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MINERAL POTENTIAL OF SELECTED FELSIC PLUTONS IN THE EASTERN AND SOUTHEASTERN ARABIAN SHIELD, KINGDOM OF SAUDI ARABIA

by

Edward A. du Bray

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ABSTRACT

Sixteen well-defined geochemical anomalies associated with felsic plutons and (or) muscovite-bearing plutons of Proterozoic age have been identified in the eastern and southeastern Arabian Shield. The majority of these plutons are highly evolved, granitophile-element-enriched muscovite-bearing granites that are weakly peraluminous.

A followup study of the mineral potential of these plutons included detailed geologic mapping, extensive geochemical sampling, ground traverses, and petrographic and petrologic studies. A total of 212 samples was collected for geochemical analysis, and a lesser number were collected for petrographic studies.

Most of the plutons studied are similar to metallogenically specialized granites described elsewhere in the world and found associated with deposits of tin, tungsten, or molybdenum and other rare metals. Only four of the plutons, the Sitarah, Tarban, and Gaharra monzogranites and the Bwana granite, contained highly anomalous amounts of tin, tungsten, or molybdenum and altered zones and (or) numerous quartz veins and otherwise appeared to have noteworthy mineral potential. Additional work on at least these four plutons is suggested.

INTRODUCTION

A reconnaissance geochemical survey of the Arabian Shield (P. K. Theobald, written commun., 1982) demonstrated that parts of the eastern and southeastern Arabian Shield are geochemically anomalous and may contain deposits of tin, tungsten, molybdenum, and (or) other rare metals. Other studies (Theobald, (1970/1971); Dodge, 1973; Theobald and Allcott, (1973/1975) Dodge and Helaby, 1975) had already defined some of these anomalies and emphasized their potential. In 1977, as part of the Felsic Plutonic Rocks Project (FPRP), the U.S. Geological Survey (USGS) outlined a series of regional studies of mineral potential associated with felsic plutonic rocks. One study was initiated during 1977 by J. E. Elliott in the eastern and southeastern Arabian Shield and was completed by du Bray and others (unpub. data). Elliott (in press) completed a

1/ US Geological Survey, Menlo Park, CA

detailed followup study of the Gaharra monzogranite, one of the geochemically anomalous felsic plutons in the southeastern Arabian Shield. The present report pertains to 16 plutons (fig. 1) that were identified by du Bray and others (unpub. data) and deemed to have some mineral potential. The Gaharra monzogranite is mentioned throughout this report, and the reader is directed to the work of Elliott (unpub. data) for its description and evaluation.

Geologic investigations conducted elsewhere in the world have demonstrated an association between highly evolved granitoid rocks (in the IUGS classification (Streckeisen, 1976), intrusive rocks with Q between 20 and 60 percent) and deposits of tin, tungsten, molybdenum, and (or) other rare metals (Chappell and White, 1974; Tischendorf, 1977; Groves and McCarthy, 1978; Ishihara and others, 1980). Investigations conducted in the Arabian Shield (Drysdall, 1979; Elliott, unpub. data; Stoeser and Elliott, 1980; du Bray, unpub. data; Ramsay, 1982a,b) have suggested that there exist, amongst numerous calc-alkaline plutons, varieties of granite that are similar to those found elsewhere in the world associated with deposits of tin, tungsten, molybdenum, and (or) other rare metals. The potential for certain types of ore deposits in the highly evolved felsic plutons of the Arabian Shield, however, is as yet undocumented. Discovery of a quartz-wolframite vein stockwork, associated with a small, highly evolved granite in the northeastern Arabian Shield (Cole and others, 1981), indicated that the Arabian Shield geologic environment is appropriate for deposits of tin and tungsten associated with highly evolved felsic plutons and that other similar deposits may be present.

The geochemically anomalous granitoid rocks discussed here are among the younger plutonic rocks exposed in the Proterozoic Arabian Shield. These plutons intrude andesitic and dacitic volcanic and volcaniclastic rocks of the Hulayfah group and immature sedimentary rocks of the Murdama group. Layered rocks assigned to the Hulayfah group were deposited between 800 and 700 Ma ago and then intruded by coeval dioritic rocks and are thought to be part of ensimatic arc terranes that were successively accreted to the Arabian plate during its cratonization (Greenwood and others, 1982/1983). Rocks of the Murdama group were deposited after accretionary events coincident with the beginning of a collisional event 670 Ma ago and then intruded by batholiths composed of granite, granodiorite, and tonalite (Schmidt and others, 1979; Greenwood and others, 1980, 1982/1983). Rocks of the Murdama and Hulayfah groups were regionally metamorphosed at greenschist-facies conditions and were locally contact metamorphosed at amphibolite facies conditions during pluton emplacement and have been multiply deformed.

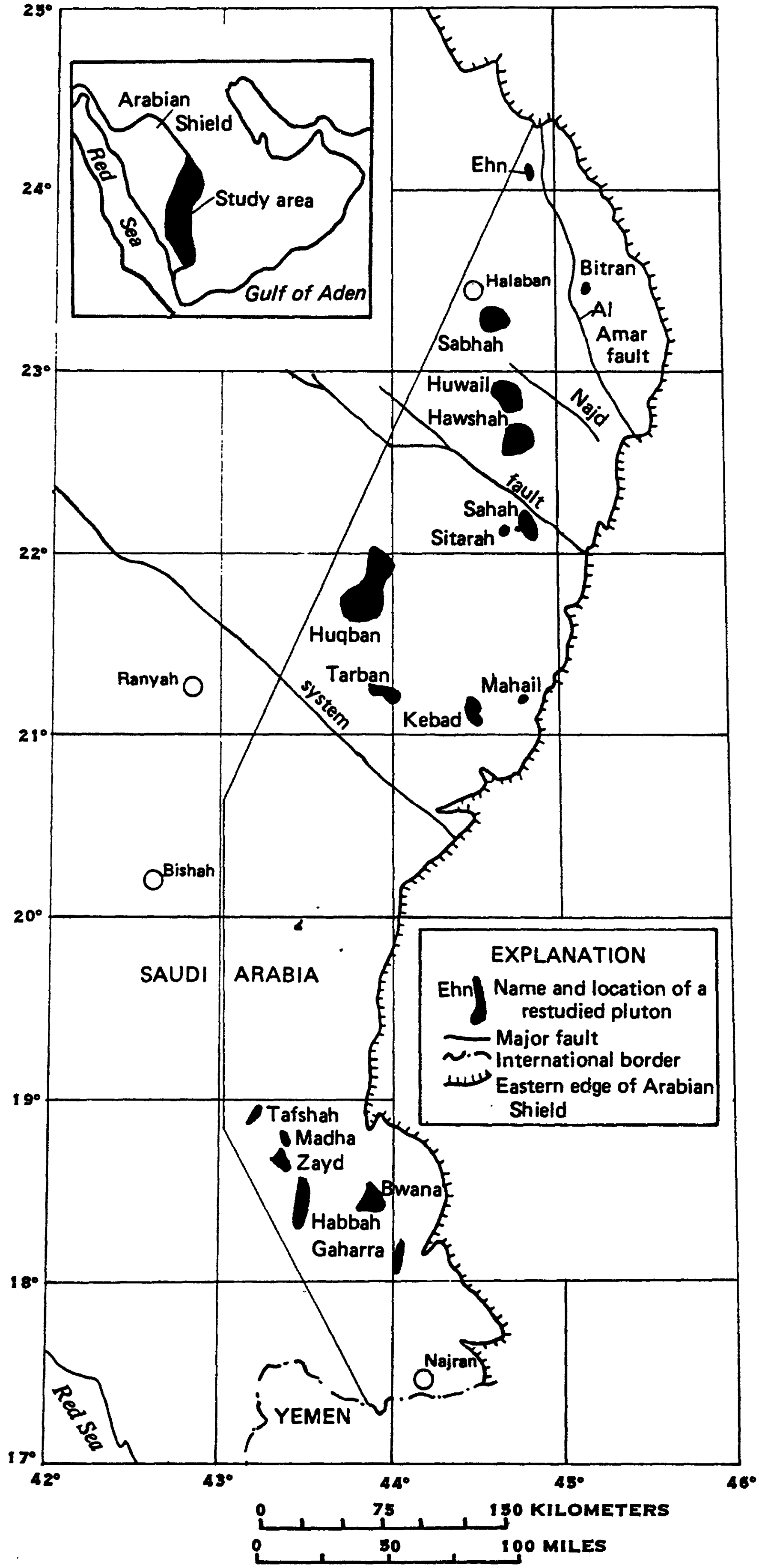


Figure 1.—Map showing location of the felsic plutonic rocks study area and locations of the plutons studied in the eastern and southeastern Arabian Shield.

Most of the 16 plutons described in this report are associated with well-defined geochemical anomalies, as determined by du Bray and others (unpub. data). In particular, many contain anomalous concentrations of tin and (or) tungsten and are granitophile element enriched. Pan concentrates collected from wadis draining these plutons typically contain highly anomalous concentrations of tin. Twelve of the plutons studied contain primary muscovite; the remaining four plutons lack muscovite but are geochemically anomalous. The petrology and petrogenesis of the muscovite-bearing plutons are further discussed by du Bray(unpub. data). Four of the thirteen muscovite-bearing plutons are not geochemically anomalous but were selected for further study because muscovite-bearing plutons are commonly associated with deposits of tin, tungsten, molybdenum and (or) other rare metals (Chappell and White, 1974; Tischendorf, 1977; Ishihara and others, 1980).

The intent of this study was to gather and summarize additional geochemical, petrographic, and field data pertaining to mineral-deposit potential and to determine which of the plutons studied warrant additional investigation. This study was performed by the U.S. Geological Survey as part of a work agreement with the Saudi Arabian Ministry of Petroleum and Mineral Resources as part of subproject 3.12.03.

DATA STORAGE

Documents relating to this project have been archived in data files USGS-OF-01-05 and 02-3 (du Bray, unpub. data). These files contain all of the geochemical data accumulated during the study.

Geochemical data for all samples are also recorded in the Saudi Arabian Deputy Ministry for Mineral Resources (DMMR) Rock Analysis Storage System (RASS) data bank, and each sample is identified by a unique six-digit number. Additional data analysis or study may be facilitated by use of this system.

Because this study pertains to geochemically anomalous plutons and not to specific mineral localities, no mineral locality data were entered in the DMMR Mineral Occurrence Documentation System (MODS).

CHARACTERISTICS OF THE ANOMALOUS PLUTONS

The postorogenic granitoid plutons studied range between 3 and 200 km^2 in areal extent and average about 20 km^2. Their ovoid to elliptical shapes, intrusive relations, and lack of postcrystallization deformation suggest that they are among the youngest Proterozoic rocks that crop out in the Arabian Shield. The Tafshah, Zayd, Habbah, and Madha plutons (fig. 1) differ from the others in many ways (du Bray, unpub. data) and may have been emplaced earlier. Limited geochronologic data indicate that the Sabhah monzogranite crystallized 590 Ma ago, whereas the Madha granodiorite crystallized 670 Ma ago (J. S. Stacey, written commun., 1982).

The geochemically anomalous plutons are usually enriched in incompatible granitophile elements. Concentrations of Be, Pb, Li, F, Rb, Y, Nb, Bi, Ag, Sn, W, and Mo are high relative to global averages for granites. Most of these plutons are weakly to moderately peraluminous (Shand, 1947) as indicated by the molecular ratio (peraluminous index), $Al_2O_3/CaO+K_2O+Na_2O$, which ranges from about 0.95 to 1.15. Peraluminous granites are defined as those having a peraluminous index greater than one. Silica contents range between 72 and 78 weight percent, and the contents of total iron, MgO, TiO_2 and CaO are low (table 1). The evolved major- and trace-element chemistry and the anomalously radiogenic lead isotopic compositions of these plutons (Stacey and Stoeser, unpub. data) suggest that they are contaminated by or are partial melts of older continental crust. The position of normative quartz-albite-orthoclase compositions on the appropriate ternary diagram indicates that slight compositional dissimilarities between the plutons may be a function of depth of emplacement.

Modal compositions of the plutons studied range between syenogranite and granodiorite (Streckeisen, 1976), but analyses for most of the plutons straddle the monzogranite-syenogranite border (fig. 2). The plutons are composed of hypidiomorphic to xenomorphic inequigranular, medium-grained leucogranite and leucogranodiorite. Most of the plutons contain two nonperthitic alkali feldspars. Biotite and garnet, the latter forming as much as 1 modal percent in seven of the plutons, are the only mafic silicate minerals. Twelve of the sixteen plutons contain muscovite. The accessory mineral suites include combinations of zircon, fluorite, apatite, and topaz. Ilmenite was the only opaque oxide identified, and most of the plutons contain about 0.1 percent ilmenite.

There is no evidence of a genetic relation between the plutons studied and the enclosing wall rock. Only the Sitarah and Tarban plutons contain xenoliths of wall rock or refractory residuum. Both these plutons have locally stoped and engulfed large blocks of wall rock, but there is no indication of chemical interaction between the blocks and the enclosing rock. The Tafshah, Madha, Zayd, and Habbah plutons are characterized by local mafic schlieren layering, which suggests that some interaction with wall rock, including its partial assimilation, may have occurred. Otherwise there is no indication of chemical interaction between the granites and their wall rock.

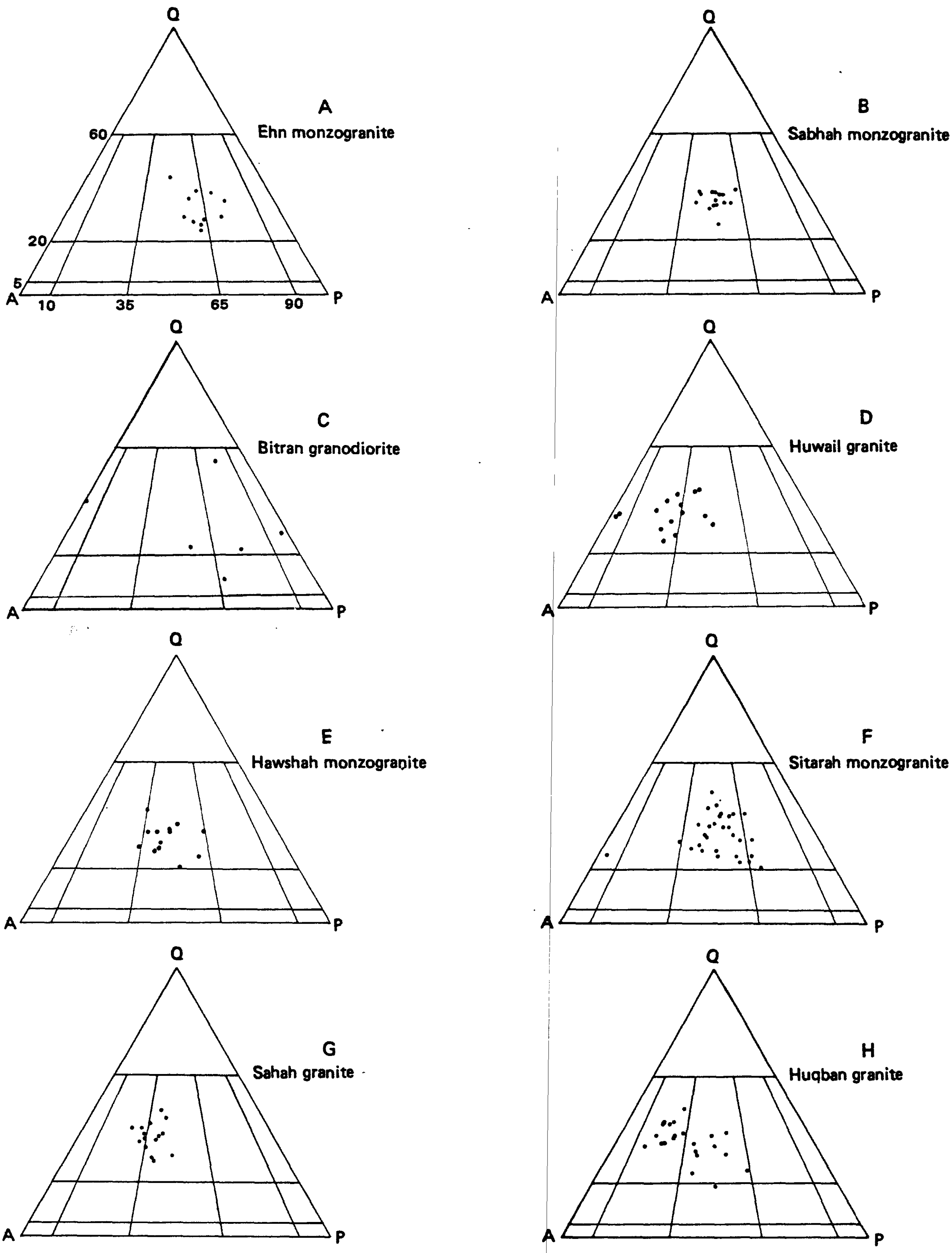


Figure 2.--Ternary quartz-alkali feldspar-plagioclase diagrams (QAP) (Streckeisen, 1976) showing modal compositions of selected felsic plutons in the eastern and southeastern Arabian Shield. Each plotted point represents between 400 and 800 points counted on a slab at least 50 cm^2 in area.

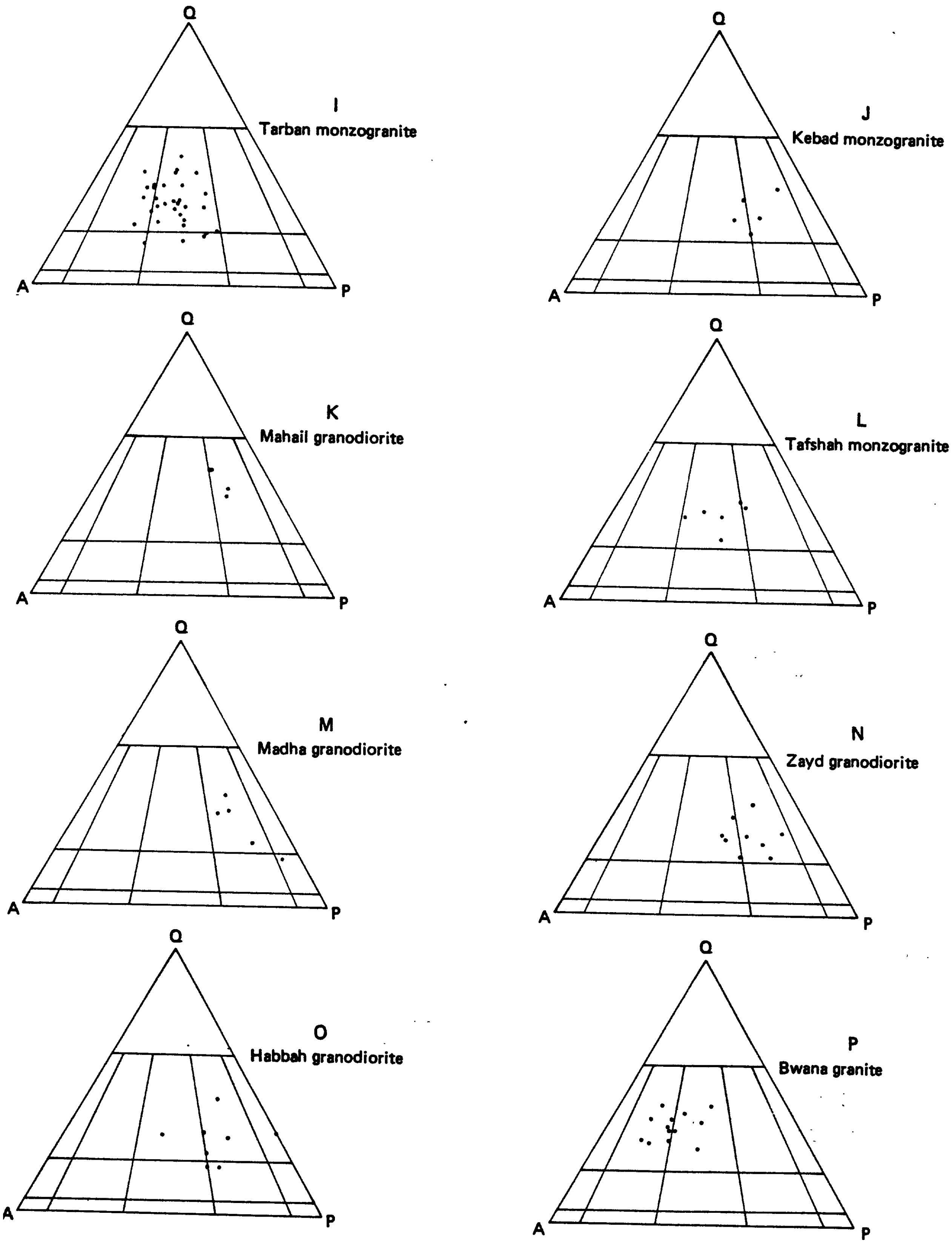


Figure 2.—Continued.

TERMINOLOGY AND METHODS

Geologic investigations conducted throughout the world have defined a clan of petrologically similar granitoid rocks known variously as S-type, ilmenite series, peraluminous, or metallogenically specialized. S-type granites are characterized by relatively low Na_2O content, greater than 1 percent CIPW normative corundum content, initial $^{87}Sr/^{86}Sr$ ratios greater than 0.708, high silica content, irregular patterns on interelement variation diagrams, and muscovite content. I-type granites, in comparison, are characterized by relatively high Na_2O content, less than 1 percent CIPW normative corundum content, initial $^{87}Sr/^{86}Sr$ ratios in the range 0.704-0.706, broad compositional range, regular interelement variation within plutons, and commonly hornblende content (Chappell and White, 1974). Ishihara (1977) has divided granitoid rocks into the magnetite series and the ilmenite series. Magnetite-series granitoid rocks contain easily recognizable magnetite and many are similar to I-type granites, whereas ilmenite-series granitoid rocks contain ilmenite but are practically free of opaque oxide minerals (less than 0.1 volume percent), and many are similar to S-type granites. Peraluminous granites are defined as having a peraluminous index greater than one (Shand, 1947). Metallogenically specialized or tin-mineralized granites are characterized by incompatible-element (Be, Li, F, Pb, Rb, Y, and Nb) enrichment relative to global granite averages, compatible-element (strontium, barium, zirconium, and lanthanum) depletion, the presence of muscovite, and high silica content. These granites also are peraluminous (Tischendorf, 1977). Granites that are precursors to the tin-mineralized granite clan are found in the same geotectonic position and geologic setting as the tin-mineralized granites and are similarly enriched in the incompatible elements. In other properties, principally their petrographic characteristics, the precursor granites are more like normal granites.

Followup studies of the plutons were completed during three weeks of helicopter-supported fieldwork conducted between February and April 1981. The plutons were geologically mapped during ground and helicopter traverses. Geologic sketch maps of each pluton were prepared (figs. 3-18). Localities and numbers are indicated on these maps for samples collected both during this study and during the initial study by du Bray and others (unpub. data). Data for the latter group of samples are available in that paper and in a data file compiled by du Bray (unpub. data), base data file USGS-DF-01-5. Sufficient ground traverses were made across the larger plutons to enable characterization of their field relations and petrographic character, and low-level helicopter traverses were made in an attempt to identify obviously mineralized zones.

Both fresh and altered rock samples of the various plutons were collected. Quartz veins and pegmatite dikes were sampled locally, especially where alteration or mineralized rock was suspected. Metamorphosed country rock was collected at pluton contacts to determine if tin, tungsten, or other rare metals were deposited in the wall rock by circulating magmatic fluids.

All rock samples were submitted to the Directorate General of Mineral Resources (DGMR)-USGS chemical laboratory, Jiddah, Saudi Arabia, for 30-element semiquantitative spectrographic analysis and for quantitative determination of lithium (by atomic absorption), fluorine (by the selective-ion-electrode method), and tungsten (by colorimetry). Selected samples were submitted to the DGMR-USGS chemical laboratory for major-element analysis, and trace-element analyses were completed for all granitoid rock samples by use of radioisotope-excitation X-ray fluorescence techniques. Thin sections and stained slabs were also prepared for all granitoid rock samples.

The results of major- and trace-element analyses are summarized, by pluton, in table 1. A complete compilation of semiquantitative spectrographic data for the samples collected during the followup study is presented by du Bray (unpub. data) in base data file USGS-DF-02-3. Selected semiquantitative spectrographic data for these samples are presented in tables 2-4, in which samples are separated by pluton and rock type (granite, quartz vein, or wall rock). Previously established threshold values (du Bray and others, unpub. data) for granitoid rocks of the study area are given in table 5.

The discussion that follows addresses the plutons recommended by du Bray and others (unpub. data) for additional study. The evaluations offered represent a synthesis of available ground-traverse, geochemical, and petrographic information. Type, intensity, and quantity (if any) of both alteration and veining are discussed. The geochemical data indicate the degree to which plutons or parts of plutons are mineralized and can be compared (table 5) to data on workable ore grades (Rose and others, 1979). This comparison provides some idea of the additional metal concentration that would be necessary for rocks of a particular pluton to qualify as a workable deposit. An effort was made during petrographic studies to identify alteration that might indicate conditions favorable to ore deposition. A search for cassiterite, scheelite, wolframite, and molybdenite was also conducted during petrographic studies. The petrography of the plutons, including mineralogy and textural features, was compared to that of granitoid rocks known to host rare-metal deposits (Tischendorf, 1977; Groves and McCarthy, 1978; Ishihara and others, 1980; Cole and others, 1981).

Table 1.--Average major-element, trace-element, and CIPW normative compositions for selected felsic plutons in the eastern and southeastern Arabian Shield

[N indicates number of samples on which mean and standard deviation (±) are based; leader in standard deviation column indicates zero variance. Pluton element averages normalized to 100 percent, anhydrous. Major-element analyses and CIPW normative compositions in weight percent; trace-element analyses in parts per million. ND indicates no data available]

	Khn monzogranite	Sabhah monzogranite	Bitran granodiorite	Ruwail granite	Hawshah monzogranite	Sitarah monzogranite	Sahah granite	Huqban granite	Tarban monzogranite	Kebad monzogranite
					Major-element analyses [1]					
	N = 2	N = 5	N = 0	N = 2	N = 6	N = 6	N = 4	N = 4	N = 7	N = 2
SiO_2	70.60 ± 0.28	75.30 ±1.69		74.25 ± 0.42	75.01 ± 1.12	76.81 ± 0.97	75.72 ±0.83	76.45 ±0.33	75.82 ±0.77	74.93 ± 1.27
Al_2O_3	14.55 ± .07	13.13 ±0.35		13.60 ± 2.33	13.59 ± 1.00	12.74 ± .25	12.80 ± .31	12.18 ± .15	13.61 ± .35	14.52 ± 0.57
Fe_2O_3	1.74 ± .09	0.63 ± .27		0.99 ± .16	0.84 ± 0.10	0.43 ± .16	0.68 ± .23	0.71 ± .17	0.37 ± .21	0.67 ± .40
FeO	0.93 ± .17	.77 ± .60		.23 ± .13	1.01 ± .47	.45 ± .11	.77 ± .27	.67 ± .27	.35 ± .26	.35 ± .26
MgO	.72 ± .16	.11 ± .10		.20 ± .16	.14 ± .11	.30 ± .64	.11 ± .04	.09 ± .01	.08 ± .09	.04 ± .01
CaO	2.77 ± .04	.69 ± .25		.90 ± .28	.81 ± .50	.56 ± .38	.67 ± .14	.60 ± .06	.41 ± .26	.42 ± .08
Na_2O	4.07 ± .38	4.43 ± .34		4.00 ± .63	3.62 ± 1.21	4.24 ± .49	4.08 ± .50	3.98 ± .13	4.62 ± .75	4.60 ± .31
K_2O	3.50 ± .30	4.53 ± .35		4.73 ± .58	4.52 ± .98	4.09 ± .09	4.78 ± .28	4.58 ± .10	4.40 ± .15	4.08 ± .35
TiO_2	.29 ± .03	.11 ± .09		.16 ± .15	.12 ± .05	.04 ± .02	.09 ± .03	.07 ± .01	.04 ± .05	.03 ± -
P_2O_5	.11 ± .02	.04 ± .04		.14 ± .13	.04 ± .01	.04 ± .07	.03 ± .03	.03 ± .01	.02 ± .01	.14 ± .04
MnO	.06 ± .01	.03 ± .02		.04 ± .01	.04 ± .02	.06 ± .06	.03 ± .01	.04 ± .01	.11 ± .06	.04 ± .03
F	.18 ± .18	.02 ± .13		.18 ± .03	.26 ± .25	.24 ± .06	.24 ± .05	.25 ± .14	.17 ± .07	.18 ± .05
					CIPW norms					
Q	27.7	31.01		31.8	35.20	35.52	32.64	35.0	31.51	32.47
C	0	0.34		1.1	2.06	1.05	0.42	0.3	1.00	2.54
or	20.8	26.79		28.1	26.74	24.19	28.26	27.2	26.02	24.13
ab	34.6	37.52		34.1	30.67	35.19	34.54	33.7	39.12	38.95
an	11.2	1.65		2.3	1.88	0.79	1.39	1.0	0.67	0
wo	0.3	0		0	0	0	0	0	0	0
en	1.8	.27		0.5	0.35	.75	.27	.2	.20	0.10
fs	0	.77		0	1.04	.52	.76	.6	.48	.11
mt	2.4	.91		.4	1.22	.62	.99	1.0	.54	.97
il	.6	.21		.3	.23	.08	.17	.1	.08	.06
ap	.3	.10		.3	.10	.10	.07	0	.05	.33
fr	.4	.43		.3	.53	.49	.49	.5	.35	.33
					Trace-element analyses [2]					
	N = 3	N = 18	N = 11	N = 16	N = 13	N = 36	N = 15	N = 25	N = 34	N = 5
Li	48 ± 28	85 ± 62	4.2 ± .7	38 ± 56	105 ± 79	139 ± 105	61 ± 40	51 ± 27	67 ± 77	52 ± 19
F	2136 ± 2053	2035 ± 917	340 ± 100	1513 ± 896	1915 ± 1421	2320 ± 2162	2083 ± 708	2638 ± 1123	1316 ± 1139	1117 ± 366
Cu	15 ± 14	16 ± 15	18 ± 28	10 ± 10	34 ± 55	14 ± 16	6 ± 4	16 ± 28	15 ± 22	12 ± 4
Rb	213 ± 82	354 ± 106	16 ± 7	226 ± 67	427 ± 188	582 ± 177	252 ± 72	296 ± 59	488 ± 205	377 ± 72
Sr	163 ± 59	22 ± 35	110 ± 68	26 ± 27	46 ± 45	15 ± 8	18 ± 7	22 ± 19	32 ± 68	10 ± 3
Y	74 ± 33	181 ± 73	35 ± 8	106 ± 40	96 ± 50	107 ± 30	135 ± 39	108 ± 24	82 ± 38	19 ± 5
Zr	128 ± 16	123 ± 41	108 ± 25	128 ± 27	100 ± 37	76 ± 17	142 ± 25	152 ± 35	89 ± 30	22 ± 6
Nb	13 ± 6	43 ± 20	3 ± 0	34 ± 18	19 ± 9	48 ± 16	67 ± 19	100 ± 43	31 ± 20	16 ± 1
Pb	<21 ±	53 ± 25	<11 ±	21 ± 8	38 ± 7	82 ± 118	33 ± 8	42 ± 10	61 ± 39	<11 ±
Sn	< 7 -	<10 ±	< 7 -	< 7 ±	12 ± 9	31 ± 23	<10 ±	21 ± 6	13 ± 10	12 ± 4
Ba	428 ± 131	< 8 -	435 ± 209	69 ± 99	123 ± 143	30 ± 46	84 ± 15	67 ± 91	193 ± 217	12 ± 7
La	24 ± 6	23 ± 12	17 ± 10	32 ± 15	33 ± 20	13 ± 6	32 ± 16	42 ± 22	15 ± 10	< 7 ±
Ce	48 ± 11	55 ± 21	33 ± 15	75 ± 28	75 ± 39	33 ± 14	79 ± 26	26 ± 17	38 ± 26	<15 -
Nd	<25 ±	<25 ±	<25 ±	32 ± 16	30 ± 15	<25 ±	34 ± 14	26 ± 17	<25 ±	<12 -
Be	4 ± 2	6 ± 6	< 1 -	4 ± 2	4 ± 4	6 ± 3	8 ± 7	6 ± 5	7 ± 20	7 ± 5

Table 1.--Average major-element, trace-element, and CIPW normative compositions for selected felsic plutons in the eastern and southeastern Arabian Shield-Continued

Mahail granodiorite	Tafshah monzogranite	Madha granodiorite	Zayd granodiorite	Habbah granodiorite	Bwana granite	Gaharra monzogranite	Specialized granites[3]	Precursor granites[3]	Granites[4]
Major-element analyses[1]									
N = 2	N = 3	N = 2	N = 4	N = 4	N = 4	N = 5	N = 962	N = 226	N = 2,327
74.67 ±0.99	75.43 ±0.40	74.24 ±0.57	74.81 ±1.05	73.60 ± 1.09	75.14 ± 1.29	75.18 ± 0.51	74.30 ± 1.39	73.80 ± 1.18	71.42 ± 1.41
14.50 ± -	13.63 ± .25	15.06 ± .21	14.47 ±0.41	15.22 ± 0.52	14.20 ± 1.08	13.98 ± .37	14.15 ± 1.07	14.29 ± 0.53	14.45 ± 0.23
0.52 ± .11	0.58 ± .06	0.42 ± .08	0.37 ± .05	0.36 ± .23	0.35 ± 0.08	0.33 ± .09	0.81 ± 0.47	0.49 ± .17	1.32 ± .29
.48 ± .11	.29 ± .16	.35 ± .07	.23 ± .10	.42 ± .24	.43 ± .05	.41 ± .11	1.11 ± .47	1.37 ± .47	1.79 ± .38
.05 ± .01	.06 ± .04	.23 ± .01	.08 ± .03	.14 ± .07	.07 ± .04	.05 ± .01	.48 ± .56	.46 ± .36	0.82 ± .23
.50 ± .08	.76 ± .10	.23 ± .01	.08 ± .03	1.92 ± .54	.39 ± .29	.32 ± .05	.76 ± .41	1.06 ± .34	1.91 ± .40
4.84 ± .04	5.01 ±1.03	5.29 ± .04	4.46 ± .24	4.74 ± .76	5.31 ± .90	5.27 ± .54	3.24 ± .61	3.27 ± .50	3.47 ± .32
4.16 ± .33	4.12 ±1.33	3.08 ± .03	3.71 ± .65	3.35 ±1.60	3.90 ± .54	3.95 ± .64	4.75 ± .68	4.91 ± .45	4.38 ± .52
.03 ± .01	.03 ± .01	.07 ± -	.05 ± .01	.06 ± .03	.02 ± .01	.02 ± .01	.16 ± .10	.24 ± .11	.34 ± .08
.05 ± -	.03 ± -	.08 ± .02	.03 ± .01	.05 ± .04	.02 ± .02	.01 ± .01	ND	ND	ND
.10 ± .05	.03 ± .02	.07 ± .03	.02 ± .02	.06 ± .03	.04 ± .01	.06 ± .01	.05 ± .04	.05 ± .26	.06 ± .03
.07 ± .02	.03 ± .03	.03 ± -	.03 ± .01	.02 ± -	.13 ± .05	.42 ± .14	.32 ± .38	.11 ± .04	.09
CIPW norms									
29.48	29.13	29.19	30.97	28.92	28.62	29.13	35.42	32.57	28.69
1.40	0	1.31	0.10	0.47	0.93	1.04	3.16	1.98	0.79
24.59	24.35	18.20	21.92	19.80	23.06	23.38	28.06	29.03	25.86
40.97	42.40	44.77	37.74	40.11	44.96	44.67	27.42	27.66	29.35
1.73	2.54	4.67	8.24	9.09	.87	0	1.40	4.42	8.79
0	0.35	0	0	0	0	0	0	0	0
0.13	.15	0.57	.20	.35	.17	0.13	1.19	1.14	2.03
.66	.06	.31	.07	.49	.54	.56	1.20	1.81	1.75
.75	.84	.61	.54	.52	.51	.48	1.18	0.71	1.92
.06	.06	.13	.10	.11	.04	.04	0.31	.46	.65
.10	.07	.19	.07	.12	.05	.02	ND	ND	ND
.14	.06	.05	.06	.03	.26	.43	.67	.23	.19
Trace-element analyses[2]									
N = 5	N = 6	N = 5	N = 9	N = 8	N = 16	N = 48	N = 962	N = 226	N = 2,327
80 ± 21	5 ± 3	11 ± 22	6 ± 3	7 ± 5	231 ± 304	306 ± 91	400 ± 200	130 ± 50	30
361 ± 153	188 ± 182	265 ± 157	161 ± 101	199 ± 142	1614 ± 815	3060 ± 1054	3700 ± 1500	810 ± 200	850
<5 -	<5 -	11 ± 11	<5 - 288	<5 -	<5 -	13 ± 9	ND	ND	10
± 23	31 ± 9	31 ± 10	40 ± 19	36 ± 12	486 ± 273	603 ± 111	580 ± 200	250 ± 50	150
7 ± 3	40 ± 30	316 ± 200	403 ± 113	446 ± 130	11 ± 17	7 ± 6	ND	ND	285
32 ± 3	46 ± 16	7 ± 2	4 ±	6 ± 4	90 ± 57	97 ± 64	ND	ND	40
28 ± 4	43 ± 11	47 ± 18	39 ± 12	52 ± 35	89 ± 24	56 ± 15	ND	ND	180
10 ± 3	5 ± 5	1	<1 ± -	<1 ± -	38 ± 20	38 ± 13	ND	ND	20
<11 -	<11 -	<21 -	<11 ± -	<21 -	65 ± 8	49 ± 19	ND	ND	20
<10 -	<10 -	<10 -	< 7 -	<7 -	35 ± 26	40 ± 26	40 ± 20	10 ± 5	3
< 8 -	681 ± 847	1170 ± 503	1170 ± 561	1009 ± 318	< 8 -	< 8 -	ND	ND	600
<13 -	<13 -	16 ± 1	<13 -	<13 -	<13 -	<13 -	ND	ND	40
15 ± 2	15 ± 6	21 ± 3	<15 -	<15 -	38 ± 17	37 ± 13	ND	ND	87
<12 -	12 -	<12 -	<12 -	<12 -	<25 -	<25 -	ND	ND	35
4 ± 2	< 1 -	< 1 -	< 1 -	<1 -	8 ± 6	5 ± 2	13 ± 6	7.5 ± 2	5

1 Data from several laboratories, using a combination of X-ray fluorescence, atomic absorption, and wet chemistry methods.
2 Li by atomic absorption; F by selected-ion electrode; Cu and Be by semiquantitative spectrography, Rb, Sr, Y, Zr, Nb, and Pb by X-ray fluorescence using a ^{109}Cd excitation source; Sn, Ba, La, Ce, and Nd by X ray fluorescence using an ^{241}Am excitation source.
3 Tischendorf (1977).
4 Krauskopf (1967).

Table 2.--Selected geochemical data for granitoid rocks, by pluton

[All results in parts per million. Be, Bi, Mo, Nb, Pb, Sn, Y, and Zn determined by semiquantitative spectrography. Li determined by atomic absorption analysis. W determined by colorimetry. F determined by selective-ion-electrode method. All analyses by the DGMR-USGS chemical laboratory, Jiddah. N indicates not detected at the limit shown. L indicates less than the limit shown]

Sample number	Latitude (north)	Longitude (east)	Be	Bi	Mo	Nb	Pb	Sn	Y	Zn	Li	W	F
						Sabhah monzogranite							
169383	23°18'23"	44°37'53"	2	10N	5N	20L	20	10L	50	200N	122.50	20N	1440
169384	23°17'45"	44°37'11"	3	10N	5N	20	20	15	70	200N	150.00	20N	2664
169387	23°16'55"	44°36'52"	5	10N	5N	20N	10	15	50	200N	7.50	20N	440
169388	23°16'21"	44°34'24"	3	10N	5N	20L	10L	15	10L	200N	21.25	20N	2400
169437	23°16'31"	44°37'38"	3	10N	5L	20	50	10N	100	200N	35.00	25	1199
169438	23°15'43"	44°38'13"	2	10N	5	20N	100	30	50	200N	188.00	20N	2302
169439	23°16'40"	44°39'04"	3	10N	5N	20L	15	10N	50	200N	83.80	25	1656
						Sitarah monzogranite							
169391	22°06'26"	44°42'38"	3	10N	5N	50	15	10L	15	200N	181.25	20N	2174
169392	22°06'14"	44°42'28"	5	10N	5N	20	20	15	10L	200N	353.75	20N	1944
169394	22°05'56"	44°42'19"	3	10N	5N	20	20	20	15	200N	217.50	20N	2592
169400	22°05'31"	44°42'45"	2	10N	5N	20L	70	50	50	200N	137.00	20N	2304
169402	22°05'24"	44°42'56"	3	10N	5L	20	50	30	50	200N	265.00	20N	2244
169403	22°05'24"	44°43'25"	15	10N	5	20	50	10N	20	200N	52.50	20N	1000
169404	22°05'19"	44°43'32"	5	10N	15	20L	50	10N	15	200N	10.00	20N	278
169405	22°05'26"	44°43'35"	5	10N	5L	20	30	10N	50	200N	15.00	20N	1824
169406	22°05'35"	44°43'39"	7	10N	7	20L	20	10N	50	200N	25.00	20N	1680
169407	22°05'52"	44°43'38"	7	10L	20	20L	30	10N	50	200N	21.00	20N	1229
169408	22°05'42"	44°43'26"	5	10L	70	20	70	10N	30	200N	24.00	20N	240
169410	22°06'08"	44°43'31"	10	10N	5L	20	20	10N	30	200N	91.20	20N	916
169412	22°06'17"	44°43'20"	5	10N	5N	20	30	15	50	200N	245.00	20N	2400
169420	22°05'46"	44°42'51"	3	10N	5N	20L	15	50	30	200N	108.70	20N	2208
169423	22°05'59"	44°42'43"	2	10N	5N	20L	10	200	50	200N	110.00	25	2280
169424	22°06'10"	44°42'40"	5	10N	5N	20	20	15	50	200N	351.30	25	3036

Table 2.--Selected geochemical data for granitoid rocks, by pluton--Continued

Sample number	Latitude (north)	Longitude (east)	Be	Bi	Mo	Nb	Pb	Sn	Y	Zn	Li	W	F
					Sitarah monzogranite-Continued								
169425	22°06'13"	44°42'48"	7	10N	5N	20	100	100	70	200N	162.50	20N	3264
169427	22°06'04"	44°42'54"	5	10N	5N	20	70	30	50	200N	188.80	25	2746
169428	22°05'52"	44°43'04"	5	10N	5	20L	10N	10L	50	200N	105.00	20N	1200
169430	22°05'26"	44°42'52"	5	10N	5	20L	100	30	30	200N	357.50	25	1680
169440	22°06'07"	44°43'22"	10	10N	5N	20L	50	20	70	200N	55.00	50	1447
169441	22°05'55"	44°43'22"	3	10N	5N	20	100	30	70	200N	56.30	25	2184
169444	22°05'38"	44°43'17"	3	10N	5L	20L	15	15	50	200N	41.30	20N	2794
169445	22°05'39"	44°43'11"	2	10N	7	20L	500	100	50	200N	147.50	20N	13200
169446	22°05'52"	44°43'14"	15	15	20	20L	300	30	30	200N	87.50	100	1624
169447	22°06'03"	44°43'04"	2	10N	5	20L	100	50	50	200N	125.00	25	2654
169451	22°06'19"	44°43'00"	3	10N	7	20L	50	50	50	200N	141.30	250	3528
					Bitran granodiorite								
169396	23°28'00"	45°11'18"	1L	10N	5L	20N	10N	10N	30	200N	8.70	20N	878
169397	23°27'38"	45°11'09"	1L	10N	5N	20N	10N	10N	50	200N	1.25	20N	252
169398	23°27'28"	45°10'54"	1L	10N	5N	20N	10N	10N	50	200N	3.70	20N	1037
169399	23°27'15"	45°10'45"	1L	10N	5N	20N	10N	10N	15	200N	5.00	20N	413
					Huwail granite								
169453	22°55'01"	44°53'13"	2	10N	5N	20N	15	10N	70	200N	25.00	20N	2152
169454	22°52'11"	44°55'40"	5	10N	5N	20N	20	10N	100	200N	6.30	20N	2720
169456	22°51'27"	44°50'48"	5	10N	5N	20N	20	10N	50	200N	8.80	25	1888
169457	22°51'07"	44°50'20"	3	10N	5N	20N	10L	10N	50	200N	3.80	25	1822
169459	22°50'52"	44°49'37"	5	10N	5N	20N	20	10N	70	200N	207.50	25	1718
169483	22°48'43"	44°54'24"	2	10N	5N	20N	10	10N	10	200N	17.50	25	309
169484	22°48'48"	44°53'56"	3	10N	5N	20N	50	10N	20	200N	18.00	20N	722
169486	22°48'54"	44°52'58"	10	10N	5N	30	70	10N	70	200N	3.00	20N	1800

Table 2.--Selected geochemical data for granitoid rocks, by pluton--Continued

Sample number	Latitude (north)	Longitude (east)	Be	Bi	Mo	Nb	Pb	Sn	Y	Zn	Li	W	F
						Ehn monzogranite							
169462	24°05'27"	44°51'51"	7	10N	5N	20N	20	15	100	200N	21.30	25	2160
169464	24°05'02"	44°51'59"	5	10N	5L	20N	10L	10N	50	200N	50.00	20N	768
169466	24°03'26"	44°52'22"	5	10N	5N	20N	10	10	70	200N	87.50	20N	2300
169467	24°05'10"	44°51'38"	1	10N	5N	20N	10L	10N	30	200N	36.30	20N	2496
169468	24°04'44"	44°51'45"	1	10N	5N	20N	10L	10N	30	200N	40.00	25	798
169469	24°04'17"	44°51'49"	2	10N	5N	20N	10	10N	30	200N	47.50	25	1800
169470	24°03'57"	44°52'12"	2	10N	5N	20N	10	10N	20	200N	30.00	25	7776
169472	24°03'35"	44°52'36"	2	10N	5N	20N	20	10N	30	200N	15.00	20N	2064
						Hawshah monzogranite							
169474	22°33'16"	44°43'56"	2	10N	5N	20N	15	20	30	200N	285.00	75	3600
169476	22°33'41"	44°44'21"	2	10N	5N	20N	20	20	70	200N	185.00	50	2700
169479	22°36'04"	44°43'38"	2	10N	5	20N	50	10	15	200N	83.80	50	384
169481	22°36'31"	44°43'49"	15	10N	5N	20N	30	20	50	200N	147.50	25	2112
						Sahah granite							
169487	22°07'44"	44°49'52"	7	10N	5N	30	70	10N	100	200N	59.00	20N	1952
169489	22°07'36"	44°50'22"	3	10N	5	100	30	10N	100	200N	24.00	80	1210
169491	22°07'37"	44°50'47"	5	10N	5L	70	50	10N	100	200N	20.00	60	1560
169493	22°09'27"	44°51'02"	7	10N	5L	20	50	10N	100	200N	109.00	20N	3808
169495	22°09'58"	44°48'39"	7	10N	5	30	50	10N	100	200N	30.00	20N	1444
169497	22°09'54"	44°49'19"	5	10N	5L	20	50	10N	50	200N	14.00	20N	1932
169499	22°09'47"	44°49'47"	7	10N	5L	30	30	10N	100	200N	61.00	20N	1550
169501	22°09'42"	44°50'24"	5	10N	5L	20	20	10N	100	200N	29.00	20N	1737

Table 2.--Selected geochemical data for granitoid rocks, by pluton--Continued

Sample number	Latitude (north)	Longitude (east)	Be	Bi	Mo	Nb	Pb	Sn	Y	Zn	Li	W	F
						Tarban monzogranite							
169518	21°13'08"	44°02'23"	1	10N	5L	20N	10L	10N	30	200N	12.50	20N	529
169519	21°13'11"	44°02'37"	2	10N	5N	20N	70	10N	50	200N	60.00	20N	1102
169520	21°12'55"	44°02'54"	1L	10N	5N	20N	10	10N	15	200N	5.00	20N	286
169523	21°13'25"	44°03'17"	1L	10N	5N	20N	20	10N	10L	200N	12.50	20N	144
169524	21°14'01"	44°03'08"	3	10N	5N	20N	70	10N	100	200N	102.50	20N	1836
169525	21°13'57"	44°02'39"	1L	10N	5N	20N	10L	10N	10N	200N	21.30	20N	443
169526	21°14'04"	44°02'16"	2	10N	5N	20L	20	10N	20	200N	30.00	20N	1944
169528	21°13'59"	44°01'38"	2	10N	5N	20L	15	10N	20	200N	35.00	20N	2255
169529	21°13'24"	44°02'12"	1	10N	10	20	20	10N	30	200N	5.00	20N	158
169530	21°12'30"	44°01'44"	1L	10N	5N	20N	10L	10N	30	200N	6.30	20N	1026
169531	21°13'42"	44°02'35"	1	10L	7	20	50	50	30	200N	28.80	60	360
169532	21°13'43"	44°02'50"	2	10N	5L	20L	70	20	50	200N	32.50	20N	525
169533	21°13'46"	44°03'07"	1	10N	5N	20L	20	50	50	200N	13.80	20N	488
169534	21°13'46"	44°03'19"	1L	10N	7	20L	50	10N	15	200L	27.50	20N	336
169535	21°13'46"	44°03'26"	1L	10N	5N	20L	10L	10N	30	200N	151.30	20N	630
169537	21°13'21"	44°02'36"	70	10N	5N	500	30	30	200	700	15.00	20N	594
169538	21°13'20"	44°02'23"	100	10N	5N	500	200	100	500	300	15.00	20N	303
169539	21°13'05"	44°02'56"	3	10N	5	30	70	10N	50	200	3.80	20N	1147
169541	21°16'09"	43°58'28"	3	10N	5	20	10	10N	70	200	141.30	20N	1188
169542	21°15'57"	43°58'19"	2	10N	5L	20	10L	10N	50	200N	152.50	20N	1160
169543	21°15'41"	43°58'13"	2	10N	7	50	15	10N	70	200N	342.50	20N	2830
169545	21°15'28"	43°59'05"	1	10N	5N	20L	10	10N	20	200N	37.50	20N	1854
169546	21°15'41"	43°58'54"	2	10N	5N	20	10L	10N	50	200N	53.80	20N	720
169547	21°15'56"	43°58'42"	1	10N	5L	20L	10L	10N	30	200N	171.30	20N	1952
169548	21°14'39"	44°00'25"	1	10N	5	20L	10L	10N	30	200N	1.30	20N	1800
169549	21°14'42"	44°00'49"	1L	10N	5N	20L	10L	10N	15	200N	18.80	20N	1314
169551	21°15'01"	43°59'59"	3	10N	5N	20L	70	10N	20	200N	83.80	20N	3226

Table 2.--Selected geochemical data for granitoid rocks, by pluton--Continued

Sample number	Latitude (north)	Longitude (east)	Be	Bi	Mo	Nb	Pb	Sn	Y	Zn	Li	W	F
						Huqban granite							
169558	21°52'23"	43°48'33"	3	10N	5N	20L	70	10N	30	200N	47.50	20N	2860
169560	21°51'36"	43°48'36"	1	10N	5N	20N	10L	10N	10L	200N	33.80	20N	3110
169562	21°50'48"	43°48'25"	1	10N	5N	20L	50	20	70	200N	58.80	20N	2600
169564	21°49'55"	43°48'19"	1	10N	5N	20	20	10N	30	200N	61.30	20N	2568
169566	21°48'51"	43°48'09"	10	10N	5N	20	50	10N	70	200N	21.30	20N	2023
169568	21°48'01"	43°48'24"	5	10N	5N	50	50	10N	100	200N	28.80	20N	1561
169576	21°46'32"	43°49'29"	7	10N	5N	100	50	10N	70	200N	37.50	20N	2369
169577	21°46'41"	43°50'05"	7	10N	5N	50	50	10N	70	200N	48.80	10	2912
169578	21°46'49"	43°51'02"	3	10N	5N	20	30	10N	50	200N	21.30	20N	2702
169579	21°47'10"	43°51'54"	5	10N	5N	50	50	10N	70	200N	55.00	20N	2485
169581	21°47'22"	43°52'42"	5	10N	5N	50	30	10N	70	200N	33.80	100	3179
169582	21°47'35"	43°53'36"	3	10N	5N	50	50	10N	70	200N	40.00	20N	2543
169583	21°47'53"	43°54'12"	3	10N	5N	50	30	10N	50	200N	40.00	20N	2800
169591	21°59'59"	43°56'43"	7	10N	5N	20	30	10N	50	200N	47.50	20N	3120
169593	21°59'46"	43°56'38"	3	10N	5N	20L	20	10N	30	200N	38.80	20N	1288
169594	21°59'04"	43°56'15"	5	10N	5N	20	50	10N	50	200N	62.50	20N	2649
169596	21°57'34"	43°55'14"	5	10N	5N	20	20	10N	30	200N	10.00	20N	1994
						Kebad monzogranite							
169573	21°12'15"	44°32'12"	5	10N	5N	20L	10L	10N	10N	200N	53.80	10	809
169575	21°12'03"	44°32'40"	3	10N	5N	20L	10L	10N	10N	200N	56.30	20N	1012
						Mahail granodiorite							
169584	21°19'31"	44°47'24"	3	10N	5N	20N	10L	10N	10	200N	96.30	20N	457
169585	21°19'53"	44°47'38"	3	10N	5N	20N	10	10N	10L	200N	82.50	20N	368
169586	21°20'00"	44°47'55"	2	10N	5N	20L	10	10N	10L	200N	82.50	20N	497
169587	21°19'41"	44°47'56"	7	10N	5N	20L	10	10N	10	200N	95.00	20N	380

Table 2.--Selected geochemical data for granitoid rocks, by pluton--Continued

Sample number	Latitude (north)	Longitude (east)	Be	Bi	Mo	Nb	Pb	Sn	Y	Zn	Li	W	F
						Zayd granodiorite							
169600	18°42'01"	43°12'56"	1L	10N	5N	20N	10N	10N	10N	200N	5.00	20N	124
169601	18°41'41"	43°13'20"	1L	10N	5N	20N	10N	10N	10N	200N	6.30	20N	104
169603	18°41'03"	43°14'05"	1L	10N	5N	20N	10N	10N	10N	200N	3.80	20N	105
169604	18°40'47"	43°14'23"	1L	10N	5N	20N	20N	10N	10N	200N	5.00	20N	100
169606	18°40'45"	43°14'39"	1L	10N	5N	20N	10N	10N	10N	200N	5.00	20N	117
169607	18°40'31"	43°15'09"	1L	10N	5N	20N	10N	10N	10N	200N	3.80	20N	73
169608	18°40'24"	43°15'15"	1L	10N	5N	20N	10N	10N	10N	200N	11.30	20N	178
						Habbah granodiorite							
169609	18°39'31"	43°16'52"	1L	10N	5N	20N	10N	10N	10N	200N	16.30	40	198
169610	18°39'05"	43°17'04"	1L	10N	5N	20N	10N	10N	10N	200N	5.00	20N	92
169611	18°38'43"	43°16'58"	1L	10N	5N	20N	10N	10N	10N	200N	5.00	20N	100
169612	18°37'41"	43°16'52"	1L	10N	5N	20N	10N	10N	10N	200N	6.30	10L	100
169613	18°37'15"	43°16'55"	1L	10N	5N	20N	10N	10N	10N	200N	3.80	10L	83
						Tafshah monzogranite							
169614	18°59'42"	43°09'56"	1L	10N	5N	20N	10N	10N	70	200N	6.30	20N	104
169617	18°58'53"	43°10'08"	1L	10N	5N	20N	10N	10N	20	200N	2.50	20	116
169618	18°58'12"	43°09'59"	1N	10N	5N	20N	10N	10N	50	200N	2.50	20	152
169620	18°58'02"	43°09'33"	1L	10N	5N	20N	10N	10N	50	200N	2.50	20N	79
169622	18°57'39"	43°09'25"	1L	10N	5N	20N	10N	10N	30	200N	5.00	20N	121
						Bwana granite							
169623	18°31'33"	43°56'10"	7	10N	5N	20N	70	10L	70	200N	117.50	20N	1296
169624	18°31'01"	43°56'32"	7	10N	5N	20L	70	10L	70	200N	127.50	20N	1242

Table 2.--Selected geochemical data for granitoid rocks, by pluton--Continued

Sample number	Latitude (north)	Longitude (east)	Be	Bi	Mo	Nb	Pb	Sn	Y	Zn	Li	W	F
						Bwana granite-Continued							
169625	18°30'27"	43°56'49"	7	10N	5N	20L	70	20	70	200N	103.80	20N	960
169626	18°29'58"	43°56'38"	7	10N	5N	20	100	30	70	200N	125.00	20N	1584
169627	18°30'42"	43°54'11"	7	10N	5N	70	150	100	15	200N	266.00	10L	1325
169628	18°30'22"	43°54'20"	7	10N	5N	30	70	70	15	200N	194.00	20N	1208
169629	18°28'36"	43°54'14"	7	10N	5N	30	70	70	70	200N	169.00	10L	1800
169630	18°28'49"	43°54'02"	7	10N	5N	20N	70	30	30	200N	181.00	20N	1152
169631	18°29'10"	43°53'57"	7	10N	5N	20N	100	30	70	200N	144.00	20N	1920
						Madha granodiorite							
169632	18°48'10"	43°19'49"	1N	10N	5N	20N	10L	20	10N	200N	6.30	10L	191
169634	18°48'47"	43°19'40"	1N	10N	5N	20N	10N	10N	10N	200N	5.00	10L	135
169635	18°49'17"	43°19'55"	1N	10N	5N	20N	10N	10N	10N	200N	1.30	10L	215
169636	18°49'47"	43°19'45"	1N	10N	5N	20N	10N	10N	10N	200N	11.30	10L	247

Table 3.--Selected geochemical data for quartz veins cutting granitoid rocks, by pluton

[All results in parts per million. Ag, Mo, Pb, and Sn determined by semiquantitative spectrography. Li determined by atomic absorption analysis. W determined by colorimetry. Fluorine determined by selective-ion-electrode method. All analyses by the DGMR-USGS chemical laboratory, Jiddah. N indicates not detected at the limit shown. L indicates less than the limit shown]

Sample number	Latitude (north)	Longitude (east)	Ag	Mo	Pb	Sn	Li	W	F
			Sabhah monzogranite						
169385	23°16'34"	44°36'23"	0.5N	5N	10N	15	76.25	20N	348
169386	23°16'47"	44°36'51"	.5N	5	10N	15	96.25	20N	408
			Siṭarāh monzogranite						
169421	22°05'51"	44°42'48"	.7	70	150	20	61.30	20N	3476
169422	22°05'54"	44°42'49"	.5L	5N	15	70	186.30	20N	3696
169426	22°06'07"	44°42'53"	.5N	50	70	10N	121.30	50	255
169442	22°05'50"	44°43'20"	20.0	1000	1000	30	63.80	250	1680
169448	22°06'08"	44°42'59"	.5	5	10	10N	86.30	20N	5600
			Huwail granite						
169455	22°51'27"	44°50'48"	.5N	5L	10N	10N	36.30	20N	1109
169458	22°51'07"	44°50'20"	.5N	5N	100	20	233.80	20N	3606
169485	22°48'53"	44°53'19"	15.0	5N	1000	10N	39.00	20N	1366
			Ehn monzogranite						
169460	24°06'20"	44°51'03"	.5N	150	10	10N	10.00	100	4608
169461	24°05'27"	44°51'51"	.5N	5L	10N	10N	1.30	20N	1935
169463	24°05'02"	44°51'59"	.5N	5L	10N	10N	10.00	20N	137
169465	24°04'02"	44°52'49"	.5N	5	10N	10N	21.30	20N	1888

Table 3.--Selected geochemical data for quartz veins cutting granitoid rocks, by pluton--Continued

Sample number	Latitude (north)	Longitude (east)	Ag	Mo	Pb	Sn	Li	W	F
				Hawshah monzogranite					
169473	22°33'16"	44°43'56"	0.5N	5N	10L	10N	27.50	20N	1001
169475	22°33'29"	44°44'04"	.5N	5N	10L	10N	31.30	25	4000
169477	22°34'04"	44°44'23"	.5N	5N	10N	10	42.50	50	422
169478	22°35'57"	44°43'39"	.5N	10	10	10L	27.50	25	1978
169480	22°36'14"	44°43'40"	1.0	5N	10L	15	27.50	75	944
169482	22°36'44"	44°43'59"	.5N	5N	10L	30	40.00	50	1757
				Sahah granite					
169488	22°07'41"	44°50'12"	.5N	10	10	10N	89.00	10	187
169490	22°07'39"	44°50'35"	.5N	5L	10	10N	101.00	60	201
169492	22°07'27"	44°51'02"	.5N	5	20	10N	106.00	60	1560
169494	22°10'01"	44°48'33"	.5N	5L	10L	10N	116.00	20N	760
169496	22°09'56"	44°49'04"	.5L	5L	70	10N	131.00	20N	151
169498	22°09'53"	44°49'31"	.5N	7	10L	10N	78.00	20N	528
169500	22°09'41"	44°50'14"	.5N	7	10	10N	176.00	20N	240
				Tarban monzogranite					
169521	21°12'55"	44°02'54"	.5N	5	15	10N	8.80	59200	432
169536	21°13'24"	44°02'40"	.5N	5N	50	10N	3.80	20N	102
169540	21°13'05"	44°02'56"	.5N	5N	20	10N	3.80	20N	124
169550	21°15'03"	43°59'58"	.5N	5N	100	10N	26.30	20N	493
				Huqban granite					
169559	21°52'11"	43°48'29"	.5N	5N	50	30	23.80	20N	1294
169561	21°51'22"	43°48'33"	.5N	5N	50	10	5.00	20N	280
169563	21°50'20"	43°48'24"	.5N	5N	50	10N	11.30	20N	204
169565	21°49'32"	43°48'10"	.5N	5N	30	10N	8.80	20N	217

Table 3.--Selected geochemical data for quartz veins cutting granitoid rocks, by pluton--Continued

Sample number	Latitude (north)	Longitude (east)	Ag	Mo	Pb	Sn	Li	W	F
			Huqban granite-Continued						
169567	21°48'50"	43°48'09"	0.5N	5N	15	10N	18.80	20N	335
169580	21°47'08"	43°52'24"	.5N	5N	10L	10N	60.00	20N	318
169592	21°59'00"	43°56'35"	.5N	5N	10N	10N	38.80	20N	104
169595	21°58'26"	43°56'14"	.5N	5N	10	10N	23.80	20N	578
			Kebad monzogranite						
169569	21°09'11"	44°34'45"	.5N	5N	10L	10N	23.80	20N	271
169570	21°09'51"	44°33'47"	.5N	5N	10L	10N	11.30	20N	128
169571	21°10'29"	44°33'07"	.5N	5N	10L	10N	5.00	20N	124
169572	21°11'29"	44°32'07"	.5N	5N	10L	10N	5.00	20N	162
169574	21°12'09"	44°32'27"	.5N	5N	10L	10N	46.30	20N	734
			Zayd granodiorite						
169602	18°41'31"	43°13'41"	.5N	5N	10N	10N	2.50	20N	100
169605	18°40'44"	43°14'32"	.5N	5N	10N	10N	1.30	20N	50L
			Tafshah monzogranite						
169615	18°59'15"	43°10'04"	.5N	5N	10N	10N	2.50	20N	121
169616	18°59'03"	43°10'09"	.5N	5N	10N	10N	3.80	20N	50L
169619	18°58'04"	43°09'53"	.5N	5N	10N	10N	2.50	20N	98
169621	18°57'51"	43°09'26"	.5N	5N	10N	10N	3.80	20N	96
			Madha granodiorite						
169633	18°48'18"	43°19'52"	.5N	10	10N	10N	1.30	20N	132

Table 4.--Selected geochemical data for wall rock hosting granitoid rocks, by pluton

[All results in parts per million. Ag, Mo, Pb, and Sn determined by semiquantitative spectrography. Li determined by atomic absorption analysis. W determined by colorimetry. Fluorine determined by selective-ion-electrode method. All analyses by the DGMR-USGS chemical laboratory, Jiddah. N indicates not detected at the limit shown. L indicates less than the limit shown]

Sample number	Latitude (north)	Longitude (east)	Ag	Mo	Pb	Sn	Li	W	F
			Sitarah monzogranite						
169389	22°06'26"	44°43'05"	0.5N	5N	10	15	7.50	20N	252
169390	22°06'28"	44°42'46"	.5N	5N	10N	10N	21.25	20N	288
169393	22°06'12"	44°42'20"	.5N	5N	10N	10N	43.75	20N	946
169395	22°05'27"	44°42'42"	.5N	5N	10N	10N	35.00	20N	1560
169401	22°05'20"	44°42'55"	.5N	5L	30	10N	25.00	20N	387
169409	22°05'44"	44°43'26"	.5N	5L	15	10N	8.70	20N	960
169411	22°06'16"	44°43'26"	.5N	5N	15	20	13.70	20N	389
169429	22°05'38"	44°43'03"	.5N	7	20	10N	50.00	25	1536
169443	22°05'47"	44°43'19"	.5N	7	10L	10L	41.30	25	1340
169450	22°06'20"	44°42'56"	.5N	5N	10L	10L	17.50	25	378
169452	22°06'18"	44°43'08"	.5N	5N	15	10N	12.50	20N	680
			Ehn monzogranite						
169471	24°03'29"	44°52'35"	.5N	5N	10L	10N	172.70	25	1558
			Tarban monzogranite						
169527	21°14'02"	44°02'08"	.5N	5N	10L	10N	20.00	20N	612
169544	21°15'30"	43°58'21"	.5N	5L	10	10N	62.50	20N	1728

Table 5.--Threshold values for 30-element semiquantitative spectrographic data and for quantitative analyses based on 700 granitoid samples from the eastern and southeastern Arabian Shield

[All values in parts per million. Leaders indicate not available]

Element	Detection limit	Threshold value[1]	Content in workable ore[2]
Silver	0.5	0.5	500
Arsenic	200	200	-
Gold	10	10	10
Boron	10	30	-
Barium	20	1,000	-
Beryllium	1	10	-
Bismuth	10	10	-
Cadmium	20	20	-
Cobalt	5	20	5,000
Chromium	10	300	250,000
Copper	5	100	10,000
Lanthanum	20	70	-
Molybdenum	5	15	5,000
Niobium	20	100	-
Nickel	5	70	15,000
Lead	10	70	50,000
Antimony	100	100	-
Scandium	5	15	-
Tin	10	15	10,000
Strontium	100	700	-
Vanadium	10	70	25,000
Tungsten	50	50	5,000
Yttrium	10	150	-
Zinc	200	200	80,000
Zirconium	10	500	-
Lithium	1	110	-
Tungsten[3]	10	10	5,000
Fluorine	50	1,900	-

[1] du Bray and others (1982/1983)
[2] Rose and others (1979).
[3] By colorimetry.

The accumulated data were evaluated, and a preliminary assessment was prepared for each pluton. No indication of noteworthy mineralization was found in association with any of the plutons, although a few certainly warrant additional study.

DISCUSSION

Ehn monzogranite

The Ehn monzogranite forms a recessive-weathering elliptical body in the southeastern corner of the Jabal al Urd quadrangle (24/44 D) and crops out over about 5 km^2 (fig. 3). Modal analyses of this pluton (fig. 2A) straddle the monzogranite-granodiorite boundary on a quartz-alkali feldspar-plagioclase (QAP) ternary diagram, but the majority of samples plot in the monzogranite field. The Ehn monzogranite is medium gray, hypidiomorphic inequigranular to subporphyritic, and medium grained and contains biotite (color index, that is, the mafic silicate content of the rock, is 6). Microcline occurs as scattered subphenocrysts. Apatite, zircon, fluorite, and sphene are the accessory minerals. The pluton intrudes sedimentary rocks of the Abt formation and is the source of numerous quartz veins and aplite dikes that cut the Abt formation at the northern end of the pluton.

Initial sampling of the Ehn monzogranite (du Bray and others, 1982/1983) indicated that it is associated with a weak geochemical anomaly. Several samples collected during the reconnaissance study contained anomalous concentrations of lithium, fluorine, rubidium, and yttrium, and the petrography of the pluton was similar to that of other highly anomalous plutons in the study area.

No altered or mineralized rock was observed during followup work, and few quartz veins were found cutting the pluton. Aplite dikes and quartz veins in a system that emanates from the northern and eastern margins of the pluton were sampled. One of the quartz-vein samples (169460, table 3) contained 150 parts per million (ppm) molybdenum and 100 ppm tungsten. Otherwise, no anomalous values were recorded, and no other indications of mineral potential were observed. A more detailed evaluation of the tungsten and molybdenum potential associated with the quartz veins may be warranted, but additional work is not indicated.

Sabhah monzogranite

The Sabhah monzogranite forms a prominent ellipsoidal mountain in the west-central part of the Sabhah quadrangle (23/44 D) and crops out over about 50 km^2 (fig. 4). Modal analyses of this rock (fig. 2B) form a compact cluster that centers in the monzogranite field. The Sabhah monzogranite

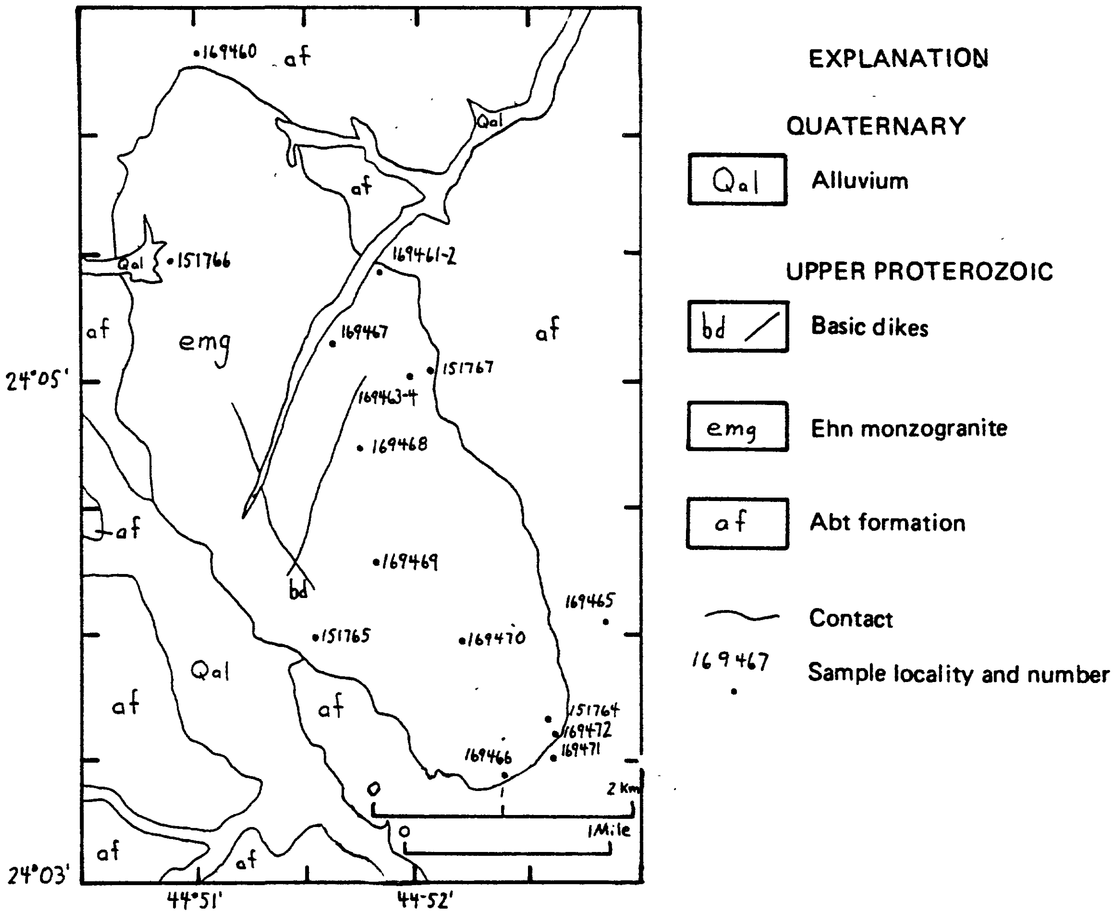


Figure 3.--Geologic sketch map of the Ehn monzogranite.

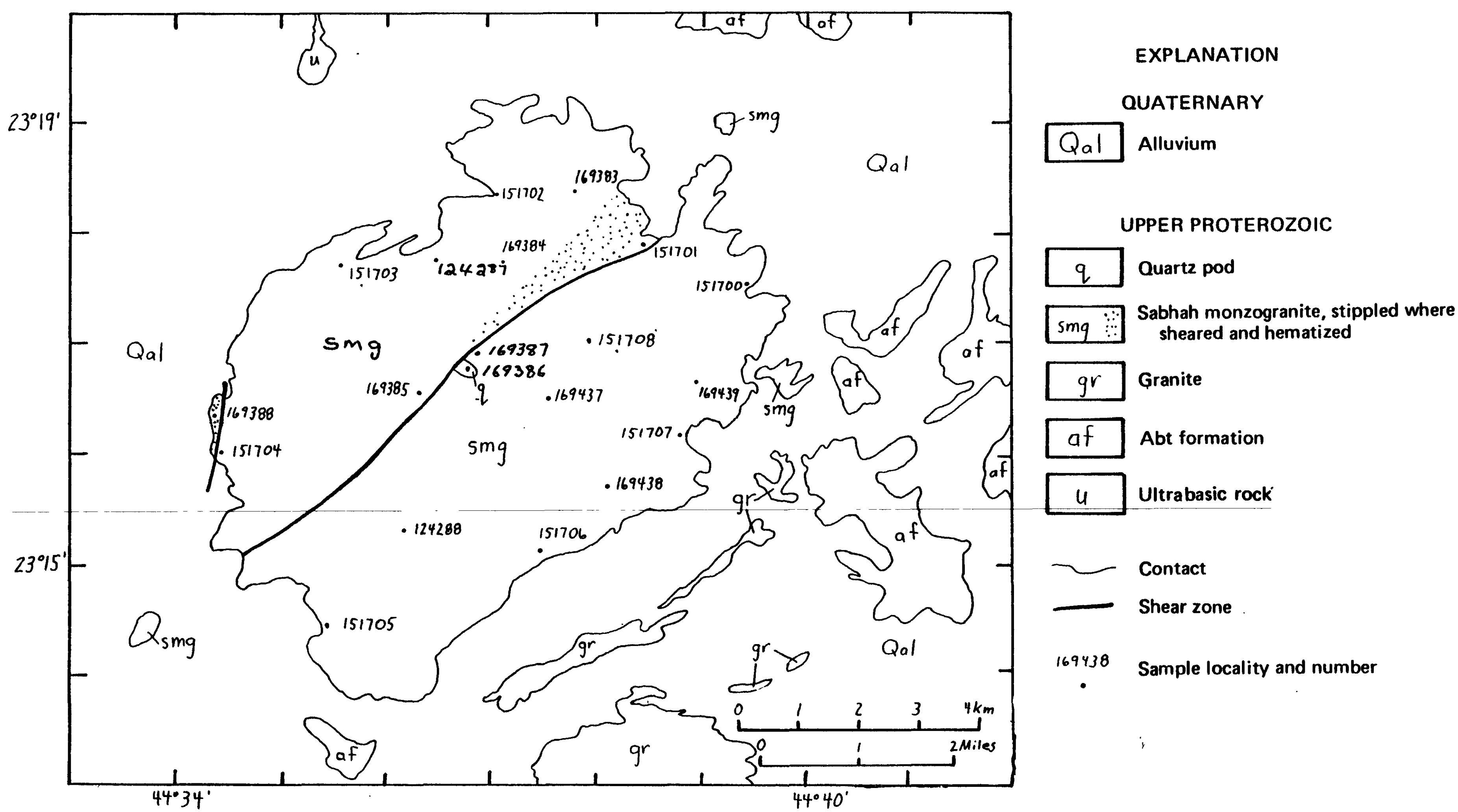


Figure 4.--Geologic sketch map of the Sabhah monzogranite.

is light pinkish gray, medium grained, and hypidiomorphic inequigranular. Gridiron-twinned microcline is nonperthitic. Biotite is only mafic silicate, and colorless to very-light-tan-pleochroic white mica is locally present (color index 3). Zircon, opaque oxides, apatite, and fluorite comprise the accessory mineral suite. The pluton intrudes the Abt formation on the east and other, less evolved, granitoid rocks on the west.

Initial sampling of the pluton (du Bray and others, 1982/1983) indicated that it contains anomalous concentrations of Be, Bi, Pb, La, Y, Rb, Nb, Li, F, and Ag and that it is depleted in strontium, zirconium, and barium. Although neither tin nor tungsten was detected, the geochemical and petrographic characteristics are reminiscent of tin-bearing granitoid rocks. The pluton is also one of the most radioactive plutons in the area. As noted by du Bray and others (1982/1983), the radioactivity of this pluton is locally four times the background value for the study area.

Followup sampling (tables 2-4) indicated that the pluton does contain weakly anomalous concentrations of tin and tungsten. However, no alteration or mineralized rock was observed, and quartz veins cutting the pluton are rare. A major northeast-trending shear cutting the northern end of the body contains neither mineralized nor altered rock. Coarse-grained quartz-potassium feldspar pods as much as 30 m in diameter that also crop out at the northern end of the pluton are similarly barren. Zircon, which occurs as abundant, very small, prismatic grains in colorless to pale-brown pleochroic white mica, is especially abundant in this pluton and is the probable source of the anomalous radioactivity. All evidence indicates that the mineral potential of the Sabhah granite is low, and further work is not warranted.

Bitran granodiorite

The Bitran granodiorite, which has weathered to a dark-reddish-brown color, crops out over about 5 km^2 in the northwestern part of Jabal Bitran quadrangle (23/45 C) and forms a prominent circular mountain (fig. 5). Modal analyses of this granite (fig. 2C) indicate that the pluton is compositionally inhomogeneous, and petrographic studies indicate that it is texturally inhomogeneous. The following petrographic description is generalized on the basis of a number of slightly different rock types. The Bitran granodiorite is fine-grained, allotriomorphic, and equigranular and contains biotite (color index 2). It includes local medium- to coarse-grained phases. Apatite, zircon, and epidote are the accessory minerals. The host rocks for this pluton are other granodioritic rocks and meta-andesite hornfels.

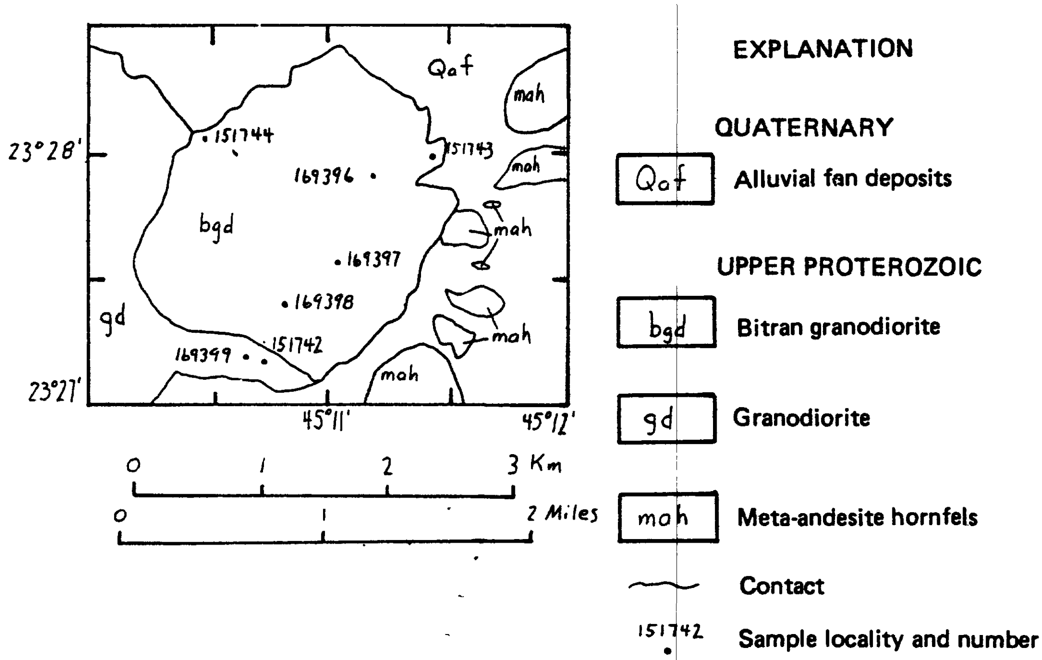


Figure 5.--Geologic sketch map of the Bitran granodiorite.

These rock samples collected at Jabal Bitran during the reconnaissance study each contained 10 ppm tungsten. Pan concentrates collected from wadis draining the mountain did not contain anomalous metal values nor were there other geochemical indicators that this pluton is anomalous. No altered or mineralized rock was observed, and few quartz veins cutting the pluton were observed.

Followup sampling of the pluton did not replicate the tungsten anomaly (table 2). Features that might suggest noteworthy mineral potential were not observed on traverses across the pluton. Petrographic and trace-element geochemical studies indicated that the Bitran granodiorite is unlike the remaining plutons studied here and unlike highly evolved felsic plutonic rocks associated with rare-metal deposits elsewhere in the world. The tungsten-anomalous samples may have resulted from technical difficulties in the chemical laboratory. The Bitran granodiorite has no known mineral potential, and further work is not recommended.

Huwail granite

The Huwail granite forms a very prominent mountain in the northeastern part of the Jabal Sahah quadrangle (22/44 D) and crops out over about 110 km^2 (fig. 6). Modal analyses of this granite (fig. 2D) cluster near the syenogranite-monzogranite boundary, although two samples plot in the alkali-feldspar granite field. The granite is grayish orange pink, hypidiomorphic inequigranular to subporphyritic, and medium grained. Microcline is strongly perthitic, and biotite is the mafic silicate (color index 3). The accessory minerals are fluorite, zircon, opaque oxides, and apatite. The Huwail granite intrudes amphibolite on the east and older granitoid rocks on the west.

Initial sampling of the pluton (du Bray and others, 1982) indicated that it contains anomalous concentrations of Be, La, Y, Rb, Nb, Li, F, and Sn and that it is depleted in barium, strontium, and zirconium. Geochemical sampling conducted by Kanaan (1979) identified as much as 2,000 ppm molybdenum in quartz veins.

Followup study of the Huwail granite indicated that it is an evolved granite but not so highly evolved as many of the other plutons studied (table 1). Although many of the granites studied are tin-mineralized granites according to Tischendorf's (1977) nomenclature, the Huwail granite has characteristics most like those of Tischendorf's precursor to the tin-mineralized granite clan.

Although no altered or mineralized outcrops were identified, the Huwail granite is cut by a moderate number of east-striking quartz veins 0.5 to 3 cm in width. The granite is

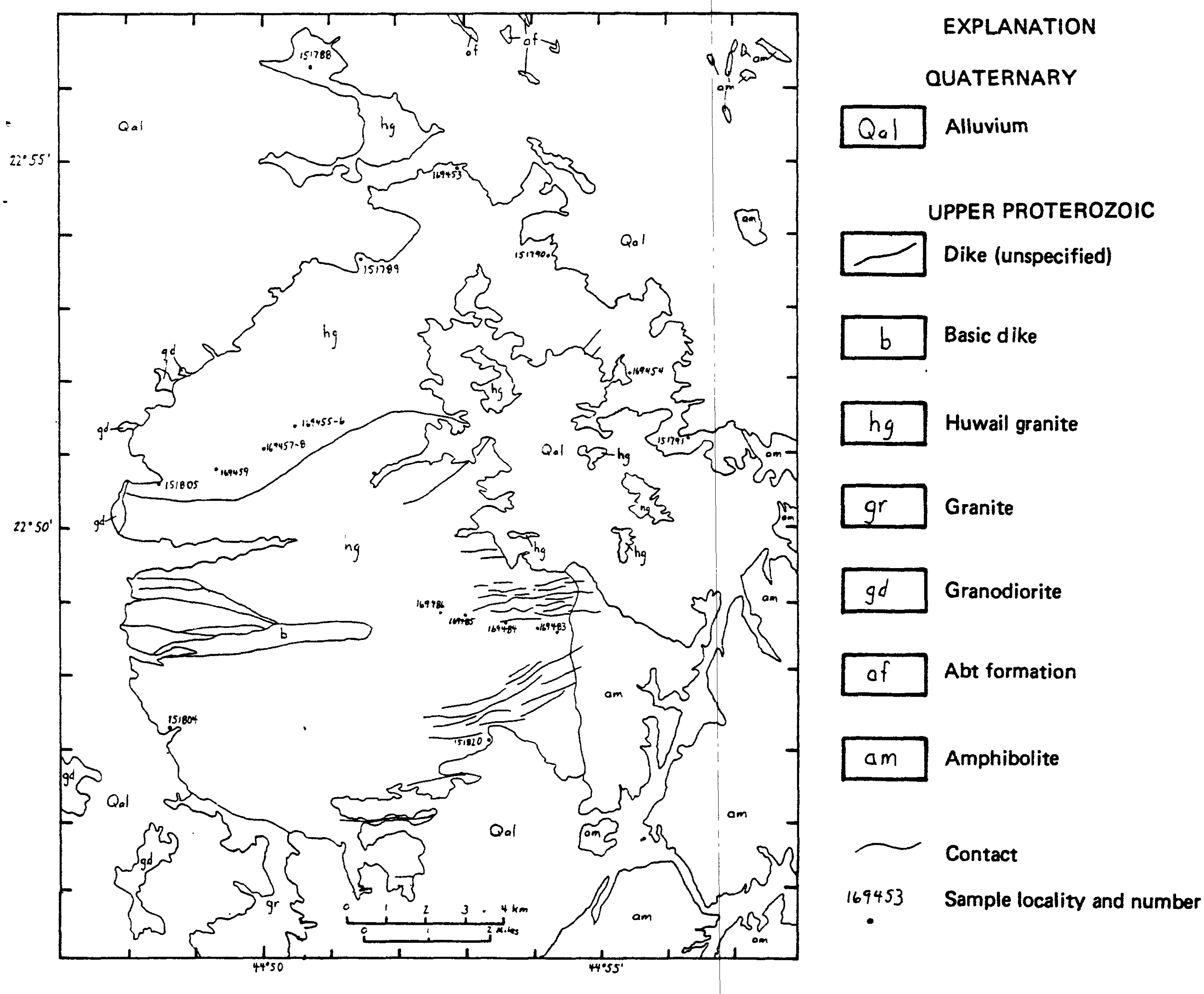


Figure 6.--Geologic sketch map of the Huwail granite.

weakly tungsten anomalous (table 2), and quartz veins locally contain anomalous concentrations of silver, lead, tin, and tungsten (table 3). Kanaan (1979) indicated that flakes of molybdenite were observed in the quartz vein from which he collected a sample containing 2,000 ppm molybdenum. The scattered geochemical anomalies associated with quartz veins and the overall granitophile-element enrichment of this relatively large pluton suggest that it may have some mineral potential; however, only a few areas have been sampled and additional detailed work may be warranted.

Hawshah monzogranite

The Hawshah monzogranite forms a prominent, ellipsoidal mountain in the southeastern part of the Jabal al Hawshah quadrangle (22/44 B) and crops out over about 120 km^2 (fig. 7). Modal analyses of the rocks (fig. 2E) plot in the monzogranite field. The monzogranite is very light gray, hypidiomorphic inequigranular to subporphyritic, and medium grained and contains biotite and muscovite (color index 1). Microcline is nonperthitic and plagioclase is unzoned albite. The accessory minerals are zircon, fluorite, and opaque oxides. The Hawshah monzogranite intrudes both older, less evolved granitoid rocks and metagraywacke of the Murdama group.

Initial sampling of the pluton (du Bray and others, 1982/1983), indicated that it contains anomalously high concentrations of Be, Bi, Nb, Sn, W, Rb, Y, Ag, Li, and F and that it is depleted in zirconium, lanthanum, barium and strontium. The pluton was also one of the most radioactive plutons in the area (du Bray and others, 1982/1983). Kanaan (1979) sampled quartz veins in this intrusion and found anomalous concentrations of molybdenum and silver. The most striking feature of this pluton is macroscopically visible beryl disseminated in the rock at many locations. Many of the small pegmatite dikes that cut the pluton contain coarse-grained clusters of beryl. Otherwise, no visibly altered or mineralized rock was identified during the reconnaissance study of this pluton.

Followup study of the Hawshah monzogranite showed that an average sample of the pluton contains about 20 ppm tin and 50 ppm tungsten (table 2), whereas anomalous concentrations of silver, molybdenum, tin, and tungsten were identified in quartz veins cutting the pluton (table 3). The petrographic and geochemical characteristics (table 1) of the Hawshah monzogranite are very similar to those attributed to the precursor to tin-mineralized granites as described by Tischendorf (1977).

No obvious signs of mineralized rock were found, but the mountain is relatively large and characterized by extreme relief; not many parts of the pluton were visited or sampled. Because of the observed granitophile-element enrichment, the presence of beryl, and the weakly anomalous concentrations of

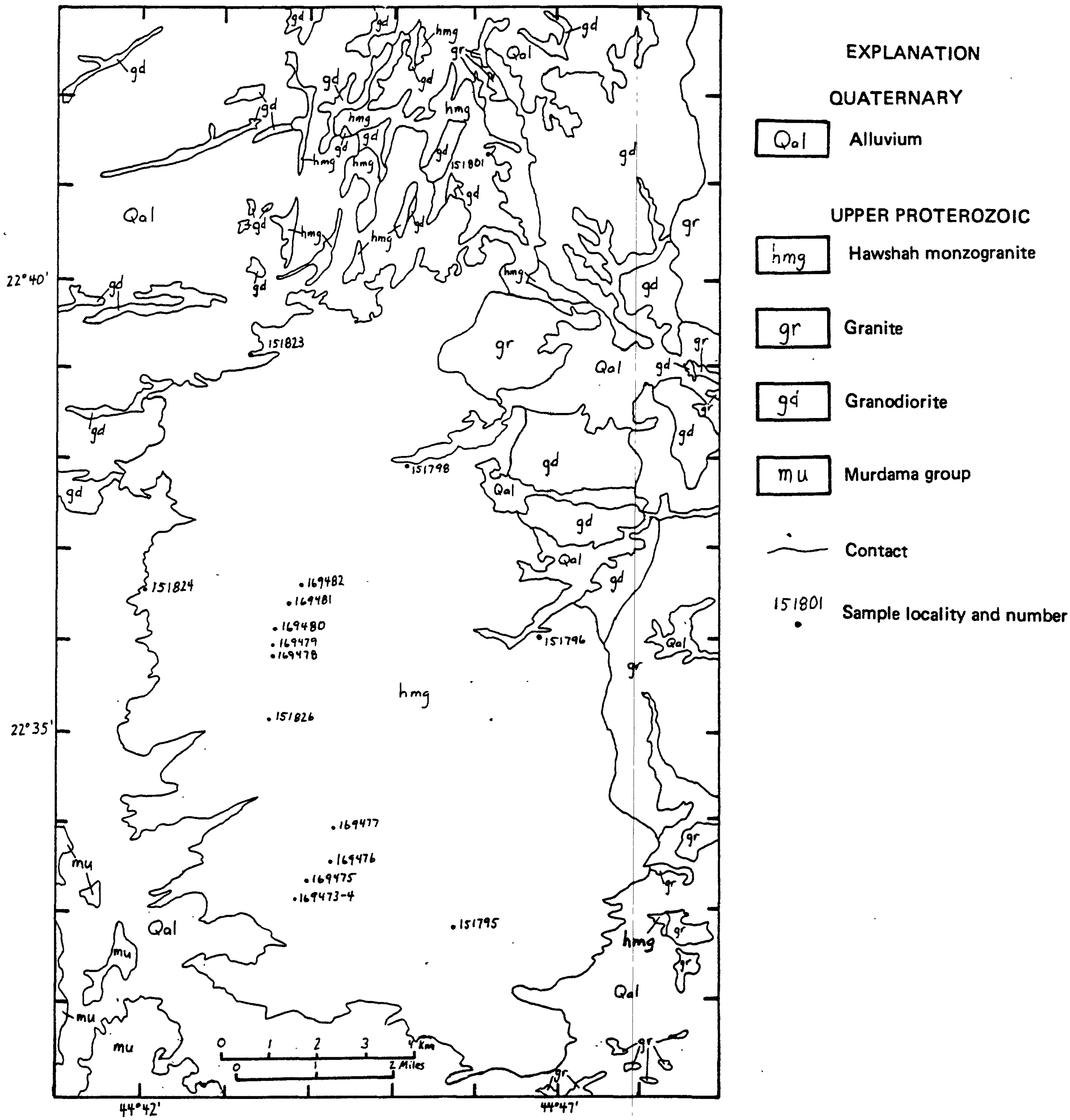


Figure 7.--Geologic sketch map of the Hawshah monzogranite.

silver, molydenum, tin, and tungsten, the pluton probably merits further study.

Sitarah monzogranite

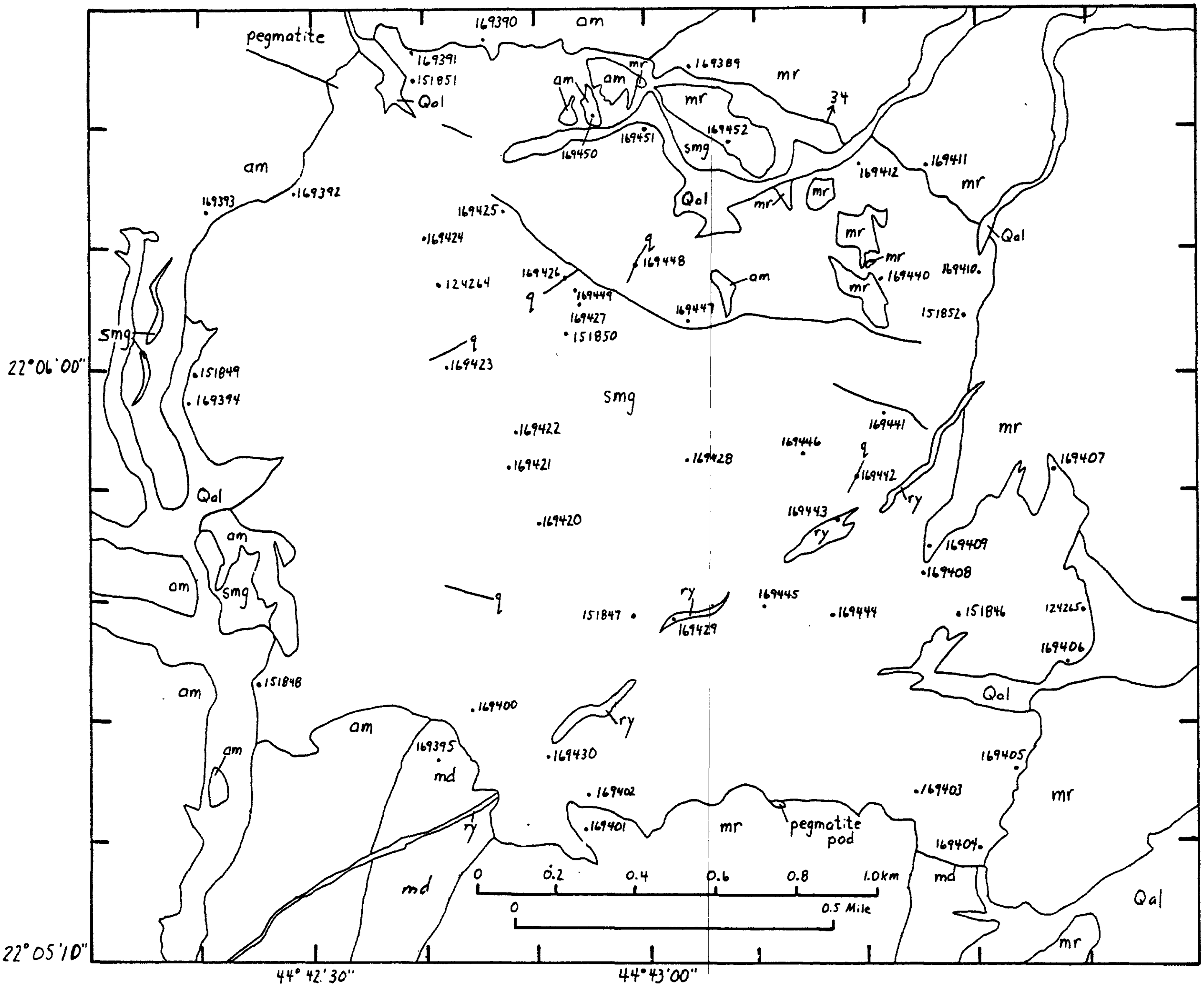
The Sitarah monzogranite crops out prominently in Jabal as Sitarah. It forms a small pluton in the southwestern part of the Jabal Sahah quadrangle (22/44 D) and crops out over 3 km2 (fig. 8). Modal analyses of the rocks (fig. 2F) plot in the monzogranite field. The monzogranite is pinkish gray to light gray, hypidiomorphic inequigranular to subporphyritic, and medium grained and contains biotite and muscovite (color index 1). Microcline is nonperthitic and locally forms anhedral to subhedral subphenocrysts, whereas plagioclase is unzoned albite. The accessory minerals are zircon, fluorite, and apatite. The pluton intrudes volcanic rocks of the Hulayfah group.

Initial sampling indicated that this pluton is one of the most geochemically anomalous plutons in the study area (du Bray and others, 1982/1983). Anomalously high concentrations of Sn, W, Bi, Ag, Pb, Rb, Y, Nb, F, Mo, Li, and Be and anomalously low concentrations of Sr, Zr, Ba, La, Ce, and Nd were observed. Samples of the pluton, which appear to be unmineralized, collected during the followup study contained highly anomalous concentrations of tin, tungsten, and molybdenum (table 2). Quartz-vein samples were similarly anomalous and included one sample that contains 20 ppm silver, 1,000 ppm molybdenum, 1,000 ppm lead, 30 ppm tin, and 250 ppm tungsten (table 3). Several samples of the metamorphic host rock contained weakly anomalous concentrations of tin and tungsten (table 4). These elements were probably deposited in the surrounding rock from fluids exsolved during crystallization. West-striking quartz veins, although not especially numerous, cut the pluton; some of these veins have weakly altered selvages. A small, apparently unmineralized quartz breccia pipe cuts the northern part of the pluton.

The petrographic and geochemical characteristics of this granite pluton indicate that it is a member of the tin-mineralized granite clan as described by Tischendorf (1977). Although no obvious deposits were identified, the anomalous geochemistry of the pluton and its quartz veins indicates the need for significant study of its mineral potential.

Sahah granite

The Sahah granite forms a prominent, elliptical mountain that crops out over about 55 km2 in the east-central part of the Jabal Sahah quadrangle (22/44 D) (fig. 9). Modal analyses of the rocks (fig. 2G) plot near the syenogranite-monzogranite boundary. The granite is grayish orange pink, hypidiomorphic equigranular, and medium to coarse grained and



EXPLANATION

QUATERNARY

Symbol	Unit
Qal	Alluvium

UPPER PROTEROZOIC

Symbol	Unit
q	Quartz vein
(line)	Basic dike
ry	Rhyolite dike
smg	Sitarah monzogranite
mr	Metarhyolite
md	Metadacite
am	Amphibolite
34	Contact, showing degree and direction of dip
151852	Sample locality and number

Figure 8.--Geologic sketch map of the Sitarah monzogranite.

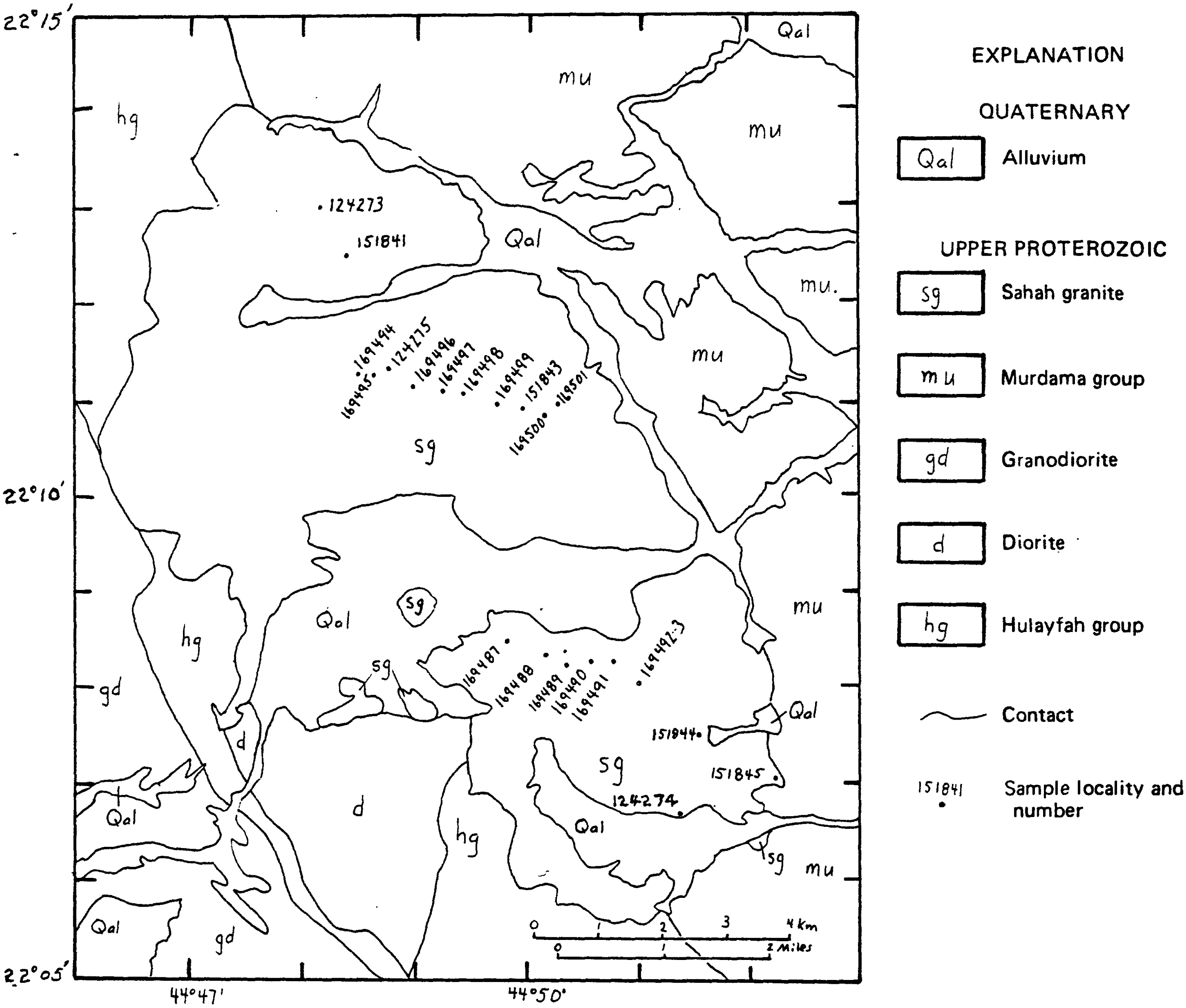


Figure 9.--Geologic sketch map of the Sahah granite.

contains biotite and muscovite (color index 2). Microcline is very weakly perthitic, and plagioclase is unzoned albite. The accessory minerals are fluorite, zircon, and opaque oxides. The Sahah granite intrudes weakly metamorphosed, immature sedimentary rocks of the Murdama group on the east and volcanic rocks of the Hulayfah group on the west.

Initial sampling of the pluton indicated that it contains anomalously high concentrations of Be, Sn, F, Y, and Nb and that it is depleted in barium and lanthanum (du Bray and others, 1982/1983). The pluton is cut by a moderate number of west-trending quartz veins that are between 1 mm and 3 cm thick. Followup sampling indicated that the granite is tungsten anomalous. Several apparently unmineralized rock samples contained between 20 and 60 ppm tungsten, and nearly half of the quartz-vein samples contained tungsten in this concentration range (tables 2 and 3). Otherwise, no significant mineral potential was identified.

The Sahah granite is characterized by petrographic and geochemical features typical of the precursor to Tischendorf's (1977) tin-mineralized granites. Because its potential for tungsten deposits is currently unknown, the pluton may warrant additional study; however, because the observed values are relatively low, additional work is not recommended at this time.

Huqban granite

The Huqban granite forms a large, locally prominent, dumbbell-shaped massif that crops out over about 200 km^2 in the northeastern part of the Jabal as Sukkah quadrangle (21/43 B) (fig. 10). Modal analyses of the granite straddle the monzogranite-syenogranite boundary (fig. 2H). The granite is light gray, hypidiomorphic equigranular, and medium grained and contains biotite and a trace of muscovite (color index 3). Microcline is strongly perthitic, and plagioclase is unzoned albite. The accessory minerals are allanite, apatite, sphene, fluorite, zircon, and opaque oxides. The Huqban granite intrudes a terrane of older, deformed granitoid rocks. This pluton is the subject of a separate study by du Bray and Ramsay (unpub. data, 1982).

Initial sampling of the pluton indicated that it contains anomalously high concentrations of Ag, Be, Bi, Nb, F, W, La, Li, Mo, Zr, and Rb and depleted concentrations of strontium, lanthanum, barium, cerium, and neodymium. In addition, the pluton is one of the most radioactive in the study area (du Bray and others, 1982/1983). Strongly mineralized rock was not identified during followup sampling. A few samples contained weakly anomalous concentrations of tin and tungsten and one sample contained 100 ppm tungsten (table 2). Several quartz-vein samples contained weakly anomalous concentrations

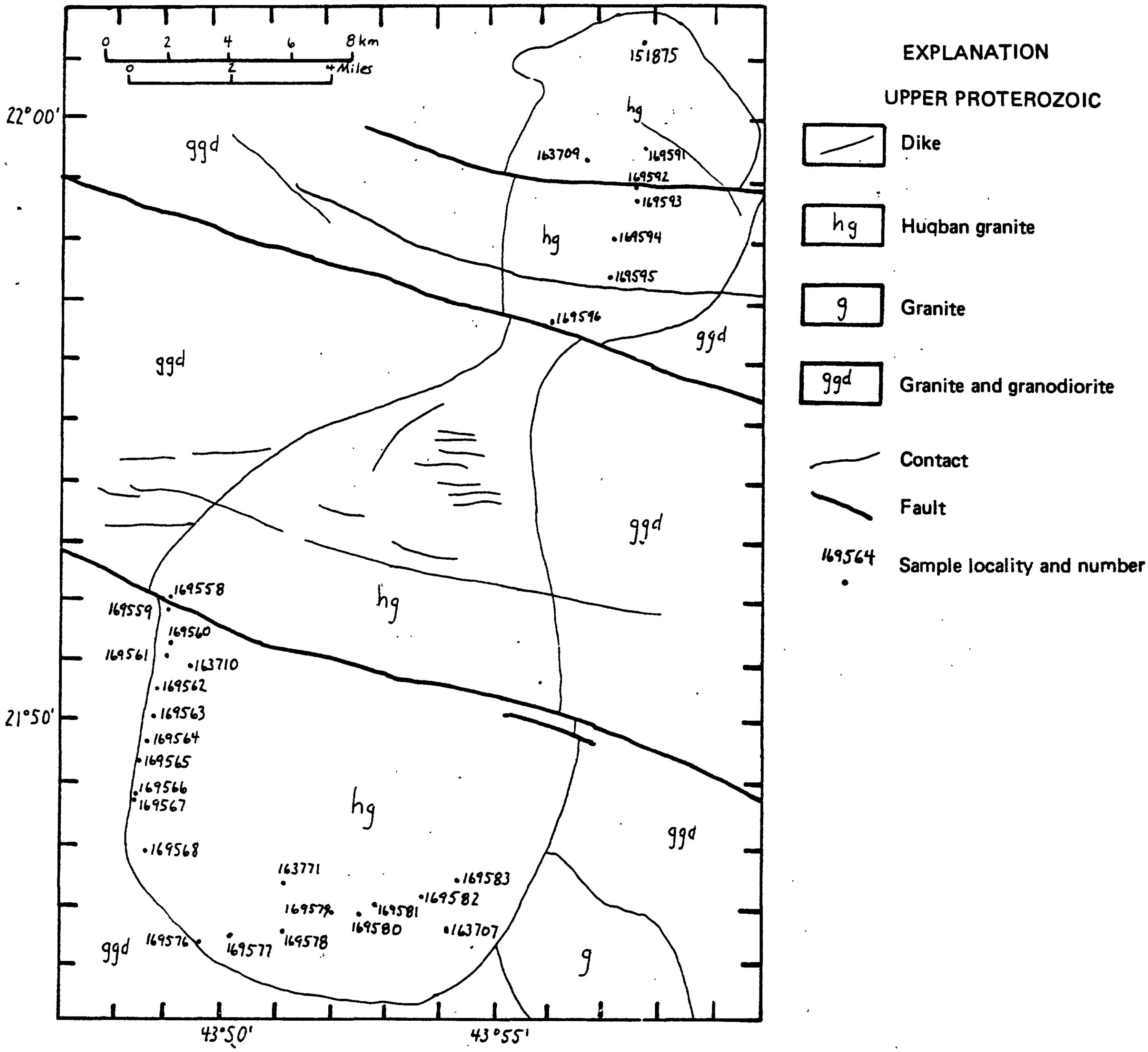


Figure 10.--Geologic sketch map of the Huqban granite.

of tin. Quartz veins cutting this pluton are scarce. Two pockets of unmineralized, open-space-filling quartz, 10 m in diameter, were sampled and found to be barren.

Because the Huqban granite is only weakly anomalous and belongs to the precursor to tin-mineralized granite clan (Tischendorf, 1977), additional work is not merited.

Tarban monzogranite

The Tarban monzogranite crops out in an elongate series of prominent hills that occupy about 5 km^2 midway along the border between the eastern Badwah and Bir Juqjuq quadrangles (21/44 C and 21/43 D) (fig. 11). Most modal analyses of the granite plot in the monzogranite field, although some plot on the plagioclase-rich side of the syenogranite field (fig. 2I). The monzogranite is very light gray to bluish white, hypidiomorphic inequigranular, and medium grained and contains muscovite, biotite, and a trace of almandine-spessartine garnet (color index 1). Microcline is nonperthitic and locally amazonitic; plagioclase is unzoned albite. The accessory minerals are fluorite, zircon, and opaque oxides. The Tarban monzogranite intrudes a terrane of older granitoid and dioritoid rocks.

Initial sampling of the pluton indicated that it is one of the most geochemically anomalous plutons in the study area (du Bray and others, 1982/1983). Anomalously high concentrations of Ag, Be, Bi, Pb, Sn, W, Li, F, Rb, Zn, and Nb and anomalously low concentrations of Cu, Sr, Zr, Ba, La, Ce, and Nd were observed. The pluton is locally characterized by surface coatings as much as 1 cm thick and pods 10 cm in diameter, both composed of a black amorphous material. X-ray fluorescence analyses of this material indicated that it contains as much as 250 ppm zinc. In addition, the pluton is cut by a moderate number of thin quartz veins.

Followup sampling of the pluton showed that apparently unmineralized rock samples (table 2) contain locally anomalously high concentrations of Be, Nb, Pb, Sn, Y, and Zn but that quartz veins (table 3) cutting the pluton do not. An exception is sample 169521, which was specially collected because wolframite was visible in hand samples and is from a small wolframite-bearing quartz vein that contained nearly 6 percent tungsten. No obviously mineralized rock was observed elsewhere in the pluton.

The petrographic and geochemical signatures of this pluton are those of tin-mineralized granites (Tischendorf, 1977). Both the extremely anomalous values of tin and tungsten obtained for some samples and the similarities between this pluton and plutons with associated rare-metal deposits

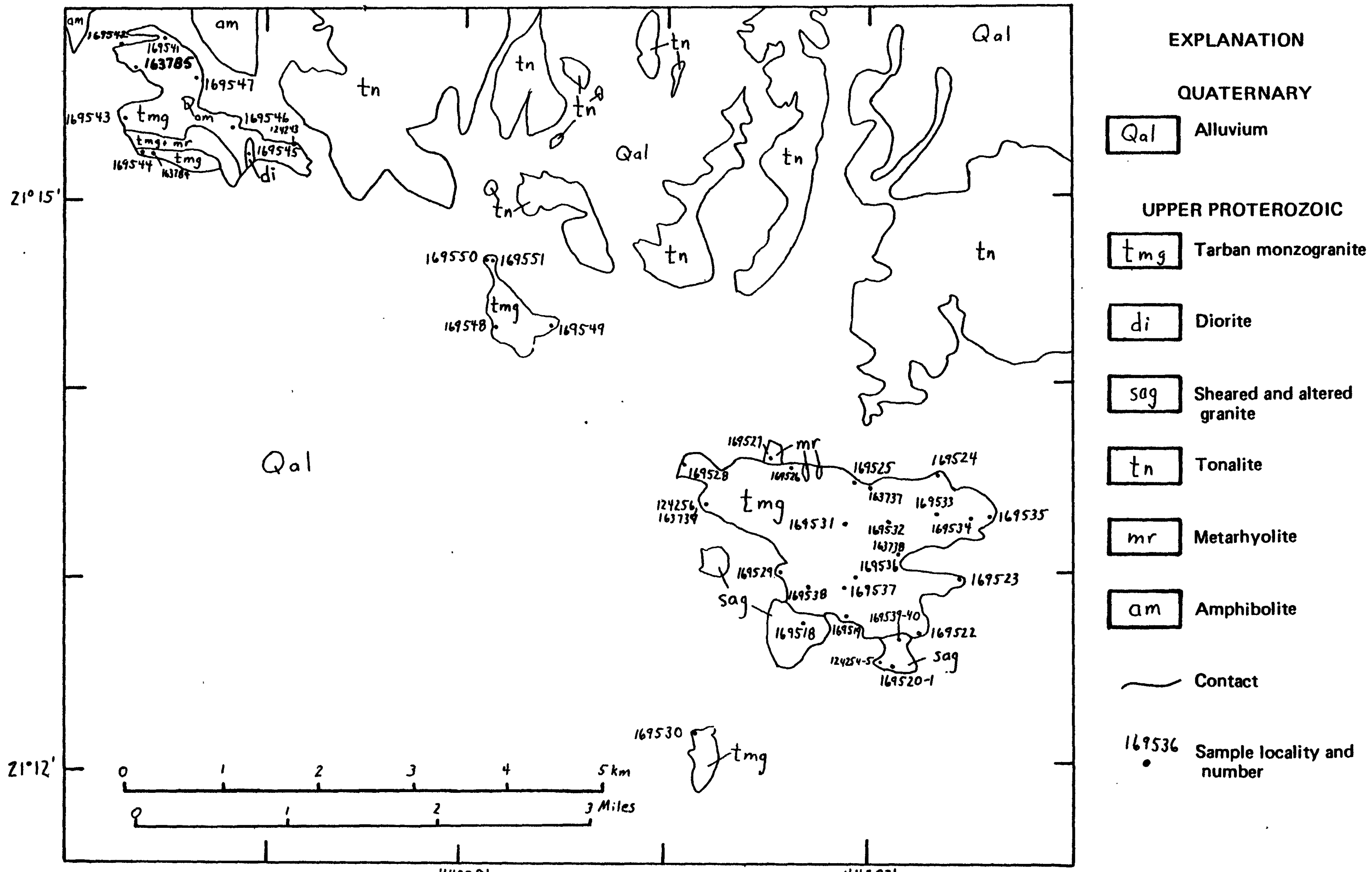


Figure 11.--Geologic sketch map of the Tarban monzogranite.

located elsewhere in the world indicate that this pluton should receive additional study.

Kebad monzogranite

The Kebad monzogranite crops out in a roughly circular area measuring about 4 km^2 in the southwestern part of Jabal Khidah quadrangle (21/44 D) (fig. 12). Modal analyses of the Kebad monzogranite straddle the monzogranite-granodiorite boundary but center in the monzogranite field (fig. 2J). The monzogranite is grayish orange pink, hypidiomorphic inequigranular, and medium grained; it contains biotite, muscovite, and garnet (color index 1). Microcline is nonperthitic, and plagioclase is unzoned albite. Partially albitized potassium feldspar indicates the activity of late-stage magmatic fluids. The accessory minerals are apatite, fluorite, and opaque oxides. The Kebad monzogranite intrudes older granitoid rocks.

Initial sampling of this pluton indicated that it contains weakly anomalous concentrations of silver, beryllium, and tin but is otherwise depleted in granitophile elements (du Bray and others, 1982/1983 The pluton was restudied principally because it was muscovite bearing. Followup sampling substantiated the previous finding that this pluton is not especially geochemically anomalous. The pluton is cut by a moderate number of quartz veins and crops out immediately east of a massive northwest-trending quartz vein that extends for about 5 km. The geochemistry of these veins (table 3) is not anomalous. Pods in the monzogranite containing abundant muscovite are similarly nonanomalous. All evidence indicates that the mineral potential of this pluton is low, and additional work is probably not warranted.

Mahail granodiorite

The Mahail granodiorite forms a recessive-weathering, circular pluton that crops out over 3 km^2 in the northeastern part of the Jabal Khidah quadrangle (21/44 D) (fig. 13). Modal analyses of the Mahail granodiorite plot in the quartz-rich part of the granodiorite field (fig. 2K). The granodiorite is very light gray, hypidiomorphic equigranular, and medium grained and contains muscovite and almandine-spessartine garnet (color index 1). Microcline is nonperthitic and is locally albitized by late-stage magmatic fluids; plagioclase is unzoned albite. No accessory minerals were observed. The granodiorite intrudes older granitoid rocks on the west and mixed ultramafic rocks on the east.

Initial sampling of this pluton indicated that it is not associated with a geochemical anomaly (du Bray and others, 1982/1983). In fact, the granodiorite was extremely depleted in all granitophile elements. It contained several percent

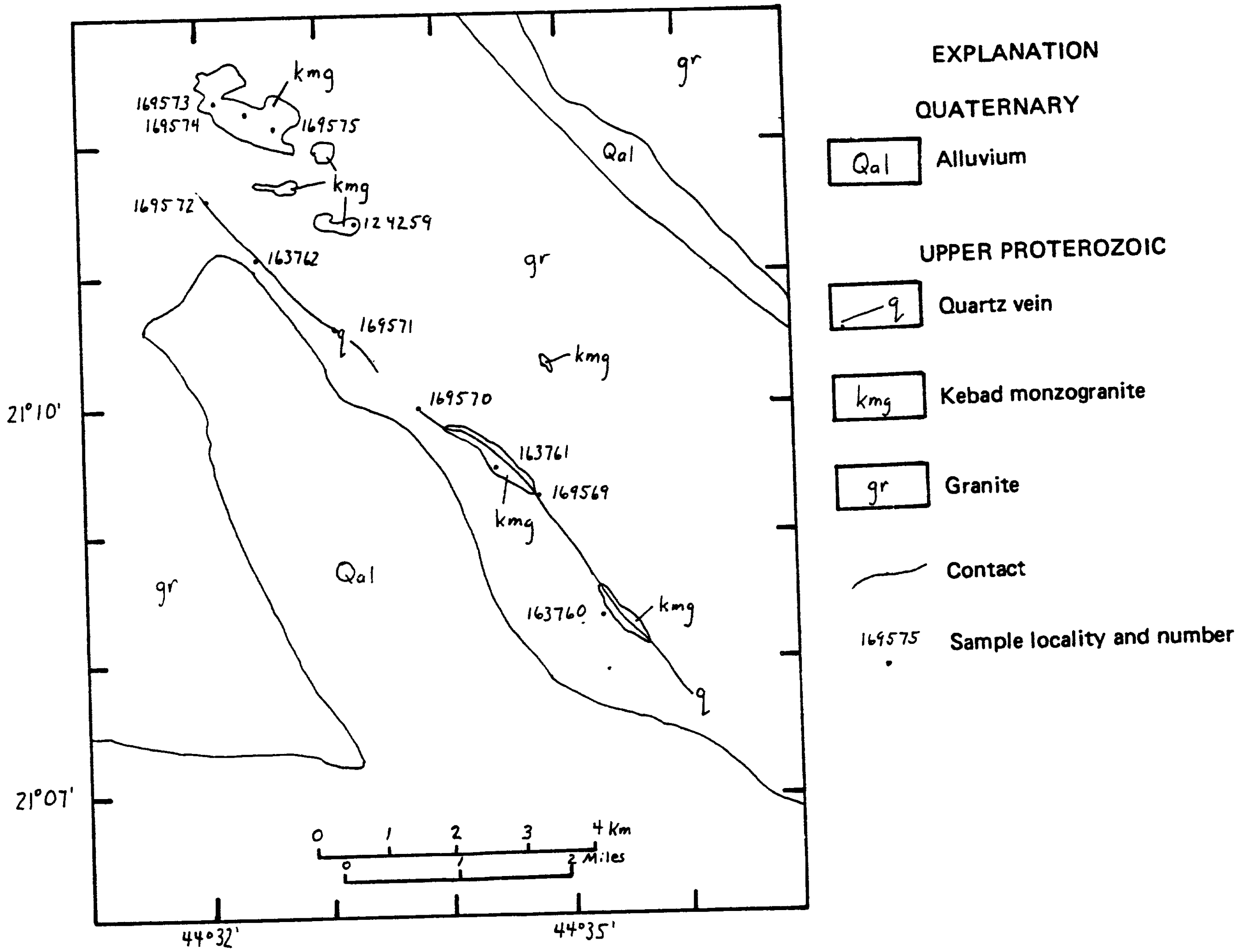


Figure 12.--Geologic sketch map of the Kebad monzogranite.

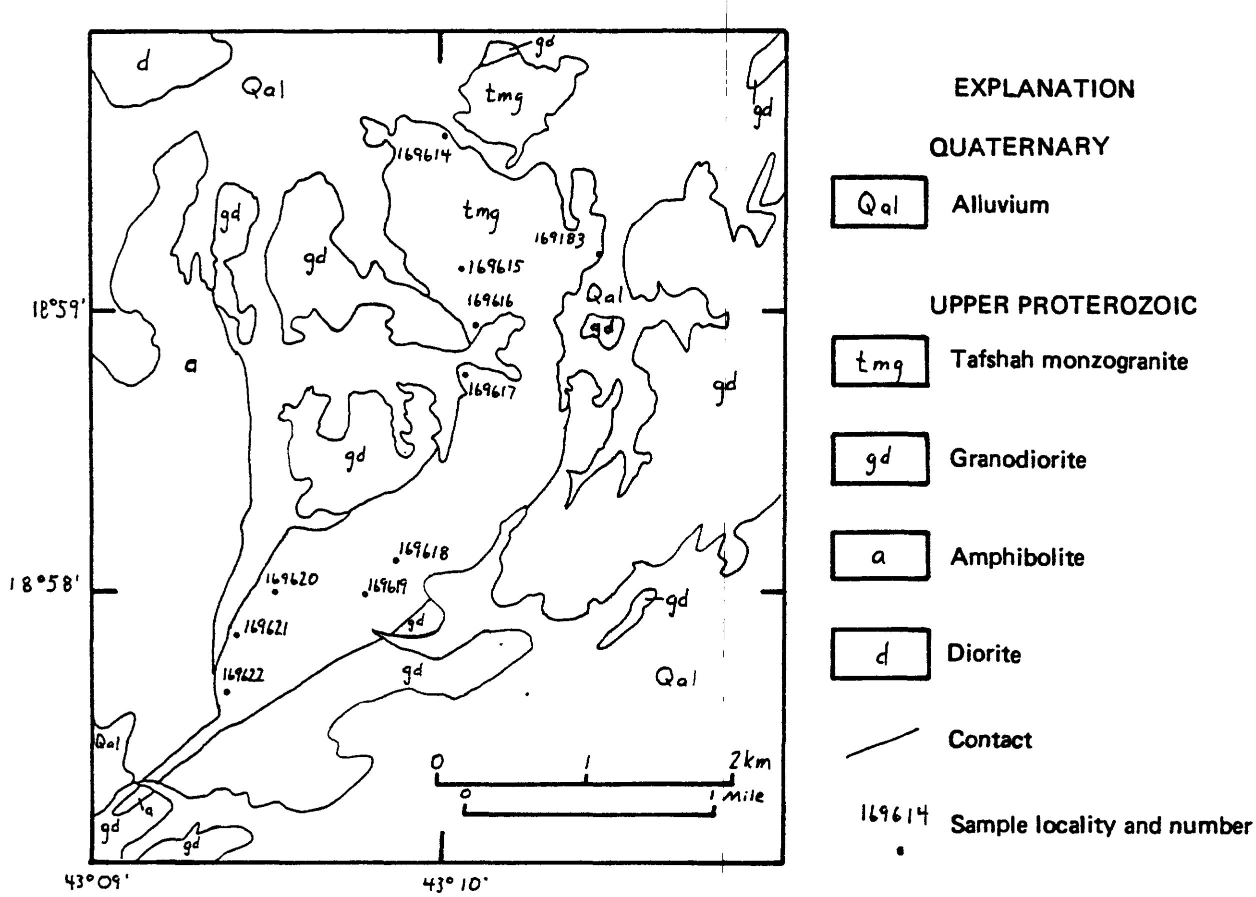


Figure 14.--Geologic sketch map of the Tafshah monzogranite.

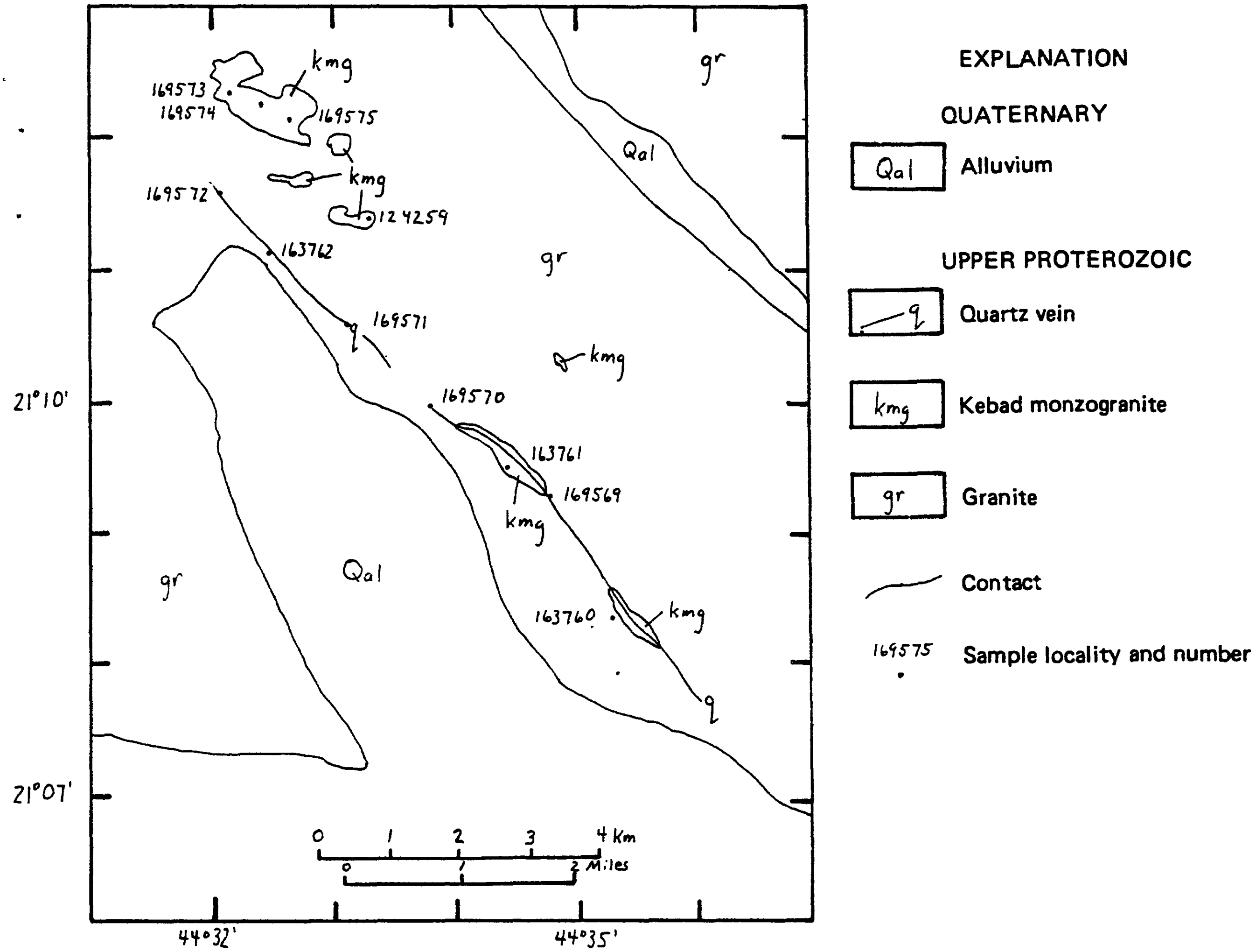


Figure 12.--Geologic sketch map of the Kebad monzogranite.

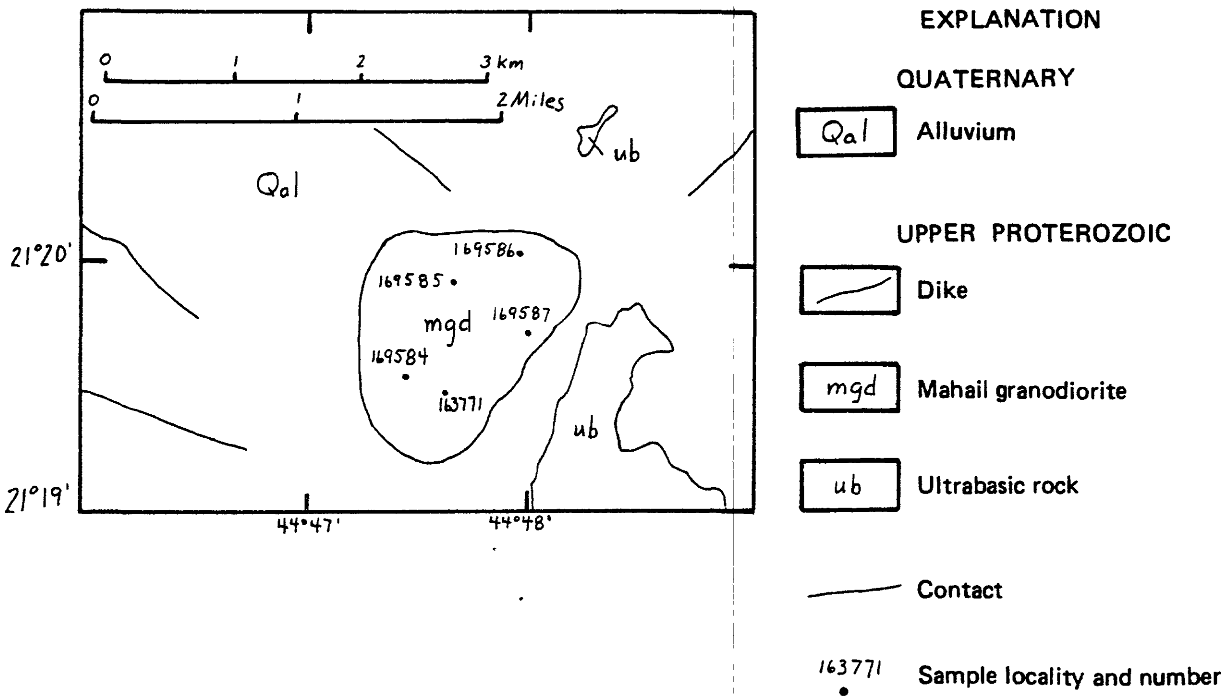


Figure 13.--Geologic sketch map of the Mahail granodiorite.

primary muscovite, and the correlation between muscovite-bearing granites and deposits of tin, tungsten, and other rare metals warranted the restudy of this pluton. This granitophile-element-depleted pluton was restudied because it contained primary muscovite, not because it was geochemically anomalous.

Followup sampling of the Mahail granodiorite failed to identify any associated geochemical anomalies. No quartz veins cut this pluton. The mineral potential of this pluton is low, and additional work is probably not warranted.

Tafshah monzogranite

The Tafshah monzogranite forms a moderately prominent, elliptical hill that crops out over about 5 km^2 in the northwestern part of the Madha quadrangle (18/43 A)(fig. 14). Modal analyses of the rocks plot in the monzogranite field (fig. 2L). The monzogranite is very light gray, hypidiomorphic inequigranular, medium grained, and locally gneissic and contains muscovite and garnet (color index 1). Microcline is nonperthitic, and plagioclase is unzoned albite. The accessory minerals are zircon and opaque oxides. The Tafshah monzogranite intrudes older gneissic granodiorite.

This pluton was resampled solely because initial studies inidcated that it contained muscovite (du Bray and others, 1982/1983). Followup sampling of the pluton indicated that it is weakly anomalous in tungsten (table 2). Several massive, podlike bodies of milky quartz and several quartz veins were sampled but contained no anomalous concentrations (table 3). The majority of the geochemical evidence indicates that the mineral potential of this pluton is low, and additional work is probably not warranted.

Madha granodiorite

The Madha granodiorite forms an elliptical, locally prominent massif that crops out over about 6 km^2 in the west-central part of the Madha quadrangle (18/43 A) (fig. 15). Modal analyses of the rocks plot in the granodiorite field (fig. 2M). The granodiorite is very light gray, hypidiomorphic inequigranular, medium grained, and locally gneissic and contains muscovite, biotite, and almandine-spessartine garnet (color index 1). Microcline is nonperthitic, and plagioclase is unzoned albite. No accessory minerals were observed. The pluton intrudes granite and granodiorite on the west and amphibolitic rocks on the east.

Initial sampling did not indicate an associated geochemical anomaly (du Bray and others, 1982/1983), but the presence of muscovite suggested the need for followup study. Additional sampling confirmed that the geochemistry of this pluton is

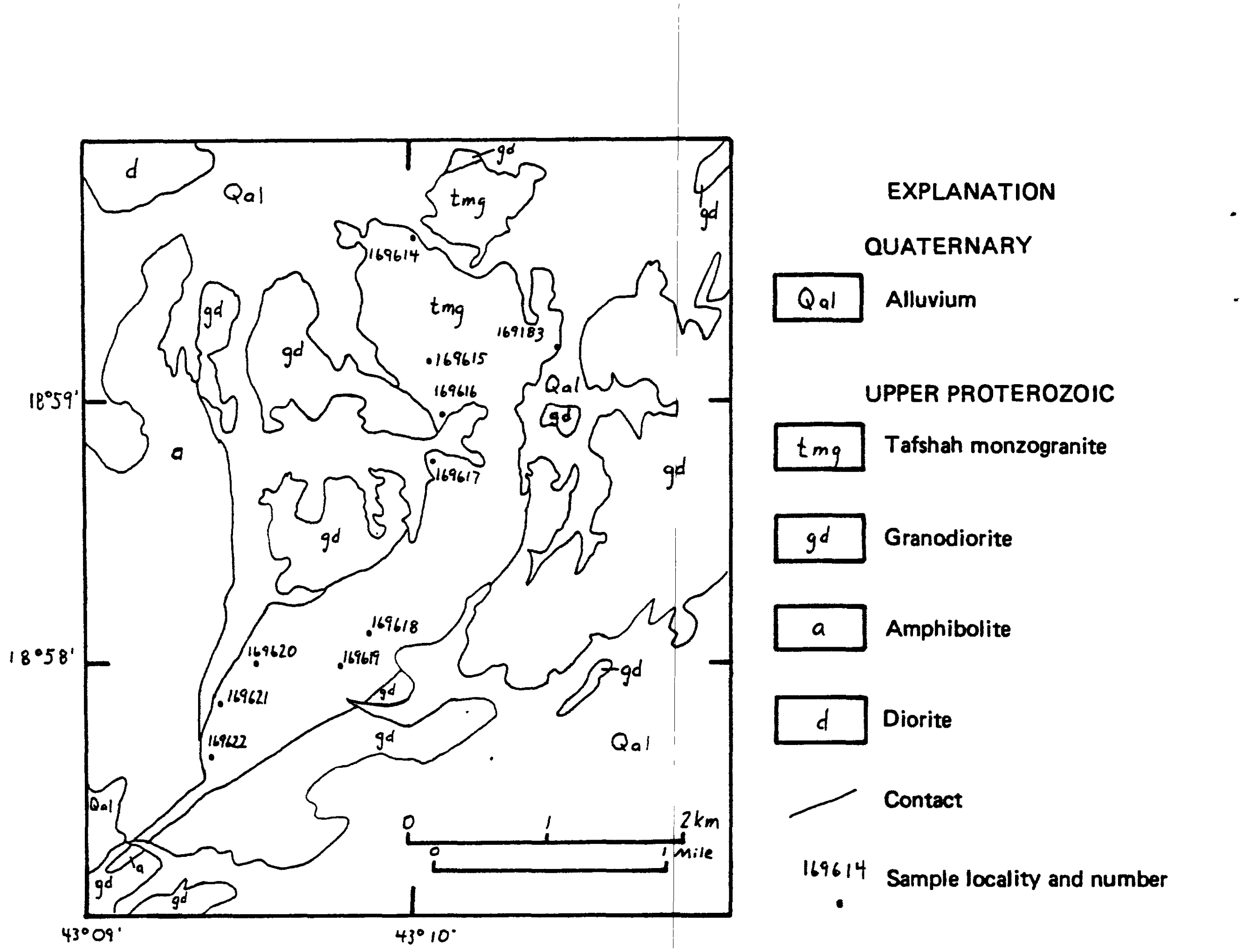


Figure 14.--Geologic sketch map of the Tafshah monzogranite.

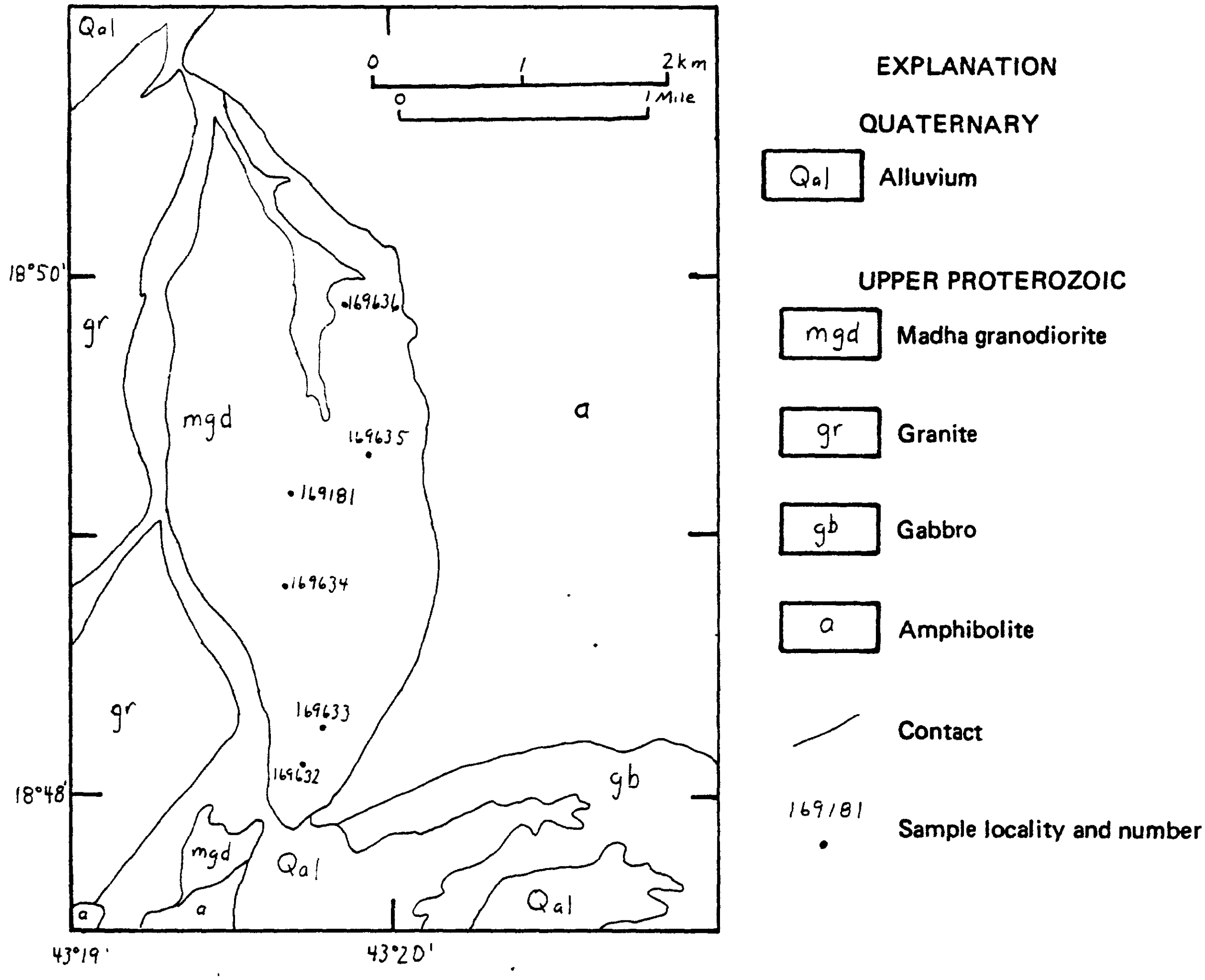


Figure 15.--Geologic sketch map of the Madha granodiorite.

not anomalous. A single value of 20 ppm tin was the only anomalous concentration obtained. Quartz veins cutting the pluton are scarce. All geochemical evidence indicates that the mineral potential of the pluton is low and that additional work is probably unwarranted.

Zayd granodiorite

The Zayd granodiorite forms a prominent mountain that crops out over about 12 km^2 in the center of the Madha quadrangle (18/43 A) (fig. 16). Modal analyses of the rocks straddle the monzogranite-granodiorite boundary but center in the granodiorite field (fig. 2N). Microcline is nonperthitic, and plagioclase is unzoned albite. The granodiorite is very light gray, hypidiomorphic equigranular, and medium grained and contains muscovite and garnet (color index 1). Similar to the plutons discussed above, no accessory minerals were observed. The Zayd granodiorite intrudes quartz diorite.

The Zayd granodiorite was restudied only because it contained primary muscovite. Followup sampling confirmed that the pluton is not associated with a geochemical anomaly and that quartz veins are rare. Evidence indicates that the mineral potential of the pluton is low, and additional work is probably unwarranted.

Habbah granodiorite

The Habbah granodiorite crops out in a prominent elongate, elliptical massif that covers about 40 km^2 and crosses the center of the border between the Madha and Wadi Tarib quadrangles (18/43 A and 18/43 C) (fig. 17). Modal analyses of the rocks plot principally in the granodiorite field (fig. 2O). The granodiorite is very pale gray, pegmatitic, hypidiomorphic inequigranular, and medium grained; it contains biotite, muscovite, and garnet (color index 1). Microcline is nonperthitic, and plagioclase is unzoned albite. The pluton contains no accessory minerals. The Habbah granodiorite intrudes granodiorite, quartz diorite, and amphibolitic rocks; intrusive relations are locally complex.

The presence of primary muscovite justified additional study of this pluton. Followup sampling indicated that the pluton is not geochemically anomalous. A single sample of the pluton (table 2) contained 40 ppm tungsten. No quartz veins were observed, but a pegmatitic carapace, similar to the apical, mineralized parts of tin-mineralized stocks described by Groves and McCarthy (1978), was observed. The carapace on the Habbah granodiorite, however, is unmineralized. Geochemical evidence indicates that the mineral potential of this pluton is low, and additional work is probably unwarranted.

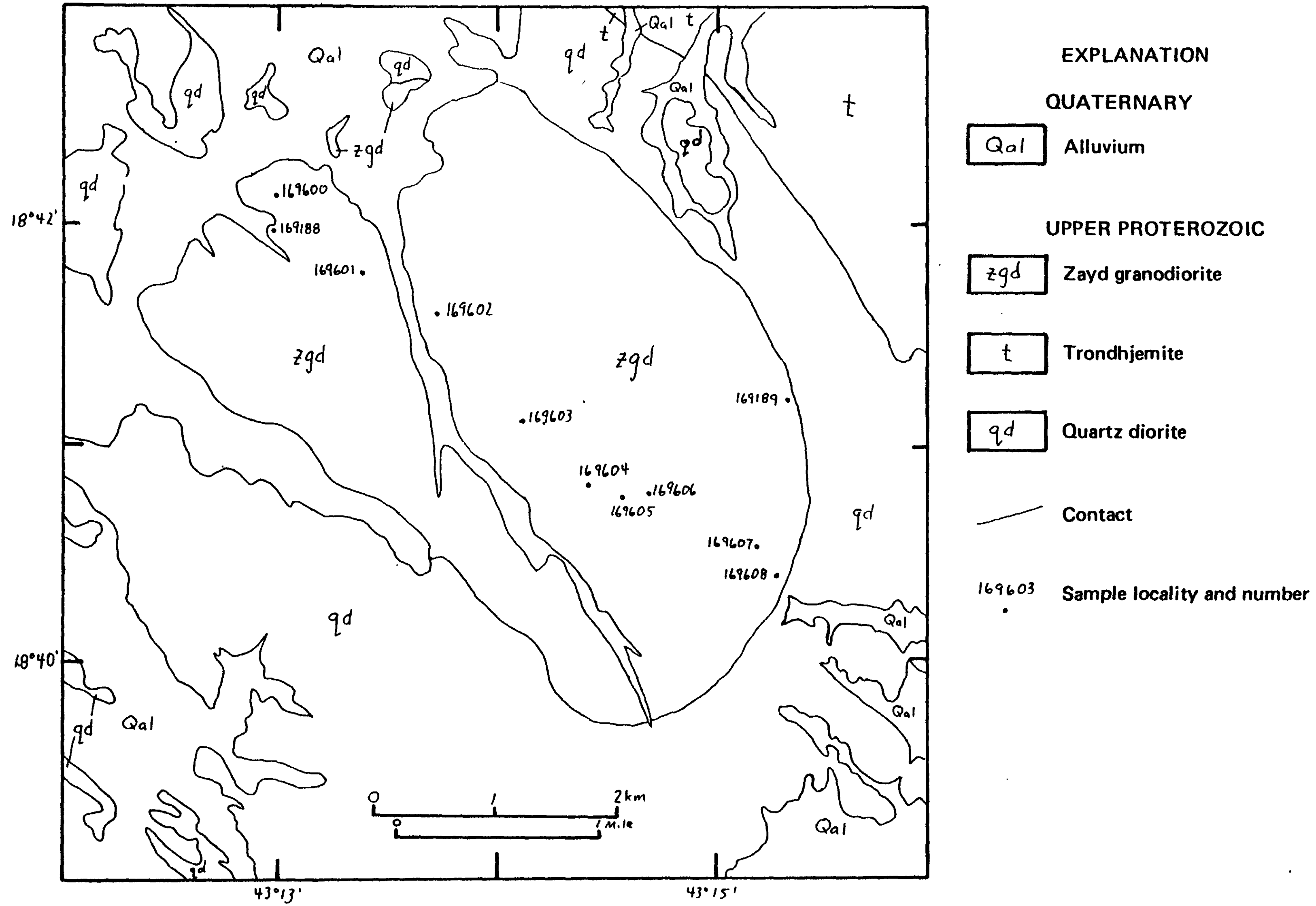


Figure 16.--Geologic sketch map of the Zayd granodiorite.

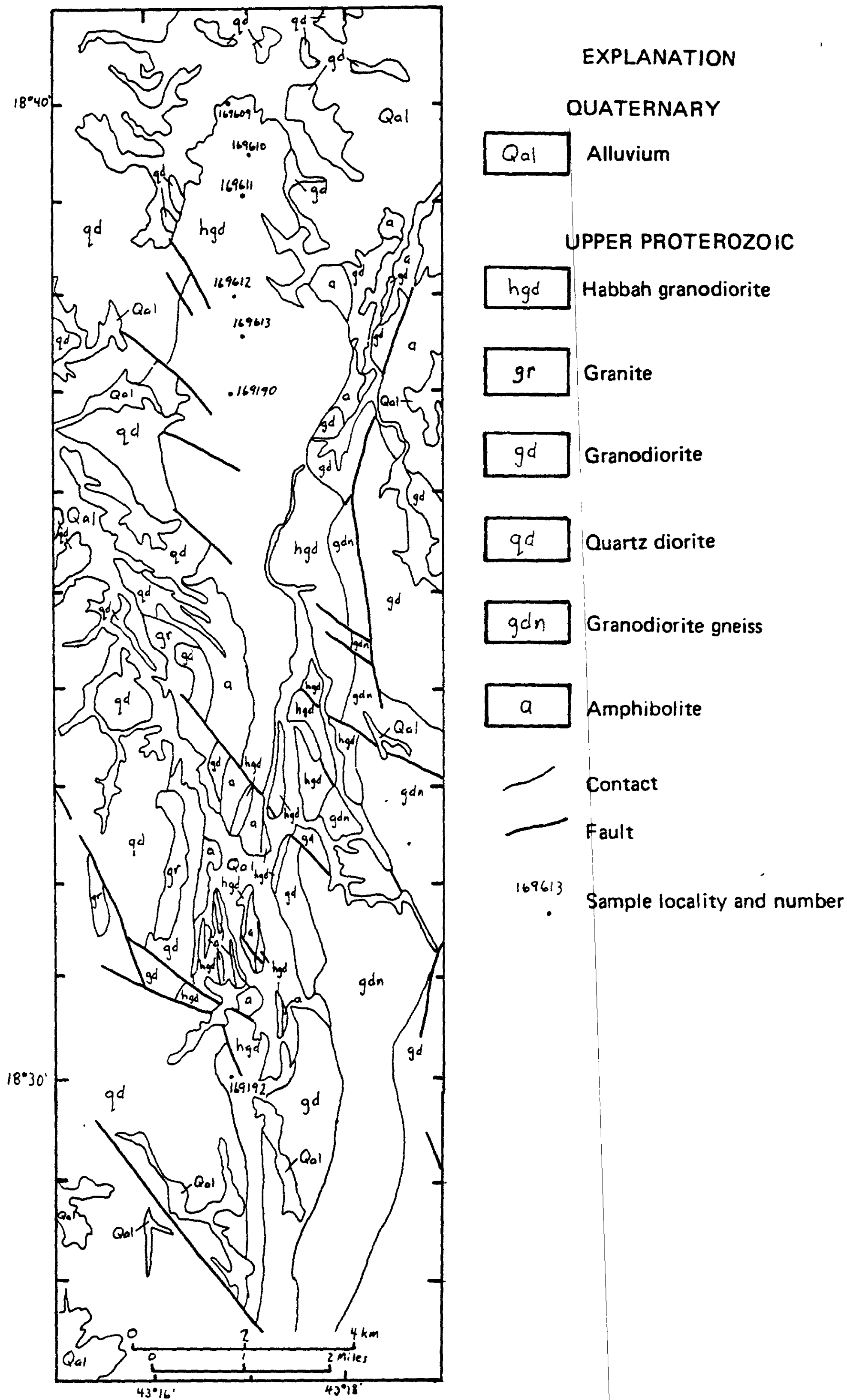


Figure 17.--Geologic sketch map of the Habbah granodiorite.

Bwana granite

The Bwana granite is intermittently exposed beneath the Wajid Sandstone at the eastern end of the border between the Markas and Wadi Malahah quadrangles (18/43 B and 18/43 D) (fig. 18). The estimated cross-sectional area of this pluton is 20 km^2. Modal analyses of the Bwana granite straddle the monzogranite-syenogranite boundary (fig. 2P). The granite is very pale bluish gray, hypidiomorphic inequigranular to subporphyritic, and medium grained and contains muscovite (color index 1). Microcline is nonperthitic and locally amazonitic; plagioclase is unzoned albite. The accessory minerals are zircon, fluorite, and opaque oxides. The pluton intrudes quartz diorite and pelitic schist.

Initial sampling indicated that the pluton contains anomalously enriched concentrations of Be, Sn, Pb, Li, F, Rb, Y, Nb, and Zn, and depleted concentrations of Cu, Sr, Zr, Ba, La, Ce, and Nd (du Bray and others, 1982/1983). The rocks of the Bwana granite are strongly geochemically anomalous. Apparently unmineralized samples collected in a followup study of the pluton contained between 10 and 100 ppm tin. Quartz veins cutting the pluton are scarce.

The geochemical and petrographic data for the Bwana granite suggest that it is a member of tin-mineralized granite clan (Tischendorf, 1977). The outcrop pattern of the Bwana granite suggests that it presents one of the best opportunities in the Arabian Shield for seeing the apical part of a pluton because the time available to erosive agents between pluton emplacement, unroofing, and deposition of the Wajid Sandstone may have been limited. The Wajid Sandstone is considered to be Permian and older in age (Powers and others, 1966), whereas the Bwana granite is probably late Proterozoic (Stoeser and Elliott, 1980). The Bwana granite is a good candidate for discovery of the deposit type described by Groves and McCarthy (1978). Consequently, this pluton warrants additional study on a priority basis.

RECOMMENDATIONS AND SPECULATIONS

The plutons described above are ranked into three groups on the basis of mineral potential: those having little or no known mineral potential, those having moderate potential, and those having high potential. Mineral potential is defined as the potential for locating economic mineral deposits within the bounds of the individual pluton or nearby in the form of vein deposits, mineralized satellitic cupolas, or greisens.

The low-potential group includes the Bitran granodiorite, the Kebad monzogranite, the Mahail granodiorite, the Tafshah monzogranite, and the Madha, Zayd, and Habbah granodiorites. Geochemical data (du Bray and others, 1982/1983), that indicated a

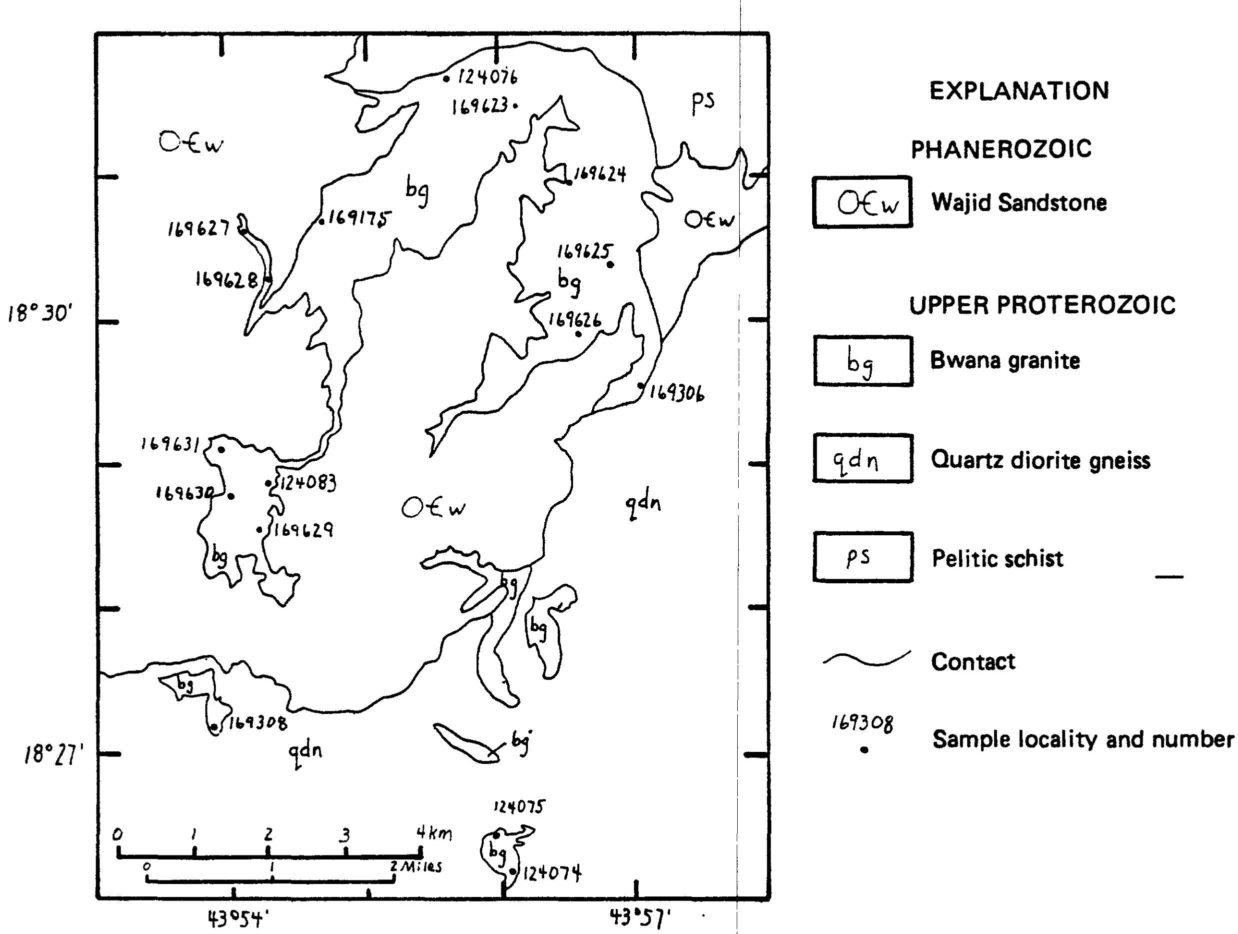


Figure 18.--Geologic sketch map of the Bwana granite.

weak tungsten anomaly associated with the Bitran granodiorite are probably spurious. The geochemistry of the next two plutons in this group (table 1) shows that they are only moderately evolved, and there is little evidence that deposits of tin, tungsten, or other rare metals are associated with these plutons (tables 2-4). The last four plutons, which were restudied only because they contained primary muscovite, probably have a genesis and source different from the other plutons investigated (du Bray, unpub. data). Restudy of these four plutons confirmed that they are not characterized by granitophile-element enrichment and that associated mineral potential is very low. These plutons are of insufficient interest to warrant additional study.

The second group of plutons, those having moderate potential for associated mineral deposits, includes the Ehn, Sabhah, and Hawshah monzogranites and the Huwail, Sahah, and Huqban granites. These plutons are characterized by an intermediate degree of geochemical evolution, including moderate granitophile-element enrichment (table 1). However, values for tin, tungsten, and other metals in pan concentrates collected from wadis draining these plutons (du Bray and others, 1982/1983) and in rock samples (table 2), though elevated in some instances, were in general not highly anomalous. Quartz veins cutting these plutons contained anomalous concentrations of tin, tungsten, and other metals. The geochemical and petrographic characteristics of these plutons are similar to those of the precursor to tin-mineralized granite clan (Tischendorf, 1977). Plutons of this group are among the larger ones restudied, and their associated mineral potential, which is only partly known because followup sampling was spotty, may be noteworthy on a local scale. Further study of these plutons is warranted.

The four plutons in the eastern and southeastern Arabian Shield deemed to have high potential for associated deposits of tin, tungsten, and other rare metals are the Sitarah, Tarban, and Gaharra monzogranites and the Bwana granite. These plutons are very geochemically evolved (table 1), and their petrography is similar to that of plutons associated with tin, tungsten, and other rare-metal deposits located elsewhere in the world. Pan concentrates collected from wadis draining these plutons contained highly anomalous concentrations of tin and locally tungsten (du Bray and others, 1982/1983). Many associated quartz-vein samples contained anomalous metal concentrations. These four plutons resemble the tin-mineralized granite clan (Tischendorf, 1977) and should be studied further.

Additional studies of mineral potential associated with the last two groups of plutons should be multifaceted. Large-scale geologic mapping and detailed geochemical sampling, particularly of quartz veins, should be conducted. At the same time, available 1:100,000-scale aeromagnetic maps should be examined to try to identify unexposed satellitic cupolas because tin- and tungsten-mineralized rocks are typically found in such structures (Groves and McCarthy, 1978). Because these plutons contain no strongly magnetic phases, they may be coincident with aeromagnetic lows. Landsat imagery and local gravity surveys may also be useful in the search for unexposed cupolas. In well-exposed areas such as the Arabian Shield, structural and tonal discontinuities apparent on Landsat imagery may indicate the existence of plutons emplaced slightly below the present erosional level, and because of the highly differentiated composition of tin-precursor and tin-mineralized plutons, they will be associated with gravity lows. Drilling should be considered for those plutons having high economic potential. Drilling might indicate if any of these plutons contain unexposed lode deposits in subcupola fractures of the type described by Groves and McCarthy (1978).

A few observations help establish the mode of occurrence of tin in the plutons. First, tin concentrations are as much as 100 times greater in pan concentrates than in related rock samples. Second, because micas are removed from wadi sediment samples during panning, tin is probably not concentrated in them but rather in a heavy mineral such as cassiterite. However, cassiterite has not yet been identified during petrographic examinations.

The failure to locate either mineralized quartz-vein stockworks or greisens, despite the appropriateness of the geologic environment, should be discussed. Formation of a tin deposit requires a manyfold concentration of tin in a late-stage magmatic fluid, possibly through volatile complexing, and its subsequent precipitation in a stanniferous phase included either in quartz veins or in a greisen. A fluid phase must be present in order for tin to be concentrated in late-stage processes. The occurrence of primary muscovite and of two independently nucleated alkali feldspars (du Bray, unpub data, 1982) suggests that most of the plutons studied here were emplaced at depths of from 7 to 17 km. These depths may preclude early evolution of a fluid phase during crystallization, such that tin was partitioned not into a fluid phase but into the melt. To a limited extent, tin may have been incorporated in the micas, but the tin-saturation maximum was probably reached in melts of the various high-potential plutons. Such tin saturation resulted in nucleation of a tin-bearing phase, probably cassiterite, that was then widely disseminated throughout the plutons. When a fluid phase ultimately did exsolve, tin was no longer available for concentration, and relatively barren quartz veins were deposited in fractures.

The occurrence of disseminated cassiterite in the granites studied suggests that alluvial deposits of tin associated with these plutons may exist. The potential for this type of deposit in Saudi Arabia has not been adequately evaluated. The low grades typical of this deposit type necessitate large tonnages of alluvium to be economic. Because the alluvial cover on pediment surfaces and alluvium in wadi channels is generally considered to be negligibly thin in the Arabian Shield, the necessary ore tonnage is probably absent even if the requisite grade exists.

Deposits of tin, tungsten, molybdenum, and other rare metals are generally found associated with plutons emplaced at fairly shallow levels, perhaps at depths of less than 5 km. Regional studies of the Arabian Shield (D. B. Stoeser, oral. commun., 1982, and J. W. Whitney, oral. commun., 1982) suggest that the depth of erosion is much greater in the southeastern Arabian Shield than in the northeastern Shield. Consequently, mineral potential associated with felsic plutonic rocks is greater in the plutons of the northeastern region. The discoveries in the northeastern part of the Arabian Shield of both a tungsten and tin quartz-vein stockwork associated with the peraluminous granite at Baid al Jimalah (Cole and others, 1981) and a highly tin-anomalous muscovite-topaz monzogranite in a caldera ring fracture (du Bray, unpub. data) corroborate this finding.

EXPLORATION METHODOLOGY

The initial and followup studies of mineral potential associated with the felsic plutonic rocks of the eastern and southeastern Arabian Shield have resulted in a simple and reliable exploration program for identification of plutons having noteworthy potential for associated deposits of tin and tungsten. Petrographic observations, 30-element semiquantitative spectrographic analyses of both rock and pan concentrate samples, and quantitative determinations of fluorine, lithium, and tungsten in rock samples were the principal methods used to discriminate between plutons having potential for associated deposits of tin and tungsten and plutons having no apparent potential.

Work elsewhere in the world and in the Arabian Shield indicates that these hypidiomorphic to xenomorphic, inequigranular to subporphyritic, medium- to coarse-grained, muscovite-bearing intrusions are typically associated with anomalous concentrations of tin and tungsten. Both the study of du Bray and others (1982/1983) and the present study show, however, that not all muscovite-bearing granites have associated mineral potential. Preliminary evaluation of these plutons is most efficiently achieved by use of a combination of rock and wadi-sediment sampling. The geochemical contrast between potentially mineralized plutons and barren plutons is sufficiently great such that just a few samples per pluton will distinguish the former from the latter.

Rock samples of plutons having associated rare-metal potential are enriched in combinations of Sn, W, Zn, Mo, Y, Nb, Pb, Bi, Ag, Li, and F. All of these elements except the last two can be adequately determined by use of relatively inexpensive semiquantitative spectrographic methods; of the latter two elements, fluorine is a far more sensitive and reliable indicator of the geochemical affinities being measured (du Bray and others, 1982/1983). Fluorine is determined by more costly wet chemical methods, but the additional information obtained probably compensates the cost. Pluton-specific combinations of the elements just enumerated exceed their respective thresholds (table 5) among plutons having rare-metal potential, but the best pair of elements to use to distinguish rare-metal potential is tin and fluorine. Rock samples of plutons warranting additional study contained more than 15 ppm tin and more than 1,900 ppm fluorine.

Equally useful in identification of plutons having associated rare-metal potential is the concentration of tin in pan concentrates of wadi sediment. Tin content in pan concentrates collected from wadis draining plutons having potential for associated deposits of tin exceeds 150 ppm in many samples and exceeds 1,000 ppm in some samples.

The field observations that arouse the interest of the exploration geologist searching for tin and tungsten are obvious. Quartz stockworks, such as those identified at Al Kushaymiyah (Dodge, 1973) and Baid al Jimalah (Cole and others, 1981), are a good indicator of a target that needs additional study. Less obvious indicators are isolated quartz veins that contain wolframite and (or) cassiterite, such as the wolframite quartz vein found cutting the Tarban monzogranite, and hydrothermally altered plutonic rocks or altered fracture envelopes, which suggest that a mineralizing fluid evolved during late-stage processes. Once a target has been identified by field observation, additional evaluation techniques such as those described in the preceding section can be used to further assess mineral potential.

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