	Mostly calcareous schist, phyllite, and quartzite
hlmc	Brown-weathering marble
Hll	Hail Group--Lower part mostly biotite-quartz schist and biotite-muscovite- quartz schist, gneissic near contacts with quartz nomzonite

INTRUSIVE ROCKS

qm	Quartz monsonite--Includes some granite, granodiorite, pegmatitie dikes of Hali Group (qm); shwon as Qap/qm wher covered by terrace depostis

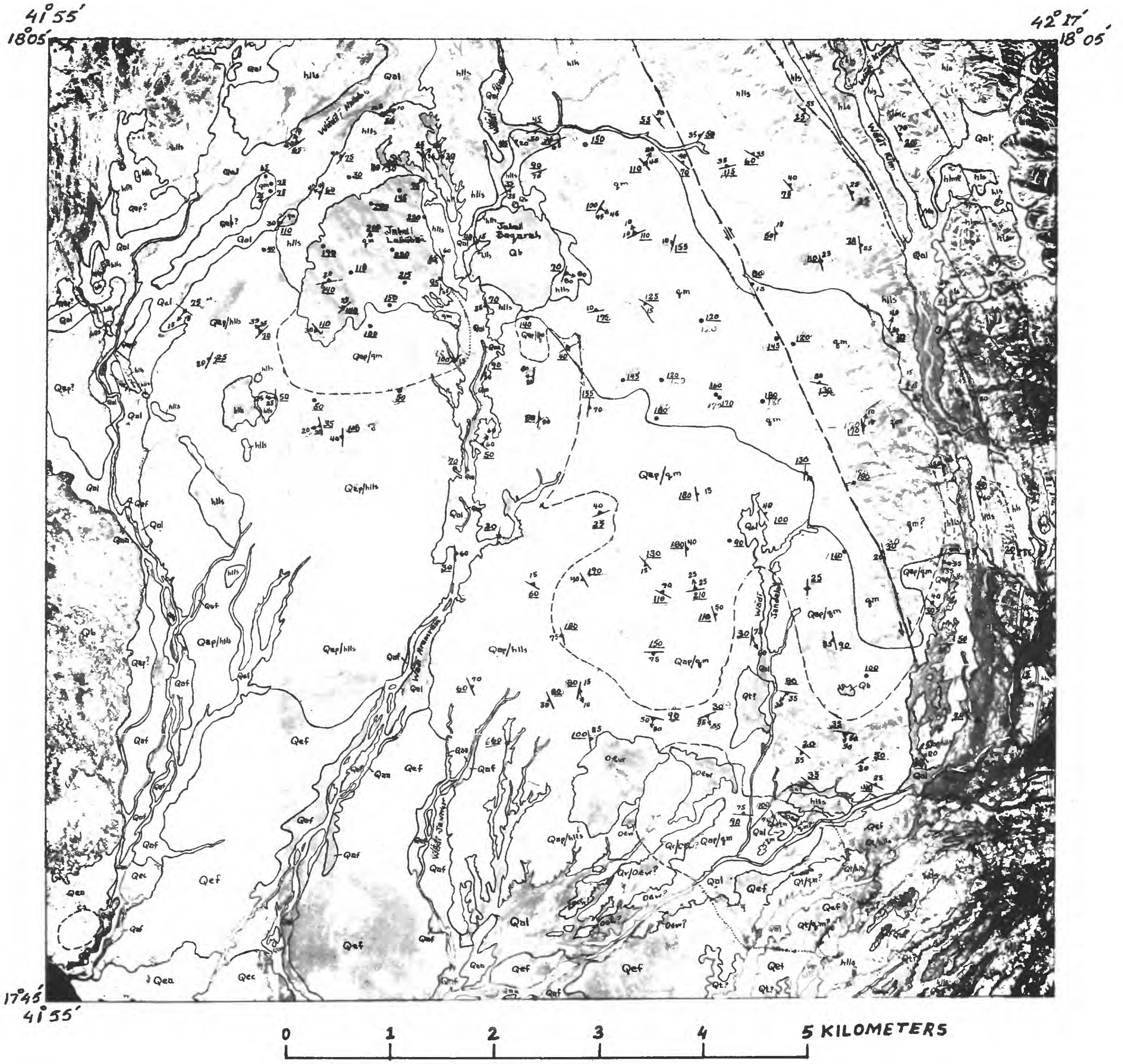


Figure 2.--Reconnaissance geologic map of the Jabal Lababa area, showing the radioactivity of selected geologic units.

plutons become progressively more gneissic; at their borders the gneissic layering of the plutons is locally emphasized by inclusions of metamorphic rocks. The dominant phase of the plutons is biotite quartz monzonite composed of quartz, oligoclase, and microcline with accessory biotite and, locally, muscovite. The massive, high-relief parts of the plutons may have been the last parts to be emplaced, exclusive of the dikes and veins, and the high-relief part of the western pluton at Jabal Lababa may be the youngest part of these intrusive bodies. Such compositional zoning of the plutons is consistent with some of the geochemical data.

Dikes of biotite granite, aplite, and pegmatite, and veins of quartz, are emplaced in the plutons and in the wallrocks. Through changes in grain size, texture, and relative percentages of feldspar and quartz the dikes grade into one another and into the interior quartz veins in the plutons. The pegmatite dikes are simple mixtures of quartz and feldspar that pass from mainly feldspar to eutectic mixtures of quartz and feldspar to essentially pure quartz. Most pegmatite dikes are too narrow to have well-developed zoning, but some dikes a meter or more in width tend to have quartz cores. Small books of muscovite, commonly flawed by A-structure, are present along the walls of the quartz cores. Coarse crystals of magnetite, up to 3 cm across, are also present in the quartz cores of some pegmatite dikes and in thick quartz veins. Large crystals and crystal aggregates of black tourmaline and of dark red garnet also are present locally in the contacts of pegmatite dikes and quartz veins with the quartz monzonite, which itself may be partly replaced by quartz, tourmaline, and garnet.

These dikes and veins are interpreted to be late-stage magmatic products genetically related to the plutons of quartz monzonite. However, large amounts of vein quartz present in the wall rocks are interpreted to have originated as metamorphic differentiation products of the metasedimentary rocks. They do not indicate highly aqueous phases associated with the quartz monzonite magma. This white quartz of metamorphic origin gives prominent surface lag gravel throughout the eastern part of the area.

Remnants of reddish-brown, tan, and white crossbedded sandstone and conglomerate rest unconformably on the metasedimentary rocks and on the quartz monzonite in the southern part of the area covered by figure 2. They are downfaulted blocks of Wajid Sandstone of Cambrian and Ordovician age. Massive expanses of this sandstone are exposed to the east of the area some 2,000 m higher than the remnants in the Jabal Lababa area.

Flows of olivine basalt and cinder cones of Quaternary age are exposed at Jabal Baqarah in the north-central part of the area and along the west-central edge of the area. A subdued dome-like structure in the alluvium immediately south of the lava field at the western edge of the area may be a buried cone or possibly a buried salt dome. The Quaternary age of these basalt flows appears probable from the sparse amount of erosion and weathering.

Sedimentary rocks of Quaternary age consist of unconsolidated deposits of alluvial and aeolian origin. The oldest alluvial deposit is terrace gravel (Qt) with strong desert varnish exposed in the southeastern part of the area. Desert varnish is also characteristic of some of the cobble and gravel deposits of the outwash gravel on pediment surfaces (Qap), but that unit also contains much unstained white quartz in small angular pebbles and coarse-grained sand. Some outwash sand and gravel forms a thin veneer no more than 10 to 15 cm thick overlying orange to deep-red silt of possible aeolian origin which in turn overlies eroded Precambrian rocks. Various sheetwash and coalescing alluvial fan deposits are included with the unit of outwash sand and gravel. Together they constitute the principal surficial deposits. Alluvial sand in floodplain deposits along the flanks of major wadis (Qaf) was separated from younger alluvial sediments in the active channels of intermittently flowing wadis (Qaa). Silt is a more common component of the wadi alluvium than of the outwash deposits on pediment surfaces. The general term alluvium (Qal) was used for undivided surficial deposits of sedimentary origin.

The aeolian sedimentary deposits are classed as sand in vegetation-fixed dunes (Qef), sand in active dunes (Qea), and aeolian sand under cultivation (Qec). The classification was based on interpretation of aerial photographs. None of these types of sedimentary deposits was the source of geochemical samples.

An area of badlands topography (Qr) was interpreted from aerial photographs to be present on part of the Wajid Sandstone. This feature was not included in the reconnaissance geochemical sampling.

The main local structural features are an asymmetrical dome formed by the plutons and the regional faults younger than the plutons. Gneissic layering in the two large plutons defines a broad dome with steeper layering in the center, where the igneous rocks are separated by a septum of metasediments, than on the flanks. The intrusive bodies of quartz monzonite have molded their wallrocks to conform to their outline. Regional faults younger than the quartz monzonite are a common feature of the possible synclinal belt of metasedimentary rocks to the east of the pluton. Only the most prominent of these north-northwest-striking faults are shown. One intersects the eastern pluton. Many small cross faults are present in the plutons, where they are sculptured into north-northeastward- to northeastward- and westward- to northwestward-trending valleys. They have not been shown on figure 2, but they are clearly reflected in the topography.

Radioactivity of the rocks

Scintillometer measurements of the radioactivity of the rocks in the Jabal Lababa area showed that the quartz monzonite and allied rocks of the plutons are three to five times as radioactive as the metasedimentary rocks in the Hali Group of Ratte and Andreasen (fig. 2). The average value recorded on the scintillometer for 119 cps observations of plutons, dikes, and veins is 110 cps, whereas the average for 72 observations of the metamorphic rocks is 44 cps. When the radioactivity of the lithologic units in the Hali Group of Ratte and Andreasen is compared on a basis of degree of metamorphism, distance from contacts with the plutons of quartz monzonite, and population of dikes and veins derived from the plutons, the units are found to be more radioactive in an aureole extending up to 5 km from the pluton. Those areas with large populations of dikes and veins are more radioactive than areas where dikes and veins are sparse or absent, whether near or far from contacts of the plutons are shown in table 2.

Table 2.--Scintillometer measurements of the radioactivity of rocks around the plutons of the Jabal Lababa area

Position with respect to contacts of plutons	Average radioactivity
Within 5 km	
Dikes and veins lacking or sparse	45 cps
Dikes and veins common	55 cps
Greater than 5 km	
Dikes and veins lacking or sparse	25 cps
Dikes and veins common	45 cps

This effect is, however, notably less along the eastern edge of the eastern pluton where the radioactivity of the metamorphic rocks is quite low despite the presence of many small quartz veins. These relations reflect the presence of the fault along the eastern side of the pluton (fig. 2) by which some of the sequence of contact metamorphosed sedimentary rocks, including particularly metasediments intruded by exterior dikes of granite and pegmatite as well as veins of quartz genetically connected with the pluton of quartz monzonite, was removed. Also, the sparse radioactivity associated with the small quartz veins in this part of the metasediments is interpreted to indicate that the veins are metamorphic differentiation products.

The greatest values for radioactivity are found in the high-relief parts of the western pluton at Jabal Lababa. They are associated with, or are near, sources of nonmagnetic concentrates that contain positive anomalous amounts of niobium, tin, yttrium, and zirconium. At these anomalous localities part of the radioactivity is attributable to thorium and uranium in complex niobate minerals as well as associated radioactive minerals such as thorite, monazite, xenotime, and zircon. Elsewhere, the radioactivity is normal for felsic intrusive rocks and for metasediments.

Weathering

Several ages of weathering are present in the rocks of the Jabal Lababa area, including weathering prior to the deposition of the Wajid Sandstone (Ratte and Andreasen, 1974, p. 5), but the weathering of possible influence on the results of geochemical exploration is that which has been active in Quaternary time. All rocks in the area have been affected including unconsolidated sediments of Quaternary age, which show such effects as desert varnish on pebbles in some terrace deposits and the development of orange, red, and maroon colors in silt. The least-weathered rock is the Quaternary basalt, but it has not been immune to chemical attack from water, as is shown by the local presence of calcium carbonate as joint fillings, coatings, and surface crusts. The least-weathered rocks are aplite, pegmatite, quartz veins, quartzite, and marble, and the most-weathered are quartz monzonite, granite, biotite gneiss, amphibolite, and mica schist.

The only exposed parts of the quartz monzonite plutons unaffected by chemical weathering are sites where erosion has prevented the accumulation of weathering products, or where the mineral composition of the rock is locally resistant to chemical solution. The main components of the quartz monzonite are plagioclase, microcline, and quartz in similar amounts. Other components, such as biotite and muscovite, make up only a few percent of the rock. Among these five components those most resistant to chemical attack from water are quartz and microcline. Where these minerals are common, as in the dikes of aplite and pegmatite, or quartz veins, solution has been less effective than in the quartz monzonite, where plagioclase has afforded relatively easy avenues for disaggregation and solution. Nevertheless, even in the pegmatite dikes and quartz veins, biotite shows swelling and discoloration caused by weathering, books of muscovite are opened along their cleavages where micro-organisms have entered to grow and to etch the mica, and pyrite is altered to limonite. Carbonate minerals in the brown silicified marble, as well as grains of pyrite in marble and quartzite, show similar alteration. Strongest chemical alteration has taken place in the gneissic phases of the quartz monzonite and in the metamorphic rocks containing mica and amphibole.

The main visible effect of weathering in the quartz monzonite is a dull whitening of the plagioclase accompanied by reduced hardness, imperfect microbrecciation, and lowered bonding to other rock-forming minerals. Biotite takes on a brassy cast and loses flexibility. Little of the plagioclase has been changed to clay minerals. The results of these alterations are reduced hardness and elasticity of the rock and slightly modified chemical composition. These alterations are more pronounced in gneissic and in closely jointed parts of the plutons than the more massive parts. They may extend 10 m or more into the rock, but true saprolite (Becker, 1895, p. 289-290) is scarce. Gruss, however, is common owing to the failure of the plagioclase to maintain its coherence.

Grain size of wadi sediments

Grain size of wadi sediments reflects the variable factors of source and of transport and deposition. Size has been shown to affect the results of geochemical analyses whether of the sediment or of concentrates prepared therefrom (Theobald and Allcott, 1975; du Bray, 1981). A convenient way to assure some uniformity in the varied hydraulic conditions of the depositional environments is to collect sediment having similar distributions of particle sizes. Sampling of sediment having no gross differences in particle size minimizes the mineralogical and chemical variations imparted by hydraulic factors and thereby improve the degree to which the sample reflects variations in the composition of the rocks in the source area.

Sieve analyses of the wadi sediments used for geochemical analyses and for the preparation of concentrates in the Jabal Lababa area showed the average sample to consist of: >10-mesh (>1.651 mm), 32 percent; <10 +32-mesh (<1.651+0.495 mm), 38 percent; <32 +80-mesh (<0.495+0.175 mm), 24 percent; and <80-mesh (0.175 mm), 6 percent. Thus, most of the wadi sediment used for samples is very coarse to medium sand (2 mm-0.25 mm) with a small amount of fine sand (0.25-0.125 mm). Greater variation was found about the average percentage of the coarsest sand -- from 21 to 54 weight percent of the sample -- than for the finest sand -- 0 to 9 percent. Comparison of the percentages of the coarsest and finest fractions of the sediment to the gradients of the reaches of the wadis from which the samples were taken shows that the alluvium from the steeper-gradient reaches is better sorted than that from reaches with moderate or low gradients.

The distribution of the <80-mesh component of the alluvium is consistent with the hydraulic character of the gradients. Least amounts of this fine component are present in sediment from reaches with steep gradients where the velocity of water is greater than in reaches with low gradients. That is, deposition of fine-grained alluvium is promoted where the velocity of flowing water, when present, is less.

The distribution fo the >10-mesh fraction of the wadi sediments does not follow the predictable trend of being more abundant in sediment from reaches of wadis with steep gradients. The largest percentages of >10-mesh material were found in reaches with gentle gradients. This relation is caused by the extreme variations in the response of the two dominant lithologies to mechanical disintegration: the metasedimentary rocks yield a higher proportion of coarse particles than the quartz monzonite, which particles lag in the floors of wadis with gentle gradients in the metasedimentary rocks.

The distribution of the coarse and the fine fractions of wadi sediment shows marked changes across the north-northwest-trending fault on the eastern side of the mapped area (fig. 2), around Jabal Lababa, and in the pediment region in the south-central and western parts of the area. Between the fault and Wadi Rim the metasedimentary rocks are the dominant source for the wadi sand. These schists and marble disintegrate into lamellar flakes and ocicular grains in which one axis is either exceedingly short or exceedingly long compared to the other two axes. The debris from the plutons of quartz monzonite tends to form almost equant grains. The particles from the metasediments remain as fragments of rock, whereas particles from the quartz monzonite tend to disaggregate into fragments of individual minerals. Lamellar fragments, particularly, are moved more readily by water than the equant grains; thus, coarse-grained lamellar particles compose a greater part of the sand from the metasediments than coarse-grained equant particles from the quartz monzonite. Sand from the metasedimentary rocks is also characterized by low to moderate percentages of the <80-mesh fraction resulting from the low yield of fine-grained particles from the schists and marble.

The feldspathic quartz sands derived from the quartz monzonite are medium- to coarse-grained with more of the <80-mesh fraction than sands from the metamorphic rocks. The percentage of the <80-mesh fraction in the feldspathic quartz sands appears to be geomorphically controlled. The lowest percentages of the <80-mesh fraction are in the wadi sands from the pediment along the southern part of the quartz monzonite plutons, which area is also the source of the feldspathic quartz sand with the highest percentages of the >10-mesh sediment. Fine-grained fractions are also sparse in the parts of Jabal Lababa with the steepest relief, but breaks in the slope of wadi floors emerging from the high-relief areas, where the velocity of water would abruptly slow and large loads of sediment are dumped, the fine-grained component increases in abundance. On the relatively flat pediment surface the <80-mesh fraction almost disappears owing to deflation.

Intermittent stream flow, at times characterized by torrential flooding, creates a turbulent depositional environment in which alluvial sorting is imperfect. Thus, changes in grain size and mineral composition of alluvium from intermittently flowing streams like the wadis in the Jabal Lababa area are pronounced both vertically and horizontally in the wadi floor. Compensation of these abrupt discontinuities can be partly achieved by use of similar samples of wadi sediment for geochemical exploration.

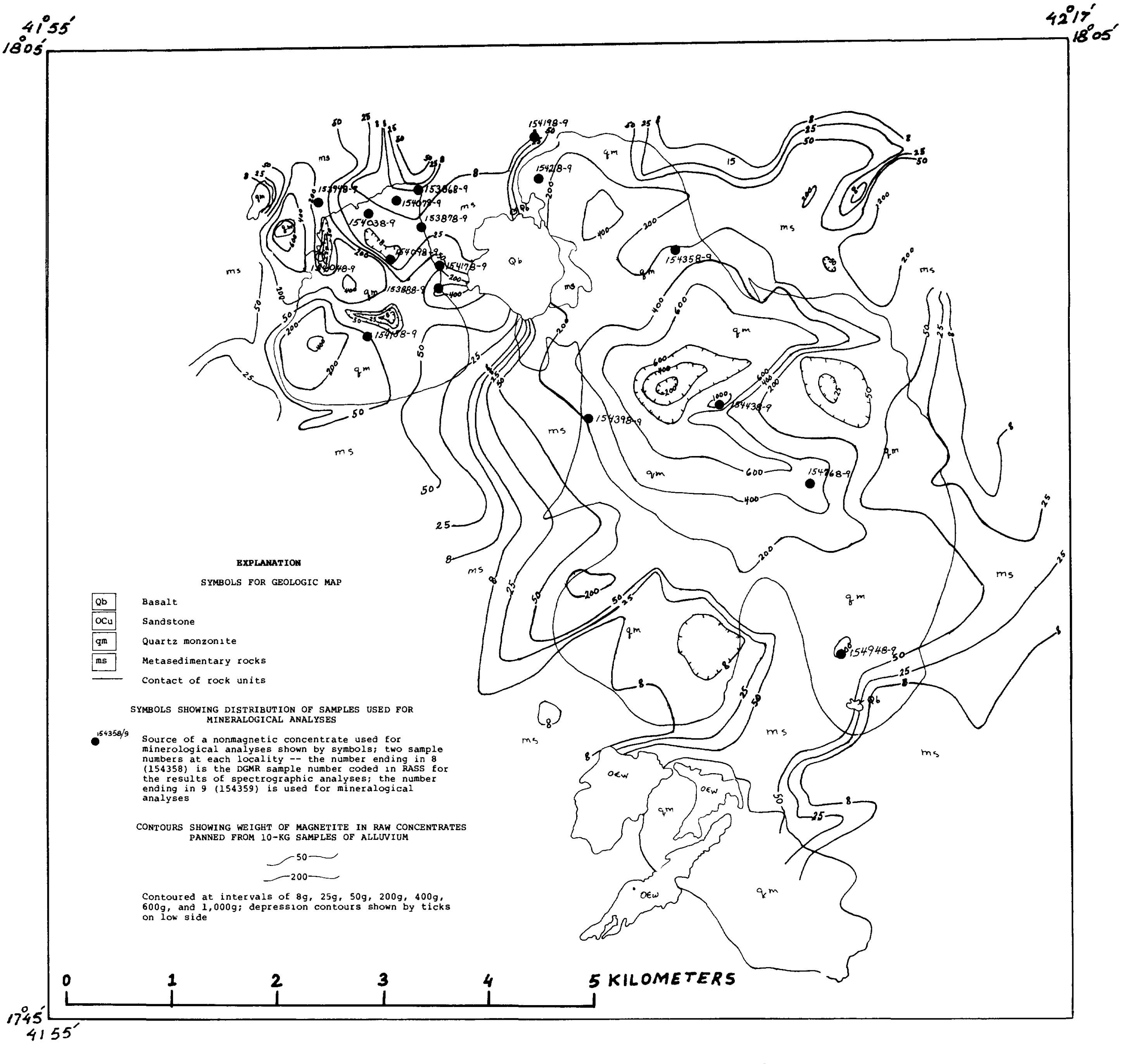
Mineralogy of nonmagnetic concentrates

The preferred geochemical sample medium adopted for granitoid terrane in Saudi Arabia is the nonmagnetic concentrate (Elliott, 1980; du Bray, 1981) which is also the most advantageous material to examine mineralogically for the sources of metals that make up positive geochemical anomalies. The mineralogical composition of 17 nonmagnetic concentrates mainly from sources in the plutons of quartz monzonite is given in table 2 and the localities represented are shown on figure 3.

Among the rare-metal-bearing minerals in these concentrates, only monazite, xenotime, and zircon are major minerals. Small amounts of the rare metals may be camouflaged in fluorapatite, rutile, and titanite, all of which are major minerals, but where the concentrates lack the rare-metal-bearing minerals shown in table 2, the tenors of the rare metals are low. Minor and (or) trace amounts of seven niobium-bearing minerals, cassiterite, and thorite were identified. All are in concentrates from Jabal Lababa, the western pluton of quartz monzonite (figs. 2 and 3; table 3).

Other minerals and mineral groups are common in the nonmagnetic concentrates, but none, except possibly the fluorapatite, rutile, and titanite, contributes to positive anomalies for the rare metals. The secondary oxide and hydrous oxide minerals hematite, limonite, and pyrolusite, through adsorption and coprecipitation in weathering products, appear to re-inforce positive anomalies for such rare metals as scandium, yttrium, and zirconium, but this role is more noticeable in the <80-mesh wadi sediment than in the nonmagnetic concentrates.

Pyrite and sphalerite are the only sulfide minerals present, but they were observed in a single concentrate each. Neither contributed anomalous values for base metals.



EXPLANATION

SYMBOLS FOR GEOLOGIC MAP

Qb	Basalt
OCu	Sandstone
qm	Quartz monzonite
ms	Metasedimentary rocks
——	Contact of rock units

SYMBOLS SHOWING DISTRIBUTION OF SAMPLES USED FOR MINERALOGICAL ANALYSES

● 154358/9 Source of a nonmagnetic concentrate used for minerological analyses shown by symbols; two sample numbers at each locality -- the number ending in 8 (154358) is the DGMR sample number coded in RASS for the results of spectrographic analyses; the number ending in 9 (154359) is used for mineralogical analyses

CONTOURS SHOWING WEIGHT OF MAGNETITE IN RAW CONCENTRATES PANNED FROM 10-KG SAMPLES OF ALLUVIUM

50

200

Contoured at intervals of 8g, 25g, 50g, 200g, 400g, 600g, and 1,000g; depression contours shown by ticks on low side

Figure 3.--Map of the Jabal Lababa area showing sources of nonmagnetic concentrates used for mineralogical analyses and contours based on the weight of magnetite in raw concentrates.

Table 3.--Rare-metal-bearing minerals in nonmagnetic concentrates from the Jabal Lababa area

Sample number on figure 3	Minerals
153869	Monazite, xenotime, zircon, (fluorapatite, rutile)
153879	Ilmenorutile, monazite, zircon, (fluorapatite, rutile, titanite)
153889	Zircon, (fluorapatite, titanite)
153949	Aexchynite, cassiterite, monazite, niobate-tantalate mineral, thorite, xenotime, zircon, (rutile, titanite)
154039	Monazite, staringite, zircon, (fluorapatite, rutile, titanite)
154049	(Fluorapatite, titanite)
154079	Monazite, titano-niobate mineral, yttro-tanta-niobate mineral, zircon, (rutile, titanite)
154099	Ilmenorutille, pyrochlore, titano-niobate mineral, xenotime, zircon, (rutile, titanite)
154159	Zircon, (fluorapatite, titanite)
154179	Cassiterite, ilmenorutile, monazite, zircon, (rutile, titanite)

Confirmation of the rarity of sulfide minerals of the base metals is had by the absence of secondary base-metal minerals from the nonmagnetic concentrates. Another indicator mineral of possible hydrothermal systems, barite, also was not identified in the nonmagnetic concentrates.

Minerals containing niobium, tantalum, and tin.--The four identified niobium-bearing minerals, one of which is also tantalum-bearing, have the compositions (Fleischer, 1980, p. 2, 74, 129, and 148):

Aeschynite	$(Ce, Ca, Fe, Th) (Ti, Nb)_2 (O,OH)_6$
Ilmenorutile	$(Ti, Nb, Fe^{+3})_3 O_6$
Pyrochlore	$(Na, Ca)_2 Nb_2O_6 (OH,F)$
Staringite	$(Fe^{+2}, Mn)_x (Ta, Nb)_{2x}Sn_{6-3x}O_{12}$

The three unidentified niobium-bearing minerals called in table 4 a niobate-tantalate mineral, a titano-niobate mineral, and a yttro-tanta-niobate mineral, were obtained from splits of low magnetic susceptibility in the range of 1.0 to 1.5 amperes on the Frantz separator, as were the identified niobium-bearing minerals. Possibly the unidentified minerals are similar or identical to the ones determined by X-ray diffraction. Thus, the unidentified titano-niobate mineral may be rutile; the niobate-tantalate mineral may be a member of the pyrochlore-microlite group; and the yttro-tanta-niobate minerals may be in the aeschynite series, possibly tanta-laeshynite-(Y) with the composition $(Y, C, Ca) (Ta, Ti, Nb)_2O_6$ (Fleischer, 1980, p. 154).

The mineral identified by X-ray diffraction to be aeschynite actually may be aeschynite-(Y), which differs in composition from aeschynite by the substitution of Y for Ce. This possibility is supported by the much larger values for Y in the concentrates than for the Ce earths, which are reflected by low values for lanthanum and scandium.

Pyrochlore and staringite are present in niobium-rich concentrates. When tin-rich concentrates are also considered, the possibility arises that staringite may be more widely distributed in the Jabal Lababa area than the mineralogical evidence shows (table 4). Ilmenorutile and the other niobium-bearing minerals also may be more widely presnt than the results of the mineralogical analyses indicate (table 5).

Staringite may be present in concentrate 153949 having 1,000 ppm tin, but cassiterite is also present, being identified in the X-ray powder pattern as a minor mineral although it was not detected in other mineralogical procedures. Conversely, the possibility exists that cassiterite is present in concentrate 154039 where the quantity of tin reaches 1,000 ppm, but only staringite and titanite are the identified tin-bearing minerals. Where rutile and ilmenorutile are identified as the niobium-bearing minerals (samples 153869, 153879, and 154179), possibly one or more of the other niobium-bearing minerals is also present, because the amount of yttrium in the concentrates is great.

Among the identified and possibly identified niobium- and tantalum-bearing minerals in these concentrates, the only one that elsewhere is an important ore for these metals is pyrochlore (Parker and Adams, 1973, p. 446). The other niobium- and tantalum-bearing minerals in the concentrates are, however, within the range in composition of the oxide, multiple oxide, and hydroxide minerals commonly used as ores. Whether they could constitute ore in the Jabal Lababa area relates to their grade and tonnage in the host rocks or in alluvium. These concentrates contain the most niobium of any samples analyzed in the survey. Where the spectrographic values of niobium exceed the upper limit of determination of 2,000 ppm, the actual amount of niobium-bearing minerals in the concentrate may not be as great as 1 percent, because the niobium-minerals cannot be uniformly detected by X-ray in powders of the concentrates, even where the concentrates have been divided into as many as 14 different magnetic fractions

Table 4.--Minerals in 17 nonmagnetic concentrates from the Jabal Lababa area.

Mineral	Abundance in concentrate			Concentrates containing mineral (number)
	Major	Minor	Trace	
Rare-metal-bearing minerals				
Aeschynite	-	-	x	1
Ilmenorutile	-	-	x	3
Niobate-tantalate	-	x	-	1
Staringite	-	-	x	1
Pyrochlore	-	-	x	1
Titano-niobate	-	x	-	2
Yttro-tanta-niobate	-	x	-	1
Cassiterite	-	x	x	2
Monazite	x	x	x	7
Xenotime	x	x	-	3
Thorite	-	-	x	1
Zircon	x	-	-	9
Amphibole group				
Anthophyllite	-	-	x	2
Hastingsite	x	x	x	4
Hornblende	x	x	-	7
Kaersutite	-	x	x	5
Pargasite	-	-	x	2
Richterite	-	x	x	3
Tirodite	x	x	x	6
Winchite	-	-	x	1
Pyroxene group				
Augite	-	-	x	1
Diopside	x	x	x	11
Pyroxene	x	-	-	1
Garnet group				
Andradite	-	-	x	1
Garnet	x	x	-	7
Spessartite	x	x	x	4
Epidote group				
Epidote	x	x	x	8
Mukhinite	-	-	x	3
Piedmontite	-	x	x	5
Feldspars and quartz				
Albite	-	x	-	1
Oligoclase	x	-	-	1
Plagioclase	-	-	x	1
Microcline	-	-	x	1
Quartz	x	x	x	8
Tourmaline group				
Dravite	-	-	x	2
Tourmaline	-	x	-	1
Other minerals				
Biotite	x	x	-	4
Phlogopite	-	-	x	1
Magnetite	-	x	x	11
Hematite	x	x	x	16
Limonite	x	x		5
Ilmenite	x	x	x	15
Antase	-	-	x	2
Rutile	x	x	x	7
Titanite	x	x	x	15
Pyrolusite	-	-	x	1
Fluorite	x	-	x	3
Fluroapatite	x	x	x	12
Kyanite	-	-	x	1
Pyrite	-	x	-	1
Sphalerite	-	-	x	1

Table 5.--Chemical analyses of niobium- and (or) tin-bearing minerals in nonmagnetic concentrates shown in figure 3

Concentrate number	Minerals	Nb (ppm)	Sn (ppm)	Y (ppm)
153869	Rutile	1,500	50	2,000
153879	Rutile, ilmenorutile	1,000	50	2,000
153949	Aeschynite, rutile, niobate-tantalate mineral (pyrochlore-microlite group?), cassiterite	G2,000	1,000	G2,000
154039	Staringite, titanite, rutile	1,500	1,000	2,000
154079	Ilmenorutile, rutile titano-niobate mineral (rutile?), yttro-tanta-niobate mineral (aeschynite series?)	G2,000	100	G2,000
154099	Ilmenorutile, rutile pyrochlore, titano-niobate mineral (rutile?)	G2,000	50	G2,000
154179	Ilmenorutile, rutile cassiterite	2,000	70	G2,000

including ranges in magnetic susceptibility at which these minerals accumulate (Rosenblum, 1958).

Cassiterite was identified as a minor mineral by X-ray diffraction in concentrate 153949 and by scanning electron microscope study of hand-picked minerals from concentrate 154179. Where peaks for cassiterite were observed by X-ray, the concentrate (153949) contained 1,000 ppm tin, but the hand-picked grains came from a concentrate having only 70 ppm tin (154179). Another concentrate (154039) enriched in tin (1,000 ppm) and niobium (1,500 ppm) lacks cassiterite, but it contains the niobium-bearing stannate mineral staringite. Other minerals that may contain niobium or tin are lacking except for the possible presence of these elements in rutile and titanite. The mineralogical evidence from the tin-bearing nonmagnetic concentrates is that cassiterite is a rare mineral in the Jabal Lababa area.

Titanite, a Ca-Ti silicate, commonly contains small amounts of tin, yttrium, and zirconium, but the mineral is not used as an ore for these elements. Titanite is quite widely present in nonmagnetite concentrates from the Jabal Lababa area (table 4), but where high values for tin, yttrium, and zirconium were observed in the concentrates, the most probable sources for these elements are cassiterite, staringite, xenotime, and zircon. Fluorapatite also commonly contains small amounts of several of the rare metals, but where it is associated with few other rare-metal-bearing minerals, as in concentrates 153889 and 154049, the tenors in rare metals are low; hence little contribution comes from this source (table 6).

The unidentified titano-niobate mineral may be rutile, and rutile is likely to be a source for some of the niobium in the concentrates. However, no data on the trace elements in rutile were obtained for the Jabal Lababa area.

Rare-earth minerals.--Monazite and xenotime are the main rare-earth minerals observed in the concentrates. Small amounts of rare-earth elements also are commonly present in epidote, fluorapatite, garnet, the niobium-bearing minerals, titanite, and zircon, but only monazite and xenotime are considered here, because they are used in industry as ores for the rare earths. The compositions of the two minerals are variable. Monazite is represented by the formula (La, Ce, Nd) PO_4 and xenotime by YPO_4 (Fleischer, 1980, p. 106 and 173).

Monazite is the main ore mineral elsewhere in the world for thorium and the rare-earth elements of low atomic number from lanthanum (57) to samarium (62). Xenotime is an ore mineral for europium (63) and rare-earth elements of higher atomic number (Staatz and Olson, 1973, p. 550). Monazite is generally more common as an accessory mineral than xenotime in granitic rocks, a relation apparently borne out by the data in table 4. However, preparation of the nonmagnetic concentrates prior to optical study included magnetic separation of grains in the range 0.6 to 1.5 amperes. Grains reacting less magnetically were identified. The magnetic susceptibility of xenotime is much greater than that of monazite; hence, the fractions of the concentrates examined optically were preferentially depleted in xenotime and enriched in monazite. X-ray diffraction studies, done on splits made at 14 different magnetic intensities, showed xenotime to be more abundant than monazite. Many of the samples where monazite was identified optically and xenotime was not observed had too small a percentage of both minerals for discrimination in the X-ray powder patterns.

The abundance of lanthanum and yttrium in the nonmagnetic concentrates containing monazite and xenotime are interpreted to indicate the probable presence of xenotime in concentrates where it was not identified, as well as a possible enrichment of the concentrates in xenotime. Lanthanum is associated with monazite, and yttrium is in xenotime as well as some of the niobium-bearing minerals (table 7).

Table 6.--Chemical analyses of nonmagnetic concentrates containing fluorapatite, titanite, and zircon

Concentrate number	Minerals	Nb (ppm)	Sn (ppm)	Y (ppm)
153889	Fluorapatite, titanite, zircon	150	30	1,500
154049	Fluorapatite, titanite	150	30	500

Table 7.--Chemical analyses of nonmagnetic concentrates containing monazite and(or) xenotime

Concentrate number	Minerals	La (ppm)	Y (ppm)
153869	Monazite and xenotime	300	2,000
153879	Monazite	300	2,000
153949	Monazite and xenotime	500	G2,000
154039	Monazite	200	2,000
154079	Monazite	G1,000	G2,000
154099	Xenotime	G1,000	G2,000
154179	Monazite	700	G2,000

The single appearance of xenotime as a major mineral in one concentrate (154099), although confirmed by a high value for yttrium, does not indicate the presence of xenotime in economically recoverable amounts. Yttrium in quantities close to or greater than its upper limit of determination (2,000 ppm) was found for eight concentrates from the Jabal Lababa area (153869, 153879, 153889, 154039, 154079, 154099, 154179; fig. 3) two of which (153869 and 153949) were found by optical examination to contain minor amounts of xenotime (table 4). Xenotime is probably present in amounts too small to be detected by X-ray diffraction in the yttrium-rich concentrates. Titanite in these concentrates was also found to contain yttrium, but the distribution of yttrium varies independently of the abnundance of titanite and directly with the abundance of niobium, which shows that yttrium is not closely associated with titanite (table 8).

Table 8.--Comparison of abundances of titanite and yttrium in nonmagnetic concentrates shown on figure 3

Titanite is major mineral	Y (ppm)	Titanite is minor mineral	Y (ppm)	Titanite is trace mineral	Y (ppm)	Titanite is absent	Y (ppm)
153869*	2,000	153889	1,500	154179*	G2,000	154769	300
153879*	2,000	154039*	2,000	154439	200	154949	100
153949*	G2,000	154099*	G2,000				
154049	500	154399	500				
154079*	G2,000						
154159	700						
154199	100						
154219	150						
154359	100						

*Concentrates containing 1,500 to G2,000 ppm niobium

The possibility for the wider presence and greater abundance of xenotime than of monazite in the Jabal Lababa area is of interest in the context of sources for europium, which is the most valuable of the rare-earth elements and is more valuable than the other rare metals in the concentrates. Xenotime is the preferred ore mineral for europium. The mineral has been recovered as a by-product from concentrates discarded during the processing of cassiterite in Malaysian placers, but elsewhere xenotime is rarely found in mineable abundance. Europium was not determined in the analyses of these concentrates; thus, it is not known if the presence of xenotime and the high values of yttrium in concentrates from the pluton at Jabal Lababa define a possible source for europium. The postorogenic granitoid rocks in Saudi Arabia have been shown to have strong negative anomalies for europium (Stuckless and others, 1982), but the abundance of europium in xenotime for these rocks in unknown.

Mineral containing thorium and zirconium.--Thorite ($ThSiO_4$) and zircon (ZrSiO4) are present in greatly dissimilar abundances in the nonmagnetic concentrates (table 4).

Thorite was found in only one concentrate (153949, fig. 3) where single-crystal, X-ray diffraction study identified it as a trace mineral associated with aeschynite, cassiterite, monazite, an unidentified niobate-tantalate mineral, rutile, titanite, and xenotime. Zircon is a major mineral in about half of the concentrates, principally from the area of the western pluton (fig. 2).

Thorite is one of the less common ore minerals for thorium (Staatz and Olson, 1973, p. 471): monazite is the most used ore. Thorium is also present in several of the niobium-bearing minerals, but thorite is the only species present in which thorium is a major element. Thorium was not determined in the spectrographic analyses of the concentrates, nor was the radioactivity of the concentrates measured, but scintillometer recordings of rocks in the vicinity of the sample locality (figs. 2 and 3) showed no unusual radioactivity for metamorphic rocks in the contact aureole of the western pluton. Because thorite was identified by special minerallogical procedures applied only to the niobium-rich concentrates, and that identification was in one concentrate although seven concentrates are rich in niobium, the mineral is probably quite rare in the Jabal Lababa area.

Zircon is a major mineral in all concentrates with anomalous amounts of niobium in the northern part of the western pluton and in metamorphic rocks just to the north of the northern contact of the western pluton. Zircon is also a major mineral in one concentrate from the south-central part of the western pluton (154159, fig. 3), but elsewhere in the area it is not reported. Nevertheless, some zircon is likely to be present in many of the mineralogically unexamined concentrates from the area of figure 2, because several positive geochemical anomalies for zirconium are present outside the western pluton. Zircon is the main industrial source for zirconium, but the mineral is available in excess of demand as a by-product from the exploitation of placer deposits for ilmenite and rutile (Klemic and others, 1973, p. 714) elsewhere in the world; thus, the presence of zircon in concentrates from wadi sediments in the Jabal Lababa area is of no economic significance.

Other minerals and mineral groups.--Of the other minerals and mineral groups identified in the nonmagnetic concentrates and not discussed above, only fluorite is closely associated with rare-metal-bearing concentrates. Ilmenite, of course, is also present in concentrates with positive anomalies for the rare metals, but it is so common (table 4) that it lacks any genetic significance.

Fluorite was recognized as a major mineral in three concentrates (154039, 154079, and 154099, fig. 3), each of which contains strong positive anomalies for niobium, yttrium, and zirconium. These fluorite-bearing concentrates are restricted to the east-central part of the area where niobium is anomalously present in the western pluton. This relation is interpreted to show that fluorite is associated with the phase of quartz monzonite in which niobium is enriched.

Ilmenite is a major mineral in many concentrates. Where it is not a major it appears among the minor and trace elements. The common presence of ilmenite in nonmagnetic concentrates, as well as the common presence of rutile and local appearance of anatase, prevents the use of titanium as a pathfinder element for niobium despite the fact that several of the niobium-bearing minerals at Jabal Lababa contain titanium.

Hematite is a nearly ubiquitous mineral in the nonmagnetic concentrates and limonite is present in nearly half of the samples (table 4). Much of the hematite and all of the limonite is secondary and may have formed as a product of weathering of other iron-bearing minerals. Where hematite is a major component of the nonmagnetic concentrates, the results of spectrographic analyses of the concentrates might be expected to show enrichment in cobalt, copper, nickel, lead, and zinc if sulfide deposits of these elements were present in the source areas, owing to the role of secondary iron oxides and hydrous oxides in co-precipitating these elements from aqueous solutions (Jenne, 1968; Chao and Theobald, 1976). However, these elements are sparse in the hematite-rich and (or) ilmonite-bearing concentrates, thereby confirming the evidence derived by the absence from the concentrates of sulfide minerals and of secondary base-metal minerals and interpreted to indicate that sulfide deposits of the base metals are lacking in the Jabal Lababa area (table 9).

None of these elements except lead at 500 ppm reaches an anomalous value for the nonmagnetic concentrates in the Jabal Lababa area. The tenors in cobalt, copper, and nickel are somewhat greater than their respective crustal abundances of 1 ppm, 10 ppm, and 4.5 ppm in granite and 19 ppm, 45 ppm, and 6.8 ppm in schists (Beus and Grigorian, 1977, table 3). Less than half of the hematite-rich concentrates contain as much lead as crustal abundances of 19 ppm in granite and 20 ppm in schist, and the data suggest that the amount of zinc in these concentrates may be near crustal abundances shown by Beus and Grigorian (1977, table 3) to be 39 ppm in granite and 95 ppm in schist. The mean abundance of these elements in the rocks in the Jabal Lababa area are (in ppm): cobalt, 5; copper, 20; nickel, 10; lead, 10; and zirconium, N(200). The small rises in the amounts of these elements in the nonmagnetic concentrates over their mean values in the rocks may be attributable to sources in other minerals, particularly the amphiboles and the pyroxenes, as well as to the iron oxides and hydroxides, which confirms the absence of base-metal sulfides.

Table 9.--Abundances of elements likely to co-precipitate with iron oxides and hydroxides during weathering (in ppm)

Hematite-rich concentrates (sample number on figure 3)	Abundances (in ppm) of elements likely to co-precipitate with iron oxides and hydroxides during weathering				
	Co	Cu	Ni	Pb	Zn
153889*	15	7	15	10	N(200)
153949*	15	50	15	150	N(200)
154039	30	150	30	100	N(200)
154099*	20	100	15	500	N(200)
154179*	15	100	7	70	N(200)
154219	10	15	10	N(10)	N(200)
154359	30	15	20	N(10)	N(200)
154399	30	70	10	N(10)	N(200)
154769	15	100	15	L(10)	N(200)
154949	30	70	10	L(10)	N(200)

* Limonite present

Garnets are geochemical sinks for the rare-earth elements (Overstreet and others, 1970), but they are not used as ores for these elements. Their effect on the reported abundances of the rare-earth elements in the nonmagnetic concentrates cannot be separated from that of the other rare-earth-bearing minerals in the concentrates, where the garnet is accompanied by one or more of fluorapatite, monazite, titanite, and xenotime. Andradite was observed in sample 154079 (fig. 3), spessartite in samples 154199, 154399, 154439, and 154769, and garnet undivided in samples 153869, 153879, 153949, 154039, 154079, 154099, and 154179.

Pyroxenes and amphiboles are common in the nonmagnetic concentrates (table 4). The pyroxenes are mainly in concentrates from the eastern pluton of quartz monzonite and from the southern parts of the western pluton (fig. 2). Only two concentrates from the northern part of the western pluton contain pyroxene (154039 and 154099, fig. 3). Amphiboles are much more common than pyroxenes in concentrates from the western pluton, suggesting that the magma of the western pluton was richer in volatiles than the eastern body of quartz monzonite. The sodium-calcium-bearing amphiboles hastingsite, richterite, pargasite, winchite, and kaersutite are more common than the more femic amphiboles tirodite and hornblende in the western pluton, although femic amphiboles are present in concentrates from the eastern margin of the western pluton.

Epidote and its varieties piedmontite and mukhinite (which contains vanadium) are hydroxyl-bearing minerals that are much more common in concentrates from the western pluton than in concentrates from the rest of the area. Of the eight epidote-bearing concentrates (table 4) only two (154219 and 154359, fig. 3) are from the eastern pluton. The others (153869, 153879, 153949, 154079, 154099, and 154179, fig. 3) are from the western pluton which is also the source of four of the five piedmontite-bearing concentrates (153869, 153879, 153949, and 154079, fig. 3) and all three of the mukhinite-bearing concentrates (153869, 153879, and 154099, fig. 3). Mukhinite is present in concentrates from a small area in the northeastern part of the western pluton, but no geologic explanation is apparent for the presence there of this vanadiam-bearing form of epidote. The manganese-rich variety piedmontite is restricted to the extreme northern part of the western pluton, to the contact zone northwest of the pluton, and to a single concentrate (154399, fig. 3) from the western edge of the eastern pluton. Again, no geologic control was observed for this distribution of piedmontite.

In the tourmaline group dravite, the common brownish-black, magnesium-bearing variety of tourmaline, was identified by single-crystal, X-ray diffraction studies of two concentrates (153949 and 154039, fig. 3) often it had been reported as tourmaline by optical examination of sample 153949. The tourmaline-bearing concentrates are from the northwestern part of the western pluton and its contact zone where the mineral is sparingly associated with source areas of positive geochemical anomalies for niobium and tin.

Pyrolusite (MnO_2) was identified in one manganese-rich nonmagnetic concentrate (153879, fig. 3) where it is associated with the secondary iron minerals limonite and hematite. However, other concentrates containing greater amounts of manganese and characterized by the presence of the secondary iron minerals lack pyrolusite. The reason for the apparent sparsity of pyrolusite in other manganese-rich concentrates may relate to its being present in quantities too small to yield recognizable peaks on the charts from X-ray diffraction analyses of the powdered concentrates. Perhaps hardness is a factor in the scarcity of pyrolusite in panned concentrates. Pyrolusite has a hardness of 2.5, but that of limonite may be as great as 5.5, and the hardness of hematite may reach 6.5. Abrasion during alluvial transport would shortly destroy grains of pyrolusite.

Sphalerite and kyanite were identified in a concentrate (154079, fig. 3) from the northeastern part of the western pluton. The amount of sphalerite was too small to raise the value of zinc above N(200) ppm. Ordinarily kyanite is of metamorphic origin, but it is also known from pegmatite, quartz veins, and alumina-rich hydrothermal deposits. The presence of kyanite in this concentrate from alluvium in a high relief part of the western pluton where quartz veins give a prominent apron of scree, might suggest an igneous or hydrothermal origin for the kyanite, but the presence of anthophyllite, andradite, and piedmontite with the kyanite more likely indicates the presence of inclusions of schist in the quartz monzonite along upper reaches of the sampled wadi.

Quartz, albite, oligoclase, and microcline in the nonmagnetic concentrates form unseparated intergrowths with minerals of greater density; thus, they persist through heavy-liquid separation into the concentrate. Titanite is commonly intergrown with quartz, particularly as cores of grains of quartz.

The presence of magnetite in the nonmagnetic concentrates is attributable to intergrowths of magnetite with other minerals that change the effective magnetic character of the magnetite sufficiently for it to persist through the various separatory operations into the nonmagnetic concentrate. Intergrowths of magnetite, if abundant, could influence the trace-element composition of the concentrate owing to camouflaged elements in the magnetite (Pan and others, 1980, p. 100-102). No such influence, however, appears to be attributable to the minor amounts of magnetite found in these concentrates.

Zoned distribution of minerals in the plutons.--The mineralogical composition of 17 concentrates is insufficient to define the zoned distribution of heavy accessory minerals in the western and eastern plutons of quartz monzonite, nevertheless indications of zoning are apparent from the distribution of niobium- and tin-bearing minerals, fluorite, and the amphiboles. The clearest demonstration is from magnetite. The weight of the magnetite removed from each raw concentrate from the whole Jabal Lababa area was recalculated to weight per 10-kg sample of wadi sand, and the weights were contoured on figure 3. The contours show a pattern that is interpreted to reflect primary igneous zoning in the plutons.

The niobium- and tin-bearing minerals are restricted to eight concentrates that cluster along the northern and northeastern part of the western pluton including one concentrate from the metamorphic rocks in the northern contact zone of the pluton. These are the concentrates shown on figure 3 by the numbers 153869, 153879, 153949, 154039, 154079, 154099, and 154179. They contain one or more of the minerals aeschynite, cassiterite, ilmenorutile, unknown niobate-tantalate, pyrochlore, rutile, staringite, unknown titanoniobate, and unknown yttro-tanta-niobate in sufficient abundance to give strong positive geochemical anomalies for niobium at all localities and for tin at two localities. The small area represented by these concentrates was also the source for all the concentrates containing monazite, xenotime, thorite, and fluorite and most of the concentrates with unusual members of the epidote group and the sodium-calcium-bearing amphiboles. This clear mineralogical zoning defines the geochemically anomalous part of the Jabal Lababa area on figure 2.

The contours showing weights of magnetite in standard samples of alluvium (fig. 3) are interpreted to reflect zoning in the igneous rocks and metamorphic crystallization in the metasedimentary rocks. Most of the zoning of magnetite in the igneous rocks is probably a primary igneous feature, but the area in the northern part of the western pluton yielding small weights of magnetite may represent late-stage magmatic or hydrothermal activity during which magnetite was a sparse primary component or was altered and removed.

A comparison of the contours on figure 3 with the magnetic contours showing total intensity of the earth's magnetic field in gammas, given by Ratte and Andreasen (1974) for the northern part of the area covered by figure 3 shows a similarity in trends of the low-value and the high-value contours in the northern part of Jabal Lababa. The eastward trend of the magnetic contours across the lava field at Jabal Baqarah into the eastern pluton is also reflected by the alignment of contours based on the weights of magnetite (fig. 3). The positions of the depression contours in the eastern pluton on figure 3 are similar to ones shown by Ratte and Andreasen (1974). A great difference, however, exists between the two maps where the contours enter the metasedimentary rocks of the Hali Group of Ratte and Andreasen (1974). The magnetic contours rise in value as they enter the metasediments, whereas the contours based on weights of detrital magnetite drop to exceedingly low values (fig. 3).

The amount of detrital magnetite in the concentrates panned from alluvium does not correlate with the amount of iron reported in the results of the analyses of the rocks. The most iron-rich rocks are the metasediments where 1.5 to 15 percent of iron is present but where the weights of magnetite in the concentrates seldom reach 50g. In the plutons of quartz monzonite, spectrographically determined iron is generally less than 1.5 percent; the weights of magnetite in the concentrates tend to exceed 50g, and in large parts of the plutons the weights of magnetite exceed 200 g. Low weights of magnetite in alluvium from the Hali Group of Ratte and Andreasen (1974) are associated with high contents of iron in the rocks, but with low grades of metamorphism in which either scant magnetite formed or the magnetite that did form was so fine grained it does not accumulate in concentrates panned from alluvium. Large weights of magnetite in concentrates from alluvium derived from the iron-poor quartz monzonite and growth of the grains of magnetite to sizes that accumulate in concentrates.

The depression contours for detrital magnetite in alluvium from wadis in the central part of the eastern pluton (fig. 3), and in the western pluton, are in parts of the plutons where the quartz monzonite is not depleted in iron compared to adjacent areas. The fact that the depression contours for the wieghts of magnetite in the alluvium tend to coincide with the positions of the magnetic contours shown by Ratte and Andreasen (1974) is interpreted to indicate that the depression contours on figure 3 define true magnetite lows in the quartz monazite caused by petrogenetic zoning in the plutons. Iron in the quartz monzonite at the sites of the magnetite lows must be in other iron-bearing minerals that are not part of the magnetite fraction from the raw concentrates.

Distribution of selected elements by sample medium

Values and frequency of determination

The minimum, maximum, and mean values for the 30 elements determined by semiquantitative spectrographic analysis, together with standard deviations, are shown in table 10. Full analytical data for these media at each site shown on figure 2 is stored in the USGS/DMMR RASS (Rock Analysis Storage System) computer system, Jiddah, Saudi Arabia, by DMMR sample numbers 153800-154999 and 156000-156159 as described in the Appendix.

The results of the analyses show strong variation in the abundances of the elements by sample medium, because the media represent different geochemical phases of the geologic environment. Results for the samples of rocks depict chemical conditions of the specimen at the site. These results are not influenced by surficial cover, but they are modified slightly by the degree of weathering of the specimen chosen for analysis. The results obtained for detrital materials -- sieve fractions of wadi sediments and panned concentrates -- reflect mixes of rock units in the source area of each sample plus possible contamination from widespread surficial mantle (fig. 2) and aeolian contributions. The values for the elements in the panned concentrates reflect the compositions of the minor accessory minerals in the source rocks modified by local contamination from the surficial mantle and by the degree of processing of each concentrate.

Elements undetermined in all sample media are arsenic, gold, cadmium, antimony, and zinc (table 10). Absent from most media are silver, bismuth, and tungsten. The frequency of determination of each element by sample medium is shown in table 11, where a modification of the scheme given by

Table 10.--Values for 30 elements determined by semiquantitative spectrographic analyses of six varieties of geochemical sample media from the Jabal Lababa area.

[Values substituted for technically censored data are given in table 1.]

B. JABAL LABABA PLUTON

1. ROCKS

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	0.01	0.01	0.02	0.00	15.00	0.10	50.00	2.00	2.00	5.00
MAXIMUM	15.00	15.00	30.00	1.50	7000.00	0.10	50.00	2.00	3000.00	2000.00
MEAN	1.86	0.86	2.02	0.19	624.81	0.10	50.00	2.00	33.57	345.22
STD.DEV.	2.31	2.14	5.15	0.26	958.79	0.00	0.00	0.00	258.01	382.73

	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	30.00	2.00	5.00	1.00	5.00	1.00
MAXIMUM	7.00	2.00	5.00	70.00	700.00	150.00	50.00	10.00	50.00	300.00
MEAN	1.14	2.00	5.00	3.61	217.99	19.50	12.05	1.40	6.46	11.75
STD.DEV.	1.14	0.00	0.00	8.12	133.50	23.79	7.68	1.50	4.69	30.94

	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	2.00	10.00	2.00	50.00	2.00
MAXIMUM	150.00	20.00	30.00	50.00	700.00	500.00	10.00	700.00	50.00	500.00
MEAN	13.93	20.00	4.83	2.36	101.87	56.43	10.00	25.04	50.00	69.87
STD.DEV.	18.89	0.00	5.24	4.13	128.25	83.99	0.00	66.43	0.00	71.45

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	0.30	0.03	0.10	0.02	100.00	0.10	50.00	2.00	5.00	70.00
MAXIMUM	20.00	5.00	5.00	1.50	3000.00	3.00	50.00	2.00	100.00	1000.00
MEAN	3.27	0.88	1.28	0.38	713.24	0.12	50.00	2.00	13.24	343.31
STD.DEV.	3.33	1.02	1.12	0.35	562.47	0.25	0.00	0.00	13.54	220.18

	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	30.00	2.00	5.00	1.00	5.00	2.00
MAXIMUM	3.00	2.00	5.00	50.00	700.00	150.00	20.00	10.00	100.00	70.00
MEAN	0.71	2.00	5.00	5.73	245.59	34.33	9.67	1.60	7.28	16.52
STD.DEV.	0.58	0.00	0.00	5.80	122.27	35.17	2.20	1.45	8.53	13.89

	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	15.00
MAXIMUM	30.00	20.00	30.00	30.00	700.00	700.00	10.00	70.00	50.00	150.00
MEAN	9.82	20.00	5.75	2.21	91.18	90.74	10.00	16.74	50.00	66.54
STD.DEV.	6.43	0.00	5.28	2.39	121.25	87.20	0.00	10.31	0.00	30.47

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	0.70	0.10	0.20	0.03	150.00	0.10	50.00	2.00	5.00	70.00
MAXIMUM	30.00	5.00	7.00	1.50	7000.00	0.10	50.00	2.00	100.00	700.00
MEAN	6.71	1.07	1.72	0.85	1372.43	0.10	50.00	2.00	12.57	262.06
STD.DEV.	5.52	1.00	1.14	0.48	1185.91	0.00	0.00	0.00	13.16	172.08

	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	5.00	2.00	5.00	70.00	1000.00	150.00	200.00	10.00	70.00	100.00
MEAN	0.74	2.00	5.00	9.68	274.71	39.96	18.97	1.63	8.57	22.76
STD.DEV.	0.80	0.00	0.00	9.83	156.22	37.16	27.02	1.63	6.56	18.38

	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	15.00	10.00	5.00	50.00	20.00
MAXIMUM	70.00	20.00	30.00	20.00	1000.00	1000.00	10.00	150.00	50.00	700.00
MEAN	9.80	20.00	9.37	2.13	106.69	225.66	10.00	33.42	50.00	102.50
STD.DEV.	9.26	0.00	6.23	1.54	130.65	207.79	0.00	26.12	0.00	69.97

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	1.50	0.30	0.70	0.20	100.00	0.10	50.00	2.00	5.00	50.00
MAXIMUM	30.00	5.00	7.00	1.50	7000.00	0.10	50.00	2.00	150.00	700.00
MEAN	7.99	1.73	2.61	1.09	1607.35	0.10	50.00	2.00	18.09	224.26
STD.DEV.	4.86	0.95	1.21	0.41	1098.57	0.00	0.00	0.00	16.67	116.06

	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	100.00	10.00	5.00	1.00	5.00	10.00
MAXIMUM	3.00	2.00	5.00	30.00	1000.00	150.00	300.00	10.00	150.00	70.00
MEAN	0.67	2.00	5.00	12.26	352.94	50.33	55.92	1.85	15.74	35.07
STD.DEV.	0.74	0.00	0.00	5.35	211.24	35.77	71.06	1.91	23.39	18.13

	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	70.00	10.00	10.00	50.00	50.00
MAXIMUM	70.00	20.00	30.00	50.00	700.00	1500.00	10.00	1000.00	50.00	1500.00
MEAN	12.21	20.00	13.88	3.37	117.50	291.99	10.00	82.79	50.00	223.01
STD.DEV.	10.77	0.00	6.01	6.37	100.84	203.86	0.00	102.87	0.00	227.44

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	0.01	0.07	0.50	300.00	0.10	50.00	2.00	2.00	5.00
MAXIMUM	30.00	5.00	7.00	1.50	7000.00	0.10	50.00	2.00	100.00	7000.00
MEAN	21.13	0.97	1.84	1.41	3539.71	0.10	50.00	2.00	10.93	115.99
STD.DEV.	7.83	0.76	1.51	0.22	2018.38	0.00	0.00	0.00	16.66	596.96

	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	20.00	2.00	5.00	1.00	5.00	2.00
MAXIMUM	3.00	15.00	5.00	300.00	1500.00	200.00	700.00	30.00	1500.00	200.00
MEAN	0.33	2.49	5.00	27.14	525.07	38.32	126.29	1.40	66.65	31.29
STD.DEV.	0.50	1.57	0.00	32.77	282.55	38.22	170.30	2.70	189.99	25.50

	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	50.00	10.00	10.00	50.00	15.00
MAXIMUM	150.00	20.00	50.00	500.00	700.00	2000.00	10.00	3000.00	50.00	1500.00
MEAN	14.03	20.00	21.02	23.99	40.37	599.41	10.00	265.18	50.00	276.40
STD.DEV.	25.20	0.00	10.39	63.32	88.48	396.06	0.00	492.19	0.00	363.94

6. NONMAGNETIC CONCENTRATES

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	10.00	0.07	0.20	1.00	700.00	0.10	50.00	2.00	2.00	5.00
MAXIMUM	30.00	7.00	10.00	1.50	7000.00	0.10	50.00	2.00	150.00	7000.00
MEAN	24.27	1.20	3.23	1.50	4997.71	0.10	50.00	2.00	8.35	109.35
STD.DEV.	6.97	0.99	2.40	0.04	2079.51	0.00	0.00	0.00	15.39	633.72

	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	50.00	2.00	5.00	1.00	10.00	5.00
MAXIMUM	0.20	15.00	5.00	300.00	1500.00	500.00	1500.00	50.00	3000.00	300.00
MEAN	0.20	2.10	5.00	30.88	451.53	74.99	202.82	1.37	159.77	25.76
STD.DEV.	0.00	1.13	0.00	38.03	241.37	64.39	281.77	4.26	518.57	29.72

	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	20.00	50.00	30.00
MAXIMUM	700.00	20.00	150.00	1000.00	500.00	1500.00	200.00	3000.00	50.00	1500.00
MEAN	25.19	20.00	44.92	41.11	26.87	564.50	12.14	496.11	50.00	371.22
STD.DEV.	82.21	0.00	30.51	137.47	46.30	319.62	18.24	737.74	0.00	380.65

Table 11.--Classification of the elements on the basis of the percentage of samples in each medium containing the element, Jabal Lababa area.

Classification of element	Percent of samples	Elements in each class by sample medium					
		Rock	Wadi sediment			Concentrate	
			<10 + 32 mesh fraction	<32 + 80 - mesh fraction	<80 - mesh fraction	Raw	Nonmagnetic
Characteristic	90 - 100	Fe, Mg, Ca, Ti, Mn, Cr, Cu	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, Ni, V, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, Ni, 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, Sc, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Co, Cr, Cu, Ni, Sc, V, Y, Zr
Abundant	50 - 89	Ba, Ni, Pb, V, Y, Zr	Co, Pb, Sc, Y	Co, Sc, Sr	B, La, Pb Sr	Ba, La, Sn	La, Sn
Common	10 - 49	B, Be, Co, La, Sc, Sr	B, Be, Sr	B, Be, La, Pb	Be, Mo, Nb	B, Nb, Pb, Sr	B, Ba, Nb, Pb
Scarce	2 - 9	Mo, Nb	La, Mo	Mo, Nb	Sn	Be, Mo	Sr
Rare	<2	Sn	Ag, Nb, Sn	Sn	None	Bi	Bi, Mo, W
Undetermined[1]	0	Ag, As, Au, Bi, Cd, Sb, W, Zn	As, Au, Bi, Cd, Sb, W, Zn	Ag, As, Au, Bi, Cd, Sb, W, Zn	Ag, As, Au Bi, Cd, Sb, W, Zn	Ag, As, Au, Cd, Sb, W, Zn	Ag, As, Au, Be, Cd, Sb, Zn

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

Lovering (1972, p. 55) is used to classify the elements on a basis of the percentage of samples in each medium containing the element.

The number of elements in the "Undetermined" and "Rare" categories of table 11, about one-third of those sought, reflects both the composition of the sample medium and the lower limits of determination available in the analytical method (table 1). Many of these lower limits are higher, commonly much higher, than the average abundance of the respective elements in granitic rocks and schists of the earth's crust (Beus and Grigorian, 1977, table 3). In order to be observed, the elements in silver, arsenic, gold, bismuth, cadmium, molybdenum, niobium, antimony, tin, tungsten, and zinc must be present in the media in greater than average crustal abundance. Sieving and panning enhances the concentrations of niobium and tin until they rise in frequency of determination to the categories of "Common" or "Abundant" elements, but for arsenic, gold, cadmium, antimony, and zinc, no preconcentration procedures used in this investigation raised their abundances to detectable values. In one sample of the many taken, silver was reported as 3 ppm, bringing the element from the "Undetermined" to the "Rare" category (table 11), but no geologic reason was found for the rise, nor is any geochemical significance attached thereto. For practical purposes in the Jabal Lababa area silver can be regarded as an "Undetermined" element.

The shifting position of some elements, particularly beryllium, lanthanum, molybdenum, niobium, tin, tungsten, yttrium, and zirconium, sought by this geochemical reconnaissance, from one category in table 11 to another as the sample media vary is significant in terms of the probable mineralogical residences of particular elements as well as in terms of the most satisfactory sample medium for a particular element. For example, tin rises in the classification from "Rare" for rock samples to "Abundant" for nonmagnetic concentrates, whereas beryllium descends from "Common" in rocks and wadi sediment to "Undetermined" in the nonmagnetic concentrates. The influence of sample medium on frequency of determination can be shown by the percentage of samples in each medium that yielded measurable amounts of the elements (table 12).

When the ranges in concentration of the elements shown in table 10 are compared by sample medium it is also seen that the highest mean values are associated with a particular medium: boron, barium, and beryllium, with samples of rocks; molybdenum, nickel, and strontium with samples of the <80-mesh fraction of wadi sediment; titanium, chromium, and vanadium with the raw concentrates; and iron, magnesium, calcium, manganese, cobalt, copper, lanthanum, niobium, lead, scandium, tin, yttrium, and zirconium with the nonmagnetic concentrates. Comparison of the highest mean values with frequencies of determination for the elements shows complex

Table 12.--Frequency of determination of elements by sample medium (in weight percent)

Element	Rock	<80-mesh sediment	Raw concentrate	Nonmagnetic concentrate
Fe	95	100	100	100
Mg	94	100	100	100
Ca	97	100	100	100
Ti	95	100	100	100
Mn	100	100	100	100
B	35	70	21	13
Ba	88	100	79	48
Be	41	36	4	0
Co	17	99	97	100
Cr	100	100	100	100
Cu	95	100	97	98
La	20	62	65	71
Mo	6	10	4	0.7
Nb	3	25	47	44
Ni	59	100	92	100
Pb	57	69	36	21
Sc	39	97	94	96
Sn	0.6	6	67	66
Sr	43	72	16	4
V	72	100	100	100
W	0	0	0	1
Y	66	100	100	100
Zr	80	100	100	100

relations among the elements and the media. The frequency of determination of some elements decreases toward the nonmagnetic concentrate (table 11) and the mean value decreases in concert (table 10). Beryllium is an example. From these relations the source mineral for beryllium appears to decrease through the media. Where maximum values (table 10) and category by medium (table 11) are compared, some elements, such as barium and lead, can decrease in frequency of determination toward the concentrates but reach their greatest abundances therein, whereas other elements, for example, lanthanum, niobium, tin, and vanadium, increase in both frequency of determination and maximum reported value toward the concentrates.

The cause of these seemingly opposite courses is to be found in the residences of the elements. Where the element is camouflaged in common rock-forming minerals of low density and is present also in sparse accessory minerals of high density, the samples of rocks and wadi sediment favor frequent determination at low concentrations, and the concentrates provide less frequent determination with high concentrations. In the examples of barium and lead, plagioclase, potassium feldspar, muscovite, biotite, barite, and apatite contain these elements (Rankama and Sahama, 1950, p. 471-473, 733). The common rock-forming minerals feldspar and mica afford frequent determinations of low concentrations of barium and lead among the samples of rocks and wadi sediment, and the barite and apatite provide infrequent determinations but large values in the concentrates. The elements lanthanum, niobium, tin, and vanadium are less commonly present in rock-forming minerals than in accessory minerals of high density. Both frequency of determination and maximum values, therefore, increase as the sample medium is depleted in common rock-forming minerals. Concentrates are the source of both the most frequent determinations and the greatest maximum values for these elements.

Some elements also shift in category from one frequency of determination to another as the lithology of the source rocks for the sample medium changes. The shift is readily identified in the results of the analyses of the rocks and the nonmagnetc concentrates (table 13). Frequencies of determination for the elements in the samples of wadi sediment closely follow the two extremes of media shown in table 13: the <10 +32-mesh and <32 +80-mesh fractions resemble the samples of rock, and the <80-mesh fraction resembles the concentrates. The categories of frequency of determination do not change for iron, calcium, titanium, manganese, silver, arsenic, gold, cadmium, chromium, copper, antimony, and zinc on the basis of either rock type or sample medium. None of the elements rises in category of determination on the basis of rock type alone, but a strongly defined rise by type of rock and medium is seen for tungsten, and by medium regardless of rock type for copper, lanthanum, niobium, nickel, scandium, tin, vanadium, yttrium, and zirconium. Declines in frequency of determination relatable to a combination of rock type and medium are noted for magnesium, boron, bismuth, and lead, and relatable to medium for barium, beryllium, molybdenum, and strontium.

For the elements sought in this geochemical reconnaissance -- beryllium, lanthanum, molybdenum, niobium, tin, tungsten, yttrium, and zirconium -- the data in tables 10 and 11 show that samples of rocks or sized wadi sediments are most likely to disclose beryllium and molybdenum, whereas the fine-grained fractions of wadi sediment and the concentrates are better indicators of lanthanum, niobium, tin, tungsten, yttrium, and zirconium than the other media. Thus, several media are required for the geochemical reconnaissance of the Jabal Lababa area.

Table 13.--Contrast in frequency of determination of elements between igneous and metamorphic rocks by extremes of sample media used for analysis, Jabal Lababa area.

Classification of element	Percent of samples	Rocks from table 4	Elements in each class by rock type and sample medium			
			Rocks		Nonmagnetic concentrates	
			Igneous	Metamorphic	Igneous rocks	Metamorphic rocks
Characteristic	90 - 100	Fe, Mg, Ca, Ti, Mn, Cr, Cu	Fe, Ca, Ti, Mn, Cr, Cu	Fe, Mg, Ca, Ti, Mn, Cr, Cu, V, Zr	Fe, Mg, Ca, Ti, Mn, Co, Cr, Cu, La, Ni, Sc, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Co, Cr, Cu, Ni, Sc, V, Y, Zr
Abundant	50 - 89	Ba, Ni, Pb, V, Y, Zr	Mg, Ba, Be, Ni, Pb, V, Y, Zr	Ba, Ni, Sc, Sr, Y	Nb, Sn	La, Sn
Common	10 - 49	B, Be, Co, La, Sc, Sr	B, Co, La, Sc, Sr	B, Be, Co, La, Mo, Pb	Ba, Pb	B, Ba, Nb, Pb
Scarce	2 - 9	Mo, Nb	Mo, Nb	None	Sr	Sr, W
Rare	< 2	Sn	Sn	None	B, Mo	Bi
Undetermined[1]	0	Ag, As, Au, Bi, Cd, Sb, W, Zn	Ag, As, Au, Bi, Cd, Sb, W, Zn	Ag, As, Au Bi, Cd, Nb Sb, Sn, W, Zn	Ag, As, Au, Be, Bi, Cd, Sb, W, Zn	Ag, As, Au, Be, Cd, Mo, Sb, Zn

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

Positive anomalous values

Positive anomalous values for the 30 elements in the six geochemical sample media from the Jabal Lababa area were determined on the basis of the mean plus 2 standard deviations (table 14) from the data given in table 10.

In determining the most suitable sample medium, however, factors in addition to the calculated anomalous value also apply. These include for each medium the spread in reported values for each element (shown by the standard deviations in table 10), the maximum reported values (table 10), and the frequency with which each element was determined (table 11) particularly at its highest values. Comparison of these data from table 10, 11, and 14 for beryllium, lanthanum, molybdenum, niobium, tin, tungsten, yttrium, and zirconium shows that rocks are the preferred sample medium for beryllium and the nonmagnetic concentrates for the other elements among the sought group. The <80-mesh fraction would be suitable as a sample medium, except for molybdenum, but the <10+32-mesh fraction would be the least useful medium. The following discussions of the distributions of the wanted elements will consider only the values in rocks, in the <80-mesh fraction of wadi sediments, and in the nonmagnetic concentrates.

Background and anomalous values in rocks

Of the 30 elements for which background and threshold values are given in tables 10 and 14, the significant values for this investigation are the eight wanted elements beryllium, lanthanum, molybdenum, niobium, tin, tungsten, yttrium, and zirconium. The other detected elements are not unusually enriched in the rocks with the local exception of boron in two samples of tourmaline-bearing pegmatite where abundances as great as 3,000 ppm were observed (table 10). Boron and other detected elements that might be sought for their industrial applications, such as barium, cobalt, chromium, copper, manganese, nickel, lead, strontium, titanium, and vanadium, have mean values (table 10) comparable to their respective average abundances in granite and schist of the Earth's crust (Beus and Grigorian, 1977, table 3), and even the threshold anomalous values for barium, manganese, lead, titanium, and vanadium (table 14) are only about twice crustal abundance. Threshold anomalous values for boron and chromium reach five times crustal abundance, but these values reflect lithologic units lacking economic potential for these elements. Even where maximum values for barium, cobalt, chromium, copper, manganese, nickel, lead, strontium, titanium, and vanadium (table 10) are reached, the samples reflect lithologic variants with no indication of economic application. Boron and lead may have a role as pathfinder elements for niobium, but titanium, which could be expected to share this role because the element is present in the niobium-bearing minerals at

Table 14.--Threshold anomalous values for 30 elements in six types of geochemical sample media, Jabal Lababa area.

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

B. JABAL LABABA 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	6.48	5.13	12.32	0.72	2542.40	0.10	50.00	2.00	549.58	1110.69

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	3.42	2.00	5.00	19.86	484.98	67.08	27.42	4.41	15.83	73.64

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	51.71	20.00	15.31	10.62	358.37	224.40	10.00	157.90	50.00	212.77

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	9.93	2.92	3.52	1.08	1838.17	0.62	50.00	2.00	40.31	703.67

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	1.87	2.00	5.00	17.33	490.13	104.68	14.08	4.49	24.34	44.29

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	22.68	20.00	16.32	6.99	333.68	265.14	10.00	37.36	50.00	127.47

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	17.75	3.06	4.00	1.82	3744.26	0.10	50.00	2.00	38.89	606.21

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	2.34	2.00	5.00	29.33	587.15	114.27	73.01	4.89	21.68	59.53

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	28.32	20.00	21.83	5.21	368.00	641.25	10.00	85.66	50.00	242.43

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	17.71	3.63	5.03	1.91	3804.50	0.10	50.00	2.00	51.43	456.39

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	2.16	2.00	5.00	22.96	775.43	121.87	198.03	5.60	62.52	71.33

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	33.75	20.00	25.90	16.11	319.18	699.70	10.00	208.53	50.00	677.89

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	36.79	2.49	4.07	1.86	7576.48	0.10	50.00	2.00	44.25	1309.91

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	1.32	5.63	5.00	92.67	1090.18	114.76	466.88	6.79	446.64	82.29

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	64.44	20.00	41.80	150.62	217.33	1391.53	10.00	1249.56	50.00	1004.28

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	38.21	3.19	8.04	1.58	9156.72	0.10	50.00	2.00	39.13	1376.79

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	0.20	4.36	5.00	106.94	934.26	203.77	766.36	9.90	1196.91	85.19

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	189.61	20.00	105.93	316.05	119.47	1203.74	48.62	1971.58	50.00	1132.53

Jabal Lababa, cannot be used in this function because of the large number of samples in which the value for titanium is truncated at the upper limit of determination.

Lack of base- and precious-metal deposits in the area, indicated by the absence of silver, arsenic, gold, bismuth, cadmium, antimony, and zinc from the samples of rocks, is supported by the low values for cobalt, copper, nickel, and lead (table 10). The abundance of barium reaches as much as 2,000 ppm at several places, but corollary geochemical data, discussed in the section on concentrates, indicates that the possibility for barite deposits is low.

The major elements in table 10 and many of the minor elements are indicators of the effects of secular weathering on the rocks.

Significant positive anomalies.--The threshold anomalous values for the wanted elements in samples of rock, as derived from table 14, are in table 15.

Table 15.--Threshold anomalous values for eight elements in rock samples from the Jabal Lababa area

Element	Threshold anomalous value (ppm)	Element	Threshold anomalous value (ppm)
Be	3	Sn	10
La	30	W	Not detected
Mo	5	Y	150
Nb	20	Zr	200

The distribution of these elements in samples of rocks from the Jabal Lababa area is shown on figure 4 where all values at or greater than the respective lower limits of determination are indicated. Threshold anomalous values for molbydenum, niobium, and tin are also their respective lower limits of determination.

Tin is a rarely detected element, and molybdenum and niobium are scarce elements (table 4) in the rocks. Tin was found in only one sample of rock, an interior feldspathic quartz vein in the west-central part of the western plutons of quartz onzonite (figs. 2 and 4). The vein contains 50 ppm tin and also has low anomalous values for beryllium, 3 ppm;

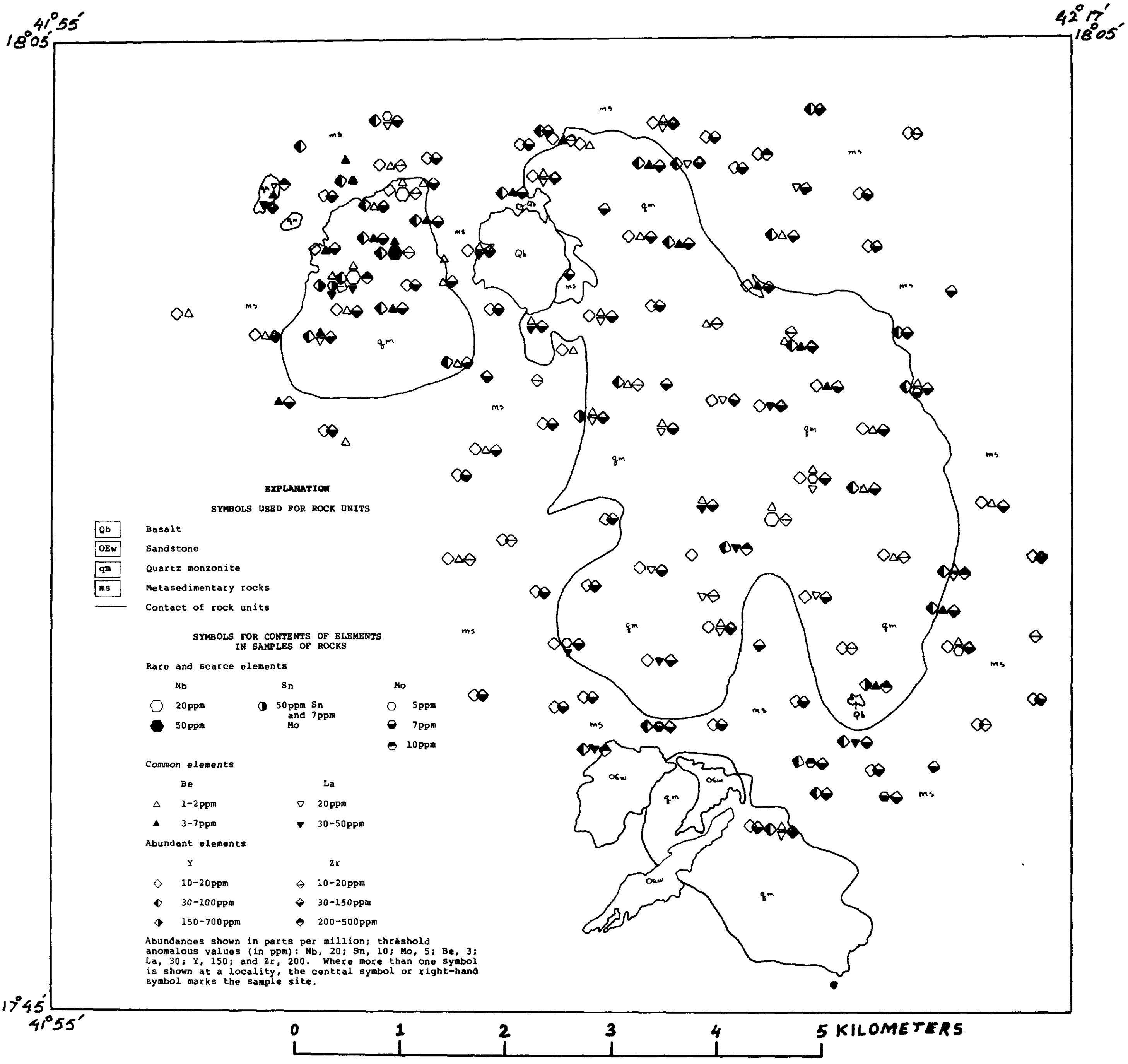


Figure 4.—Map of the Jabal Lababa area showing the distributions of values of niobium, tin, molybdenum, beryllium, lanthanum, yttrium, and zirconium that are equal to or greater than the lower limits of determination in rocks.

lanthanum, 30 ppm, and molybdenum, 7 ppm. Yttrium attains the high anomalous value of 700 ppm, but neither niobium nor zirconium reach threshold anomalous values. Manganese is unusually abundant at G(5,000) ppm. Concentrates from the locality are quite rich in lanthanum, niobium, tin, yttrium, and zirconium. The fact that tin was detected only in the specimen of interior feldspathic quartz vein where the quantity of niobium was found to be L(20) ppm, but that niobium was detected for pegmatite and for quartz monzonite suggests that the main crystallization of the tin may have been later than that of the niobium.

Although molybdenum is a scarce element in the rocks, it was detected more frequently than tin or niobium, and it is the only rare or scarce element to have been observed in determinable amounts in the metasedimentary rocks (table 13; fig. 4). However, all values for molybdenum are at the lower limit of determination for the element (5 ppm) or within two laboratory reporting intervals of that value (7-10 ppm). Thus, spectrographic confidence in the reality of these differences is not high despite the fact that they represent enrichment over crustal abundance by factors of 2 to 6. Most of the molybdenum-bearing samples of the metasediments are from the area between the eastern and southern plutons of quartz monzonite (figs. 2 and 4), but the localities are scattered. Inasmuch as the <80-mesh fraction of wadi sediment has the largest percentage of determinations for molybdenum, a discussion of the geochemical relations of the element is left for a following section of text. No indication of economic potential for molybdenum was seen.

Niobium, an element sought both for its intrinsic value and as a possible pathfinder element for tantalum-bearing minerals, is measurably present in only four samples of rock (fig. 4). Three are of quartz monzonite from the western pluton (niobium, 20 ppm in two, 50 ppm in one), and one is from an interior pegmatite dike in the eastern pluton (niobium, 20 ppm). Analytical data for the three niobium-bearing samples of rock from the western pluton show only slight increases in the abundances of yttrium and zirconium over the sample from the eastern pluton, but nonmagnetic concentrates from the same sites reveal large differences in these elements between the two plutons (table 16).

Beryllium and lanthanum are common elements in the rocks of the Jabal Lababa area (table 11), but lanthanum rises in frequency of determination to abundant in the felsic plutons (table 13). Beryllium is less common in the metasedimentary rocks than in the plutons. Even in the igenous rocks, however, the abundance of beryllium seldom exceeds twice the world average for granitic rocks of 3 ppm (Beus and Grigorian, 1977, table 3). Preferred hosts of beryllium are pegmatite dikes and the western and eastern plutons of quartz monzonite, with a distinct tendency for the higher values to

Table 16.--Analysis of pegmatite and quartz monzonite rock samples and nonmagnetic concentrates from the eastern and western plutons, Jabal Lababa area.

Element	Abundances in ppm							
	Eastern pluton		Western pluton					
			Core				Flanks	
	Interior pegmatite	Nonmagnetic concentrate	Quartz Monzonite	Nonmagnetic concentrate	Quartz monzonite	Nonmagnetic concentrate	Quartz monzonite	Nonmagnetic concentrate
Nb	20	50	20	30	50	G2,000	20	G2,000
La	N(20)	300	50	30	N(20)	G1,000	N(20)	G1,000
Sn	N(10)	15	N(10)	N(10)	N(10)	50	N(10)	100
Y	L(10)	150	30	50	30	G2,000	20	G2,000
Zr	10	100	300	150	15	G1,000	20	G1,000

be on the flanks of the plutons (fig. 4). High values for beryllium and niobium occur together in samples of pegmatite and quartz monzonite from the western pluton, but beryllium is more widespread than niobium elsewhere in the area. When the distribution of beryllium in the samples of rocks and <80-mesh wadi sediment is compared with the distribution of niobium in concentrates, the presence of beryllium is seen to serve as an indicator of niobium and confirms that the western pluton is the chief source for niobium.

The greatest amount of lanthanum, 50 ppm, is in quartz monzonite from the core of the western pluton (fig. 4) where it is associated with measurable but not generally anomalous values for beryllium, niobium, yttrium, and zirconium. Contents of 20 to 30 ppm lanthanum were observed in three samples of quartz monzonite from the flanks of the western pluton, but niobium, tin, and yttrium are low or absent. An interior feldspathic quartz vein in the western pluton also contains a little lanthanum, as does a sample of quartz monzonite from the southern pluton, but most of the lanthanum-bearing samples are from the eastern pluton and pegmatite dikes associated with it. The sparsity of lanthanum, niobium, tin, yttrium, and zirconium in the rocks fully demonstrates the need for anomaly enhancement techniques to bring out the relations of these elements.

Four of the six samples of metasedimentary rocks in which lanthanum was observed (fig. 4) are quartzite. Although the values are at the lower limit of determination, they are quite close to the world average of 30 ppm lanthanum for sandstone (Beus and Grigorian, 1977, table 3). Possibly the preferred association of lanthanum with quartzite among the metamorphic rocks is related to the presence of small amounts of detrital heavy minerals containing lanthanum. Bedded deposits of heavy minerals are absent from the quartzite; thus, fossil placers containing lanthanum-bearing minerals are not indicated. Further evidence that these beds of quartzite do not have unusual concentrations of heavy minerals is given by low values for yttrium, zirconium, and radioactivity.

Yttrium and zirconium are abundant elements in the rocks of the Jabal Lababa area (table 11). The tendency for yttrium to become enriched in the residual fluids of magmatic crystallization (Rankama and Sahama, 1950, p. 518) is demonstrated by its greater abundance in pegmatite and interior quartz veins (100 ppm and 50 ppm yttrium) than in the quartz monzonite, granite, and aplite (15 and 20 ppm yttrium). The absence of determinable yttrium in the exterior quartz veins is evidence that they tend to be products of metamorphic differentiation instead of hydrothermal products genetically connected with the quartz monzonite.

Although yttrium is commonly present in the niobium-bearing minerals identified in the Jabal Lababa area, the element cannot be said to have a pathfinder role where rocks are the sample medium. Samples of rocks with anomalous amounts of yttrium lack niobium and in samples of rocks with anomalous amounts of niobium, the yttrium content is commonly background values. Constraints on the use of yttrium as a pathfinder for niobium where rocks are the sample medium include the sparsity of the two elements in rocks and the poor areal representation of rock samples. Both problems are eliminated by the adoption of concentrates for the sample medium.

Two of the three positive anomalies for yttrium in samples of rock are from the eastern pluton, and one is from the western pluton (fig. 4). None contains anomalous amounts of niobium. At the sample sites in the eastern pluton, concentrates also contain anomalous amounts of niobium. In the western pluton, concentrates from the site of the rock sample containing anomalous amounts of yttrium have positive anomalies for both yttrium and niobium. Positive anomalies for yttrium in the rocks, and some positive anomalies for the element in concentrates, contain little or no niobium. In those samples the source of the yttrium is probably feldspar in the rocks and garnet, xenotime, monazite, or epidote in the concentrates; these minerals contain scant niobium. This relation is supported by many anomalies for lanthanum in concentrates from the eastern pluton which lack or which contain scant niobium. Lanthanum is typically present in garnet, monazite, or epidote.

Although zirconium is classed as an abundant element (table 11), a strong dichotomy exists between its frequency of detection in the plutons and in the metasedimentary rocks (table 13). The mean zirconium content of the rocks in the Jabal Lababa area (table 11), 70 ppm, is clearly less than world averages for similar rocks (Beus and Grigorian, 1977, table 3). Zirconium is more commonly lacking or present in lower abundances in the pegmatite and quartz veins than it is in the quartz monzonite. These relations follow the geochemical characteristics of calc-alkaline rocks where the concentrations of zirconium are low in the pegmatitic and later stages of crystallization (Rankama and Sahama, 1950, p. 566; Klemic and others, 1973, p. 717-718). Some of the interior quartz veins contain zirconium. Most of the exterior veins lack zirconium, but they probably are not genetically connected to the quartz monzonite.

Zirconium is not strongly associated with the other wanted elements in the samples of rocks (fig. 4). It is, however, weakly associated with yttrium and barium in the felsic rocks and with titanium in the metasediments. Lack of association of zirconium with other elements except titanium in the metasediments is interpreted to indicate that the main source of zirconium in the metamorphosed sedimentary rocks is detrital zircon.

The use of zirconium as a pathfinder element for niobium in rock samples from this area is not feasible owing to the low concentrations of both elements in these rocks. A pathfinder role is acceptable in the concentrates because zirconium is enhanced therein; nevertheless, the low upper limt of determination (1,000 ppm, table 1) serves as a constraint.

The results of analyses of the rocks in the Jabal Lababa area do not show strong positive anomalies for any element. Weak positive anomalies for niobium, supported by weak positive anomalies for one or more of the pathfinder elements beryllium, tin, and yttrium were identified in the western pluton (fig. 4). The values obtained for niobium are close both to its lower limit of spectrographic determination and to its average crustal abundance in granitic rocks. Were it not for strong positive anomalies for these elements in other sample media from the same localities, the values of beryllium, niobium, tin, and yttrium determined in the rocks would be regarded as part of the normal variation in geochemical background. The weak positive anomalies in the rocks identify the western pluton as the part of the Jabal Lababa area most favorable for niobium, but more important, the low values in the rocks put a restraint on interpretations to be drawn from the high values for niobium, tin, and yttrium in the concentrates. The final appraisal of the niobium, both in its own right and as a pathfinder for tantalum, will require further analyses of rocks from the niobium-bearing parts of the western pluton and evaluation of the possible sedimentary concentration of heavy minerals in and around the pluton. Lode deposits for beryllium, niobium, tin, tantalum, and yttrium are unlikely, and placer deposits may be too small and too low in grade to be minable. Therefore, further exploration in the Jabal Lababa area for these elements should not be undertaken unless it is done as part of other investigations such as a regional survey of placer deposits.

Chemical data from the analyses of the rocks are interpreted to show that deposits of base and precious metals, as well as other elements of possible economic interest, are absent.

Evaluation of rocks as a geochemical sample medium.--Rocks were less effective than the samples of alluvial sediments and concentrates in defining positive anomalies for the wanted elements in the reconnaissance survey. More samples of rocks were needed than of the other media to define the anomalous area. The geochemical data from wadi sediments or from concentrates provide a more reliable base for a reconnaissance of the mineral potential of the felsic plutonic rocks of the Jabal Lababa area, because the areal representation of the individual rock sample is too small. Future reconnaissance surveys could be conducted with alluvial sediments and concentrates supplemented by rock specimens from about 10 percent of the sample localities taken to establish geochemical background of lithologic units.

Chemical variation related to weathering.--Where rocks are affected by chemical weathering, elemental constituents are removed in solution in surface or ground water or accumulate in the less soluble products (Carroll, 1970, p. 91-93). The chemical characteristics of the elements determine their degree of mobilization or fixation, but in arid regions the soluble elements are not completely removed from the component minerals of the rocks. Chemical characteristics affecting behavior during weathering were diagrammed for a number of catios by Gordon and others (1958, fig. 32). With modification, that diagram is given here as figure 5 in which the two lines radiating from the origin represent constant values for ionic potential (Z/r). Elements (cations) to the left of the line Z/r=3 have low ionic potential. Many form basic oxides. During weathering these cations remain in ionic solution and tend to be removed. Cations between the lines representing ionic potentials of 3 to 12 tend to precipitate by hydrolysis and to collect in the residual products of weathering. Cations with greater ionic potential than 12 form soluble complex anions with oxygen, remain in solution, and tend to be removed from the rock by weathering processes.

If the degrees of weathering observed for the rocks in the Jabal Lababa area (Appendix) caused observable migration of the elements, then the abundances of boron, barium, lead, strontium, calcium, manganese (+2), copper, iron (+2), cobalt (+2), and magnesium in the most weathered rocks might be depleted (fig. 5) compared to their abundances in lithologically similar but unweathered rocks. Abundances of beryllium, yttrium, scandium, iron (+3), cobalt (+3), chromium, zirconium, tin, molybdenum, titanium, manganese (+4), niobium, and vanadium might be enhanced in the weathered rocks. A test of the chemical variations of the rocks related to degree of weathering was made for the 19 common, abundant, and characteristic elements (table 11) by averaging the values for each element by the degree of weathering attributed to each sample (Appendix) by lithologic unit. Weaknesses in the test include (1) samples with different degrees of weathering in the same lithologic unit were generally not from the same outcrop; (2) few truly unweathered samples, particularly among the metasediments, were analyzed; and (3) narrow spans in spectrographic reporting intervals for the average abundances of the elements between degrees of weathering. Nevertheless, the comparison showed that the common, abundant, and characteristic elements respond more readily to processes of concentration than to processes favoring removal during weathering in the arid environment (table 17).

Elements in the igneous rocks and veins follow the predicted courses more closely than elements in the metasedimentary rocks, because the samples of the igneous rocks and veins are more homogeneous than the metasediments.

Departure of chemical responses from the predicted course is typical of weathering under arid conditions where the lack of surface accumulation of decaying vegetal debris results in moderate pH for water migrating downward in the rocks. Solution of rock materials is therefore slower and less complete than that achieved in humid regions where humus lowers pH of surface water.

Iron and manganese concentrate at their higher valence states in the products of weathering (table 17). Movement of manganese 2+ silicate minerals in the unweathered rocks to manganese 4+ in oxide minerals in the weathering products is particularly evident. The data for cobalt are indeterminant. Under most geologic conditions chromium is found in the chromium 3+ state, but under exceptional conditions of high redox potential it can be oxidized to chromium 6+ and be mobilized s the chromate (Rankama and Sahama, 1950, p. 623; fig. 5), which would be removed from the weathering products. Although the data in table 17 shows removal of chromium from veins, quartz monzonite, and marble, the formation of chromate seems unlikely, and the data must be regarded as inadequate.

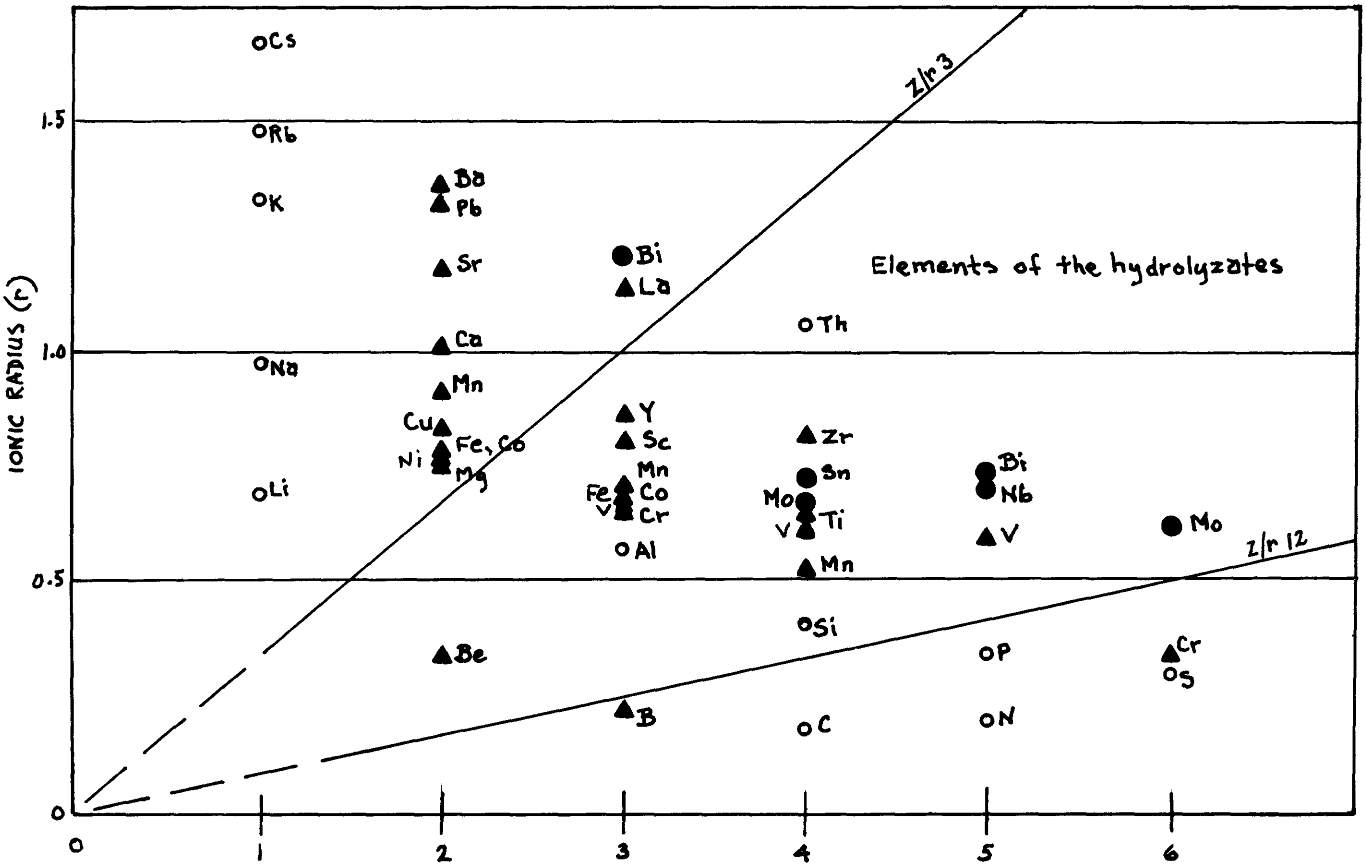
Magnesium, calcium, and barium display strong inverse trends (table 17). In marble the high values for magnesium and calcium are truncated by the upper limits of determination which prevents estimation of loss or gain. Censored values are not a factor for the other rocks, where the removal of magnesium and calcuium during weathering is imperfect, and the elements are enriched in the weathering products, possibly as secondary carbonates. Barium is absent from the marble, but in the other metasediments and

Table 17.--Response of common, abundant, and characteristic elements in the rocks to processes of weathering in the Jabal Lababa area.

[Direction of response based on predictions from figure 5: P, direction predicted; I, inverse to direction predicted; 0, indeterminant.]

Element and valence	Lithologic units						
	Quartz veins	Pegmatite	Aplite and Granite	Quartz monzonite	Granite gneiss	Metasediments	Marble
Ionic potential favoring removal from rock							
Valence 2+							
Fe	P	I*	0	0	I*	P	I*
Mg	0	I*	I*	I*	I*	P	I
Ca	0	I*	P	0	I*	I*	0
Mn	I	I	0	I	I	I*	I
Ba	I	I	P*	I	P*	I*	0
Co	0	0	0	0	0	P*	0
Cu	0	I	P	0	I	P*	I*
Ni	P	0	0	I	I	P*	P
Pb	0	P*	P	0	P	0	I
Sr	0	0	0	I	P*	I	P*
Valence 3+							
B	0	I*	I	0	I	P*	0
La	0	0	0	0	0	0	0
Valence 6+							
Cr	P	I	0	P	I*	0	P*
Ionic potential favoring concentration in products of weathering							
Valence 2+							
Be	0	P*	P	P	0	0	0
Valence 3+							
Co	0	0	0	0	0	I*	0
Cr	I	P	0	I	P*	0	I*
Fe	I	P*	0	0	P*	I	P*
Sc	0	0	0	0	P	I	0
Y	0	P*	P	0	P	0	0
Valence 4+							
Zr	0	P	P	P	P	0	I
Ti	P*	P*	0	P	P*	I*	I
V	I	P*	P	P	P*	I	0
Mn	P	P	0	P	P	P*	P
Valence 5+							
V	I	P*	P	P	P*	I	0

* Strong trend as shown by greater differences in concentrations of elements between unweathered and weathered rocks.



EXPLANATION

▲ Elements compared in table 17 for the Jabal Lababa area, Kingdom of Saudi Arabia

● Rare and scarce elements in the Jabal Lababa area, Kingdom of Saudi Arabia

○ Undetermined elements shown for comparison

Figure 5.--Diagram showing the grouping of selected elements according to their ionic radii and ionic charges, and the influence of these factors on the behavior of these elements in the zone of weathering, Jabal Lababa area, (modified from Gordon, Tracey, and Ellis, 1958, fig. 32).

in most of the igneous rocks, barium displays an inverse trend (table 17). The failure of barium to be depleted during weathering may be caused by relative insolubility of its principal host, potash feldspar, where barium substitutes for potassium (Rankama and Sahama, 1950, p. 471). Strontium also is unavailable for solution in potash feldspar, but where strontium is present in plagioclase or carbonate minerals it can be removed. The main host for lead may also be feldspars, where the response of the lead to solution would be controlled by its partition between potash feldspar and plagioclase. Lead dominantly responds as predicted in figure 5, being depleted in the most weathered igneous rocks (table 17). In the metasediments the abundance of lead is too sparse to permit detection of a response to weathering, except in marble where lead is concentrated during weathering. This reverse response from that predicted in figure 5 probably is caused by the carbonate host.

The strong inverse relation of copper in the marble (table 17), where it is concentrated in weathered phases, is caused by precipitation in the carbonate environment. Copper is also concentrated in weathered pegmatite and granite gneiss, but it follows courses predicted from figure 5 in aplite, granite, and metasediments. However, differences in the tenors of copper between unweathered and weathered rocks, except marble, are too small to be meaningful, and cast doubt on these results. Nickel also is too sparse and too similar in abundance from the unweathered to the weathered rocks to permit meaningful comparison, except in the metasediments, where nickel is clearly lost from the weathered rocks, as predicted by figure 5.

The response of lanthanum to the degree of weathering is indeterminant in all rock units. Boron follows an inverse trend and is concentrated in weathering products of the felsic plutonic rocks, but in the metasedimentary rocks boron is strongly removed from the most weathered rocks. Insoluble minerals such as tourmaline may be the dominant residence of boron in the plutonic rocks, and soluble minerals such as biotite and amphibole may be the principle source in the metasediments. The behavior of boron during weathering is constrained by the solubility of its host minerals, not by the ionic potential of boron 3+.

The elements beryllium, yttrium, titanium, zirconium, and vandadium show a tendency to concentrate in the products of the weathering of igneous rocks, but the data for scandium are indeterminant (table 17). The responses of beryllium and yttrium to weathering in the metamorphic rocks and marble are indeterminant, but the responses of titanium and vanadium in the metasediments, and of titanium and zirconium in the marble, are inverse to the direction predicted from figure 5. The analytical evidence for the removal in solution of titanium and zirconium, particularly from the marble, must be attribuable to inhomogeneous distribution of resistate minor minerals; thus, it does not reflect a real process of solution.

The rare and scarce elements bismuith, tin, molybdenum, and niobium (table 11) appear among the hydrolyzates (fig. 5) that could be expected to be concentrated in the weathering products. The extent to whi ch weathering may have contributed to the reported abundances of these elements in the rocks (table 10) cannot be evaluated, because bismuth, tin, molybdenum, and niobium were not detected in samples of fresh rock.

Bismuth is enriched in hydrolyzates (Rankama and Sahama, 1950, p. 741), which should have promoted its detection. Lack of the enhancement in the detection of bismuth through weathering affords further evidence of the sparsity of the element in the Jabal Lababa area.

Cassiterite and staringite have low solubility under conditions of weathering and accumulate in the resistates (table 4), but tin camouflaged in soluble minerals such as biotite, magnetite, and pyrite is readily liberated and becomes enriched in the hydrolyzates (Rankama and Sahama, 1950, p. 735). The rarity of tin in the weathered rocks contrasted to its abundant detection in the concentrates indicates that the main tin-bearing minerals are resistates.

Molybdenum- and tungsten-bearing minerals tend to dissolve during weathering (Rankama and Sahama, 1950, p. 628), but in the presence of calcium in water, insoluble calcium salts of the two elements are precipitated. In arid regions the precipitation can procede close to the reaction sites. The sparsity of molybdenum and the absence of tungsten in the weathered rocks, confirmed by their low abundances and sparseness in the other sample media (table 10), show that molybdenum- and tungsten-bearing minerals are most uncommon in the Jabal Lababa area. The consistency with which molybdenum was detected in wadi sediments is interpreted to indicate that some molybdenum has precipitated from solutions during rock weathering, and that molybdenum is indeed being removed from the weathered rocks instead of remaining in the residuum. Part of the molybdenum in the wadi sediment is, however, most likely present in particles derived by erosion of weathered residuum. Tungsten was not detected in the wadi sediment (table 10). Owing to the difference in the lower limits of determination of the two elements (molybdenum, 5 ppm; tungsten, 50 ppm), it is possible that low abundances of tungsten, resembling those of molybdenum, are present and that some tungsten is also being lost from the weathering products in conflict with the role predicted from figure 5.

Niobium accumulates in the hydrolyzates (fig. 5), because compounds formed during weathering are easily hydrolyzed (Rankama and Sahama, 950, p. 609). Concomitant chemical and mechanical weathering appear to influence the distribution of niobium in the sample media, because niobium is more commonly present in clay-bearing samples and in samples of resistate minerals than in rocks (table 18).

Table 18.--Percentage of samples containing niobium in abundances at or above its lower limit of determination

Rocks	2.6
Fresh	0
Moderately weathered	1.5
Strongly weathered	3.7
Wadi sediment	10.4
<10+32-mesh	1.4
<32+80-mesh	5.0
<80-mesh	24.8
Raw concentrates	46.8
Nonmagnetic concentrates	44.6

The large rise in the percentage of anaylses showing niobium in the <80-mesh fraction of wadi sediment may be caused by the possible presence of fine-grained niobium-bearing primary minerals from the source rocks and by hydrolyzed salts of niobium formed during weathering. Formation of hydrolyzed salts of niobium would actually begin at the reaction sites in the rock as weathering progressed. Some of the rise in the percentage of niobium-bearing samples of the strongly weathered rocks can be attributed to precipitation during processes of weathering.

Mechanical accumulation of niobium in weathering results from a relative increase in the abundance of chemically resistant, niobium-bearing minerals in the residuum as the more soluble components of the rock dissolve. As the weathered rocks themselves are degraded by erosion, the resistate minerals are increasingly concentrated by mechanical processes, as is shown by the rise in the percentage of niobium-bearing samples among the concentrates.

The predictable responses to weathering of the undetermined elements (table 11) in the rocks of the Jabal Lababa area is partly identified by ionic potential (table 19).

The responses for silver, arsenic, cadmium, antimony, and zinc fit their geochemical behavior (Rankama and Sahama, 1950, p. 706, 712-713, and 741). Gold is essentially inert; its compounds are readily reduced to native metal in which

Table 19.--The ionic potentials of elements and the predicted response to weathering

Element	Ionic potential	Response to weathering
Ag (1+)	0.88	Removal
As (3+)	4.35	Concentrate
As (5+)	10.64	Concentrate
Au (1+)	.73	Removal
Cd (2+)	1.94	Removal
Sb (5+)	8.33	Concentrate
W (4+)	5.88	Concentrate
Zn (2+)	2.41	Removal

state it is concentrated in the resistate materials formed by rock decay (Rankama and Sahama, 1950, p. 706). Tungsten minerals, as shown above in the discussion of molybdenum, tend to dissolve during weathering, but in arid regions the process is slow because tungsten precipitates readily from solution.

For the degrees of weathering observed in the rocks of the Jabal Lababa area, only small effects are shown on the abundances of the common, abundant, and characteristic elements. The rare and scarce elements are responsive to weathering. Niobium, the principal sought element, responds to weathering and shows concentration in strongly weathered host rocks. Inasmuch as chemical weathering persists in the products mechanically accumulated in the wadi sediments, the effects of weathering may be more pronounced in dispersion trains than in the source rocks.

Composition of wadi sediment

Values determined for the three size fractions of wadi sediments from the Jabal Lababa area are shown in table 10. The grain size of the sediment is more of a factor in the frequency with which an element was determined than the source rock. The frequency of detection increases with decreasing grain size whether the source of the sediment is igneous or metamorphic rocks (table 20); however, grain size is not a factor in frequency of detection for the characteristic elements iron, magnesium, calcium, titanium, manganese, barium, chromium, and zirconium. They are observed in all size fractions.

The distinctive role of grain size on the frequency of determination of the characteristic elements is particularly clear for those elements that rise in classification from

Table 20.--Classification of elements by frequency of determination in wadi sediment from the Jabal Lababa area.

Classification of element	Percent of samples	Elements in each class by dominant rock type in drainage basin and by sieve size of the sediment								
		Full set of wadi sediments			Sediments from areas of igneous rocks			Sediments from areas of meta-sedimentary rocks		
		<10+32-mesh	<32+80-mesh	<80-mesh	<10+32-mesh	<32+80-mesh	<80-mesh	<10+32-mesh	<32+80-mesh	<80-mesh
Characteristic	90-100	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, Ni, V, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, Ni, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Sc, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, V, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, Ni, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Sc, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, Ni, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, Ni, V, Y, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, Sc, V, Y Zr
Abundant	50-89	Co, Pb, Sc, Y	Co, Sc, Sr	B, La, Pb, Sr	Pb, Y	Co, Pb, Sc	B, La, Pb, Sr	B, Co, Pb, Sc	B, Co, Sc, Sr	B, Sr
Common	10-49	B, Be, Sr	B, Be, La, Pb	Be, Nb, Mo	B, Be, Co, Sc, Sr	B, Be, La, Sr	Be, Nb	Be, Sr	Be, La, Pb	Be, La, Mo, Nb, Pb
Scarce	2-9	La, Mo	Mo, Nb	Sn	La, Mo, Nb, Ni, Sn	Mo, Nb, Sn	Mo, Sn	Mo	Mo, Nb	None
Rare	<2	Ag, Nb, Sn	Sn	None	None	None	None	Ag, La	None	Sn
Undetermined 1/	0	As, Au, Bi Cd, Sb, W, Zn	Ag, As, Au, Bi, Cd, Sb, W, Zn	Ag, As, Au, Bi, Cd, Sb, W, Zn	Ag, As, Au, Bi, Cd, Sb, W, Zn	Ag, As, Au, Bi, Cd, Sb, W, Zn	Ag, As, Au, Bi, Cd, Sb, W, Zn	As, Au, Bi, Cd, Nb, Sb, Sn, W, Zn	Ag, As, Au, Bi, Cd, Sb, Sn, W, Zn	Ag, As, Au, Bi, Cd, 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).

"Common" or "Abundant" to "Characteristic" as the grain-size of the sediment decreases, for example cobalt and scandium. This rise is accomplished by reduction of the number of "L" and "N" values with no great increase at the high end of the concentrations.

Other examples of the role of grain size on frequency of determination is evident by rises in classification (table 20) from "Scarce" to "Common" or "Abundant" for boron, lanthanum, molybdenum, niobium, and strontium in the <80-mesh fraction. Decreasing grain size is particularly effective in promoting increased frequency of determination of boron, lanthanum, niobium, and by both a decrease in the number of "L" and "N" values and increases in the higher values.

Sieving the wadi sediment to <80-mesh increases the frequency with which about 60 percent of the elements are determined, but only for a few of these elements is the spread in values increased in the <80-mesh fraction (table 21).

Table 21.--Elements in each range of laboratory reporting interval by coarsest and finest fractions of sediment

Spread in laboratory reporting intervals	<80-mesh	<10+32-mesh
3	La	---
4	---	---
5	Mo	Mo
6	Be, Pb, Sn	Ti, Be, Ni
7	Cr, Nb, Zr	Ca, Co, Cr, Sn
8	B, Ba, Sc, Sr, Y	Mg, Mn, Ba, Cu
9	Co, Ni	Fe, B, V
10	---	La, Zr
11	Ca, Mn, Cu	---
12	Fe, Ti	---
13	V	Y
14	Mg	---

The lowest values for many of the elements are associted with the coarsest-grained fraction of the wadi sediment, and the highest values are in the finest-grained fraction (table 10).

For purposes of reconnaissance geochemical exploration the preferred sample medium should combine a broad spread in values for each element with maximum values. Where the highest values reached for a given element in the coarsest and finest size fractions are identical or nearly identical, the size fraction with the greater number of high values serves better. Where the high values are different by only one or two laboratory reporting intervals between the coarsest and the finest fractions of wadi sediment, spectrographic confidence is not sufficient to permit the maximum value to be the decisive factor in the selection of the optimum size fraction; therefore, the spread in values combined with the number of maximum values determine the choice of medium.

Preferred size fractions are different in the Jabal Lababa area for different elements. The <10+32-mesh fraction appears to be the best for iron, magnesium, calcium, titanium, and manganese because of greater spreads in values associated with the <10+32-mesh fraction than with the <80-mesh material. For 16 elements -- boron, beryllium, cobalt, chromium, copper, lanthanum, molybdenum, niobium, nickel, lead, scandium, tin, strontium, vanadium, yttrium, and zirconium -- the <80-mesh is the preferred medium. Indeed, the <80-mesh sediment is outstanding among the sieved fractions as a geochemical sample medium for lanthanum, niobium, lead, tin, yttrium, and zirconium, because the spread in values for these elements, the maximum values obtained, and the number of high values recorded for each element exceed these factors in the <10+32-mesh sediment. The highest values attained for lanthanum, yttrium, and zirconium in the <80-mesh sediment are much greater than values reported for the <10+32-mesh wadi sand (table 10).

These observations differ from the results obtained by Theobald and Allcot (1973) in the Kushaymiyah igneous complex in central Arabia where coarse-grained wadi sediment proved to be preferred size for use as a geochemical sample medium for tungsten, molybdenum, and bismuth. In that area a <10+30-mesh fraction of wadi sand yielded results for boron, barium, cobalt, chromium, copper, manganese, nickel, lead, scandium, titanium, vanadium, yttrium, and zirconium that related more directly to the major rock units than the finest fraction of wadi sediment, which was <200-mesh. Measurable natural variation in the <200-mesh material was lacking, and that size was interpreted to be of distant aeolian origin. In the Jabal Lababa area also, natural variation in the abundance of iron, magnesium, calcium, titanium, manganese, cobalt, copper, nickel, and vanadium also declines with decrease in grain size; however, massive increases in the natural variation of lanthanum, niobium, lead, tin, yttrium, and zirconium take place in the <80-mesh sediment. The wider spreads and greater maximum values for these wanted elements in the <80-mesh wadi sediment than in the coarsest fraction show that the <80-mesh material is the preferred size of sediment for use in geochemical exploration in the Jabal Lababa area. The differences in the chemical databy grain size of sediment between Jabal Lababa and the Kushaymiyah area, which lead to different choices for preferred sample medium, demonstrate that regional orientation surveys are a necessary part of geochemical exploration in Saudi Arabia before final decisions are made on selection of sample media.

Significant positive anomalies in <80-mesh wadi sediment.--The threshold positive anomalous values for the wanted elements are listed in table 14 and, rounded to the closest spectrographic reporting intervals of (in ppm) beryllium, 2; lanthanum, 200; molybdenum, 5; niobium, 70; tin, 15; yttrium, 300; and zirconium, 700, are shown on figures 6 and 7 for the Jabal Lababa area.

All positive anomalous values for niobium in the <80-mesh fraction of wadi sediment are in the area of the western pluton of quartz monzonite (fig. 6). Other localities in the western pluton and adjacent to it are the sources of wadi sediment with high-background values for niobium. A few high-background values are present in sediments from the northwestern part of the eastern pluton, where they are rarely accompanied by positive anomalies for tin and yttrium. All positive anomalies for zirconium and most for tin and yttrium are in samples from the western pluton or adjacent metasedimentary rocks. Anomalous values for beryllium are also mainly in the area of the western pluton (fig. 7), but positive anomalies for lanthanum and molybdenum are rare in that pluton. Positive anomalies for lanthanum are most common in the eastern pluton. Anomalous values for molybdenum are in and adjacent to both the eastern and western plutons (fig. 7).

Wadi sediment from areas underlain by metasedimentary rocks adjacent to the western pluton that contain high-background or anomalous amounts of niobium, as well as samples of like tenor from the margins of the western pluton, may be in dispersion trains from the core of the pluton. High values for niobium in these trains are dispersed within 3 km of the source, but a maximum dispersion of anomalous values for niobium may reach as much as 6 km on the southwestern side of the western pluton.

The samples of <80-mesh wadi sediment extend the area of niobium anomalies slightly over that defined by rock samples. Some of the increase in area of niobium anomalies results from the sampling of alluvium at places not represented by samples of rocks, and some is caused by the movement of niobium in dispersal trains, but the increase in the area of anomalies for niobium toward the eastern edge of the pluton is related to local enrichment in niobium not

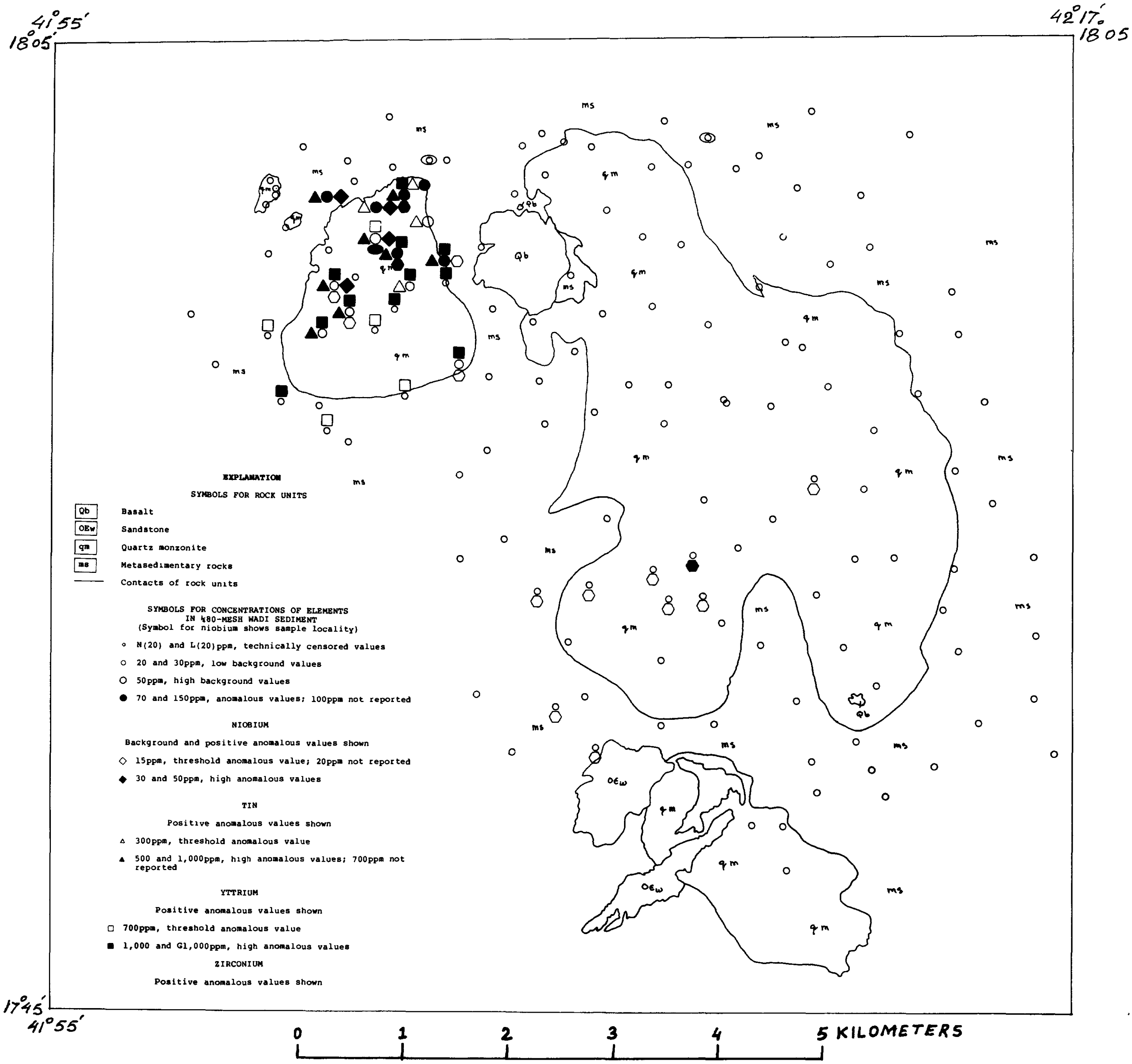


Figure 6.--Map showing the distribution of niobium and of anomalous abundances of tin, yttrium, and zirconium in <80-mesh wadi sediment from the Jabal Lababa area.

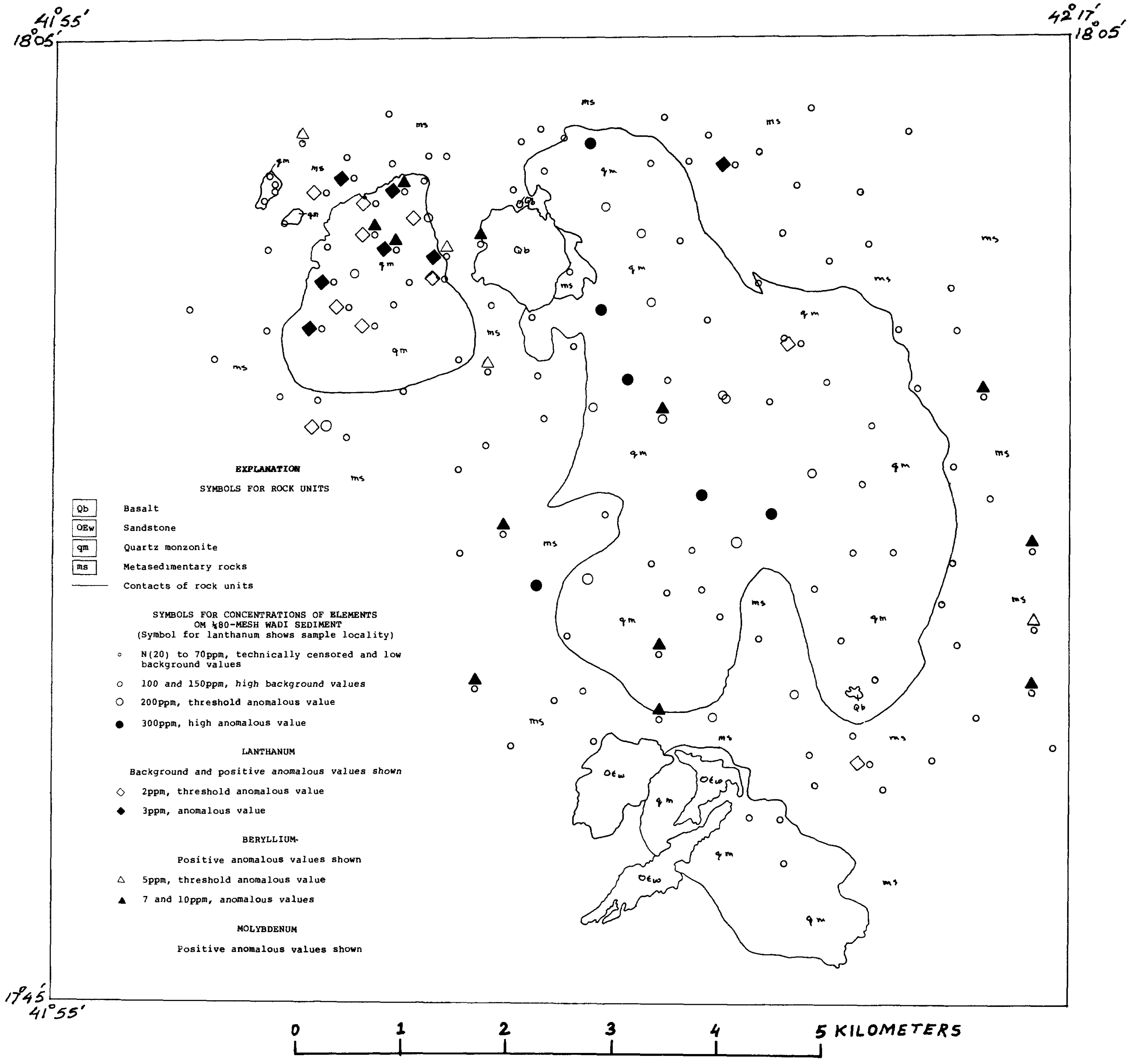


Figure 7.--Map showing the distribution of lanthanum and of anomalous abundances of beryllium and molybdenum in <80-mesh wadi sediment from the Jabal Lababa area.

identified in the rocks. Thus, the use of the <80-mesh fraction of wadi sediment increased the size of the area in which anomalous values for niobium could be found.

Among the main pathfinder elements for niobium, tin, yttrium, and zirconium strongly reflect positive anomalies for niobium in the <80-mesh sediment (fig. 6). High-background and anomalous values for tin, yttrium, and zirconium, individually or in combinations, are distributed in the central and northern part of the western pluton at all localities yielding positive anomalies for niobium. Most localities in the eastern pluton where high-background values for niobium were found lack ositive anomalies for tin, yttrium, and zirconium. The scarcity of positive anomalies for tin and yttrium, combined with the lack of positive anomalies for zirconium and niobium, confirm that the eastern pluton is not a possible source for niobium.

Beryllium has a narrow range in abundance (table 10) in the <80-mesh fraction of wadi sediment, which introduces problems in interpretation. Nevertheless, the anomalous values for beryllium are closely associated with high values for niobium (figs. 6 and 7) in the western pluton. The common presence of positive anomalous values for beryllium in the western pluton and the sparsity of such values in fine-grained alluvium in and around the eastern and southern plutons is interpreted to confirm that beryllium is a main pathfinder element for niobium in the Jabal Lababa area, even where the anomalous concentrations of beryllium are close to its crustal abundance. Confidence is thus greatly enhanced for the geochemical significance of small differences in the reported spectrographic values for beryllium. The distribution of positive geochemical anomalies for beryllium further confirms the restriction of niobium to the western pluton.

Anomalous values for lanthanum do not coincide with the distribution of positive anomalies for niobium in the <80-mesh sediment (figs. 6 and 7). Lanthanum, therefore, does not have a pathfinder role for niobium in the sediment. This relation was also observed for lanthanum in the samples of rocks. Most of the positive anomalous values for lanthanum are in wadi sediment from the eastern pluton of quartz monzonite where they tend to coincide with high-background values for niobium in the northern and north-central parts of the pluton. This relation is interpreted to confirm that lanthanum has no pathfinder role for niobium and that the eastern pluton is lean in niobium.

Positive anomalous values for molybdenum (fig. 7) in the <80-mesh wadi sediment are sparsely present in the northeastern quadrant of the western pluton and in the contact zone to the north and east of the western pluton. Three localities in the eastern pluton were sources for wadi sediment with positive anomalous values for molybdenum. The main sources for samples of sediment containing positive anomalous values for molybdenum are areas underlain by metasedimentary rocks off the eastern, southern, and western flanks of the eastern pluton. They do not closely follow the distribution of molybdenum in rock samples. Where the tenors of the sediments in molybdenum reach or exceed the lower limit of determination (5 ppm), the values only extend two spectrographic reporting intervals above that limit; thus, some may represent false anomalies.

Molybdenum was a wanted element in the present investigation (U.S. Geological Survey Saudi Arabian Mission, 1979, p. 11), but the results of the geochemical reconnaissance show that it is only sparingly present in low abundances. Values for copper in the molybdenum-bearing samples do not exceed 15 ppm, therefore copper is far below its threshold anomalous value (table 14), and molybdenum and copper are not associated as anomalous elements in the Jabal Lababa area.

The distribution of the positive anomalous values for niobium and its pathfinder elements in the <80-mesh fraction of wadi sediments define the western pluton of quartz monzonite as the part of the Jabal Lababa area in which niobium anomalies are confined. Their distribution further shows that the central and northern parts of the western pluton are the most likely sites for enrichment in niobium. Secondary pathfinder elements for niobium -- lead and strontium (not figured) -- form a halo in the northern contact zone of the western pluton that is interpreted to indicate that niobium-bearing quartz monzonite is present below a screen of metasedimentary rocks.

Chemical variations related to weathering.--The increase in the abundance of many elements in the <80-mesh fraction of wadi sediment over their tenors in rocks of the Jabal Lababa area is interpreted here to have been caused by an accession in the fine-grained sediments of locally derived products of chemical weathering. Local contributions from chemical weathering clearly override aeolian debris from distant sources as a factor in the composition of the <80-mesh sediment as shown by four relations: (1) most elements significantly enriched in the <80-mesh sediment are hydrolyzates (fig. 5); (2) about half the elements not enriched in the <80-mesh sediment form soluble cations or soluble complex anions (fig. 5) which are depleted by solution; (3) elements enriched in the <80-mesh fraction are also enriched in the most weathered rocks; and (4) differences between the distributions of the elements in the <80-mesh sediment derived from the plutons of quartz monzonite and from areas underlain by the metasedimentary rocks mimic chemical differences shown by weathered rocks (table 13). No form of aeolian addition of fine-grained sediment to the drainage basins in the Jabal Lababa area could emphasize differences already apparent between fresh and weathered rocks of different lithologies. Only by concentrating the fine-grained, locally derived weathering products into the <80-mesh sediment could the chemical differences caused by the weathering of the source rocks be further enhanced in the wadi sediment.

Owing to wide variations in thelithology and chemical composition of the metasedimentary rocks, even in one drainage basin, the chemical differences between lithologic units are greater than the chemical differences between a given metamorphic rock and wadi sediments in the basin. Therefore, the paths followed by elements during the weathering of these rocks and the formation of wadi sediments canot be interpreted satisfactorily. For this reason, the following discussion of the role of weathering on the formation of wadi sediments and on the chemical composition of coarse-grained fractions of wadi sediments is based on data from areas underlain by plutons of quartz monzonite, because the plutons are more homogeneous than the metamorphic rocks.

Elements enriched in the <80-mesh fraction of wadi sediment compared to the source rocks are seen from table 22 to be mainly cations represented among the hydrolyzates of figure 5 -- Fe^{+3}, Ti^{+4}, Mn^{+4}, Co^{+3}, Cr^{+3}, Sc^{+3}, V^{+5}, Y^{+3}, and Zr^{+4} -- but also include the several elements of low ionic potential that under *non-arid* weathering conditions tend to be removed in solution -- Mg^{+2}, Ca^{+2}, Cu^{+2}, La^{+3}, and Ni^{+2}. Means for boron, molybdenum, niobium, and tin are below their respective lower limits of determination; thus, comparisons based on means cannot be made. Little or no change in the values of the means between fresh and weathered rocks and wadi sediments were observed for Pb^{+2}, and Sr^{+2} which might be removed in solution, and Be^{+3} which might precipitate with the other hydrolyzates (fig. 5). Ba^{+2} is depleted in the <80-mesh fraction of wadi sediment, which follows the pattern predicted by figure 5.

The clear increase in the amounts of iron and manganese in the <80-mesh sediment is interpreted to arise from the preferred accumulation of secondary iron and manganese minerals through size classification. These secondary minerals form either in place in the weathered parts of the exposed plutons of quartz monzonite or are precipitated directly in the wadi sediment and adjacent surficial deposits as secondary products of weathering. The presence of goethite and other secondary minerals formed by weathering has been widely identified in unleached soils of Saudi Arabia (El

Table 22.--Mean values of selected elements in fresh and weathered quartz monzonite and in sized fractions of associated wadi sediment, Jabal Lababa.

Element	Quartz monzonite		Wadi sediment		
	Fresh	Strongly weathered	<10+32-mesh	<32+80-mesh	<80-mesh
Fe	2	1.5	1.5	3	7
Mg	1.5	1	0.7	2	3
Ca	2	2	1.5	3	5
Ti	0.3	0.2	.2	0.3	0.7
		In parts per million			
Mn	300	200	200	700	1,000
B	L(10)	L(10)	L(10)	L(10)	L(10)
Ba	1,500	1,500	1,000	700	500
Be	2	2	1.5	2	2
Co	L(5)	L(5)	L(5)	10	15
Cr	200	150	200	200	300
Cu	20	20	20	30	50
La	20	20	L(20)	20	50
Mo	L(5)	L(5)	L(5)	L(5)	L(5)
Nb	L(20)	L(20)	L(20)	L(20)	L(20)
Ni	15	15	15	30	50
Pb	50	30	20	30	30
Sc	5	L(5)	L(5)	7	20
Sn	L(10)	L(10)	L(10)	L(10)	L(10)
Sr	1,000	700	700	700	700
V	50	30	50	100	150
Y	L(10)	L(10)	L(10)	10	30
Zr	100	100	50	100	500

Prince and others, 1979; Aba-Husayn and Sayegh, 1977; Aba-Hasayn and others, 1980; Viani and others, 1983). The secondary iron and manganese minerals are fine-grained and friable. When wadi sediment is sieved, these secondary weathering products accumulate more abundantly in the <80-mesh fraction than in coarser-grained fractions of the wadi sediments. The interpretation that the excess iron and manganese in the <80-mesh sediment over the amount in the source rocks requires only part of the iron and manganese to be in secondary oxide minerals. The rest is in the original minerals and in secondary silicate and carbonate minerals also produced by chemical weathering (Aba-Husayn and others, 1980).

Iron and manganese are readily dissolved from primary minerals of the quartz monzonite during chemical weathering by aqueous solutions containing carbon dioxide, but the iron compounds so formed are less stable than equivalent compounds of manganese (Rankama and Sahama, 1950, p. 664). Oxides and hydroxides of iron and manganese tend to precipitate as coatings on other mineral grains, as well as to form discrete particles, thereby giving a surface area and chemical activity to these secondary products that is far out of proportion to their concentrations in the weathering solutions. Chemical activity between the precipitates and the weathering solutions causes fixation of other cations (Jenne, 1968). Sols and gels of manganese, being negatively charged, are notable scavengers of other cations in solution (Rankama and Sahama, 1950, p. 650).

The relative concentration or depletion of elements in the strongly weathered rocks and in the sized fractions of wadi sediments, compared to initial abundances in fresh and moderately weathered rocks, can be shown as ratios obtained by dividing the abundance of a given element in the fresh and moderately weathered rocks into the abundances of the same element in the strongly weathered rocks and in the size fractions of sediment. Elements with ratios greater than 1 have been concentrated in the given geochemical sample medium. Where ratios are less than 1, the elements have been depleted. These ratios are given in table 23 where the direction and degree of partition of elements by sample medium is emphasized over the means shown in table 22. Only beryllium and lead are depleted. Little change is shown by chromium and molybdenum. Concentration of the other elements except strontium progresses from the strongly weathered rocks to the <80-mesh wadi sediment. The most concentrated elements are iron, magnesium, titanium, cobalt, copper, lanthanum, nickel, vanadium, yttrium, and zirconium, which include several (magnesium, copper, lanthanum, and nickel) that would tend to be lost under non-arid conditions of weathering but which in the local arid environment are concentrated. The enrichment ratios for iron and manganese (table 23) conform well with the observation that iron

Table 23.--Ratios identifying concentration or depletion of selected elements in deeply weathered rocks, sized fractions of wadi sediments, and concentrates compared to original elemental abundances in fresh and moderately weathered felsic plutonic rocks in the Jabal Lababa area.

[Concentrated if greater than 1; depleted if less than 1]

Element	Strongly weathered rocks	Wadi sediment		Concentrates	
		<10+32-mesh	<80-mesh	Raw	Nonmagnetic
Fe	2.9	4.3	14.3	33.1	34.4
Mg	3.3	4.7	10.0	4.7	6.7
Ca	3.0	2.0	4.0	2.0	4.0
Ti	4.0	6.0	22.0	28.0	30.0
Mn	1.4	1.0	3.0	6.0	10.0
B	1.3	1.3	2.0	0.8	0.4
Ba	1.5	1.5	1.0	.4	.1
Be	0.7	0.5	0.5	.3	.1
Co	2.0	3.6	7.1	21.4	21.4
Cr	1.0	1.0	1.5	2.5	2.5
Cu	1.5	2.0	5.0	3.0	7.0
La	1.0	1.0	7.0	15.0	30.0
Mo	1.0	1.3	1.6	1.6	1.6
Nb	1.3	1.5	3.4	17.0	51.0
Ni	1.8	2.6	7.9	7.9	5.3
Pb	.7	.5	.7	1.0	2.5
Sc	1.2	1.4	4.8	4.8	9.7
Sn	1.0	1.2	2.3	15.0	25.0
Sr	1.8	1.8	1.8	.9	.3
V	2.5	5.0	15.0	35.0	25.0
Y	1.5	1.0	5.0	15.0	35.0
Zr	2.3	2.3	10.0	10.0	16.7

compounds produced by weathering are less readily soluble than the equivalent manganese compounds (Rankama and Sahama, 1950, p. 664). The enrichment ratio for iron is greater than that for manganese because relatively more of the original manganese is removed in solution. On a sample-by-sample basis, the rise in contents of iron and manganese from fresh quartz monzonite to the <80-mesh wadi sediment is matched particularly by sympathetic increases in the abundances of titanium, cobalt, scandium, vanadium, yttrium, and zirconium. The sources of these elements are mainly the femic constituents of the felsic plutonic rocks, principally biotite, amphibole, garnet, epidote, magnetite, and titanite. The parallel enrichment of these elements through different intensities of weathering in the source rocks to the fine-grained sediments is interpreted to result from concentration during weathering, not by the introduction of exotic aeolian contaminants.

Titanium has the highest concentration ratios of any element shown in table 23. When the element is brought into solution during weathering it is quickly hydrolyzed and enters hydrolizate sediments (Rankama and Sahama, 1950, p. 563). Its rise in abundance in the fine-grained fraction of wadi sediment is paralleled by increases in the contents of iron and mangnese, suggesting possible solution and precipitation of titanium from soluble minerals such as biotite, amphibole, and titanite, but the main residence of titanium may be the insoluble minerals shown in table 4 that include several of the niobium-bearing minerals, rutile, and anatase. The concentration ratios for titanium in panned concentrates (28 and 30) are not sufficiently greater than that for the <80-mesh sediment to confirm the dominance of residual concentration of the resistate minerals over hydrolysis in the cycle of titanium during weathering in the Jabal Lababa area. Partial solution techniques of chemical analysis to determine the relative abundance of titanium in the secondary iron and manganese minerals would resolve the question.

The characteristic tendency of cobalt to deposit preferentially with manganese compared to iron is shown by the greater number of manganese-rich samples of <80-mesh sediment containing 10 ppm or more cobalt than the iron-rich samples (table 24). This pattern is evidence for solution of cobalt and preferential precipitation with manganese during weathering.

The abundance of scandium compared to the amounts of iron and manganese in the weathered rocks and in the wadi sediment confirms geologic observations that the weathering is immature in the Jabal Lababa area. Although the amount of scandium rises in the <80-mesh fraction of sediment (table 22), partitioning of scandium toward the iron-rich and away from the manganese-rich material is not evident. A rise in

Table 24.--Cobalt abundances in iron-rich and manganese-rich sediments

Manganese-rich <80-mesh sediment		Iron-rich <80-mesh sediment	
Mn (ppm)	Number of samples with 10 ppm or more cobalt	Fe (percent)	Number of samples with 10 ppm or more cobalt
1,000	13	10	7
1,500	9	15	9
2,000	10	20	4
3,000	8		---

the content of scandium with an increase of iron would be expected under conditions of advanced weathering, but little rise in the abundance of scandium with increasing content of manganese would take place (Rankama and Sahama, 1950, p. 516).

Vanadium is both less commonly reported and less abundant where present in the felsic plutonic rocks than in the metamorphic rocks. However, the concentration ratio (15) of vanadium in <80-mesh sediment from the felsic plutonic rocks (table 23) is much greater than that from the metasediments (2.9). To achieve this difference in the concentration ratios of vanadium in fine-grained sediments from these different lithologic sources, the principal host for vanadium in the plutonic rocks must be more susceptible to solution during weathering than the host in the metamorphic rocks. Among the metasediments, the muscovite schists with biotite or chlorite generally contain more vanadium (150-500 ppm) than biotite and chlorite schists lacking muscovite (20-70 ppm). The metasedimentary rocks contain more muscovite than the plutonic rocks, but by comparison, the schists are deficient in such vanadium-bearing minerals as apatite and magnetite (fig. 3), a difference perhaps accounted for the variation in the concentration ratios, because muscovite is much less soluble during weathering than apatite or magnetite. Thus, the sources that might release vanadium during chemical weathering tend to be locked (muscovite) in the metasediments and leachable (apatite and magnetite) in the plutonic rocks. This concept appears to be valid for vanadium even if the postulated preferred hosts for vanadium prove to be other minerals than those cited.

High tenor of vanadium in the <80-mesh wadi sediment from the quartz monzonite are more strongly associated with manganese than with iron (table 25). These relations are interpreted to indicate the preferential presence of vanadium in secondary manganese minerals in the sediment.

Table 25.--Vanadium abundances in iron-rich and manganese-rich sediments

Manganese-rich <80-mesh sediment		Iron-rich <80-mesh sediment	
Mn (ppm)	Number of samples with 100 ppm or more vanadium	Fe (percent)	Number of samples with 100 ppm or more vanadium
1,000	14	10	8
1,500	12	15	9
2,000	11	20	6
3,000	9		

The noteworthy relation between the concentration ratios for vanadium in the <80-mesh sediment from the felsic plutonic rocks and sediment from the metasedimentary rocks is that no aeolian contribution to the wadis could produce only a small concentration ratio for vanadium in <80-mesh sediment from metamorphic rocks and a large concentration ratio for vanadium in the <80-mesh sediment from the plutonic rocks where the plutonic rocks contain less vanadium than the metamorphic rocks.

Concentration ratios for yttrium progress from 1.5 in the strongly weathered rocks to 5 in the <80-mesh sediment (table 23). They are similar to those of the other rare-earth elements lanthanum and scandium (table 23), although the maximum abundance of yttrium in rocks and wadi sediments, 1,000 ppm (table 10), exceeds the maximum for lanthanum, 300 ppm, and for scandium, 30 ppm. In the <80-mesh sediment the content of yttrium rises sympathetically with those of iron and manganese, and the maximum value for yttrium is reached with the greatest values for iron, whereas values of yttrium are somewhat less than maximum with the largest concentrations of manganese. These relations may indicate that secondary manganese minerals can accommodate more yttrium than was available in the weathering solutions, because many more high values for yttrium are associated with high values for manganese than for iron (table 26).

Table 26.--Yttrium abundances in iron-rich and manganese-rich sediments

Mn (ppm)	Number of samples with 50 ppm or more yttrium	Fe (percent)	Number of samples with 50 ppm or more yttrium
1,000	10	10	8
1,500	9	15	7
2,000	10	20	6
3,000	8		
	37		21

Zirconium reaches the concentration ratio of 10 in the <80-mesh wadi sediment (table 23). Many high values for the abundance of zirconium are associated with less than the greatest abundances of iron and manganese in the sediment. Fine-grained zircon is one of the sources for zirconium in all sample media, but zircon is rather inert to chemical attack. Garnet, amphibole, and biotite, which are not inert during chemical weathering, contain zirconium. Zirconium brought into solution by weathering of soluble mineralogical sources is readily removed by hydrolysis (fig. 5) and is fixed in secondary iron and manganese minerals (Rankama and Sahama, 1950, p. 566). This process is more likely to account for the sympathetic rise in the zirconium content of the <80-mesh sediment with increasing tenors in iron and manganese than residual enrichment or aeolian addition of fine-grained zircon. Mechanical additions of zircon to the <80-mesh sediment are unlikely to conform to the changes in abundances of iron and manganese in the sediment although residual enrichment of zircon would increase the total zirconium and override the general sympathetic rise in abundances of zirconium, iron, and manganese. The relations of zirconium with iron and manganese suggest that solution and hydrolysis are important factors in the geochemical cycle of zirconium in the Jabal Lababa area. This factor could also be evaluated through the use of partial solution techniques in chemical analyses of the sediment.

Less-enriched elements in the <80-mesh sediment include such wanted elements as beryllium, molybdenum, niobium, and tin of which beryllium is depleted in the <80-mesh sediment (table 23). The method used to interpret the censored values "L" and "N" (tables 1 and 10) probably gives too great an estimate for each censored value; thus, the fewer the number of "L" or "N" values, as for example beryllium (table 10), the more realistic is the concentration ratio in table 23. For elements with many censored values, such as molybdenum, niobium, and tin, the less realistic are the estimated concentration ratios; however, the rise in ratios toward the <80-mesh fraction for molybdenum, niobium, and tin (table 23) is real and conforms to the predicted paths of these elements during weathering. The decline in the concentration ratio for beryllium is also real, but it does not conform to the position in figure 5.

Molybdenum-bearing minerals are soluble during weathering, but where soluble molybdates contact calcium-bearing solutions, insoluble salts of molybdenum precipitate (Rankama and Sahama, 1950, p. 629-630). Manganese oxides and hydroxides also promote the accumulation of molybdenum. In the Jabal Lababa area the molybdenum-bearing wadi sediments are from the sites of rock samples that contain the element. In none of the 13 molybdenum-bearing samples of rocks or wadi sediment does the maximum tenor exceed 10 ppm molybdenum (table 10). With these low tenors in the sediments occupying sites near bedrock sources with equally low contents of molybdenum, it seems probable that the molybdenum does not migrate far. The proximity of source rocks to the sediments that contain molybdenum is interpreted to indicate that the molybdenum in the wadi sediments is locally derived, and that the molybdenum behaves as a hydrolyzate instead of as a soluble complex anion. However, the low molybdenum content of the calcium-rich wadi sediments may relate to a lesser scavenging effect of a calcium carbonate than of the iron and manganese oxides (Patchineelam, 1978; table 27).

Tin was reported in measurable quantities in only eight samples of rocks and wadi sediments. In these media the concentration ratio for tin rises from 1 in the rocks to 2.3 in the <80-mesh sediment (table 23). Much larger concentration ratios were observed for the panned concentrates (15-25). Although tin-bearing resistate minerals such as cassiterite, staringite, and rutile (table 4), which account for the tin in the concentrates, also are the sources of some of the tin in the rocks and wadi sediment, part of the tin in these media appears to be derived from soluble minerals, because the number of tin-bearing samples rises as the amount of iron and manganese increases (table 28).

Minerals soluble during weathering and known elsewhere to contain tin (Sainsbury and Reed, 1973, p. 641; Hesp and Rigby, 1971, p. 139) include magnetite, biotite, amphibole, garnet, and titanite. Tin in amounts up to 150 ppm was found in detrital magnetite from the Jabal Lababa area; the element may also be present in other of these minerals. The preferential association of tin with the iron- and manganese-rich samples is interpreted to indicate that some tin is brought into solution during weathering and is precipitated

Table 27.--Number of molybdenum-bearing samples compared to contents of iron, manganese, and calcium

Fe (percent)	Mo (number of samples)
0.3 - 2	4
3 - 7	9
Mn (ppm)	
150 - 500	5
700 - G5,000	8
Ca (percent)	
0.1 - 1	10
2 - 7	3

Table 28.--Number of tin-bearing samples compared to contents of iron and manganese

Fe (percent)	Sn (number of samples)
5	1
7 - 20	7
Mn (ppm)	
300 - 1,000	2
1,500 - G5,000	6

with the hydrolyzates.

Beryllium during rock weathering follows the geochemical cycle of aluminum and enters clay minerals in the hydrolyzate sediments (Rankama and Sahama, 1950, p. 446). In the Jabal Lababa area, however, measurable quantities of beryllium are less common in the <80-mesh fraction of wadi sediment (26 percent) than in the rocks (41 percent), a difference also revealed by the concentration ratios in table 23. This relation reflects the relative sparsity of true clay minrals, as distinguished from clay-size particles of rock-forming minerals, in the finest fractions of alluvial sediments formed in the arid environment (El Shazly and others, 1977). Beryllium is also known to be adsorbed in iron and manganese oxides produced by weathering (Levinson, 1980, p. 866), but only an imperfect tendency for the higher values of beryllium to be associated with high values for tin and manganese was found.

Varied results for beryllium in the arid environment have been reported in exploration. Where the main beryllium mineral is bertrandite, as at Aguachile Mountain, Mexico (Griffitts and Cooley, 1978a), the beryllium content of fine-grained alluvium directly reflected mineralization, rising from about 1 ppm in unmineralized parts of the area to as much as 500 ppm immediately downstream from an orebody. Where beryl is the main beryllium (3.3 ppm) than either the source rock or coarse-grained alluvium (5-30 ppm). These differences were attributed to an influx of beryllium-poor (2-3 ppm), fine-grained, aeolian sediment that contaminated fine-grained debris from the granite and reduced the beryllium content of the sediment. Analysis of silt- or clay-sized fractions of alluvium from the Sheeprock Mountains would not have given evidence of the beryllium mineralization. At the ancient emerald (beryl) mines in Wadi Sikait, Egypt (El Shazly and others, 1977), a gradual decrease downstream in the amount of beryllium in the sediment was attributed to the influx of beryllium-poor alluvium from small wadis not reaching the emerald deposits. Values for beryllium in alluvium decreased abruptly from 20 to 40 ppm at the site of mineralization to 1 to 1.5 ppm in the main wadi owing to the chemical stability of emerald under arid conditions of weathering and transport and to the introduction of emerald-free alluvium (El Shazly and others, 1977).

The host minerals for beryllium in the Jabal Lababa area are unknown, but the range in reported values is so small, and the maximum abundance is so low (table 10), that the beryllium content of the rocks and sediments is close to the world average abundance of 2 to 3.5 ppm (Griffitts, 1973, p. 88). Most of the beryllium is probably camouflaged in common rock-forming minerals like plagioclase and mica. High values for beryllium in pegmatite dikes and quartz veins, locally reaching 7 ppm and commonly associated with high values for niobium, tin, yttrium, and zirconium (figs. 6 and 7), may result from beryl. Beryllium-bearing samples of rock tend to be clustered near the walls of the plutons and in the pegmatite-rich parts of the western pluton.

The choice of rock samples has an influence on the apparent partition of beryllium between rocks and sediment that overrides any effect of weathering on the dispersal of beryllium. In wadis where the rock sample was a beryllium-bearing dike or vein, only 47 percent of the samples of alluvium contained measurable quantities of beryllium. At localities where the beryllium-bearing samples were quartz monzonite or granite of the plutons, 61 percent of the samples of wadi sediment had measurable amounts of beryllium. Locally in the plutons samples of rock lacked beryllium where the sediment contained the element. In wadis yielding beryllium-bearing samples of metamorphic rocks, only 33 percent were the source of beryllium-bearing alluvium, but 41 percent of the wadis where the metamorphic rocks lacked detectable beryllium, the element was observed in the wadi sediment. Evidently, the choice of the rock sample for analysis where the tenor of the element to be determined is at or near crustal abundance (as contrasted to the limit of spectrographic determination) can give misleading results when compared with the results from the wadi sediment, because of differences between the sample of rock selected for analysis and the average rock in the distributive province supplying sediment to the wadi. Beryllium-enriched dikes and veins represent less of the volume of rock available for the production of alluvium than the main bodies of rock; thus the high values for beryllium in the dike or vein are submerged in the large bulk of lower-value debris from the plutons. A reverse relation is apparent for the metamorphic rocks in which detectable amounts of beryllium are present in wadi sediment where the sample of rock represented a less common chemical composition than the distributive province as a whole.

The geochemical behavior of beryllium in wadi sediment of the Jabal Lababa area is similar to that reported for the Wadi Sikait area, Egypt (El Shazly and others, 1977). Mechanical factors of source and transport appear to override chemical factors of weathering. Beryllium has been as subject to weathering and solution as other elements in minerals vulnerable to chemical attack, because most of the beryllium is probably in plagioclase. However, the sparsity of the element and the restriction of high values to rock types having small areas of outcrop prevent tracing the effect of weathering on the distribution of beryllium. The most likely positive evidence for slight chemical concentration of beryllium in the wadi sediment during weathering is provided by the data from the metamorphic rocks. At the many localities where beryllium was detected in the wadi sediment but not in the rocks, the possibility exists that enhanced detection in the <80-mesh fraction of wadi sediment represents concentration of beryllium resulting from weathering, in conformity with the position of the element in figure 5.

The low concentration ratios for chromium in rocks and sediments (table 23) are also reflected in results for panned concentrates (2.5 for both types of concentrates). These ratios show no pronounced difference between the hydrolyzates (<80-mesh sediment) and the resistates and thus conform to reported geochemical dispersion of the element (Rankama and Sahama, 1950, p. 623).

Low concentration ratios for niobium in the strongly weathered rocks and <10+32-mesh sediment increase slightly to 3.4 in the <80-mesh sediment (table 23), but they rise in the nonmagnetic concentrates to the highest ratio (51) for any of the determined elements. This high concentration ratio in the nonmagnetic concentrates shows that the main sources for niobium are resistate minerals, but some niobium evidently enters solution during weathering and is fixed in the hydrolyzates, because the content of niobium in the <80-mesh sediment rises sympathetically wih increases in the amounts of iron and manganese. These relations conform in part with the geochemical behavior of niobium predictable from figure 5 and with the comment of Rankama and Sahama (1950, p. 609) that niobium tends to be readily hydrolyzed during rock weathering. The departure from these observations is caused by the less intense chemical activity resulting from weathering under arid climatic conditions.

The soluble cations Ca^{+2}, Cu^{+2}, La^{+3}, Mg^{+2}, and Ni^{+2} depart in their responses to chemical weathering in the arid environment from the responses predicted in figure 5. They appear among the enriched elements in the <80-mesh wadi sediment (table 23). Solution during weathering would be expected to remove them, but in arid situations these elements tend to appear as precipitates in the weathering products.

The amounts of calcium and magnesium increase sympathetically with increasing contents of iron and manganese from strongly weathered rocks to the <80-mesh sediment, and the abundance of magnesium rises as the amount of calcium increases in the weathered materials. Part of the calcium and magnesium tends to accumulate as carbonate crusts, which are seen in the Jabal Lababa area as white to light gray and light grayish-brown coatings on pebbles and cobbles, as as veinlets and concretions in mottled zones of alluvial deposits perched above the active channels of wadis. Comminuted particles of the secondary carbonate minerals, as well as films and grains precipitated with the active wadi sediments, account for the rise in the tenors of calcium and magnesium in the <80-mesh fraction of wadi sediments. These chemical precipitates have been successfully used as a geochemical sample medium in other arid regions (Erickson and Marranzino, 1960).

The rise in the abundances of copper, lanthanum, and nickel in the <80-mesh sediments is thought to result from fixation in secondary iron and manganese minerals (Jenne, 1968; Chao and Theobald, 1976) and with secondary calcium minerals (Erickson and Marranzino, 1960). Coatings of these secondary products on grain surfaces, or their presence as micron-sized or larger discrete secondary particles, are thought to provide sources for the enrichment of copper, lanthanum, and nickel, but studies of mineral composition and surface properties of the <80-mesh sediment are needed to define the host minerals. Partial solution techniques (Chao and Theobald, 1976) to determine the secondary minerals that are hosts for copper, lanthanum, and nickel would be appropriate.

The amount of copper in the wadi sediments is low (table 10), being at or within a few laboratory reporting intervals of crustal abundance. Concentration ratios for copper in the raw and nonmagnetic concentrates (3 and 7) are scarcely greater than in the <80-mesh sediment (table 23). This indicates that the copper is camouflaged in easily weathered minerals that release small smounts of Cu^{+2} in ionic solution, in conformity with figure 5, but under the prevailing arid conditions, copper is fixed in secondary minerals of the hydrolyzates (Rankama and Sahama, 1950, p. 699) or carbonates. Association of the highest values for copper with fine-grained sediment is indirect evidence for the absence of copper mineralization. For example, in the Eastern Desert of Egypt positive geochemical anomalies identifying copper deposits were found preferentially in coarse-grained wadi sediment and were attributed to the dominance of mechanical over chemical weathering (Bugrov, 1974, table 1).

Concentration ratios for lanthanum are distinctly higher in the <80-mesh sediment than in coarse-grained wadi sand or weathered rocks (table 23). The highest values for lanthanum are associated with the highest values for iron and manganese, but peak values for lanthanum in the <80-mesh sediment are reached in samples where only intermediate abundances of calcium are present. Iron appears to be the most effective scavenger for lanthanum. These relations conform with the finding that $CaC0_3$ is a less effective scavenging agent than the secondary oxides and hydroxides of iron and manganese (Patchineelam, 1978).

Nickel is enriched with iron and manganese in the <80-mesh sediment of Jabal Lababa. Other examples 4f nickel precipitated with iron-rich secondary products of weathering in Saudi Arabia are the gossans at Wadi Qatan (Blain, 1979) and Jabal Jedair (Puffett and others, 1976). The chemical processes are similar but the source rocks are different at Jabal Lababa, gossans are absent, and the tenors in nickel are low. The Co:Ni ratio (0.25) of the <80-mesh sediment at Jabal Lababa is similar to the average Co:Ni ratio of 0.4 reported for hydrolyzate sediments (Rankama and Sahama, 1950, p. 685). Nickel appears to be removed from weathering solutions by the secondary iron and manganese minerals, and secondary calcium minerals may also participate in the fixation of nickel, because high values for nickel are associated with high values for calcium in the <80-mesh sediment.

Low values for nickel in wadi sediments downstream from sulfide ore bodies in the Eastern Desert, Egypt, were ascribed to the removal of nickel in aqueous solution (El Shazly and others, 1977) in conformity with the stability of the ion (Rankama and Sahama, 1950, p. 683). Amazingly short distances, on the order of 100 m, where the limit to which the dispersion of nickel reached and to which positive anomalies of nickel could be detected. Another cause for this rapid depletion of nickel in wadi sediments may be its ready removal from weathering solutions through coprecipitation with, or adsorption on, secondary iron, manganese, and calcium minerals. Tests in Saudi Arabia at known nickel deposits would be useful in the evaluation of the movement of nickel during weathering under arid conditions.

The soluble cations Ba^{+2}, Pb^{+2}, and Sr^{+2} (fig. 5) yield low concentration or depletion ratios (table 23). Decreases in the ratios for barium extend into the nonmagnetic concentrates (0.1) and identify the probable regional sources for barium as minerals such as feldspars, which do not persist into the concentrates. Strontium also is strongly depleted in the nonmagnetic concentrates (0.2), but its ratios in weathered rocks persist unchanged into the wadi sediments. The ratios for lead are also little changed from weathered rocks to wadi sediments; however, in the concentrates the ratios tend to rise (2.5). When the amounts of barium, lead, and strontium are compared to the tenors of iron, manganese, and calcium in the sample media, it appears that barium, lead, and strontium are being removed from the rocks by weathering solutions, but that fixation of barium andstrontium with secondary calcium minerals and of lead with secondary iron minerals has also taken place.

The highest values for barium in the weathered igneous rocks and wadi sediments are associated with low to intermediate amounts of iron and manganese. Weathered rocks contain more barium than the <80-mesh sediments (table 23), but the most notable change cuased by weathering is to reduce the wide variations in the barium content of the rocks progressively to small variations in the <80-mesh sediment as the quantities of iron, manganese, and calcium increase.

High values for the abundance of lead tend to be associated with low to intermediate quantities of iron, manganese, and calcium in the weathered rocks and the wadi sediments, but a distinctly greater tendency exists for these high values of lead to accompany iron. Lead adsorbed from weathering solutions by secondary iron minerals may be accumulating as lead-bearing limonite. In contrast to the ratios showing depletion of lead in the rocks and wadi sediments (table 23), the nonmagnetic concentrates where limonite would accumulate show a small positive concentration ratio for lead (2.5). The negative ratios for lead in the rocks and derived sediment combined with positive ratios in the nonmagnetic concentrates are interpreted to indicate that some lead is being removed by solution during weathering and some also remains in the secondary minerals of the hydrolyzates.

In the Eastern Desert of Egypt, lead was thought by El Shazly and associates (1977) to leach from wadi sediments. The behavior of the element in the Jabal Lababa area largely conforms to the pattern observed in Egypt. Elsewhere in Arabia, as at the Ash Sha'ib ancient mine, the lead content of alluvium also failed to give positive anomalies in mineralized areas, although gossan over sulfide bodies was lead-rich (Allcott, 1970). A combination of adsorption of lead in secondary iron minerals and removal of unadsorbed lead may account for these observations, but the geochemical partition of lead by weathering under arid conditions merits study to determine the most suitable sample medium for exploration. From the data at Jabal Lababa, the concentrate is certainly to be preferred over samples of rocks or wadi sediment, the later of which may be the least useful medium.

Enrichment of wadi sediments in strontium was noted at the Ash Sha'ib ancient mine in Saudi Arabia and was regarded as a common response to weathering in arid regions (Allcott, 1970). At Jabal Lababa the concentration ratios for strontium remain constant for weathered rocks and for wadi sediments (table 23). However, strongly rising tenors in strontium with increasing content of calcium in the wadi sediments follow the geochemical association of the two elements (Rankama and Sahama, 1950, p. 480). Low to intermediate abundances of strontium are associated with sample media having the highest contents of iron and manganese. These relations are interpreted to show that strontium precipitates preferentially with calcium, possibly in diadochic substitution in secondary aragonite or calcite. Depletion ratios for strontium in the nonmagnetic concentrates (0.3) show that the element is very sparse in the resistate minerals.

The relations of strontium to barium and lead in the rocks and weathering products indicate that strontium and barium precipitate with secondary calcium minerals, but that lead does not. The greatest amounts of strontium are associated with the highest tenors of barium in the most weathered rocks and in wadi sediments, and the abundances of strontium and barium increase sympathetically with rising quantities of calcium. These relations may indicate diadochic substitution of barium for strontium in strontium-bearing secondary calcium minerals, because the large size of the Ba^{+2} ion makes isomorphous substitution possible only with strontium (Brobst, 1973, p. 77). Lead, however, displays a strong negative correlation with strontium: the most lead-rich samples of weathered rocks and of wadi sediments contain the least strontium. Although aragonite commonly contains some lead, and the ionic radius of lead is closer to that of strontium than to barium (fig. 5), substitution of lead for strontium is not a significant factor in the weathering products at Jabal Lababa.

Boron is shown in figure 5 as the soluble complex ion B^{+3}; however, the concentration ratio for boron in weathered rocks and wadi sediments shows a weak rise in the <80-mesh sediment (table 23). The main source of boron in these media may be tourmaline (table 4), the residual enrichment of which during weathering would cause a rise in the concentration ratio of boron in the <80-mesh sediment. Owing to the resistance of tourmaline to solution, the boron content would increase through residual enrichment in tourmaline. Such an increase would be independent of the rise in the contents of iron, manganese, and calcium, because the increase in boron would be caused my mechanical factors whereas the rises in iron, manganese, and calcium would be controlled by chemical processes of weathering.

That tourmaline is probably the main source for boron in these sample media is supported by the concentration ratios or boron in the panned concentrates. Boron is depleted in both types of concentrates (table 29). Because the density of tourmaline is about 3.0, and the heavy liquid used to prepare the nonmagnetic concentrate has a density of 2.96, some tourmaline was removed from the nonmagnetic concentrates. In response, the nonmagnetic concentrates are depleted in boron, showing that tourmaline is an important boron-bearing component in the various sample media. Other hydroxyl-bearing silicate minerals, such as biotite, may contain camouflaged boron which would contribute to the boron content of all media.

Table 29.--Concentration ratios for boron in raw and nonmagnetic concentrates

Sample medium and source	Concentration ratio for boron
Raw concentrates	
From felsic plutonic rocks	0.8
From metamorphic rocks	.8
Nonmagnetic concentrates	
From felsic plutonic rocks	.4
From metamorphic rocks	.5

Boron camouflaged in silicate minerals would enter solution from hosts vulnerable to chemical weathering and be removed as soluble borate or would be precipitated locally as insoluble calcium borate. Present data do not give evidence for the presence of this secondary product.

Elsewhere in Saudi Arabia boron has been reported to have precipitated in wadi sediments by the evaporation of ground water of Al Kushaymiyah (Theobald and Allcott, 1975). Plant ash from the Ash Sha'ib ancient mine is enriched in boron (Allcott, 1970), which shows that the element moves in ground water. Anomalously great abundances of boron in sand on pediment surfaces in the eastern part of the Arabian Shield was attributed to wind-borne particulates (Overstreet, 1978). Evidence was not detected in Jordan, however, for enhancement of the boron content of wadi sediment through aeolian contamination from sabkhah deposits in the Wadi Rum area (Overstreet and others, 1981).

Thin alluvial deposits on pediment surfaces in the southwestern part of the Jabal Lababa area near the Red Sea (fig. 2) contain less boron than alluvial sediments farther inland. These spatial relations are interpreted to show that no enrichment in boron attributable to airborne salts from the Red Sea has taken place despite the fact that boron is characteristically enriched in coastal areas elsewhere (Rankama and Sahama, 1950, p. 488). In contrast, soils near the Dead Sea in Jordan are enriched in boron by wind-introduced salts from that body of water (Overstreet and others, 1981). In Egypt, boron was found to be partly mobilized during processes of weathering and transportation in wadi sediments. It was traced for long distances (El Shazly and others, 1977), but the source of the boron was not identified. The great lengths of the dispersion trains described in Egypt suggest that detrital tourmaline is the main host for the boron.

Chemical weathering of the rocks and the detritus formed by the disintegration of the rocks in the Jabal Lababa area is thought to be a far more pervasive factor in setting the chemical composition of the fine-grained wadi sediment than the possible aeolian introduction of particulates from outside the area. In contrast, a narrow range in abundance of the elements in wadi sand was reported for fine-grained fractions in the Al Kushaymiyah area, where the least variations in concentration of the elements was seen for the finest fraction, <200-mesh (Theobald and Allcott, 1973). Between the <80-mesh materials studied at Jabal Lababa which includes the <200-mesh sediment, and the <200-mesh wadi sediment analyzed at Al Kushaymiyah, lies a break in size that may promote the broad and the narrow chemical variations in the two size fractions of sediment. When that is determined, a single size of wadi sediment, such as the <80+120-mesh fraction, may prove to be of exceptional utility in the wetter parts of southwestern Arabia as a geochemical sample medium, because the less indicative coarse-grained and fine-grained weathering products would be screened out.

Influence of gradient and contamination from pediment deposits.--The gradient of the wadi floor at each sample locality was classed visually as "Gentle", "Moderate", or "Steep" (Appendix). As previously shown, the gradient of the wadi was less of a factor on the grain-size distribution in the wadi sediment than the lithology of the source rocks. Inasmuch as grain size and lithology are dominant controls on the chemical composition of the wadi ediment it is unlikely that gradient would have much effect. A comparison of the values for the determined elements in the wadi sediments by gradient of the wadi and lithology of the distributive province showed that, except for iron, titanium, copper, and vanadium, the variation in the mean values of the elements reached a maximum of three laboratory reporting intervals. Thus, for most elements the variation attributable to gradient is within the spectrographic confidence levels of the method used for analysis.

The greatest variance by gradient is restricted to the <10+32-mesh fraction, which reflects poor homogenization of particles. For areas of varied relief, where the gradients of wadis undergo large local changes, the <80-mesh fraction of wadi sand may be a more consistent sample medium than the <10+32-mesh material, but both would be inferior to concentrates.

Sand from wadis on the pediment surfaces of the Jabal Lababa area (fig. 2) was shown to contain less of the <80-mesh fraction than sand from wadis outside the pediment area. Inasmuch as the sediments on the pediment are derived from wider distributive provinces than the sources of the wadis used for sampling, the possibility exists that alluvium in wadis entrenched through the pediment deposits and into the underlying crystalline rocks would contain sediment from more varieties of rocks than those exposed in the bed of the wadi. Contamination of the local wadi sediment with alluvium from the pediment deposits might lead to false anomalies or to the suppression of an actual anomaly. The extent the chemical composition of sediment from wadis in the pediment differed from that of wadis in rocks was compared for the determined elements on a basis of geomorphic and lithologic setting. Variation was found to be two laboratory reporting intervals or less, with more than half of the samples having the same abuandances of the elements in both geomorphic settings.

The largest spreads in the concentration of the elements between the geomorphic settings are in areas of the most homogeneous rock types and are for the elements most likely to be in the resistate fractions of the sediments, such as niobium, yttrium and zirconium. The effect is caused by the presence of anomalous values for niobium, yttrium, and zirconium in the steep parts of the western pluton. On the pediment the values for these elements are subdued in short distances. The contribution of sediment from pediment surfaces tends to reduce the tenor of the <80-mesh sediment in niobium, yttrium, and zirconium, but even this reduction is within the accepted range of laboratory variance. For the other elements, except possibly strontium, no significant influence on the chemical composition of the <80-mesh sediment can be attributed to sedimert from distant sources on the pediment. In this area, the <80-mesh sediment is well suited for use to identify short dispersion trains of niobium, as can be seen by comparing figures 4 and 6.

Evaluation of wadi sediments as a geochemical sample medium.--Factors such as the spread in values and the maximum value reported for an element favor the <80-mesh fraction as the preferred part of the wadi sediment for use as a geochemical sample medium for boron, beryllium cobalt, chromium, copper, molybdenum, nickel, scandium, strontium, and vanadium in the Jabal Lababa area and contribute to its outstanding utility, compared to samples of rocks, for lanthanum, niobium, lead, tin, yttrium, and zirconium. This size of sediment has the additional advantage over rocks as a sample medium of permitting definition of short dispersion trains. Size fractions between <80-mesh and <200-mesh need study to determine if they are particularly suited to geochemical exploration in the wetter parts of Saudi Arabia.

Chemical characteristics of concentrates

The chemical characteristrics of the raw and the nonmagnetic concentrates from the Jabal Lababa area are given in table 10. From these data it can be seen that the removal of quartz, feldspar, and magnetite from the raw concentrate leads to the residual enrichment of iron, magnesium, calcium, titanium, manganese, cobalt, copper, lanthanum, niobium, lead, scandium, tin, tungsten, yttrium, and zirconium in the nonmagnetic concentrates. Elements depleted in the nonmagnetic concentrates compared with the raw concentrates are boron, barium, beryllium, chromium, nickel, strontium, and vanadium. Little difference is seen for bismuth and molybdenum, and no difference was made in the reported abundances of the undetected elements silver, arsenic, gold, cadmium, antimony, and zinc. The elements least affected by processing after panning and before spectrographic analysis are magnesium, titanium, cobalt, chromium, molybdenum, nickel, and vanadium; these ferride elements are commonly present in the nonmagnetic as well as magnetic minerals of the concentrates.

Panned concentrates are the only media in which bismuth and tungsten were detected. Removal of magnetite and the low-density minerals is necessary to raise the amount of tungsten above the lower limit of determination, but cleaning the raw concentrate has little influence on the detection of bismuth. For both elements the analytical response has been determined by the random presence of an appropriate mineral in the split of the concentrate taken for analysis --the well-known problem of size of sample related to meaningful analytical results where sparse small particles of ore minerals are present among overwhelmingly large amounts of other minerals in the sample (Clifton and others, 1969; Harris, 1982). For example, the amount of scheelite required to give the maximum value for tungsten in table 10, 200 ppm, would be only 0.015 volume percent of the concentrate (Theodore Botinelly, written commun., 1982).

A partition of the elements is effected by the removal of the magnetite from the raw concentrate in one process and the removal of quartz, feldspar, and other low-density minerals in the other process. Those elements most affected by the removal of magnetite are chromium, molybdenum, nickel, and vanadium. Elements whose abundances are lowered in the nonmagnetic concentrate by the removal of the low-density minerals are boron, barium, beryllium, and strontium. The removal of the low-density minerals raises the abundances of iron, titanium, manganese, copper, niobium, and tin in the nonmagnetic concentrates. Removal of both the magnetic and low-density fractions of the raw concentrats is required to cause an enrichment in magnesium, calcium, cobalt, lanthanum, lead, scandium, yttrium, and zirconium in the nonmagnetic concentrates.

The results of the spectrographic analyses of the two types of concentrates are seldom greater than two reporting intervals apart. Where they differ more widely, the range in reporting intervals for the nonmagnetic concentrates tends to be less than that for the raw concentrates. Where the greatest reported value for an element is not the same (generally censored) for the two media, the maximum values are most commonly in the nonmagnetic concentrates. Increase in both the range in reporting intervals and in the maximum values is achieved for the wanted elements lanthanum, molybdenum, niobium, tin, tungsten, yttrium, and zirconium through the use of nonmagnetic concentrates as the geochemical sample-medium of choice. Beryllium is not determined in this medium (table 10).

Concentration ratios affected by panning wadi sediments can be expressed as a comparison of the weights of the concentrate to the weight of sediment taken for panning, or as a comparison of mean abundances for elements in concentrates and in source rocks (table 23), or as a comparison of individual anomalous values for elements in the concentrates with their respective tenors in the wadi sediment or source rocks. Use of the first method leads to some extremely high ratios (table 30).

The enhancement of the abundances of the elements is not measured by these ratios, because their abundances depend on the presence of appropriate host minerals that could be absent from the concentrate. Ratios based on comparisons of weight are much more variable than ratios based on comparisons of anomalous values, because the high values for ratios based on weights identify the sparsity of heavy minerals in alluvium. The largest ratios based on weight also are for the concentrates with the greatest abundances of niobium. That is, the most niobium-rich samples from the Jabal Lababa area are those most strongly concentrated by panning. The implication of this relation, but not the certain conclusion, is that placer deposits enriched in niobium may be

Table 30.--Concentration ratios for 10-kg samples of wadi sediments

Concentrate	Weight (g)	Concentration ratio
Raw		
Maximum weight	1,877	5.3
Minimum weight	7	1,428
Mean weight	492	20.3
Nonmagnetic		
Maximum weight	1,133	8.8
Minimum weight	0.8	12,500
Mean weight	252	39.7

rare in the Jabal Lababa area.

The use of mean values for the elements to compare their abundance in various sample media to their contents in source rocks, employed in table 23 to evaluate the effects of weathering on the relative enrichment or depletion of elements, fails to show the degree of enrichment reached for the the anomalous abundances of the wanted elements. Because the number of samples with positive anomalous amounts of those elements is small, the anomalous values are lost in the large number of background values.

Concentration ratios for the wanted elements in raw and nonmagnetic concentrates containing anomalous amounts of niobium are much less than the ratios based on weights and several times greater than the ratios based on means of elemental abundance (table 23; table 31).

Table 31.--Average concentration ratios in panned concentrates containing anomalous amounts of niobium

Basis for ratio	Concentration ratios					
Raw concentrates	Weight	Nb	La	Sn	Y	Zr
Weight	789	--	--	--	--	--
Tenor in rocks	--	83	78	70	83	34
Tenor in alluvium	--	66	39	20	52	17
Nonmagnetic concentrates						
Weight	3,438	--	--	--	--	--
Tenor in rocks	--	233	133	164	388	123
Tenor in alluvium	--	179	67	164	72	36

These ratios show natural concentration taking place between rocks and alluvium for the wanted elements as well as the concentrations resulting from panning and further mechanical processing.

Some loss of niobium-bearing minerals may take place during magnetic separation of the nonmagnetic minerals owing to the weak magnetic susceptibilities of some niobium-bearing minerals. If the loss does occur, its effect is obscured by reduction of dilution caused by the presence of magnetite, quartz, and feldspar in the raw concentrate, because the positive anomalous values for niobium are greater in the nonmagnetic than in the raw concentrate (table 14).

Significant positive anomalies.--Threshold anomalous values adapted from table 14 to fit the laboratory reporting intervals for the wanted elements in the nonmagnetic concentrates are: lanthanum, 700 ppm; molybdenum, 10 ppm; niobium, 1,000 ppm; tin, 300 ppm; tungsten, 50 ppm; yttrium, 2,000 ppm; and zirconium, 1,000 ppm. The distribution of threshold and high anomalous values for these elements in the nonmagnetic concentrates is shown on figure 8. All positive anomalies for molybdenum, niobium, tin, yttrium, and zirconium are in the western pluton or immediately adjacent wall rocks. High-background values for niobium are also restricted to the western pluton. Lanthanum is present in threshold and high anomalous values in the western pluton, but a distinct field of threshold anomalous values are resent in and near the southwestern part of the eastern pluton. Absence there of the other pathfinder elements for niobium shows that the element is particularly sparse in the eastern body of quartz monzonite. The two localities in metasedimentary rocks in the northern part of the Jabal Lababa area that were the sources for positive anomalous amounts of tungsten lack anomalies for the other wanted elements in concentrates and <80-mesh sediment (fig. 6 and 7).

Concentrates from the core of the western pluton tend to contain a full suite of the elements lanthanum, niobium, tin, tungsten, and zirconium in anomalous amounts, whereas concentrates from the margin of the pluton and its contact aureole contain a restricted suite of anomalous elements consisting of niobium and yttrium to which anomalous amounts of either tin or zirconium are individually added and anomalous quantities of lanthanum appear toward the core. With the appearance of lanthanum the quantity of niobium tends to retreat to high background levels. Anomalous amounts of molybdenum and lead are present in the core of the pluton, and anomalous quantities of barium appear in nonmagnetic concentrates from the margins and the contact aureole of the western pluton. The concentrates identify a chemical zoning in the pluton and show that lanthanum is not a strong

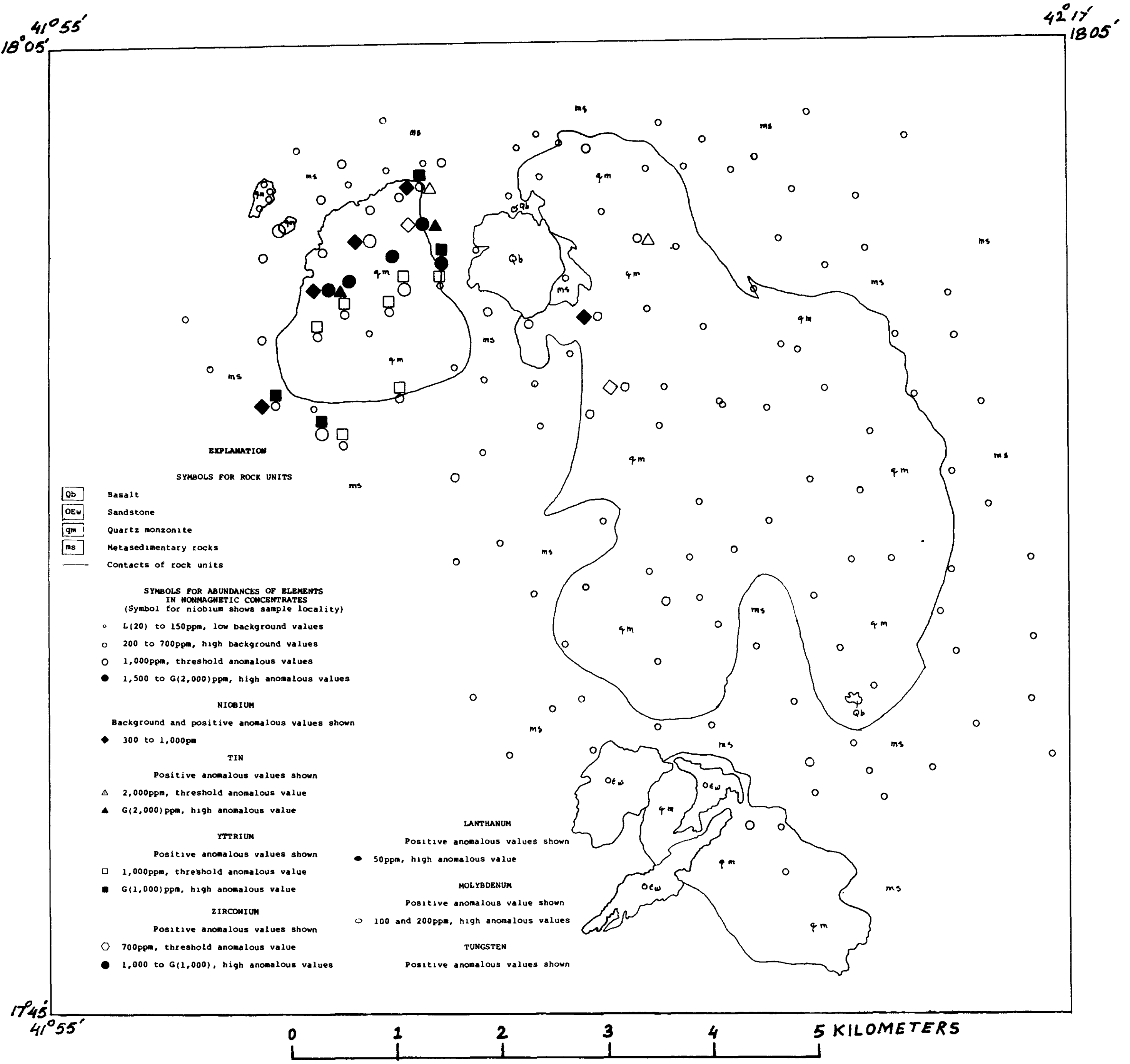


Figure 8.--Map showing the distribution of niobium and anomalous abundances of tin, yttrium, zirconium, lanthanum, molybdenum, and tungsten in nonmagnetic concentrates from the Jabal Lababa area.

pathfinder for niobium.

Anomalous amounts of lanthanum in the nonmagnetic concentrates from the eastern pluton and its contact aureole associated with anomalous quantities of cobalt, chromium, nickel, scandium, and vanadium emphasize the difference between the southwestern part of the eastern pluton and the western pluton.

About half of the localities in the western pluton from which lead-rich concentrates were obtained were also the sources of <80-mesh wdi sediment that contained anomalous amounts of lead. Thus, the part of the pluton yielding niobium-rich concentrates also is relatively enriched in lead, but independent lead-bearing minerals were not observed. Lead is probably camouflaged in high-density minerals such as fluorapatite, monazite, and xenotime. The relative abundance of the lead-bearing minerals decreases in the marginal parts of the western pluton where anomalous concentrations of niobium are present. Lead cannot be regarded as a pathfinder element for niobium in the Jabal Lababa area.

Pathfinder elements for niobium and tantalum.--Lanthanum, tin, yttrium, and zirconium were provisionally regarded to be pathfinder elements for niobium in panned concentrates, and beryllium, molybdenum, and lead were inferred to be possible pathfinders. These inferences were based on the distributions of these elements in samples of rocks and wadi sediments. In the raw and nonmagnetic concentrates, however, only tin, yttrium, and zirconium in anomalous amounts are generally associated with positive anomalies for niobium. Beryllium and lead emerge as possible pathfinder elements in the raw concentrates but not in the nonmagnetic concentrates. Although lanthanum and molybdenum are present in anomalous amounts in a few raw and nonmagnetic concentrates containing anomalous abundances of niobium, both elements also form positive anomalies in many concentrates that lack niobium.

Niobium itself is the main pathfinder element for tantalum, an element not sought in the spectrographic analyses. Some nonmagnetic concentrates qualitatively analyzed by electron microprobe and by energy dispersive spectrometric procedures showed tantalum in niobate-tantalate and yttrotanta-niobate minerals (table 4). X-ray diffraction analyses of individual minerals provided identification of staringite, a tin-bearing niobium-tantalum oxide. Yttrium and tin might therefore be regarded as possible pathfinder elements for tantalum in concentrates.

The most radioactive rocks in the Jabal Lababa area are in the high-relief part of the western pluton (fig. 2), where counts average 50 in the contact aureole, 120 in the margin, and 175 in the core. Only measurements exceeding

200 are distinctive from measurements in the eastern and southern plutons. Too few high-value measurements are associated with localities having positive anomalies for niobium to give a general usefulness to measurements of radioactivity as a method for identifying areas likely to contain anomalous amounts of niobium.

Influence of gradient and effects from pediment deposits.--The influence of the gradient in the reach of the wadi where a sample was taken is less of a factor than variation in the lithology of the source rocks. The gradient can be neglected as an extraneous factor in geochemical exploration where samples are taken using as control the grain size of the wadi sediment. For example, iron, titanium, beryllium, chromium, molybdenum, strontium, and vanadium vary by three reporting intervals or less by all gradients and lithologies, but many of these elements are commonly represented by censored values. Elements with scant variation in abundance by gradient in basins underlain by the plutons, such as magnesium, boon, cobalt, copper, lanthanum, manganese, nickel, yttrium, and zirconium, display wide variation where the sources are metasediments. The type of concentrate and the lithology of the basin are greater influences on the abundances of cadmium, barium, niobium, lead, scandium, and tin than the gradient of the wadi.

The amount of magnetite in the raw concentrates was shown to be depleted in areas covered by pediment sand and gravel (fig. 2, unit Qap) compared to areas of exposed crystalline rocks. These differences in the amount of magnetite constitute mineralogical evidence that the pediment materials produce a change in the concentrate than can affect its chemical composition. If other mineralogical differences are also present, the resulting chemical changes can be best observed in nonmagnetic concentrates where extraneous variations caused by magnetite, quartz, and feldspar are suppressed.

An element is depleted in nonmagnetic concentrates from sources that are covered, compared to sources that are exposed, if the sum of the number of samples yielding values below the mean abundance from exposed sources plus the number of samples above the mean value from covered sources is greater than the sum of the number of samples greater than the mean from exposed sources plus the number of samples less than the mean from covered sources. These sums, expressed as percentages of the number of samples in each data set, are given in table 32, where magnesium, barium, nickel, and tin are seen to be more abundant in nonmagnetic concentrates from exposed areas in both lithologic units than in covered areas. Nonmagnetic concentrates from covered areas contain more iron, cobalt, copper, lanthanum, manganese, scandium, and vanadium than concentrates from exposed areas in each lithologic unit.

Table 32.--Relative increase or decrease in the abundances of 16 elements in nonmagnetic concentrates compared to the presence or absence of surficial cover in the Jabal Lababa area.

Element	Sums of percentages of elements above and below their mean abundances in nonmagnetic concentrates from exposed and covered sources.			
	Source in plutons (43 exposed; 21 covered)		Source in metasediments (38 exposed; 39 covered)	
	Greater in exposed plus lesser in covered areas	Lesser in exposed plus greater in covered areas	Greater in exposed plus lesser in covered areas	Lesser in exposed plus greater in covered area
Fe	24	60	28	45
Mg	82	59	98	63
Ca	64	88	81	65
Ba	121	56	100	90
Co	59	77	67	86
Cr	46	89	68	48
Cu	73	97	54	73
La	69	98	86	106
Mn	56	111	31	66
Nb	121	74	90	105
Ni	99	59	86	73
Sc	50	117	39	106
Sn	114	79	92	84
V	42	128	69	71
Y	109	82	50	114
Zr	90	61	51	123

cause for this partition of Nb, Y, and Zr is the locations of their anomalous sources: Nb, Y, and Zr reach their greatest values in high-relief parts of the western pluton where cover is lacking, in the metasediments of the southern contact aureole of the western pluton where pediment sand is present but where outwash from the areas of high relief has contributed these elements.

Iron and Mn rise in abundance (table 11) in nonmagnetic concentrates from the covered areas compared to the exposed areas concomitantly with Sc. Lack of high values for Fe, Mn, and Sc in nonmagnetic concentrates from the exposed areas (fig. 2) is interpreted to reflect a lesser degree of weathering in the rapidly eroding exposed areas than in the covered parts of the pediment.

Five elements display opposite trends in nonmagnetic concentrates depending upon the lithologic unit drained by the wadi that was the source of the samples. Niobium, yttrium, and zirconium are most abundant in concentrates from exposed areas of the plutons of quartz monzonite and in oncentrates from covered areas in the metasedimentary rocks. Calcium and chromium are most abundant in concentrates from covered areas in the plutons and exposed areas in the metasediments. The cause for this partition of niobium, yttrium, and zirconium is the locations of their anomalous sources: niobium, yttrium, and zirconium reach their greatest values in high-relief parts of the western pluton where cover is lacking, in the metasediments of the southern contact aureole of the western pluton where pediment sand is present but where outwash from the area of high relief has contributed these elements.

Iron and manganese rise in abundance (table 32) in nonmagnetic concentrates from the covered areas compared to the exposed areas concomitantly with scandium. Lack of high values for iron, manganese, and scandium in nonmagnetic concentrates from the exposed areas (fig. 2) is interpreted to reflect a lesser degree of weathering in the rapidly eroding exposed areas than in the covered parts of the pediment. Although cobalt, copper, scandium, and vanadium are present in ferromagnesian minerals in the rocks, their rise in abundance in concentrates from the covered aeas compared to the exposed areas is more likely to be related to increased fixation in secondary hematite and limonite in concentrates than to some selective winnowing of ferromagnesian silicate minerals between exposed and covered areas.

Less of a difference was found for the contents of vanadium in concentrates from sources in plutonic rocks and in metasediments than was seen for the vanadium content of the <80-mesh sediment, but quite remarkable differences are displayed by the vanadium in concentrates from exposed and from covered areas in the two rock units (table 32). Covered sources in the plutonic rocks yield vanadium-enriched concentrates in contrast to exposed areas, but in the metasediments the differentiation of vanadium is extremely slight (table 32) between exposed and covered areas. These differences may also be attributable to poorly soluble sources for vanadium in the metasediments.

Lanthanum is more abundant in concentrates from the covered areas than in ones from exposed areas (table 32), a relation opposite to that found for niobium, tin, yttrium, and zirconium. The reason is thought to be that niobium, tin, yttrium, and zirconium are most abundant in the exposed parts of the western pluton, but lanthanum is widely present in anomalous amounts in the southwestern part of the southern pluton where pediment deposits are common.

Anomalously high values for tin are present in the exposed, high-relief parts of the western pluton, but in the covered parts of the eastern and southern plutons and in the metasedimentary rocks the abundances of tin are generally below the limit of determination (10 ppm). Tin shows little secondary dispersion and is not enriched in the products of weathering in the covered areas.

Lengths of dispersion trains.--Heavy mineral concentrates have long been regarded as products of mechanical dispersion in which the dispersed materials are only slightly, if at all, differentiated. Recently, concentrates have been recognized to include chemically derived materials that have precipitated from weathering solutions (Alminas and others, 1978; Watts, Alminas, and others, 1978; Watts, Hassemer, and others, 1978; Levinson, 1980, p. 356) either as coatings on resistate grains or as discrete heavy minerals. Heavy minerals in the Jabal Lababa area include secondary species of hydromorphic origin as well as resistate minerals derived by erosion of the rocks. The relative abundance of the resistate and the secondary minerals, the response of minerals in the rocks to solution during weathering, the mobility of the ions in solution, and the relative ease of adsorption of the ions during the formation of secondary minerals of hydromorphic origin are factors determining the length of the dispersion train. The most important factors, however, are original abundance, age of alluvium, hydraulic regime, and volume of barren sediments entering the drainage system below the site of mineralization.

The dominant processes reflected by the tenors of the detected elements in the nonmagnetic concentrates are mechanical dispersion and mechanical dispersion augmented by hydromorphic dispersion. Magnesium, barium, chromium, niobium, nickel, tin, yttrium, and zirconium move mainly mechanicaldispersion, whereas iron, calcium, cobalt, copper, lanthanum, manganese, scandium, and vanadium move by mechanical dispersion augmented by hdyromorphic dispersion.

Around the high-relief core of the western pluton the gradients of the wadis decrease abruptly where the wadis reach the low-relief pediments. Within 2 to 4.5 km of the high-relief areas with positive anomalies for niobium, tin, yttrium, and zirconium the tenors of these elements in nonmagnetic concentrates decline to background values. The maximum lengths of dispersion trains for these elements in the nonmagnetic concentrates is about 4.5 km (table 33).

Table 33.--Average decrease in tenors (in ppm) between nonmagnetic concentrates from areas of low relief

By distance between samples				By distance of low-relief samples from break in slope			
Nb	Sn	Y	Zr	Nb	Sn	Y	Zr
	1 to 2 km				0 to 1 km		
1,500	700	1,000	700	1,500	1,000	1,000	700
	2.5 to 3.5 km				1.5 to 2.5 km		
None	200	700	200	200	200	1,000	300
	4 to 4.5 km				3 to 4 km		
1,000	1,000	G(2,000)	700	300	300	G(2,000)	200

High values for niobium, tin, yttrium, and zirconium in the nonmagnetic concentrates are not positively correlated with high values for iron and manganese as they are in the <80-mesh sediment. Where the nonmagnetic concentrates are anomalously rich in niobium, tin, yttrium, and zirconium, these four elements are derived mainly from ore-type resistate minerals (table 4) that are more abundant in the anomalous concentrates than are the secondary iron and manganese minerals formed in hydromorphic processes. Because the amount of niobium, tin, yttrium, and zirconium derived from the ore-type minerals far exceeds that from secondary minerals, the contribution of these four elements from the secondary minerals is overridden by that from the ore-type minerals. Because of reduced abundances of the ore-type minerals, hydromorphic influences might be expected to be reasserted where niobium, tin, yttrium, and zirconium are sparse. The result might be a sympathetic rise of these elements with increases in the amounts of iron and manganese; but such a rise does not take place. The mechanical dispersion train is, therefore, the target in geochemical exploration for niobium, tin, yttrium, and zirconium in the arid environment where concentrates are used as the sample medium.

The elements whose abundances appear to be augmented in mechanical dispersion trains by hydromorphic processes -- iron, calcium, cobalt, copper, lanthanum, manganese, scandium, and vanadium -- lack localized sources from which the lengths of dispersion trains can be estimated. However, scandium and vanadium are more common in the more distantly transported concentrates than in concentrates from the heads of wadis. High-background and anomalous values for scandium and vanadium are present in concentrates taken 2 to 4 km from the heads of wadis and low-background values are present in concentrates from the heads of wadis. These differences are thought to reflect enrichment of the concentrates in scandium and vanadium throug precipitation with secondary iron and manganese minerals. These additions override the variations in composition imparted by changes in lithology. They represent true hydromorphic augmentation of mechanical dispersion. Lengths of the resulting dispersion trains are indeterminant from present data, but they appear to exceed 4 km.

No evidence for hydromorphic dispersion is found for lanthanum in nonmagnetic concentrates from the high-relief part of the western pluton. The immature sediments of that area are enriched in lanthanum-bearing heavy minerals, but mechanical dispersion trains 1 to 2 km long are sufficient to reduce the lanthanum content from anomalous to background values. Where the sediments are somewhat more mature, as in the pediment on the southwestern part of the eastern pluton, lanthanum may be slightly enriched in the nonmagnetic concentrates because of co-precipitation with iron and manganese from weathering solutions. Anomalous values for lanthanum are more common in iron and manganese-rich concentrates from downwadi than from upwadi localities. The effect of addition of lanthanum by fixation from weathering solutions is to increase dispersion trains from lengths of 1 to 2 km in areas of high gradient and immature sediments to lengths up to 4 km in areas of low gradient and more mature sediment. Another effect, possibly operative in the Jabal Lababa area, is that false lanthanum anomalies arise where high tenors in lanthanum may result by hydromorphic concentration unrelated to ore minerals.

Mechanical dispersion trains for niobium, tin, yttrium, and zirconium in nonmagnetic concentrates in the Jabal Lababa area do not exceed 4.5 km and are generally less than 2 km in length. Lanthanum has similarly short dispersion trains in areas of high relief, but where relief of wadi floors is low, mechanical dispersion is augmented by hydromorphic processes and dispersion trains greater than 4 km may be present, possibly accompanied by false positive anomalies. The abundances of scandium and vanadium are conspicuously enhanced in nonmagnetic concentrates by fixation in secondary iron and manganese minerals. Dispersion trains of scandium and vanadium exceed 4 km in length. Possibly the presence of anomalous amounts of scandium and vanadium could be used as an indication of false anomalies for other elements.

Evaluation of concentrates as a geochemical sample medium.--The clearest information on the distribution of sitive anomalous values for niobium, tin, yttrium, tungsten, and zirconium in the Jabal Lababa area is derived from concentrates, but they are unsuitable as a geochemical sample medium for beryllium, and they may possibly introduce false anomalies for lanthanum, scandium, and vanadium. The nonmagnetic concentrates are superior to raw concentrates owing to their freedom from contaminating minerals that reduce the concentration ratios for the wanted elements. Nonmagnetic concentrates can be readily examined mineralogically to determine the source minerals for an elemental anomaly, thus permitting the rapid elimination of anomalies not connected with ore minerals.

The principal disadvantage in the use of concentrates, particularly nonmagnetic concentrates, as a geochemical sample mediu is the time and labor consumed in preparation for anlaysis. Nevertheless, the excellent quality of the information they provide justifies the planning of mineral exploration programs around them as the preferred medium for ore minerals of high density in arid regions.

Principal positive geochemical anomalies and other possible ore-related features

Positive geochemical anomalies for beryllium, lanthanum, molybdenum, niobium, tin, tungsten, yttrium, and zirconium were found in the Jabal Lababa area. Tantalum is present in several niobium-bearing minerals, and thorite was identified. Positive anomalies for beryllium, lanthanum, molybdenum, niobium, tin, tantalum, thorium, tungsten, yttrium, and zirconium are mainly present in the western pluton. Thus, evaluation of the economic potential of the positive anomalies in the Jabal Lababa area focuses on the western pluton, on the kinds and amounts of the host minerals for these elements, on the way these minerals are obtained for commerce, and on the likelihood for the geologic environment at Jabal Lababa having minable deposits for some of these elements.

Beryllium

The maximum value found for beryllium in the Jabal Lababa area, 7 ppm, is only about twice as great as the crustal abundance of the element. None of the beryllium minerals with densities greater than 2.95 and known to form commercially exploitable deposits -- phenakite, chrysoberyl, helvite, and barylite (Griffitts, 1973, table 17) -- was identified in the concentrates, either mineralogically or by the presence of beryllium in the nonmagnetic concentrates. Common ore minerals with densities less than 2.95 -- beryl and bertrandite -- were not detected. The highest values for beryllium were obtained from samples of interior and exterior pegmatite dikes related to the western and eastern plutons. Raw concentrates from the core of the western pluton commonly contain positive anomalous amounts of beryllium associated with anomalous quantities of niobium, whereas niobium is lacking in beryllium-bearing concentrates from the eastern pluton.

No economic source for beryllium was found. Inasmuch as the ores for beryllium are recovered industrially by the mining and processing of rock, the remote possibility exists that some beryl might be recovered as a minor by-product if the pegmatite dikes and quartz monzonite in the core and northern flank of the western pluton were to be mined for niobium, tantalum, and the heavy rare earths. Such exploitation is most unlikely.

Lanthanum, niobium, tin, tantalum, thorium, ytrium, and zirconium

Sources.--This group of positive anomalous elements are present in resistate minerals of high density derived from the western pluton (fig. 8):

Aeschynite $(Ce, Ca, Fe, Th) (Ti, Nb)_2 (O,OH)_6$
Cassiterite SnO_2 (may contain Nb)
Ilmenite $Fe^{+2}TiO_3$ (may contain Nb)
Ilmenorutile $(Ti, Nb, Fe^{+3})_3O_6$
Monazite $(Ce, La, Nd, Th)PO_4$
Pyrochlore $(Na, Ca)_2 Nb_2O_6 (OH, F)$
Rutile TiO_2 (may contain Nb)
Staringite $(Fe^{+2}, Mn)_x (Ta, Nb)_{2x}Sn_{6-3x}O_{12}$
Thorite $ThSiO_4$
Titanite $CaTiSiO_5$ (may contain Y earths)
Xenotime YPO_4
Zircon $ZrSiO_4$ (may contain Nb)

Several unidentified species of niobium-bearing minerals are also present: a titano-niobate mineral that may be ilmenorutile; a niobate-tantalate mineral that may be a member of the pyrochlore-microlite group, and a yttro-tantaniobate minerals that may be a member of the aeschynite series, possibly tantalaeschynite-(Y) with composition $(Y, Ce, Ca) (Ta, Ti, Nb)_2O_6$. Niobium may also be present in cassiterite, ilmenite, rutile, and zircon.

The composition of most of these minerals includes a wider variety of the rare-earth elements than the general formulas indicate. The actual chemical composition of each of these minerals needs to be determined. Analyses are particularly needed for xenotime, because xenotime is the preferred ore mineral for europium, which is the most valuable of the rare-earth elements. Postorogenic granitoids in Saudi Arabia have been shown to have strong negative anomalies for europium (Stuckless and others, 1982).

Therefore, the quantity of europium in xenotime from these rocks must be considered when ores are evaluated. Present data does not include determinations of europium in these minerals, but the discussion that follows is made on the premise that the local xenotime has normal abundances of europium.

An ususual feature of the rare-earth-bearing minerals in the western pluton is the apparent dominance of yttrium earths over cerium earths. Ordinarily in granitic rocks the rium-bearing minerals monazite, apatite, fluorite, and allanite are as much as 10 times as common as the yttrium-earth minerals such as xenotime and titanite. Monazite, apatite, fluorite, and allanite dominantly contain rare-earth elements of low atomic number (lanthanum, 57; cerium, 58; neodymium, 60; and samarium, 62). Xenotime is enriched in yttrium (39) and the rare earths of high atomic number (europium, 63; gadolinium, 64; dysprosium, 66; erbium, 68; and ytterbium, 70). The tendancy for the yttrium earths to dominate over the cerium earths in the heavy minerals at Jabal Lababa is also seen in the niobium-and tantalum-bearing minerals where tantalaeschynite-(Y) and aeschynite-(Y) may be present.

The common presence of xenotime and titanite in the concentrates, as well as higher values for yttrium than for lanthanum in the concentrates (tables 4 and 10), has an economic significance in the evaluation of the positive anomalies in the western pluton (fig. 8). The ores for lanthanum and the other cerium earths have much lower market values than the ore for the yttrium earths (Industrial Minerals, 1982, p. 91; table 34).

Table 34.--Market values of ores of lanthanum and cerium earths, and yttrium and yttrium earths

	Quoted prices converted to US$ per metric ton
Ores for lanthanum and cerium earths:	
Bastnaesite concentrate, 70 percent rare-earth oxides, per pound, US $1.05	2,315
Monazite, minimum 55 percent rare-earth oxides, long ton, FOB Australia, US $400-440	393-433
Ore for yttrium and yttrium earths:	
Xenotime concentrate, 60 percent Y_2O_3, FOB Malaysia, per kg, US $46.00	46,000

This disparity in prices for the ores reflects the market values of the industrial products derived therefrom (table 35; Cannon, 1982; Molycorp, Inc., 1982):

Table 35.--Market values of rare-earth metals and oxides

Oxides (99.9 percent)	Base quantity (pounds)	US$ per pound of contained oxide
La	300	7.00
Ce	200	8.00
Nd	50	33.00
Sm (95 percent)	110	25.00
Y	50	45.00
Eu	25	825.00
Gd	70	55.00

Metals (99.9 percent (minimum)	Base quantity (pounds)	US$ per pound of metal
La	1,000	30.00
Ce	500	26.00
Nd	<10	100.00
Sm	2,000	60.00
Y	500	165.00
Gd	<10	210.00

Niobium appears from the mineralogy of the concentrates to be as much as two or three times as abundant as tantalum. Only the specialized niobium- and tantalum-bearing minerals can be considered as potential ore for these elements. Prices for the areas of these elements in 1981 are shown in table 36 (Agoos, 1982; Emerson, 1982).

The little thorite is only a small part of the thorium-bearing minerals in the concentrates. Others include aeschynite, monazite, and xenotime of which monazite is the main commercial source for thorium. On present evidence, thorium is of very minor consequence and, like beryllium, possibly could be recovered as a by-product if niobium and tantalum could be mined.

Tin is also a possible minor by-product, through the presence in the western pluton of cassiterite and

Table 36.--Market values of niobium and tantalum oxides

Niobium	US$ per pound of Nb_2O_5
Pyrochlore, Canadian	3.25
Columbite, Nigerian	8.00-10.00
Tantalum	US$ per pound of Ta_2O_5
Tantalite, minimum of 25 percent Ta_2O_5 and 55 percent of combined Ta and Nb oxides	36.85

staringite, if niobium and tantalum could be mined.

The positive anomalies for zirconium (fig. 8) are of no economic significance, because the main ore, zircon, is recovered elsewhere in quantities exceeding demand as a by-product from placers mined for ilmenite and rutile (Klemic and others, 1973, p. 714).

Rutile and ilmenite are also present in concentrates from the western pluton (table 4), but they are unlikely to contribute to the value of the deposit. Small lots of these industrial minerals are seldom salable; if they did enter commerce, it would be at discounted prices.

Essentially unweathered ilmenite from rocks has lower value than weathered ilmenite from beach placers, because of the control of the TiO_2 content by weathering and the effect of the TiO_2 content on the economics of shipping and processing. Unweathered ilmenite from igneous rocks contains 52.7 percent of TiO_2, but the ratio of titanium to iron varies widely, and some fresh ilmenite contains as little as 47 percentTiO_2. Weathered ilmenite on beaches contains as much as 60 to 62 percent TiO_2 owing to the residual enrichment resulting from the leaching of iron. Lode deposits of ilmenite are exploited for use in nearby processing plants. Where ilmenite must be shipped long distances, the cost of the contained TiO_2 becomes greater for fresh ilmenite from rocks than for weathered ilmenite from placers, and the market is therefore greater for placer ilmenite than for lode ilmenite.

The weathering history of ilmenite at the western pluton, either in the rocks or in nearby eluvial and alluvial placers, is too brief to have effected an upgrading of the

TiO_2content to acceptable specifications for economic entrance into commerce where long-distance shipping is necessary.

Where heavy minerals containing lanthanum, niobium, tin, tantalum, thoriuim, yttrium, and zirconium are mined elsewhere in the world, they are taken from deposits of quite variable size in igneous rocks or in placers. Typical commercial sources for minerals found at Jabal Lababa are shown in table 37.

Table 37.--Types of ore deposits exploited for minerals found at Jabal Lababa

Mineral identified at Jabal Lababa	Type of deposit commercially exploited elsewhere in the world
Pyrochlore	Large open-pit mines in alkalic rocks
Aeschynite, staringite, and ilmenorutile	Not generally mined, but are found in deposits resembling those of thorite
Thorite	Pegmatite dikes, small lodes and plutons containing cassiterite, residual and elluvial placers on and adjacent to the source rocks, nearby small alluvial placers
Cassiterite	Large deposits in and adjacent to granitic rocks, associated large residual, elluvial, and alluvial placers of which the last may be distant from sources; some tantalum is derived from strueverite, (Ti, Ta, $Fe^{+3})_3O_6$ recovered from cassiterite lode and placer mines; strueverite not identified at Jabal Lababa
Monazite, ilmenite, and rutile	Marine beach, bar, and related geomorphic forms, alluvial placers, rare lodes, fossil equivalents of the alluvial and marine placers
Zircon	Marine beach placer mined for ilmenite and rutile
Xenotime	Recovered through the re-working of concentrates left from the mining of alluvial placers for cassiterite

Evaluation.--On present data, none of the rocks and alluvial sediments in the Jabal Lababa area is sufficiently rich in the wanted elements to be mineable. Only a low priority for further investigations of lanthanum, molybdenum, niobium, tin, tantalum, thorium, tungsten, yttrium, and zirconium in the Jabal Lababa area is indicated until evaluations of richer sources in the northern part of the Arabian Shield in the Nidian and Ha'il-Gassim areas are made.

None of the maximum tenors of the wanted elements (table 10) approaches ore grade in rocks of the western pluton. Except for yttrium and tin, the tenors of these elements are about their respectivecrustal abundances and would require increases in concentration of 200 times or more before they would reach ore grade.

Some increases in the tenors of the wanted elements are shown in concentrates prepared from alluvium, but the nonmagnetic concentrates with anomalous contents of niobium range in weight from 0.8 to 26.6 g per 10 kg of alluvium, equal to about one-tenth of the average weight of nonmagnetic concentrates from the Jabal Lababa area. Assuming that losses in panning are equal to about 30 percent of the original weight of the concentrate in the alluvium, and that the niobium-bearing minerals constitute 3 percent of these concentrates, then a metric ton of similar alluvium would contain 100 g of niobium-bearing minerals yielding possibly 40 g of Nb_2O_5 and 10 g of Ta_2O_5. At prices in 1981-82, the value of the combined oxides in 1 metric ton of alluvium would be about US $1. If xenotime makes up as much as 6 percent of the concentrate, and is europium-bearing, its contribution to the value of the concentrate could be as much as US $9 per metric ton, and the placer deposits would be recognized as europium placers with by-product niobium and tantalum minerals. If mineable deposits for europium, niobium, and tantalum were found, then monazite, cassiterite, and thorite might become by-products. Beryl would probably not be recoverable from placers.

The weight and the mineralogy of the concentrates will vary widely with changes in the source area, age, and grain size of the sediment. These factors afford the remote possibility that coarse-grained alluvium buried under fine-grained sediment may contain larger amounts of the europium-, niobium-, and tantalum-bearing minerals than the sampled material. A combined value of US $10 per metric ton of alluvium is one-fourth or less than the minimum value needed to exploit eluvial or alluvial placers assuming that an industrial supply of water could be found for mining. The use of water for placer mining in Saudi Arabia needs independent study (United Nations, 1968).

Realistic analytical data on the europium, niobium, tin, tantalum, and thorium contents of concentrates through vertical profiles of the eluvial and alluvial sediments are needed for a reliable estimate of the tenors of placer deposits in the Jabal Lababa area. The fact that the tenors of niobium in the beds of shallow wadis near the source rocks drop off quite abruptly around the flanks of the high-relief parts of Jabal Lababa may indicate that the basal parts of the sedimentary units Qap and Qal (fig. 2) are insufficiently enriched in detrital heavy minerals to serve as an economic source for the wanted metals.

Quartz veins

Quartz lag gravel is common in the Jabal Lababa area. Most is derived from small veins formed by metamorphic differention in the rocks of the Hali Group of Ratte and Andreasen (1974). This quartz is barren. Small interior and exterior quartz veins of hydrothermal origin expelled by the plutons of quartz monzonite are geochemically nearly barren of ore metals despite the fact that some veins contain copious tourmaline. The interior veins in the western pluton locally grade into pegmatite dikes and are commonly present in parts of he pluton where concentrates have positive anomalies for the wanted elements. These veins are sparse in and around the western pluton. This spatial relation is interpreted to indicate that erosion has removed parts of the pluton in which volatile products of magmatic crystallization were segregated. Present levels of exposure of the western pluton may be too deep for enrichment in beryllium, lanthanum, molybdenum, niobium, tin, tantalum, thorium, tungsten, the yttrium earths, and zirconium.

Muscovite

Small exposures of muscovite mica were observed in some of the pegmatite dikes in and adjacent to the plutons, particularly in the northern part of the western pluton. Books of muscovite reached only about 3 cm across in deposits up to a few kilograms in weight. Weak to moderately strong A-structure was present in much of the muscovite, which would lower the value of the material in applications where sheet mica is used. These small deposits are of noncommercial size.

Possible salt dome

The gentle, subcircular, dome-like structure shown by the symbol CS on figure 2, near the coast of the Red Sea between the southern end of the westernmost lava field and the mouth of Wadi Nahb, may be a buried salt dome or buried volcanic cone. The feature was interpreted from aerial photographs but was not visited. It should be examined to determine if it reflects a salt dome.

Recommendations

Further exploration for possible lode deposits related to felsic plutonic rocks in the Jabal Lababa area is not recommended.

An evaluation of possible eluvial, alluvial, and marine beach placer deposits of niobium, tin, tantalum, thorium, and yttrium earths in the Jabal Lababa area is recommended as a low-priority phase for inclusion in future investigations of placers in Saudi Arabia. Localities for study in the Jabal Lababa area should include:

1. Alluvial deposits in short tributaries to Wadi Aramram and to Wadi Nahb in the narrow, arcuate area of low relief around the east-central, northern, and west-central breaks in slope of Jabal Lababa.
2. Eluvial deposits in the same area as 1.
3. Alluvial and eluvial deposits in the area of outwash to the south of Jabal Lababa.
4. Marine beach placers at and near the mouth of Wadi Nahb.

Two large drainage systems lead southward past the east and west sides of Jabal Lababa (fig. 2). That on the east is Wadi Aramram and that on the west is Wadi Nahb. They reach the Red Sea about 30 km to the south-southwest of Jabal Lababa. Owing to the proximity of Wadi Aramram to the northeastern and eastern sides of the western pluton, small alluvial placers containing ore minerals of niobium, tin, tantalum, thorium, and yttrium earths may have formed in the short western tributaries to Wadi Aramram that reach into the northeastern and southeastern flanks of the high-relief parts of Jabal Lababa. Short eastern tributaries to Wadi Nahb from the northern, northwestern, and western flanks of the high-relief parts of the pluton may also contain small alluvial placers. A narrow, arcuate surface of low relief, from 0.5 to 2.5 km wide, is defined between the two wadis and the west-central, northern, and east-central parts of the high-relief area of Jabal Lababa. On this surface, particularly at the breaks in slope, small alluvial placer deposits may have formed. The largest target for possible small eluvial and alluvial placers is the low-relief area extending southward from the southern and southwestern flanks of Jabal Lababa between the two main wadis.

The main channels of Wadi Aramram and Wadi Nahb are unlikely sites for minable placers of minerals containing niobium, tin, tantalum, thorium, and the yttrium earths, because the source area for these minerals, Jabal Lababa, is small in contrast to the sizes of the upwadi distributive provinces. Detrital minerals from upwadi would greatly dilute contributions from the pluton at Jabal Lababa. Lengthy alluvial transport tends to disperse the wanted heavy minerals. Dilution could be so great that the tenors in the alluvium along the channels of the two main wadis would become less than the tenors in the rocks of the western pluton.

Tributaries to Wadi Nahb drain a much larger part of Jabal Lababa and its outwash deposits than do tributaries to Wadi Aramram (fig. 2). The amount of minerals containing niobium, tin, tantalum, thorium, and the yttrium earths in the lower reaches of Wadi Nahb should be greater than in Wadi Aramram. At the mouth of Wadi Nahb the distribution of dune sand indicates movement of sand inland toward Wadi Aramram. The possibility therefore exists that beach placers may have formed at and near the mouth of Wadi Nahb through combined action of coastal currents, waves, and wind.

Conventional methods of test pitting, trenching, and sampling used for the evaluation of placers (Griffith, 1960) would probably be satisfactory for exploration of the eluvial and alluvial deposits. At each test pit the stratigraphic sequence of the alluvium, depth to bedrock, and degree of weathering of the bedrock should be recorded and heavy-mineral concentrates be prepared of measured volumes and weights of alluvium. Detailed mineralogical analyses of the concentrates should be made for each lithologic unit including weights of concentrates. Chemical analyses for the rare-earth elements, niobium, tin, tantalum, thorium, titanium, and zirconium should be made of the concentrates so that estimates of grade and reserves would not be truncated by upper limitations such as those imposed by the upper censored values reported in semiquantitative spectrographic analyses. Monomineralic samples of possible ore minerals must be analyzed to determine the actual abundances of the elements. Material suitable for radiocarbon dating should be preserved, and the micro- and megafossil record, if any, preserved in the alluvium should be examined to add to the knowledge of the Quaternary geology of Saudi Arabia.

Evaluation of beach placers on the coast of the Red Sea would be hampered by shallow water table causing flooding of test pits. To reduce the interference of flooding a two-stage evaluation is recommended in which the first stage would be based on near-surface samples, emphasizing dark streaks of natural concentrations of heavy minerals, to determine if the beach sand contains host minerals for the wanted elements. Positive resuls from the first stage would identify the need for a more costly second stage.

The second stage would be based on cribbed and pumped test pits or borehole evaluation of the beach deposits. If the inflow proved to be too great to be controlled by pumping, then drilling would be required. Owing to high water table and the tendency for beach sand to compact around the casing of churn drills, specialized drilling equipment and techniques are necessary. Various jet and vibratory drills are generally used to explore onshore and offshore marine placers (Fick, 1967; Hill, 1967; Hosking, 1971). The jet drill developed during the 1940's by the U.S. Bureau of Mines and CARPCO Engineering and Research, Inc. (1972), of Jacksonville, Fla., or a drill operating on a similar principle and manufactured by the New York Engineering Company, 159 Alexander Street, Yonkers, N. Y., are designed for use in exploration for ilmenite in marine beach placers. The jet drill is effective in fine- and even-grained sediments. It has been proven through many years of exploration for placer ilmenite, and it would be effective on the species of heavy minerals present at the mouth of Wadi Nahb.

Small jet drills are not successful in coarse gravel or bouldery ground, where a percussion drill with casing may be required. Large jet drills have been used successfully to explore bouldery offshore placers (Hill, 1967, p. 217-220). Vibratory drills are favored over the percussion drill for some conditions met in offshore placer exploration. Thus, the kind of drilling equipment needed for evaluation depends upon the kind of placer ground to be explored: gravelly and bouldery beaches require percussion or vibratory drills, but fine- and even-grained sand can be explored with small jet drills. The first stage of the beach-placer investigation would give the necessary data on which to base the selection of drill-sites. Training in the use of the jet drill is provided by CARPCO Engineering and Research, Inc., at its facility in Florida where demonstrations are also given in techniques for exploration of beach placers and in the use of the company's designs of heavy-mineral separatory equipment for placer evaluation and the industrial separation of many species of ore minerals recovered from placers.

The first and particularly the second stages can only be justified as part of a regional study of beach placers along the Red Sea coast of Saudi Arabia, because the confluence of Wadi Nahb with the Red Sea is only one of many possible sites. Geologic conditions are less favorable for marine beach placers south of Jiddah than they are to the north, particularly in the far north were drainage from the rare-metal-bearing rocks of the Midian area enters the Red Sea. A further attraction of the northern coast is the cycling of heavy minerals from the felsic plutons through sandstones of Cambrian to Devonian age to present wadis, thence to the beach. Preconcentration in the old sedimentary units would help form higher-grade beach placers than direct contributions from the felsic plutonic rocks.

A marine beach placer or alluval placers near the mouth of Wadi Nahb would have readily available industrial water from the Red Sea. However, the environmental impact of placer mining anywhere on the coast would require evaluation, particularly in the context of the effect of mining on the reef.

RESULTS IN THE AR RAYTH AREA

The pluton of porphyritic biotite granite and monzogranite (Fairer, 1982; 1983) to the southeast of Ar Rayth (fig. 9) lacks geochemical evidence of mineralization for the elements associated with felsic plutonic rocks and sought in this investigation. Niobium is below the lower limit of determination in all media, and molybdenum is at or below its lower limit of determination in all media (table 38). Tin and tungsten are at or below their lower limit of determination in all media, except the panned concentrates. Beryllium is present near or above crustal abundance, and the rare-earth elements lanthanum and yttrium are sparsely present. Zirconium is somewhat more abundant than the other wanted elements. Compared with the Jabal Lababa area (table 10), the mean values for the abundances of the wanted elements in the Ar Rayth area (table 32) are greater for beryllium and zirconium, are similar for tungsten, and are lower to considerably lower for lanthanum, molybdenum, niobium, tin, and yttrium. Positive anomalous values for the wanted elements in the various media from the Ar Rayth area are higher for beryllium and zirconium and are lower for lanthanum, molybdenum, niobium, tin, tungsten, and yttrium than in the Jabal Lababa area (tables 14 and 39). None of the positive anomalies for the wanted elements is an indication of mineralization.

Positive anomalous values for other elements mainly reflect the lithologic units: silver, arsenic, barium, bismuth, lead, and strontium are associated with the two plutons of biotite granite and cobalt, copper, manganese, scandium, and vanadium are focused in the metamorphosed wall rocks. Positive anomalies for chromium and nickel are present in the pluton where they tend to be coincident with anomalies for bismuth and lead. None provides strong indication of sulfide mineralization associated with the pluton, but these anomalies, taken with mineralogical evidence for the presence of pyrite, are interpreted to indicate sparse, locally disseminated, accessory sulfide minerals in the granite. Tramp lead, however, is the cause of the highest value for that metal.

Geologic setting and relative radioactivity of the rocks

The geologic setting of the Ar Rayth area is adapted on figure 9 from geologic maps by Brown and Jackson (1959) and G. M. Fairer (1982; 1983). Two small stocks of light gray to pink, massive, porphyritic biotite granite and monzogranite of late Precambrian age intrude metamorphosed sedimentary rocks of the Precambrian Sabya Formation and

EXPLANATION

CORRELATION OF MAP UNITS

Intrusive Rocks	Sedimentary Volcanic and Metamorphic Rocks		
	Qal Qt		QUATERNARY
	Unconformity		
g gr	bg sc sa	BAISH GROUP SABYA FORMATION	PRE-CAMBRIAN

DESCRIPTION OF MAP UNITS

(Modified from Brown and Jackson, 1959;
G.M. Fairer, 1982; 1983)

Intrusive Rocks

g	Post-tectonic porphyritic biotite granite and mongogranite
gr	Syntectonic (?) granite

Sedimentary, Volcanic, and Metamorphic Rocks

Qal	Wadi alluvium
Qt	Terrace deposits of sand and gravel
bg	BAISH GROUP Undivided -- greenstone flows, metabasalt, and massive amphibolite, local metagraywache
sc sa	SABYA FORMATION Mainly chlorite-sericite schist with local quartzite (sc); amphibolite schist of sedimentary origin with local layers of calc-silicate rocks and quartzite in upper part (sa)

———-··· CONTACT - Dashed where approximately located or inferred; dotted where concealed

STRIKE AND DIP OF FOLIATION

⊥20	Inclined
→20	BEARING AND PLUNGS OF LINEATION RELATIVE RADIOACTIVITY OF GEOLOGIC UNITS
.80	Rate of counts on scintillometer shown by underlined number; locality shown by dot or by symbol for strike and dip of foliation
.153299	Site of nonmagnetic concentrate showing sample number used for mineralogical study

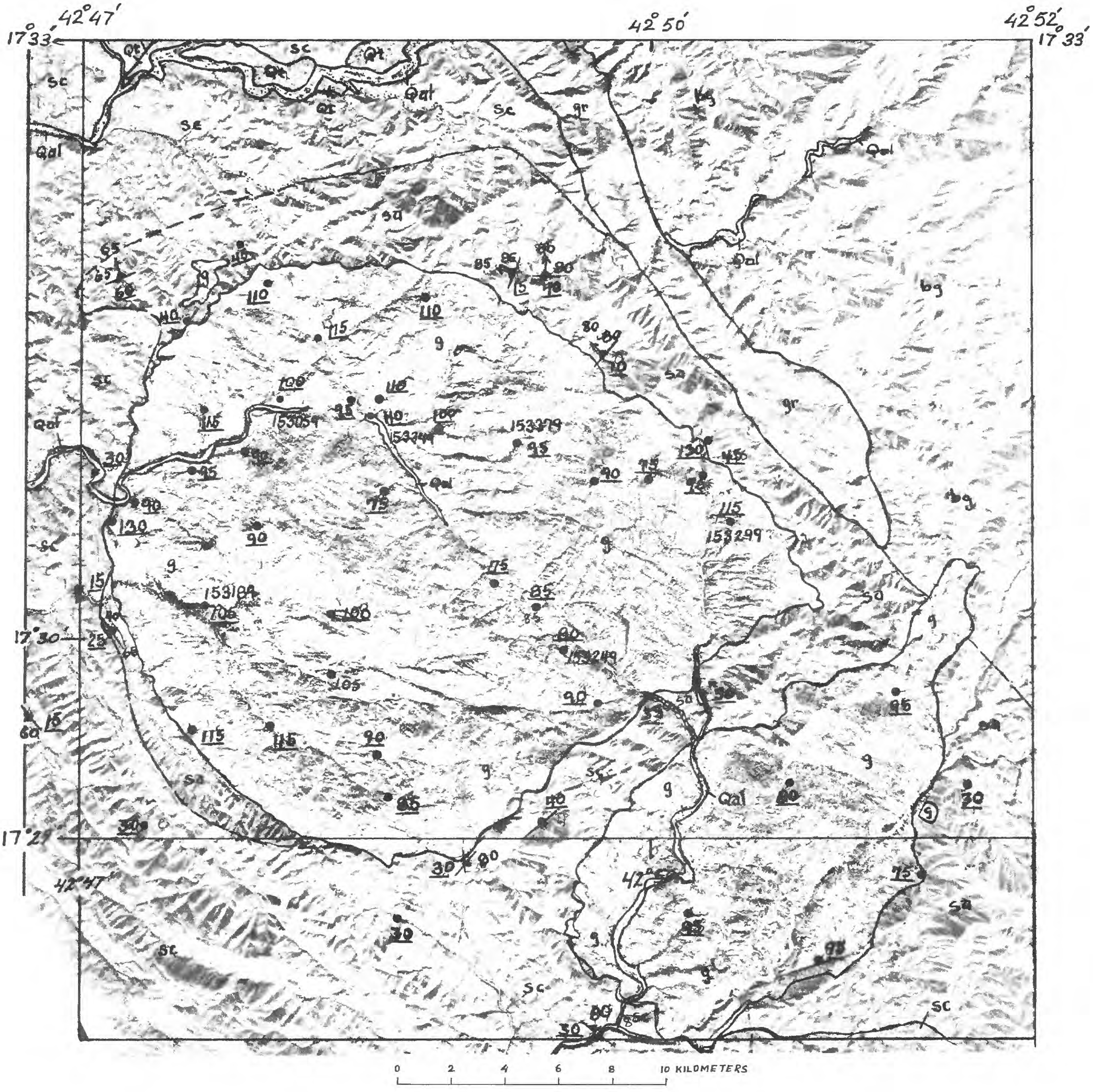


Figure 9.--Reconnaissance geologic map showing the relative radioactivity of geologic units in the biotite granite pluton to the southeast of Ar Rayth.

Table 38.--Values for 30 elements determined by semiquantitative spectrographic analyses of six varieties of geochemical sample media from the pluton of biotite granite exposed to the southeast of Ar Rayth.

[Values substituted for technically censored data are given in table 1.]

A. AR RAYTH 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	10.96	6.27	6.97	1.22	1914.12	0.94	471.93	2.00	98.03	3369.27

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	4.45	2.00	5.00	55.73	450.13	83.27	37.79	1.00	5.00	47.83

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	69.23	20.00	52.86	2.00	1359.95	329.15	10.00	51.97	93.65	345.60

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	9.53	4.58	5.49	1.13	1871.71	0.10	50.00	2.00	14.53	1599.18

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	2.65	6.07	5.00	33.37	319.42	95.51	18.76	3.03	5.00	52.42

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	44.71	20.00	45.90	7.33	1178.11	356.26	10.00	45.90	50.00	222.15

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	9.96	4.53	5.76	1.32	2378.08	0.10	50.00	2.00	14.38	1070.78

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	3.51	6.07	5.00	40.89	390.36	99.90	33.31	2.64	5.00	70.17

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	65.83	20.00	47.79	7.33	1131.77	384.30	10.00	48.60	50.00	203.36

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	9.44	5.89	6.29	1.33	1864.88	0.10	50.00	2.00	18.74	782.04

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	3.92	5.29	5.00	30.06	469.15	105.44	80.17	3.03	5.00	82.86

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	85.70	20.00	35.29	7.86	1116.52	334.36	10.00	52.55	50.00	755.39

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	25.78	5.58	7.98	1.60	3639.65	0.10	50.00	2.00	5.00	827.13

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	4.82	11.31	5.00	141.78	835.99	161.80	117.05	1.00	5.00	115.02

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	237.23	20.00	67.15	54.41	1960.71	559.54	64.23	165.15	50.00	1121.32

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	24.48	8.63	27.10	1.88	4213.65	0.10	50.00	2.00	2.00	194.88

	S-BE	S-BI	S-CD	S-CO	S-CR	S-CU	S-LA	S-MO	S-NB	S-NI
MEAN+2SD	4.59	12.78	5.00	202.37	964.54	186.24	168.34	1.00	5.00	113.58

	S-PB	S-SB	S-SC	S-SN	S-SR	S-V	S-W	S-Y	S-ZN	S-ZR
MEAN+2SD	747.41	20.00	79.29	73.11	198.20	609.20	10.00	165.01	152.69	1444.36

Table 39.--Threshold anomalous values for 30 elements in six types of geochemical sample media, Ar Rayth area.

[Anomalous values are taken as the mean plus two standard deviations from data in table 38.]

A. AR RAYTH PLUTON

1. ROCKS

	S-FE %	S-MG %	S-CA %	S-TI %	S-MN	S-AG	S-AS	S-AU	S-B	S-BA
MINIMUM	0.70	0.03	0.07	0.00	70.00	0.10	50.00	2.00	2.00	30.00
MAXIMUM	15.00	15.00	10.00	1.50	3000.00	3.00	1500.00	2.00	300.00	5000.00
MEAN	3.90	1.83	2.89	0.42	636.04	0.15	77.36	2.00	13.47	1164.91
STD.DEV.	3.53	2.22	2.04	0.40	639.04	0.39	197.28	0.00	42.28	1102.18

	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	30.00	2.00	5.00	1.00	5.00	1.00
MAXIMUM	7.00	2.00	5.00	150.00	700.00	150.00	50.00	1.00	5.00	70.00
MEAN	1.71	2.00	5.00	11.00	199.25	28.66	17.55	1.00	5.00	17.43
STD.DEV.	1.37	0.00	0.00	22.37	125.44	27.31	10.12	0.00	0.00	15.20

	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	15.00	10.00	2.00	50.00	2.00
MAXIMUM	70.00	20.00	70.00	2.00	1500.00	500.00	10.00	70.00	200.00	700.00
MEAN	26.79	20.00	14.11	2.00	608.87	107.55	10.00	15.00	52.83	135.70
STD.BEV.	21.22	0.00	19.37	0.00	375.54	110.80	0.00	18.49	20.41	104.95

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	0.50	0.15	0.70	0.03	70.00	0.10	50.00	2.00	2.00	70.00
MAXIMUM	10.00	5.00	5.00	1.50	3000.00	0.10	50.00	2.00	30.00	1500.00
MEAN	3.15	1.49	2.25	0.38	572.00	0.10	50.00	2.00	5.96	751.64
STD.DEV.	3.19	1.54	1.62	0.38	649.85	0.00	0.00	0.00	4.29	423.77

	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	2.00	2.00	5.00	1.00	5.00	5.00
MAXIMUM	3.00	10.00	5.00	70.00	300.00	100.00	20.00	5.00	5.00	70.00
MEAN	1.29	2.44	5.00	8.76	184.95	35.40	9.82	1.22	5.00	20.11
STD.DEV.	0.68	1.82	0.00	12.30	67.24	30.05	4.47	0.91	0.00	16.15

	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	2.00	10.00	2.00	50.00	5.00
MAXIMUM	70.00	20.00	50.00	10.00	1000.00	500.00	10.00	70.00	50.00	300.00
MEAN	18.87	20.00	12.33	2.73	602.73	104.13	10.00	12.58	50.00	82.91
STD.BEV.	12.92	0.00	16.79	2.30	287.69	126.07	0.00	16.66	0.00	69.62

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	1.50	0.50	1.00	0.10	200.00	0.10	50.00	2.00	2.00	70.00
MAXIMUM	10.00	5.00	7.00	1.50	3000.00	0.10	50.00	2.00	30.00	1000.00
MEAN	4.96	2.21	3.07	0.58	949.09	0.10	50.00	2.00	5.82	509.45
STD.DEV.	2.50	1.16	1.34	0.37	714.49	0.00	0.00	0.00	4.28	280.66

	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	2.00	2.00	5.00	1.00	5.00	10.00
MAXIMUM	3.00	10.00	5.00	70.00	500.00	100.00	30.00	5.00	5.00	70.00
MEAN	1.69	2.44	5.00	15.18	210.95	39.64	16.00	1.15	5.00	36.55
STD.DEV.	0.91	1.82	0.00	12.85	89.71	30.13	8.66	0.75	0.00	16.81

	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	30.00	10.00	2.00	50.00	30.00
MAXIMUM	70.00	20.00	50.00	10.00	1000.00	500.00	10.00	70.00	50.00	200.00
MEAN	26.62	20.00	15.22	2.73	580.91	141.45	10.00	17.09	50.00	109.64
STD.DEV.	19.60	0.00	16.28	2.30	275.43	121.42	0.00	15.76	0.00	46.86

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	2.00	0.30	500.00	0.10	50.00	2.00	2.00	100.00
MAXIMUM	10.00	5.00	5.00	1.50	2000.00	0.10	50.00	2.00	30.00	700.00
MEAN	6.78	3.13	4.51	0.83	1063.64	0.10	50.00	2.00	7.05	380.91
STD.DEV.	1.33	1.38	0.89	0.25	400.62	0.00	0.00	0.00	5.84	200.57

	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	2.00	10.00	5.00	1.00	5.00	30.00
MAXIMUM	3.00	10.00	5.00	50.00	700.00	100.00	100.00	5.00	5.00	70.00
MEAN	1.87	2.29	5.00	16.09	239.13	51.64	33.73	1.22	5.00	52.91
STD.DEV.	1.03	1.50	0.00	6.99	115.01	26.90	23.22	0.91	0.00	14.98

	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	10.00	2.00	150.00	70.00	10.00	15.00	50.00	70.00
MAXIMUM	150.00	20.00	30.00	10.00	1500.00	500.00	10.00	50.00	50.00	700.00
MEAN	30.58	20.00	21.45	2.87	544.55	187.64	10.00	29.45	50.00	351.45
STD.DEV.	27.56	0.00	6.92	2.49	285.99	73.36	0.00	11.55	0.00	201.97

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	0.20	2.00	0.15	700.00	0.10	50.00	2.00	5.00	50.00
MAXIMUM	30.00	5.00	7.00	1.50	5000.00	0.10	50.00	2.00	5.00	1000.00
MEAN	13.02	2.55	5.02	0.86	1536.36	0.10	50.00	2.00	5.00	331.64
STD.DEV.	6.38	1.51	1.48	0.37	1051.64	0.00	0.00	0.00	0.00	247.74

	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	20.00
MAXIMUM	5.00	10.00	5.00	200.00	1000.00	200.00	150.00	1.00	5.00	100.00
MEAN	1.86	4.18	5.00	44.91	432.73	60.00	44.64	1.00	5.00	69.27
STD.DEV.	1.48	3.56	0.00	48.43	201.63	50.90	36.20	0.00	0.00	22.87

	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	20.00	100.00	10.00	15.00	50.00	70.00
MAXIMUM	500.00	20.00	70.00	150.00	3000.00	700.00	200.00	200.00	50.00	1500.00
MEAN	71.04	20.00	29.67	6.98	772.18	280.91	13.45	61.36	50.00	468.73
STD.DEV.	83.09	0.00	18.74	23.71	594.27	139.31	25.39	51.90	0.00	326.30

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	0.20	3.00	0.50	700.00	0.10	50.00	2.00	2.00	5.00
MAXIMUM	30.00	10.00	30.00	1.50	7000.00	0.10	50.00	2.00	2.00	200.00
MEAN	13.38	3.81	11.80	1.35	1812.73	0.10	50.00	2.00	2.00	97.36
STD.DEV.	5.55	2.41	7.65	0.26	1200.46	0.00	0.00	0.00	0.00	48.76

	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	70.00	10.00	5.00	1.00	5.00	15.00
MAXIMUM	5.00	20.00	5.00	300.00	1000.00	300.00	150.00	1.00	5.00	100.00
MEAN	1.74	3.89	5.00	55.36	429.27	68.36	67.73	1.00	5.00	64.36
STD.DEV.	1.42	4.44	0.00	73.50	267.64	58.94	50.31	0.00	0.00	24.61

	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	200.00	10.00	20.00	50.00	50.00
MAXIMUM	1500.00	20.00	100.00	150.00	200.00	500.00	10.00	200.00	300.00	1500.00
MEAN	150.73	20.00	37.98	22.44	75.64	385.45	10.00	82.18	59.09	606.00
STD.DEV.	298.34	0.00	20.65	25.34	61.28	111.87	0.00	41.42	46.80	419.18

metamorphosed volcanic and sedimentary rocks of the Precambrian Baish Group. An elongate mass of possibly syntectonic granite occupies the contact between the Sabya Formation and the Baish Group in the northern part of the area. Small terrace deposits and alluvium of Quaternary age are found in the major wadis, and accumulations of aeolian silt (not shown at the scale of fig. 9) as much as 3.5 m thick overlie gruss and saprolite on some of the high ridges in the main pluton of granite.

Dikes and veins are scarce in the plutons and their wall rocks. Small, thin, interior dikes of fine-grained felsite grade by change of composition and grain size into simple pegmatite dikes and veins of milky quartz. In chlorite schist scattered massive veins of white quartz contain small boxworks of dissolved calcite, and of pyrite that is altered through weathering to powdery limonite. Evidence for hydrothermal alteration in the plutons and wall rocks is lacking.

The relative radioactivity is higher in the granitic plutons than in the metamorphic rocks (fig. 9). Average values for the main pluton and the small pluton are 100 cps and 90 cps, respectively, and for the metamorphic rocks is 35 cps. In the Ar Rayth area the radioactivity of the granite is somewhat less than that of the western pluton at Jabal Lababa but is similar to the eastern and southern plutons in that area.

The effects of rock weathering can be seen at many scales, from the lower altitude of the tops of the two plutons compared with the altitudes of the surrounding ridges of metamorphic rocks, to the presence of saprolite on all high ridges of the main pluton. The freshest rock is in the valleys. In this respect, the topographic expression of weathering in the Ar Rayth area is the reverse of that at Jabal Lababa. Coarse-grained sediment is also more common in the alluvium in the Ar Rayth area than in the Jabal Lababa area (table 40).

The tendency for the alluvium in the Ar Rayth area to be coarser-grained than that in the Jabal Lababa area relates to the porphyritic texture of the granite at Ar Rayth, where phenocrysts of feldspar in the granite reach 2 X 3 X 5 cm and produce coarse-grained debris.

Mineralogy of selected nonmagnetic concentrates

Six nonmagnetic concentrates from the area of the main granitic pluton in the Ar Rath area (fig. 9) were studied by X-ray diffraction to determine the main minerals present. Amphiboles, epidote, garnet, hematite, limonite, and apatite

Table 40.--Sieve fractions of wadi sediment from Ar Rayth and Jabal Lababa

Source of sediment	>10	<10+32	<32+80	<80
		Sieve fractions (Weight percent)		
Ar Rayth				
Granite	45	35	13	7
Metamorphic rocks	49	32	14	5
All alluvium	47	34	13	6
Jabal Lababa				
All alluvium	32	38	24	6

are the most abundant minerals (table 41). None of the niobium-bearing minerals in the concentrates from the Jabal Lababa area was found at Ar Rayth. A trace of thorite was identified in three concentrates, but the radioactivity of the sources was not anomalous (fig. 9); therefore, the pluton cannot be regarded as enriched in thorium. All six concentrates contain anomalous amounts of titanium, reflecting the common presence of titanite. Despite the presence of zircon in three concentrates, only two (153249 and 153379) have positive anomalies for zirconium. One of these, number 153249, is the only concentrate among the six to have a positive anomaly for yttrium, which may be in the zircon. Apatite and garnet may account for the positive anomalies for lanthanum in samples 153059, 153189, and 153378, none of which exceed 150 pm. Threshold anomalies for chromium and nickel in samples 153249 and 153349 may be caused by amphiboles or limonite. Three of the concentrates have the largest anomalies for lead of any samples from the area: 153059, 1500 ppm lead; 153249, 1,000 ppm lead; and 153379, 1,500 ppm lead. Tramp metallic lead was identified in 153059 (table 41), but mineralogical sources for the lead in the other nonmagnetic concentrates is obscure. Apatite or limonite are possibilities, but the presence of the tramp metal in one concentrate casts coubt on possible natural sources for the other anomalies.

No significant ore minerals were identified in the nonmagnetic concentrates from the Ar Rayth area. Weights of both the magnetic (figs. 3 and 10) and nonmagnetic fractions of concentrates panned from the standard 10-kg samples of wadi sediment at Ar Rayth are notably less than in the Jabal Lababa area (table 42).

Contours of the weights of magnetite in the wadi

Table 41.--Mineralogical composition of six nonmagnetic concentrates from the Ar Rayth area.

Sample number (fig. 9)	Major minerals	Minor minerals	Trace minerals
153059	Hematite, hornblende, tirodite, titanite, apatite	Ilmenite, epidote, limonite, zircon	Lead, garnet, kaersutite, richterite, piedmontite, rutile, thorite
153189	Tirodite, titanite, apatite	Magnetite	Diopside, mica, ilmenite
153249	Hematite, ilmenite, hornblende, tirodite, titanite, apatite	Epidote, garnet, limonite, biotite	Magnetite, rutile, piedmontite, thorite, zircon
153299	Tirodite, titanite, apatite	Hematite	Magnetite
153349	Hematite, tirodite, titanite, apatite	Magnetite	None identified
153379	Hematite, epidote, hornblende, kaersutite, richterite, titanite, apatite	Limonite, garnet	Magnetite, biotite, thorite, zircon

sediment from the Ar Rayth area (fig. 10) define a mineralogical zoning in the main pluton of biotite granite. The greatest weights of magnetite are in concentrates from the northern part of the pluton. This zoning is reflected chemically in the raw concentrates, which contain magnetite, by positive anomalies for chromiun, nickel, and vanadium, none of which appear to have economic significance.

Significance of positive geochemical anomalies

The number of both the undetermined and the characteristic elements in the sample media from the Ar Rayth area (table 43) surpass the numbers at Jabal Lababa (table 11), but the rare, scarce, and common elements are less numerous in samples from Ar Rayth. Nevertheless, a progressive rise in the frequency of identification from rock samples to the <80-mesh fraction of alluvium in the Ar Rayth area is seen for the common, abundant, and characteristic elements. Silver and arsenic, scarce elements in samples of rocks, fall to the undetermined category in the other media; tin, tungsten, and zinc rise to scarce in the concentrates, and bismuth rises to common in the nonmagnetic concentrates. Anomalous amounts of silver, arsenic, bismuth, lead, and zinc in one or more geochemical sample media (table 39) from the main pluton and its immediately adjacent wallrock (fig. 11) are the only significant positive anomalies in the area.

The single anomaly for silver in a sample of rock, 3 ppm, is accompanied by an anomalous value of 20 ppm for bismuth in the nonmagnetic concentrate from the same locality. Both anomalies could be dismissed as examples of variation in the presence of silver and bismuth in the splits of the samples taken for analysis, but variation in two samples from the same locality is not likely, and the locality is in the immeiate contact zone of the main pluton near the source of the single sample of rock yielding the highly anomalous value of 1,500 ppm arsenic (fig. 11). Elsewhere in the pluton anomalous values for bismuth and lead are closely associated, including the false anomaly attributable to tramp lead, and the sites of the zinc anomalies in the wallrocks are also sources for anomalous amounts of lead. Lead is the most common of these anomalous elements as might be expected because it is an abundant and characteristic element in the pluton (table 43). The source minerals for these anomalies have not been identified, but probably such sulfides as pyrite, arsenopyrite, and galena are present in small amounts. No evidence ,for large concentrations of these elements was found. The distribution of the multiple anomalies and of arsenic in or near the contacts of the pluton, or in the magnetite-rich part of the pluton, suggests chemical zoning, but indications of ore-grade concentrations were not observed.

Table 42.--Mean weights of magnetic and nonmagnetic fractions of panned concentrates from Ar Rayth and Jabal Lababa areas

Source	Mean weight of panned concentrates (g)		
	Raw concentrate	Magnetic concentrate	Nonmagnetic concentrate
Ar Rayth area			
Granite	65.7	8.0	29.4
Metamorphic rocks	61.2	2.5	37.3
All concentrates	63.4	5.8	32.5
Jabal Lababa area			
All concentrates	492.8	160.1	252.5

The consistent appearance of beryllium as an abundant element in all sample media (table 43), and the rise of the threshold anomalous value for beryllium from 3 ppm in the sized fractions of wadi sediments to 5 ppm in the rocks and concentrates suggests that the source may be in a resistate mineral of high density, but it was not identified. Its anomalous sources are evenly distributed through the net of samples in the main pluton, but the small pluton lacks samples having anomalous amounts of beryllium. The <80-mesh fraction of wadi sediment gives the broadcast pattern of anomalies, with 20 localities showing 3 ppm beryllium. None of these data indicates ore-grade rock, but they show that the biotite granite pluton near Ar Rayth contains somewhat more than crustal abundance of the element.

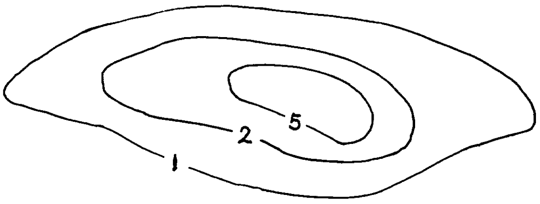
The declines in abundances of Ba and Sr from threshold anomalous values of 3,000 ppm and 1,500 ppm, respectively, in rocks to 200 ppm each in nonmagnetic concentrates show that these elements are camouflaged in feldspars, and their anomalies lack economic meaning. Anomalous amounts of these elements are widely present in both plutons, including the northern part of the main pluton where Pb is commonly present in anomalous amounts, but the values for Ba and Sr do not appear to indicate hydrothermal alteration.

EXPLANATION

SYMBOLS FOR ROCK UNITS

g	Post-tectonic granite
gr	Syntectonic (?) granite
m	Metamorphosed sedimentary and volcanic rocks
———	Contacts of rock units

CONTOURS FOR DETRITAL MAGNETITE



Contours at intervals of 1g, 2g, 5g, 10g, and 20g (Based on weights of detrital magnetite in 10-kg samples of wadi sediment.)

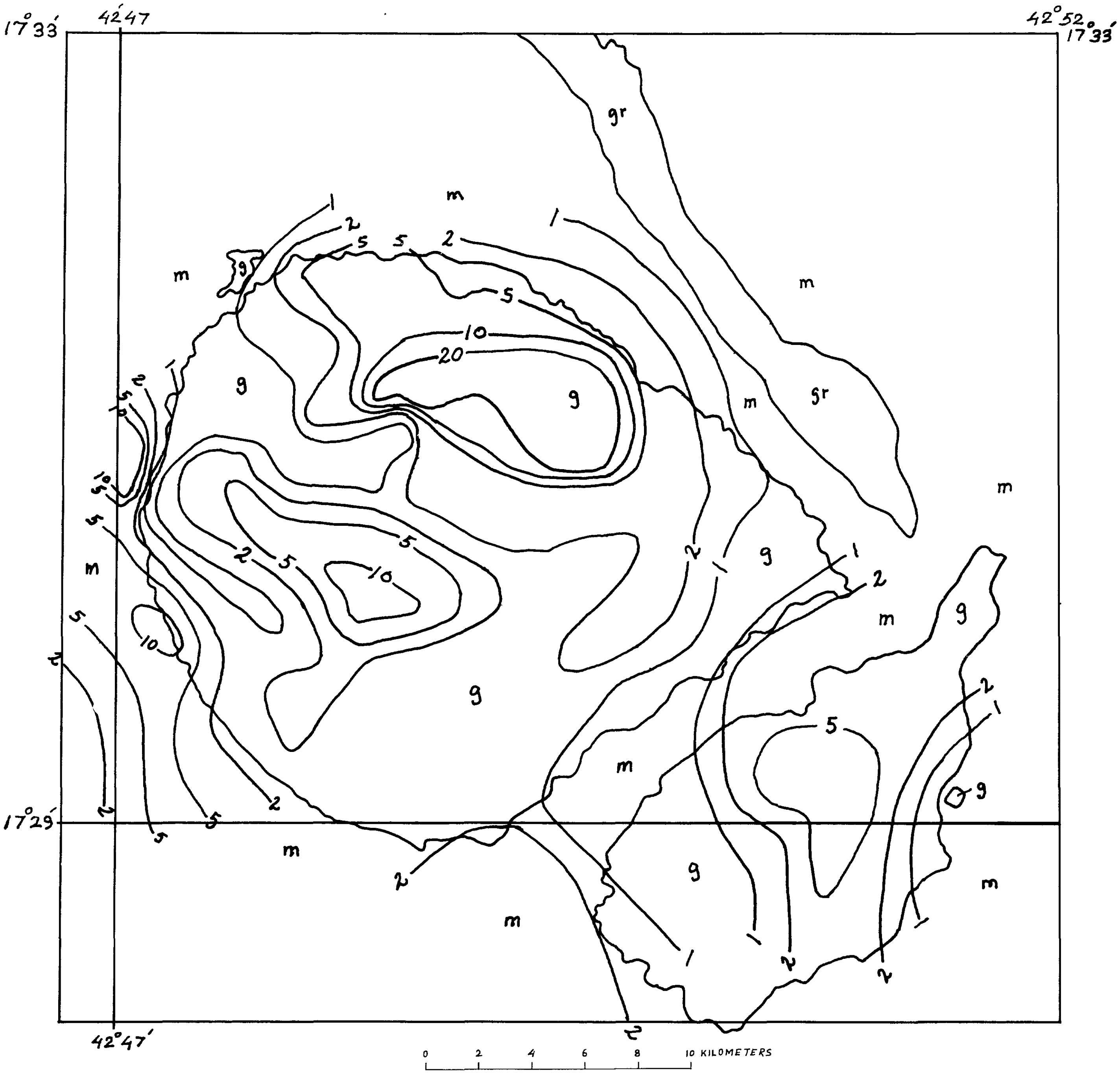


Figure 10.—Contour map showing distribution of detrital magnetite in panned concentrates from the Ar Rayth area.

EXPLANATION

SYMBOLS FOR ROCK UNITS

g	Post-tectonic granite
gr	Syntectonic (?) granite
m	Metamorphosed sedimentary and volcanic rocks

SYMBOLS FOR ANOMALOUS CONCENTRATIONS OF ELEMENTS

(All anomalous values for Ag, As, Bi, Pb, and Zn in the six media shown in table 14 are plotted, but where two or more media from one locality are anomalous for a given element, only one symbol is used)

○	Lead
◒	Bismuth
●	Lead and bismuth
△	Silver and bismuth
⧇	Zinc and lead
⬢	Arsenic

Elemental anomalies

Sample medium	Anomalous values (in ppm)				
	Ag	As	Bi	Pb	Zn
Rocks	3	1,500	-	70	200-300
Wadi sediment					
¼10+32-mesh	-	-	-	50-70	-
¼32+80-mesh	-	-	-	70	-
¼80-mesh	-	-	-	100-150	-
Concentrates					
Raw	-	-	-	300-500	-
Nonmagnetic	-	-	15-20	1,000-1,500	-

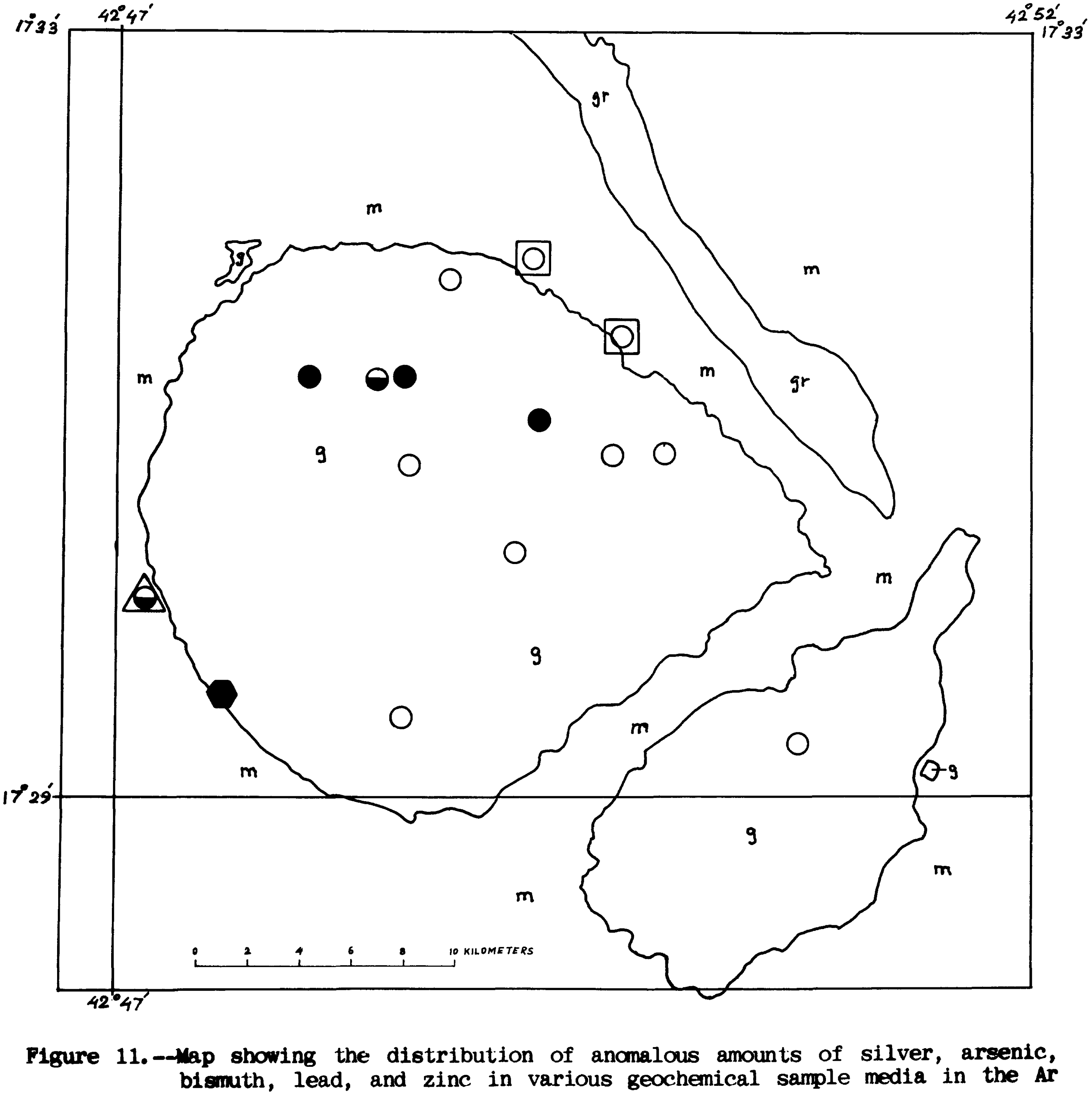


Figure 11.--Map showing the distribution of anomalous amounts of silver, arsenic, bismuth, lead, and zinc in various geochemical sample media in the Ar Rayth area.

Table 43.--Classification of the elements on the basis of the percentage of samples in each medium containing the element, Ar Rayth area.

Classification of element	Percent of samples	Elements in each class by sample medium					
		Rock	Wadi sediment			Concentrates	
			<10+32-mesh fraction	<32+80-mesh fraction	<80-mesh fraction	Raw	Nonmagnetic
Characteristic	90-100	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Ni, Sr, V, Zr	Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, Ni Sr, V	Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, Ni, 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, Pb, Sc, V, Y, Zr
Abundant	50-89	Be, Cu, La, Pb	Be, Pb	Be, Pb, Sc, Y	Be, La, Pb	Be, La, Pb	Be, La, Sn
Common	10-49	B, Co, Sc, Y	B, Co, La, Sc, Y	La	B	---	Bi, Sr
Scarce	2-9	Ag, As	---	B	---	Sn, W	Zn
Rare	<2	---	---	---	---	---	---
Undetermined	0	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, Bi, Cd, Mo, Nb, Sc, Sn, W, Zn	Ag, As, Au, B, Bi, Cd, Mo, Nb, Sb, Zn	Ag, As, Au, B, Cd, Mo, Nb, Sb, W

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

Recommendations

The plutons of biotite granite in the Ar Rayth area are not sources for the wanted elements La, Mo, Nb, Sn, W, Y, and Zr, but the main pluton is slightly enriched in Be of the wanted group of elements and possibly sulfide-associated Ag, As, Bi, Pb, and An. Collateral evidence for possible deposits of these elements was not observed; therefore, further exploration of this area is not recommended.

DATA STORAGE

No mineral occurrences were added to the Mineral Occurrence Documentation System (MODS) data base as a result of this study. Base-data file USGS-DF-04-27 (Overstreet and others, 1984) has been established for this study.

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APPENDIX

Details of the standard coding procedure used in Requests for Analysis to the DGMR-USGS Chemical Laboratory are given by Wilch (1978) for the Rock analysis storage system (RASS) used in Saudi Arabia. Special coding used in this investigation on the Rock Analysis Storage System--Sample Description Coding Form includes:

Field 3.--Identified on the form as "Personal Field No." is used for personal field station numbers. These numbers are entered on aerial photographs and in the field notebooks to identify localities where observations were made and samples were taken. More than one sample was taken at each field station.

Field 4.--Latitude and longitude of the field station is the same for each sample taken at that station.

Field 8.--This Free Coding Space is divided into 14 columns used as follows:

1. Degree of weathering of outcropping rocks: A, fresh; B, moderately weathered; C, strongly weathered.
2. Gradient of wadi floor at field station: A, gentle; B, moderate; C, steep.
3. Class of coarsest sedimentary deposits at locality in wadi where alluvium was sampled:
    A. Gruss and saprolite.
    B. Gruss with wind- or water-deposited silt and sand.
    C. Wind- and (or) water-deposited high silt and sand.
    D. Agricultural terrace deposit.
    E. Boulder-bed wadi.
    F. Boulder- and cobble-bed wadi.
    G. Boulder- and pebble-bed wadi.
    H. Boulder- and sand-bed wadi.
    I. Cobble-bed wadi.
    J. Cobble- and sand-bed wadi.
    L. Pebble-bed wadi.
    M. Pebble- and sand-bed wadi.
    N. Sand-bed wadi.
4. Features possibly contributing allochthonous minerals to sample of wadi sediment:
    A. Gravel-covered pediment.
    B. Sand dunes.
5. Sieve size of sediments used for spectrographic analysis:
    A. Minus 10-mesh plus 32-mesh.
    B. Minus 32-mesh plus 80-mesh.
    C. Minus 80-mesh.

6\. Fraction of panned concentrate used for spectrographic analysis:
   A. Raw concentrate as panned.
   B. Magnetic fraction.
   C. Raw nonmagnetic fraction.
   D. Heavy nonmagnetic fraction after separation in acetylene tetrabromide, density 2.96.

7 - 9. Scintillometer reading for rocks described in Fields 6 and 7 arranged with units in column 9, tens in column 8, and hundreds in column 7.

10 - 14. Weight in grams of sieved fractions of wadi sediment (column 5) or of concentrate (column 6) given to 01 gram. Tenths of a gram are in column 14 and a decimal point is understood to occupy a position between columns 13 and 14. Units are in column 13; tens in column 12; hundreds in column 11; and thousands in column 10.