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Mineral potential of felsic plutonic rocks in the north-central Arabian Shield, Kingdom of Saudi Arabia

by

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

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MINERAL POTENTIAL OF FELSIC PLUTONIC ROCKS IN THE NORTH-CENTRAL ARABIAN SHIELD, KINGDOM OF SAUDI ARABIA

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ABSTRACT

Fourteen plutons of Late Proterozoic age potentially favorable for rare-element mineralization have been identified in a geochemical and petrographic assessment of felsic plutonic rocks in the north-central Arabian Shield (lat 23°00'-25°00' N., long 40°00'-45°00' E.). The plutons are highly fractionated, leucocratic granitoids assigned to a major magmatic pulse that spanned the later stages of the Hijaz orogeny (about 610 Ma to about 550 Ma). Most of the targeted plutons are small or not deeply eroded. Two rock types are dominant: subsolvus, muscovite-bearing monzogranite or syenogranite; and hypersolvus, microcline perthite granite commonly containing sodic pyriboles. Enrichment in varied suites of the granitophile elements (Sn-W-Nb-Ta-Zr-Y-Th-U) is characteristic. The plutons occupy the central part of a broad arcuate belt of geochemically specialized plutons that conforms generally to the eastern limit of exposed Proterozoic basement.

The muscovite-bearing monzogranites containing anomalous tin and tungsten in rock and (or) wadi sediment samples occur generally east of long 42°30' E. Two of these, Jabal Minya and Jabal Khinzir, are recommended for immediate follow-up studies. Of the alkali granites, most of which occur in the area west of long 42°30' E., the composite plutons of Jabal Hadb ad Dayahin and Jabal Tuqfah have the highest potential for rare-element mineralization and warrant prompt systematic investigation. Evaluation of isolated one- or two-element anomalies should be coordinated with current high-density geochemical prospecting programs of the Riofinex Geological Mission.

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ACKNOWLEDGEMENTS

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INTRODUCTION

This report presents the initial results of a geochemical and petrogaphic assessment of Late Proterozoic felsic plutonic rocks in the north-central Arabian Shield to determine their potential for economic concentrations of tin, tungsten, and rare-element mineralization. The study area (fig. 1) extends from lat 23°00' to 25°00' N. and long 40°00' to 45°00' E. and lies in a part of the central Arabian Shield mapped in reconnaissance manner at a scale of 1:100,000 by geologists of BRGM. The area of approximately 100,000 km2 is bounded on the west by basalt fields (harrats) of Cenozoic age and extends eastward approximately 450 km, where the Proterozoic basement is unconformably overlain by sedimentary rocks of Phanerozoic age. It is a broad and gently east-dipping peneplained surface with a base level of approximately 1000 m above sea level. Exposures over large parts are obscured by a thin veneer of colluvial and eolian deposits. This surface of subdued relief is interrupted by belts of metamorphosed layered rocks and felsic plutons having local relief of several hundred meters.

The geologic fabric of the Proterozoic basement in the north-central Shield is dominated by north- to northwest-trending sequences of metamorphosed volcano-sedimentary, and plutonic rocks. According to prevailing theories these sequences represent intraoceanic magmatic arcs that were

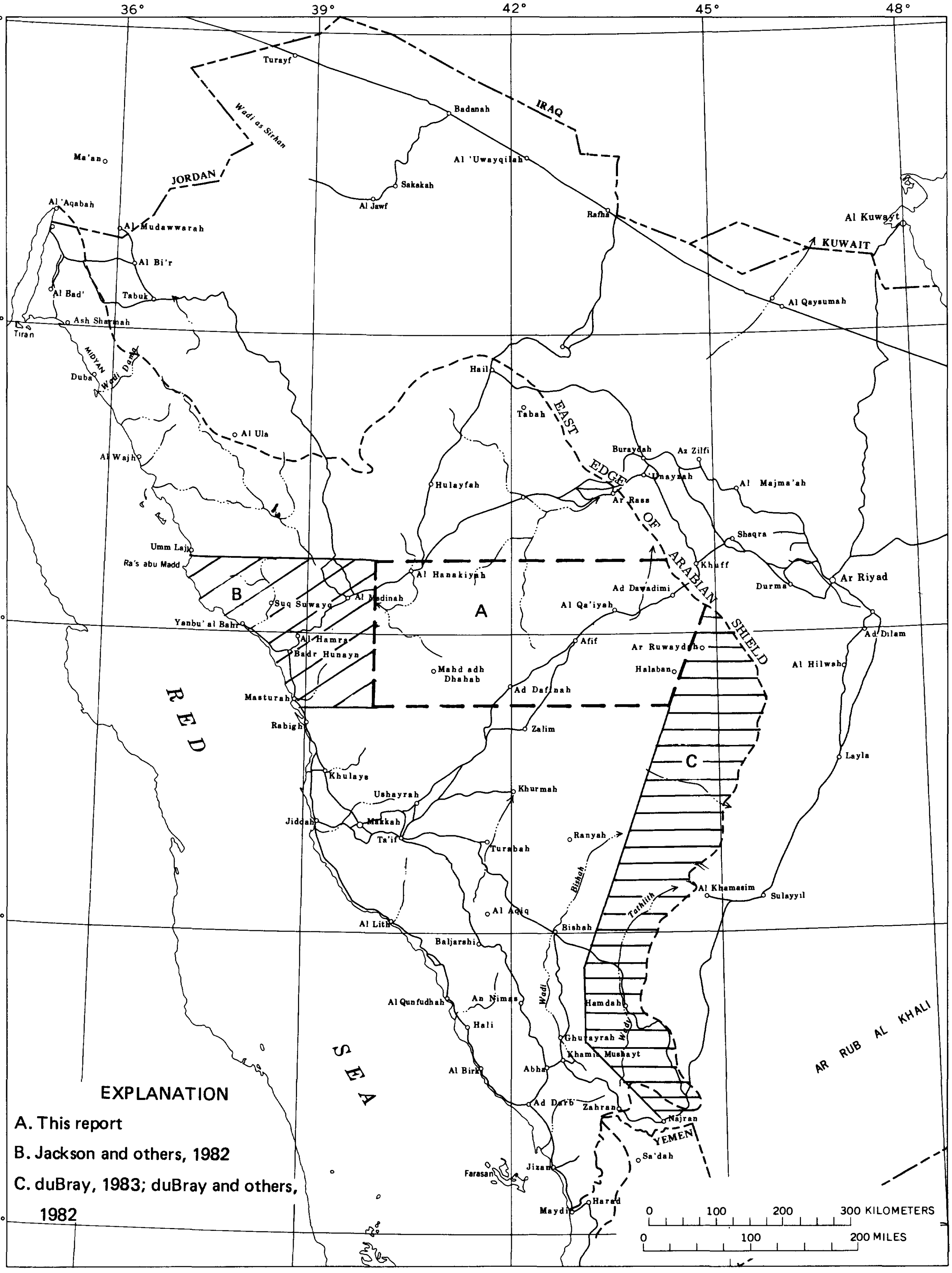

Figure 1.--Index map showing location of study area in the north-central Arabian Shield.

successively combined during at least two periods of plate convergence or accretion between approximately 760 Ma and 625 Ma (Schmidt and Brown, in press). The African craton probably provided the buttress against which these arc complexes were consolidated along east-dipping subduction zones. Final cratonization followed a major continental collisional event about 660 Ma (Schmidt and others, 1979).

Accretion of primitive crust to the African craton at about 760±40 Ma gave rise to the first major pulse of syntectonic plutonism. The plutonic rocks assigned to this event consist chiefly of foliated diorites, tonalites, and granodiorites, the batholithic and subvolcanic intrusive equivalents of comagmatic andesitic volcano-sedimentary layered rock sequences. A younger period of syntectonic plutonism was initiated by an inferred continental collision from the east at about 640±20 Ma, according to Schmidt and others (1979), and is represented by large gneissic granodiorite and monzogranite domes. It resulted in significant thickening of the primitive crust. Emplacement of the more potassic granites of the Arabian Shield, those of primary interest here, began in the waning stages of compressive deformation that resulted from continental collision (Schmidt and others, 1979). These "postorogenic" plutons were emplaced passively by stoping or in cauldron subsidence/ring dike structures from about 610 Ma to 550 Ma.

Fleck and Hadley (in press) have documented a general, shieldwide decrease in age from southwest to northeast for both dioritic and granitic-granodioritic plutonic rocks. In terms of volume or outcrop area, however, the distribution of these two major suites is antithetic: late-orogenic or postorogenic granites are several times more abundant in the northeastern part of the Shield than in the southwestern part (Greenwood and Brown, 1973; Elliott, 1983, fig. 1). These patterns reflect both the eastward youging of magmatic arc complexes accreted episodically to the African craton, and a larger or, perhaps, progressively more mature sedimentary component in the protolith from which the plutons were derived.

The tectonic history of the Arabian Shield remains a topic of lively interest and rapidly evolving interpretations. In addition to those papers already cited, readers are referred to the work of Greenwood and others (1982) and Stacey and Stoeser (1984) for fuller development of models invoking plate tectonic concepts. Fundamentally different, alternative interpretations are discussed by Calvez and others (1983).

PAST WORK

Until approximately 15 years ago, the chief targets of metallic mineral exploration in Saudi Arabia were precious metal-quartz vein deposits and stratabound polymetallic deposits of possible volcanogenic origin. These were the same types of deposits sought and in some cases successfully exploited by the ancients, and probably all areas of past interest have been revisited or resampled at least once. In recent years, increasing attention has been given to the younger granitic rocks of the Shield as sources of tin, tungsten, molybdenum, and other rare elements including niobium, tantalum, and zirconium. Recognition of the intrinsic mineral potential of these younger granites (Stoeser and Elliott, 1980) has led to regional assessments in the northwest Hijaz (Drysdall and Odell, 1982; Ramsay, 1982), the central Hijaz (Jackson and others, 1982), the eastern and southeastern Shield (du Bray and others, 1982; du Bray, in press), and that part of the north-central Shield covered in this report. In this profusion of recent work, various aspects of classification, geochemistry, petrography, mineralogy, and mineralization of the highly evolved, leucocratic, or "specialized" (Tischendorf, 1977) granites of the Shield have been considered. A prevailing view, one that provides the rationale or conceptual framework for the present mineral assessment, is that chemically peraluminous granites (typically two-feldspar muscovite or muscovite-biotite rocks having molar $Al/(Na+K+Ca)>1$) are promising targets for tungsten-tin-molybdenum mineralization, whereas chemically peralkaline granites (one-feldspar rocks commonly containing sodic pyriboles and having molar $Al/(Na+K)<1$) may be enriched in niobium, zirconium, yttrium, tantalum, rare-earth elements, and (or) the radioelements uranium and thorium (Elliott, 1983).

To date, no economic concentrations of the above elements have been identified, but numerous occurrences have been documented and characterized in some detail. These include the wolframite stockwork mineral prospect at Baid al Jimalah (Cole and others, 1981; Lofts, 1982), the tin-bearing granite of Jabal al Gaharra (Elliott, in press), the Ratama tin-tantalum specialized granite (Ramsay and Rowaihi, 1982), and the niobium-yttrium-zirconium-rare earth element-mineralized peralkaline granites of Ghurayyah and Jabal Tawlah (Drysdall, 1979b) and Jabal Sayid (Turkistany and Ramsay, 1982).

Information compiled on mineral occurrences associated with postorogenic granites of the Arabian Shield (Elliott, 1983) shows a notable paucity of occurrences in the east-central Shield. In view of the abundance of postorogenic granites in this area (Elliott, 1983, fig. 1), and the limited geochemical and petrographic information at hand, a regional assessment of mineral potential was undertaken.

OBJECTIVES

The primary objective of this mineral assessment program was to identify specific granitic plutons or granite-related mineralization worthy of follow-up investigation by either USGS or by referral the Riofinex Geological Mission. A second objective was to delineate broader tracts having permissive favorability for particular metal associations or mineralization types. A third objective was to apply a systematic nomenclature based on modal mineralogy to the felsic plutonic rocks in order to assist regional correlations. The ultimate objective of this work is the compilation of a comprehensive geochemical and petrologic data base for felsic plutonic rocks of the north-central Shield that, when combined with other regional assessments, will permit recognition and elucidation of Shieldwide patterns of magmatic and metallogenetic evolution as guides to mineral exploration.

METHODS

The conventional methods employed in this study have proven to be efficient and effective in identifying areas of granite-related mineral potential in assessments in adjoining areas (du Bray and others, 1982; Jackson and others, 1982). Initial background studies from January to mid-February 1982 included a literature review, examination of 1:250,000-scale aeromagnetic and aeroradiometric maps, and compilation of a preliminary distribution map of felsic plutonic rocks at 1:500,000-scale from published sources and photo interpretation of computer-enhanced, Landsat color imagery.

A revised map was subsequently compiled on a controlled Landsat base and then was somewhat generalized and reduced to 1:1,000,000-scale (fig. 2). The principal sources used in the compilation were 1:250,000-scale geologic maps published by the BRGM Saudi Arabian Mission, with frequent reference to component maps at 1:100,000-scale. In early stages of the work, when mapping by BRGM geologists in the northeastern part of the Shield was still in progress, the preliminary lithostratigraphic compilations of Johnson (1981, 1982a, b; also, Riofinex Geological Mission, 1979) and 1:500,000-scale geologic maps by Bramkamp and others (1963), Brown and others (1963, 1979), and Jackson and others (1963) were used extensively. Currently, 1:250,000-scale geologic maps are available for all but the Miskah quadrangle (sheet 24F), which is being compiled (Pellaton, written commun., 1982). Revision and updating continue as new petrographic and chemical data become available.

Field studies undertaken concurrently with map compilation involved approximately 40 days of helicopter-assisted sampling and spot-checking between mid-February and mid-October 1982. Approximately 300 rock samples from a broad spectrum of felsic plutons and 150 samples of sediment from wadis draining these plutons were collected at sites previously selected by inspection of 1:100,000-scale photomosaics and reconnaissance maps. During low-level transit between sites the area was scanned for veins, color anomalies resuling, perhaps, from oxidation of sulfides, or other favorable indications of mineralization.

Total-count scintillometer (gamma radiation) measurements were made at each sample site using a hand-held Scintrex Model GR101A instrument. The scintillometer was placed on a smooth outcrop or planar spall slab surface to equilibrate for 5 to 10 minutes prior to measurement. Three instruments, differing in sensitivity by as much as 2 1/2 times, were used at various stages of the study; standardization was attempted by reoccupying selected sites and determining approximate correction factors that were then applied to all readings obtained with a given instrument.

Rock samples weighed 1 to 2 kg and were trimmed and sliced in Jiddah to provide a thin-section chip, a slab for staining/point-counting, and a slab for chemical analysis. Modes were determined by counting at least 500 points on stained slabs measuring approximately 8 cm x 12 cm. Wadi sediment samples of about 10 kg were processed in the field by splitting 1:3 and panning the larger fraction to concentrate heavy minerals; the panned concentrate was submitted for chemical analysis after magnetite was removed with a hand magnet.

Samples submitted to the DGMR-USGS Chemical Laboratories for 6-step 30-element semiquantitative spectrographic analysis consisted of:

1. trimmed slices of rock weighing about 250 to 300 g from each chunk sample collected for lithologic characterization,

2. panned concentrates of wadi sediment derived from felsic plutons at nearly half of the rock sample sites; sediment was not collected at sites where there was the likelihood of significant dilution or contamination by wind-blown sand.

Subsequent data treatment, particularly definition of anomaly threshold concentrations, follow the methods developed and discussed in detail by du Bray and others (1982).

In determining anomaly threshold concentrations for individual elements (see du Bray and others, 1982), cumulative frequency diagrams are first plotted with log of

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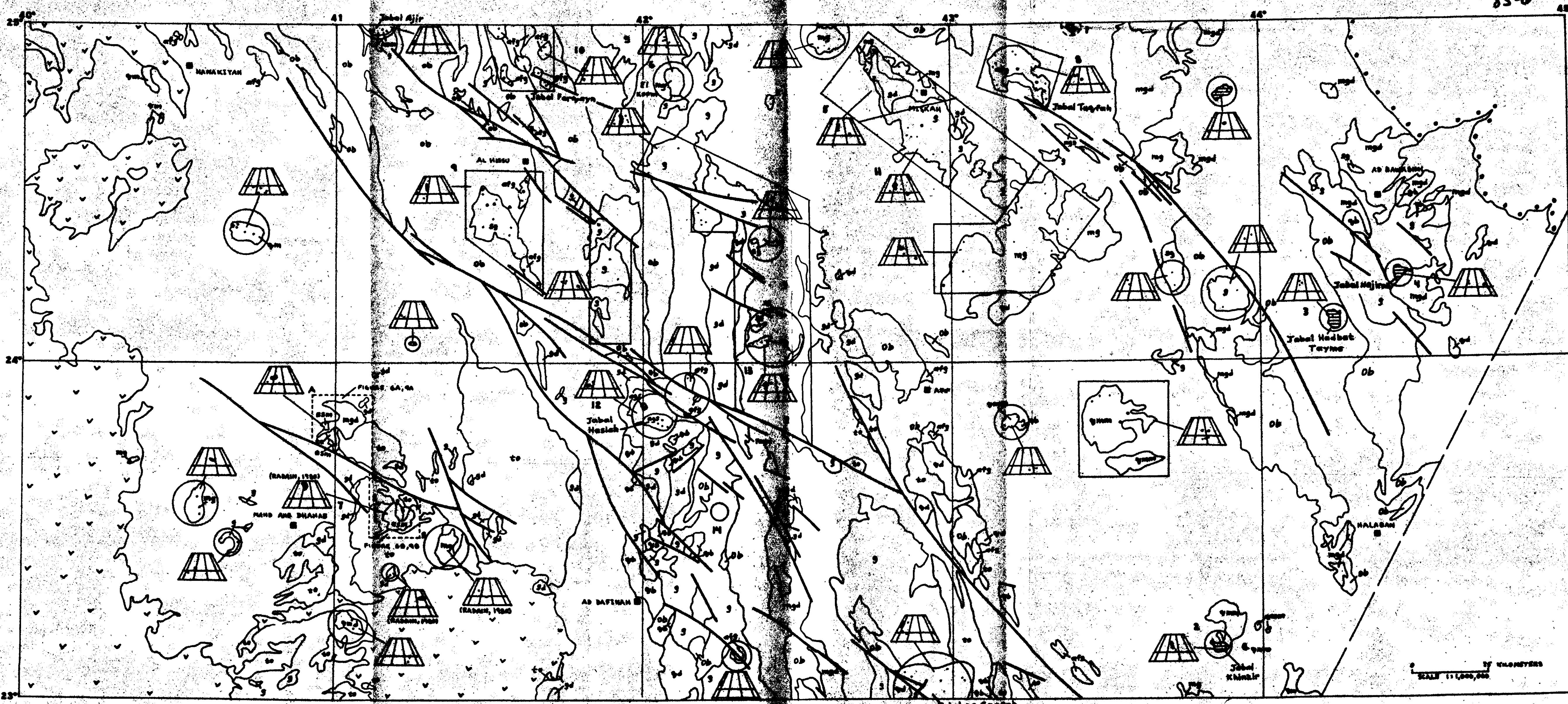


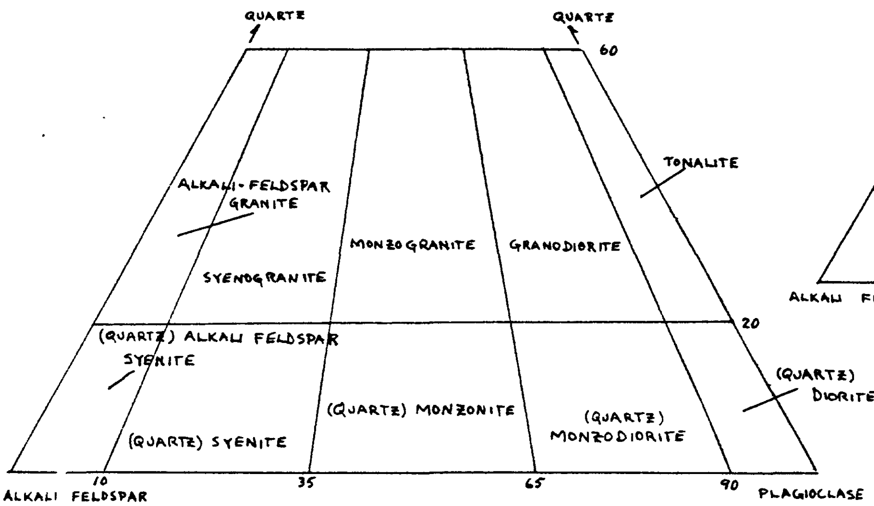
Figure 2.—Map showing distribution of felsic plutonic rocks in the north-central Arabian Shield; modal compositions of selected plutons are plotted in conventional quartz (Q), alkali feldspar (A), and plagioclase (P) ternary diagrams.

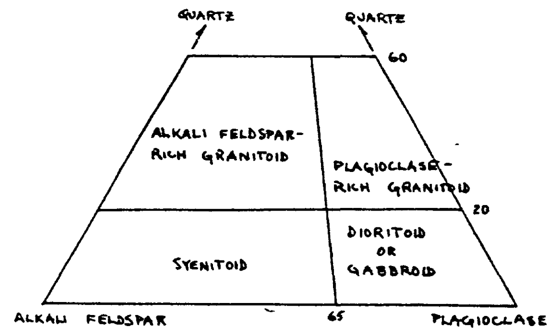
concentrations plotted on an arithmetic ordinate scale against cumulative frequency in percent on a logarithmic abscissa. For lognormally distributed elements, whose plots approximate a straight line, threshold concentrations were taken as the mean plus two standard deviations (X + 2 S) to achieve a 98 percent probability that larger values were anomalous. For elements distributed bimodally and plotting as a curve, lognormal background and anomalous populations were resolved using a method proposed by Sinclair (1981); the threshold concentration was taken as the highest reported concentration in the background population. In the case of elements for which most analytical values are qualified, thresholds were determined by inspection of frequency histograms, or by arbitrarily treating any analytical value above the detection limit as anomalous.

Rock names in this report follow the IUGS classification scheme of Streckeisen (1976), which is based on modal proportions of quartz, alkali feldspar, and plagioclase; most of these terms are defined graphically in figure 2. They supplant certain broad, field terms commonly used in the source maps andsymbolized as follows: sq, "riebeckite granite, quartz monzonite and (or) alkalic granite"; mg, "calc-alkalic granite, granite, adamellite, diorite, and (or) hornblendite"; hg, "granite, granodiorite quartz diorite, and (or) trondhjemite"; and ug, "calc-calkalic granite, granodiorite, and (or) diorite".

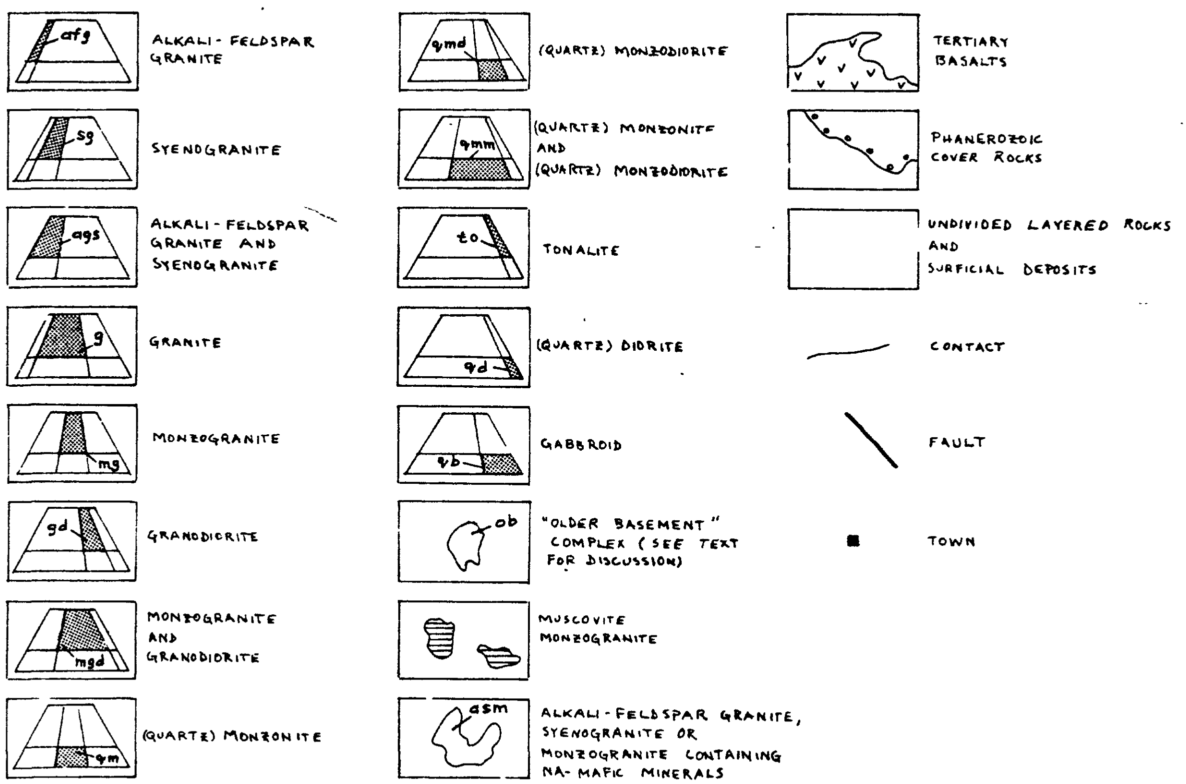
Generally one or more sample of each major granitic and syenitic pluton was collected for the purpose of petrographic characterization. "Tonalite", "diorite", and "gabbro" plutons were specifically excluded from petrographic and geochemical considerations in this study because past assessments have consistently shown them to have relatively low potential for granitophile element mineralization; these plutons were assigned approximate IUGS-equivalent names based solely on explanatory notes accompanying the geologic maps. Another source map unit not considered here is termed "older basement"; according to map explanations these are crystalline complexes including "granite, granodiorite, diorite, and (or) gabbro, commonly oriented and migmatitic, partly rejuvenated during Upper Proterozoic" (Delfour, 1981). In the northwestern part of the study area near Al Hissu, and in a belt extending northwest from Halaban, the Sawda domain of Delfour (1979), these complexes consist largely of foliated and (or) migmatitic tonalites and diorites, but may include as yet unrecognized granitic plutons.

EXPLANATION





IUGS MODAL MINERAL CLASSIFICATION (STRECKEISEN, 1976)



FELSIC PLUTONIC ROCKS

Lithology

Quartz (Q)-alkali feldspar (A)-plagioclase (P) ternary diagrams keyed to sample sites are used to illustrate the compositional range of many late orogenic and postorogenic plutons (fig. 2). Modal compositions of the felsic plutons are summarized in figure 3. Compositional fields for discrete plutons (totalling nearly 200 samples) are indicated as are individual determinations for about 90 samples from larger and generally less well-exposed plutons that may be composite or compositionally zoned. All sample sites used to establish plutonic lithologies are shown in figure 5.

Despite the considerable scatter of the data, there is a clear preponderance of monzogranite and syenogranite compositions. A subordinate clustering of modal compositions occurs in the alkali-feldspar granite field, and a weak suggestion of clustering includes granodiorites, quartz monzodiorites, and quartz monzonites. Overall, the compositional range of felsic plutons of the central Hijaz (Jackson and others, 1982) is closely similar to that of the Bishah area of the southern Shield (Schmidt and others, 1979).

The syenogranites and monzogranites are characteristically medium- to coarse-grained, hypidiomorphic inequigranular to seriate rocks; several monzogranite plutons are conspicuously porphyritic. The main mineral components are microcline, microcline perthite, sodic plagioclase (albite or oligoclase), and quartz, with 2 to 12 percent amphibole, biotite, or muscovite plus accessory sphene, apatite, zircon, and opaque minerals. These rocks, which constitute the major component of late orogenic and postorogenic magmatism in the study area, may be conveniently divided into three sub-groups.

1. Biotite-hornblende granites that comprise many of the larger nd generally older postorogenic plutons.

2. Younger, subporphyritic muscovite- or muscovite-biotite monzogranites that elsewhere in the Shield have recognized tin-tungsten mineral potential.

3. Alkali granites containing subequal amounts of quartz, alkali feldspar, and sodic oligoclase or albite; if the convention of treating albitic plagioclase as an "alkali feldspar" were followed, some of these rocks might plot as alkali-feldspar granites.

Alkali-feldspar granites in the study area are characteristically hypersolvus, medium- to coarse-grained (4 mm-6 mm average grain size) rocks. Textures are typically hypidiomorphic equigranular to inequigranular. They are composed

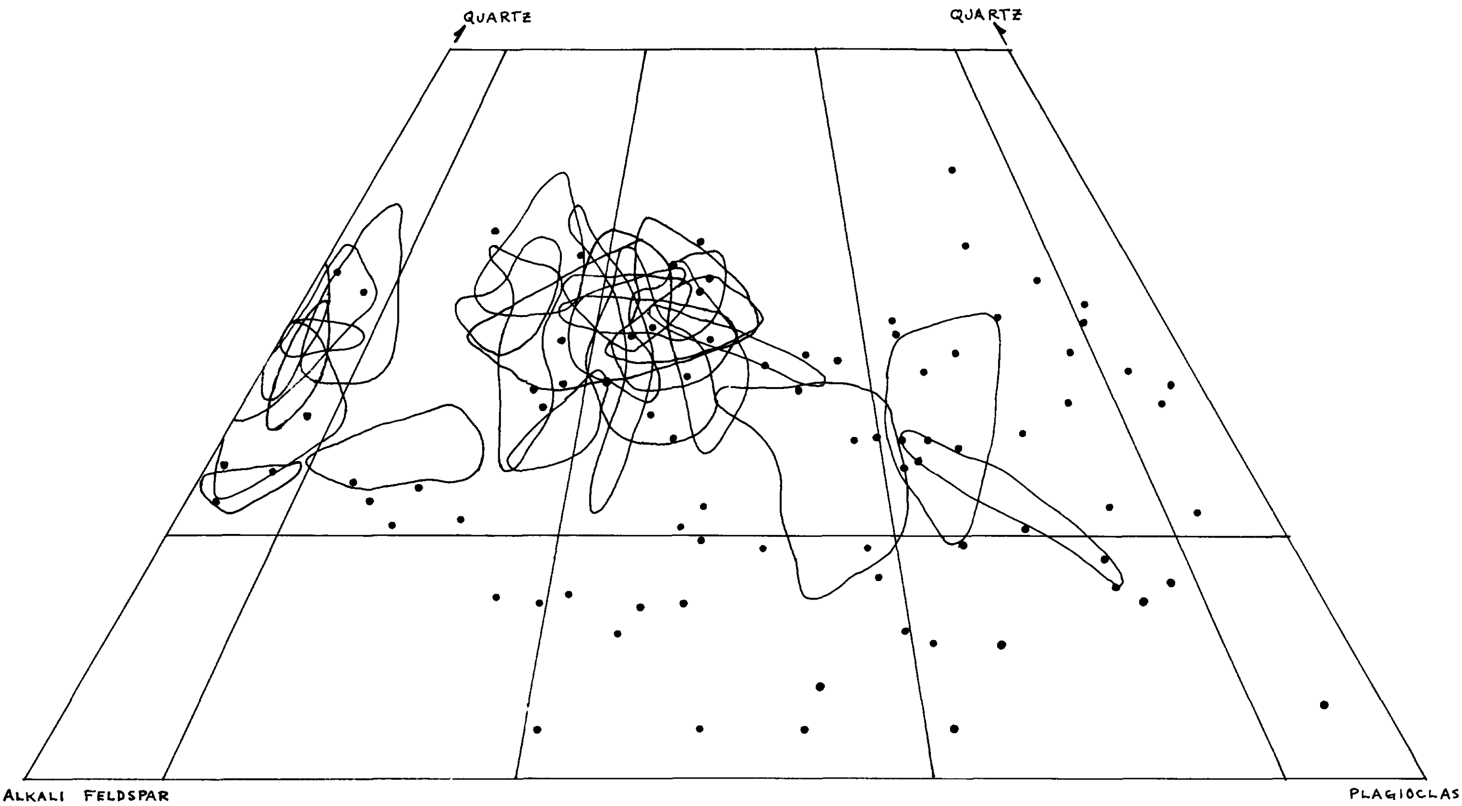


Figure 3.--Ternary diagram showing modal proportions of quartz (Q), alkali feldspar (A), and plagioclase (P) in felsic plutonic rocks of the north-central Shield. Compositional fields for discrete plutons are outlined. Points indicate modal compositions for samples from less well-exposed plutons which may be composite or compositionally zoned.

essentially of coarsely perthitic microcline, quartz, and 1to 8 percent amphibole±biotite, having sphene, zircon, apatite, and opaque minerals as common accessory constituents. A small but variable amount of albite or sodic oligoclase is present in most samples commonly as subhedral laths interstitial to the quartz and alkali feldspar, but also in anhedral, granular, exsolution intergrowths in the margins of perthite crystals. Several plutons plotting in this field contain 2 to 15 percent sodic pyroxene and (or) sodic amphiboles and are properly termed alkali granites (Streckeisen, 1976); these may contain fluorite and allanite in addition to the accessory minerals already noted.

Granodiorites, quartz monzonites, and quartz monzodiorites, comprising many of the isolated samples collected chiefly for petrographic verification of field names, are commonly medium- to coarse-grained, hypidiomorphic inequigranular to porphyritic rocks. Perthitic microcline, plagioclase (oligoclase to andesine), quartz, and 5 to 15 percent biotite, hornblende, and clinopyroxene are the main mineral constituents and sphene, apatite, and opaque phases are common accessory minerals.

Distribution

The felsic plutonic rocks, although widely distributed in the study area (fig. 2), show certain systematic space-composition patterns that may aid in understanding the magmatic evolution of the north-central Shield and provide regional guides in exploration for granitophile element mineralization. Tonalitic, gabbroic, and dioritic rocks (including the migmatitic and foliated diorites near Al Hissu) are most abundant in the western part of the area, particularly west of long 42°00' E. Conversely, the proportion of granodiorites and monzogranites increases substantially east of long 42°00' E. and in the area between long 42°00' and 43°30' E., these rocks form nearly 50 percent of the exposed Proterozoic bedrock. The distribution of granites and alkali-feldspar granites appears to be largely random. However alkali granites, particularly those forming well-developed composite ring complexes, are known only in the area west of long 43°00' E., whereas muscovite-bearing granites are recognized only east of long 43°00' E.

Controls exerted by regional structures in the distribution and emplacement of the younger felsic plutons are obscure. An alinement of plutons, such as that suggested by Ramsay (1982) for alkali granites in the Midyan region, is not apparent. Many of the granites are bounded by r offset by northwest-trending Najd faults (and thus, strictly speaking, are not "postorogenic"), but other apparently unfaulted plutons have a corresponding northwest elongation. Although most likely the result of easier emplacement along the dominant northwest-striking belts of layered rocks, this parallelism may also reflect controls exerted by "proto-Najd" zones of weakness. Ring dikes and plug-like intrusions of syenogranite and alkali-feldspar granite appear to have been preferentially emplaced in north-trending belts of monzogranite and granodiorite in the center of the study area. A number of younger plutons, including the monzogranites of Jabal Minya and Jabal Khinzir and the alkali granite of Jabal Hadb ash Sharar, have been emplaced at the margins of older and much larger monzogranites.

Geochronology

The distribution map of felsic plutons (fig. 2) was compiled without regard to the geologic or radiometric ages of individual intrusions. In fact, to attempt a chronstratigraphic compilation would have been futile as few ages were available initially, and most of these were relatively imprecise mineral ages that may record metamorphic or thermal events subsequent to emplacement. Nevertheless, it was possible by analogy with results of radiometric studies in the southern Shield (Fleck and others, 1980) and descriptive studies in the northwestern Hijaz (Drysdall and Odell, 1982), to establish an initial relative chronology based on lithologies, geologic setting, and features of occurrence. This, in turn, aided in identification of the youngest plutons that were given highest priority in subsequent mineral assessment.

The oldest felsic plutons, which received minimal attention in this study, include the tonalitic batholiths east of Mahd adh Dhahab and possibly much of the migmatized and foliated diorite and trondhjemite of the "older basement" complex near Al Hissu; these correspond generally to the foliated granodiorite (Suite I) of Drysdall and Odell (1982) and the 850 Ma to 700 Ma foliated diorite to trondhjemite batholiths of Fleck and others (1980). They are commonly elongate in a north or northwest direction and have contacts that are conformable or migmatitic and gradational with enclosing, deformed volcanic sequences. Schlieren and spindle-shaped inclusions of the intruded rock are parallel to foliation. The tonalite and diorite batholiths are poorly exposed on pediment surfaces because of deep weathering along closely-spaced joint surfaces and planes of foliation, and are intruded by numerous granitic plutons.

North-trending belts of biotite-hornblende granodiorite and monzogranite in the central part of the area are thought to represent a somewhat younger magmatic episode. Three larger coalescing monzogranite plutons southeast of Miskah and the granodiorite-monzogranite complexes north and west of Ad Dawadimi may also belong to this episode. They are provisionally equated with the "older" (Stage II) monzogranites of Drysdall (1980) and the granodiorite gneiss or gneiss domes of Fleck and others (1980). Typically these plutons weather to surfaces of low relief and are commonly distinguished on aerial photographs by the traces of erosionally resistant cross-cutting dike swarms.

Numerous monzogranite, syenogranite, alkali-feldspar granite, and quartz monzonite plutons define a third and younger magmatic episode. These correspond to the younger calc-alkaline granites (Suite III) and peralkaline granites (Suite IV) of Drysdall (1980), and the 660 Ma to 540 Ma late orogenic and postorogenic plutons of Fleck and others (1980). The plutons are generally massive and homogeneous; cross-cutting dike swarms and oriented inclusions are absent. They commonly have a maximum dimension of less than 20 km, and are typically smoothly ovoid or rounded in plan, the latter comprising both ring dike complexes and coaxial composite plutons. They occur as isolated inselbergs, or in clusters of steep-sided, elongate whalebacks or rounded knobs.

The smaller size and gently dipping contacts of many plutons assigned to this group suggest that they have not been as deeply eroded as the older granodiorites and dioritoids. Finer textural variants and large (stoped) blocks present locally near the margins are further indications of emplacement at a shallow depth.

Results of radiometric studies (Fleck and Hadley, in press; Calvez and Kemp, 1982) may be used to assign approximate age limits to the major periods of magmatic activity recognized in the north-central Shield. These results, together with earlier determinations, are plotted in figure 4; sources and nalytical data are summarized in table 1. Ages for the foliated (syntectonic) tonalites and diorites east of Mahd adh Dhahab range from 816 Ma to 718 Ma; several smaller, and provisionally correlative gneissic granodiorite plutons are present near Afif. None of the major plutons assigned to the older period of granodiorite-monzogranite magmatism has been dated, although an age of 638 Ma is reported for one pluton near Ad Dafinah shown as "older basement" by Letalenet (1979). The younger plutons yield ages ranging from 607 Ma to 552 Ma; the peak of magmatic activity at about 580±20 Ma (fig. 4, inset histogram) is in reasonable agreement with reported ages for late-orogenic and postorogenic plutonism elsewhere in the Shield.

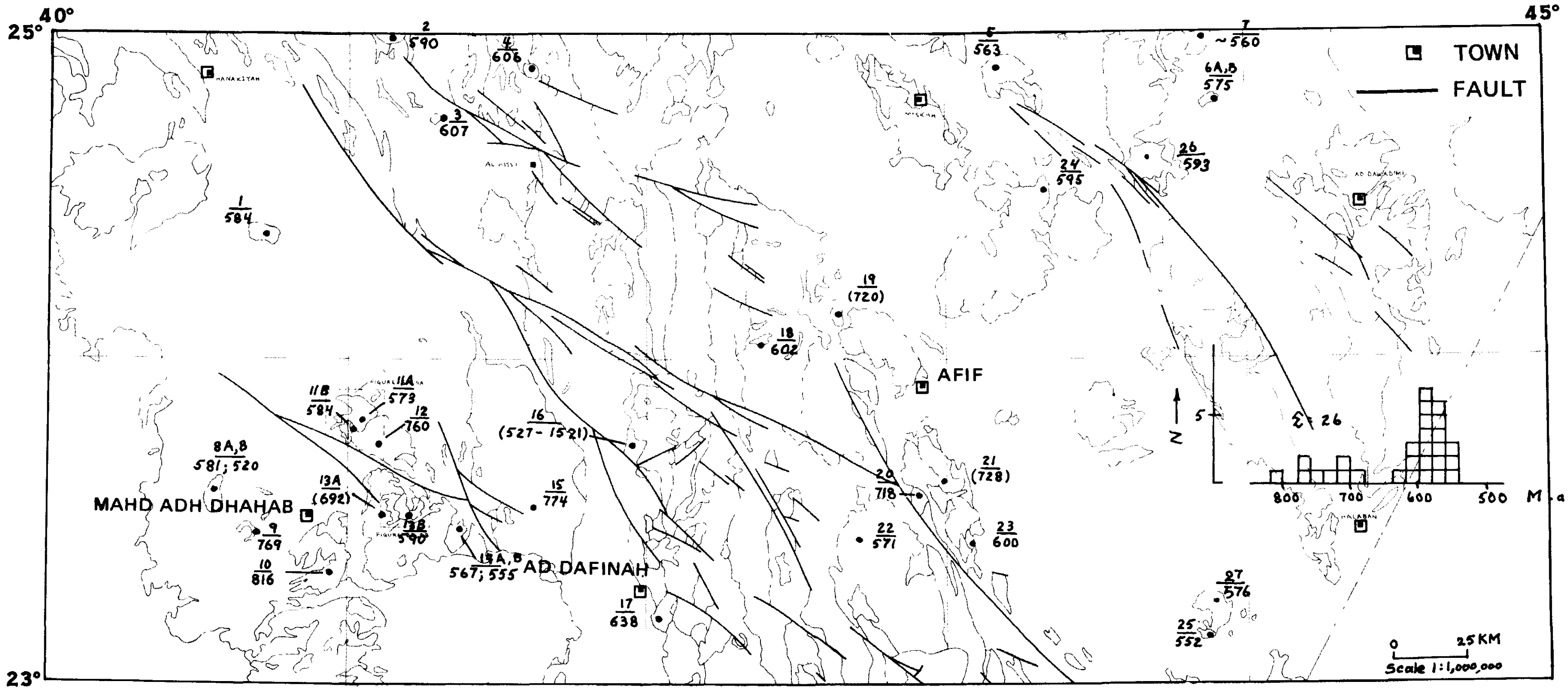


Figure 4.--Map showing radiometric ages of plutonic rocks in the study area; histogram (inset) shows distribution. Refer to table 1 for locality names and additional analytical information.

Table 1.--Radiometric ages of plutonic rocks in the north-central Arabian Shield

Sample locality no. (fig. 4)	name	Age Ma[1]	Method[2]	Material analyzed[3]	Rock type	References[4]
1	Jabal Abha	584±17	R	W (8)	quartz monzonite	4
2	Jabal Ajir	590±8	R	W (7)	alkali granite	3,4
3	Jabal Sanam	607±18	U	Z	foliated quartz monzonite	4
4	Jabal Furqayn	606±14	?	?	alkali feldspar	4
5	Jabal Tuqfah	563±71	R	W (3)	alkali-feldspar granite	5
6A	Jabal Jabalah	575±7	R	W (7)	monzogranite	5
6B		575	K	B	monzogranite	1a
7	J.Um ad Diban	525	R	B	granodiorite	1a
		585	K	B	granodiorite	1a
		575	R	P	granodiorite	1a
8A	Wadi Gharnak	581±12	R	W (6)	monzogranite	2
8B		520±15	R	B	monzogranite	1b
9	J. Ramram	769±5	U	ZZ	quartz syenite	2
10	Dhukhr	816±3	U	Z	tonalite	2
11A	J.Hadb ash Sharar	573±22	R	W (7)	monzogranite	2
11B	J.Hadb ash Sharar	584±26	R	W (7)	alkali granite	2
12	Hufayriyah	760±10	U	Z	tonalite	2
13A	J.Hadb ad Dayahin	(692±15)	R	W (2)	alkali granite ring dike	1b
13B	J.Hadb ad Dayahin	590±10	R	W (3)	alkali granite	1b

Table 1.--Radiometric ages of plutonic rocks in the north-central Arabian Shield [continued]

Sample locality no. (fig. 4)	name	Age Ma[1/]	Method[2/]	Material analyzed[3/]	Rock type	References[4/]
14A	Alse-Hairah	567±86	R	W (3)	rapakivi monzogranite	5
14B	Alse-Hairah	555±15	R	B		1b
15	--	774±101	R	W (7)	gneissic tonalite	5
16	J. Rharabah	(527-1521)	K	W (5)	gabbro	7
17	Sabkhra al Khal	638±26	R	W (6)	muscovite granite	7
18	J. al Usaybiyat	602±9	R	W (5)	syenogranite	5
19	Northwest of Afif	(720)	-	-	granodiorite	5
20	South of Afif	718±25	R	W (3)	gneissic granodiorite	5
21	South of Afif	(728)	R	W (2)	gneissic granodiorite	5
22	Al Bara batholith	571±19	R	W (3)	two-mica granite	5
23	J. Yanufi	600±13	R	W (6)	biotite granite	7
24	J. al Arayis	595±12	K	B	granite	6
25	J. Khinzir	552±5	R	W (6)	muscovite granite	7
26	Ash Shufayiyah granite	593±6	U	Z	porphyritic monzogranite	8
27	Ad Darah granite	576±20	R	?	quartz monzonite	8

Table 1.--Radiometric ages of plutonic rocks in the north-central Arabian Shield [continued]

1/ Suspect ages in parentheses.

2/ Method

R = Rb-Sr
K = K-Ar
U = U-Pb

3/ Material analyzed (no. of samples in parentheses)

W = whole rock
Z = zircon
B = biotite
P = plagioclase

4/ References

1a. Aldrich and others, 1978, sec. 1
1b. Aldrich and others, 1978, sec. 2
2. Calvez and Kemp, 1982
3. Delfour, 1977
4. Delfour, 1981
5. Fleck and Hadley, 1982
6. Gettings and Stoeser, 1981
7. Baubron and others, 1976
8. Calvez and Delfour (unpub. data)

Geochemistry

Reconnaissance geochemical prospecting proceeded concurrently with compilation and petrographic characterization of felsic plutonic rocks. A step-wise approach, although preferable, was not possible in the 12 months (including analytical turn-around time) allotted for the evaluation of this large area. In retrospect, the simultaneous geochemical and geological study appears vindicated, as independently determined lithologic, mineralogic, and geochemical indicators of granite-related mineralization have proven to be mutually convergent.

Guided by results of recent regional assessments and prospect documentation, principal emphasis was placed on valuation of the younger, leucocratic plutons. The types of mineralization and potential prospecting targets that were anticipated have been summarized by Jackson and others (1982) (table 2). As the first objective was to identify new areas worthy of more detailed study, plutons previously recognized as having mineral potential received less attention; these include the peralkalic apogranite of Jabal Sayid currently under investigation by geologists of the DGMR (Hackett and Ramsay, 1982; D. Hackett, written commun., 1983); the molybdenum-stockwork prospect at JabalKirsh now being studied by the BRGM (M. Laval, written commun., 1983); and tungsten occurrences at El Koom documented by Hummel and Ankary (1972) and Elliott (1983).

The geometric means of 26 elements in plutonic rocks from the north-central Shield were compared with those of plutonic rocks from the eastern and southeastern Shield (du Bray and others, 1982) and average granite (Krauskopf, 1967) (table 3). The two Shield sample populations are closely comparable, except for several elements for which most values are qualified (outside the limits of analytical resolution). Collectively, the rock samples from the Shield do not appear atypical with respect to values reported for average granite; mean concentrations apparently have not been distorted by inordinately large numbers of geochemically anomalous plutons. Likewise, mean values for panned concentrate samples are generally in good mutual agreement, a further indication that felsic plutons of the north-central, eastern, and southeastern Shield belong to a geochemically coherent/homogeneous magmatic terrane.

The threshold concentrations for rock and panned concentrate samples in the study area were compared to corresponding thresholds for plutonic rocks of the eastern Shield (du Bray and others, 1982) and central Hijaz (Jackson and others, 1982) (table 4). Anomaly definition is particularly close for rock samples from the north-central and eastern Shield. With the exception of copper, threshold concentrations, which average 2 to 4 times the concentration

Table 2.--Summary of mineralization types and potential prospecting targets in the felsic plutonic rocks of the Arabian Shield

[Data sources for Arabian Shield examples (1) Cole and others (1981), (2) Elliott (in press), (3) Ramsay (1982), (4) Dodge and Helaby (1975), (5) Drysdall (1979b), (6) Turkistany and Ramsay (1982), (7) Jackson and Douch (1982). The terms plumasitic and agpaitic are derived from Tischendorf (1977) and a description of their usage is given in Ramsay (1982)]

Type	Mineralization	Mode of emplacement	Associated rocks	Arabian Shield examples
W-Sn	W and (or) Sn	Vein system, stockwork or disseminated	Metaluminous and peraluminous biotite, 2-mica or Li-mica syenogranite, monzogranite, or granodiorite	Baid al Jimalah[1] (W) Al Gaharra[2] (Sn)
Plumasitic	Ta, Nb, Sn, Li, Be, F, W, Au	Vein system, stockwork or disseminated	Metasomatized or chemically specialized calc-alkalic granite	Ratama[3] (Sn, Ta) Al Wajj W-Au district
Mo-Cu	Mo and (or) Cu (Au, Ag, Pb, Zn)	Vein system or stockwork	Generally porphyritic hornblende and (or) biotite monzogranite, granodiorite or quartz monzonite	Jabal Thaaban[4] (Mo) No known examples of Cu-mineralized granites
Agpaitic	Nb, Zr, Y, Ta, Sn (REE, U, Th)	Disseminated	Alkali (peralkaline) granite or quartz syenite	Ghurayyah[5], Sayid[6] Hamra'[7]

Table 3.--Elemental geometric means of semiquantitative spectrographic data for rock and panned concentrate samples

[Results are in parts per million (ppm), except for Fe, Mg, Ca, and Ti, which are in weight percent. Leader (--) indicates element undetected in all samples. Means were calculated using the method of Cohen (see du Bray and others, 1982); when this was not possible, the geometric mean of unqualified data is given (*). Geometric means for Ag, Bi, Mo, Sn, W, and Zn are based on very few unqualified values and have little significance. Number of samples on which means are based is shown in parentheses. Average granite values from Krauskopf, 1967. Arsenic, gold, cadmium, and antimony were not detected in any of the samples]

	Rock samples			Panned concentrate samples	
Element	Mean (324), this report	Mean (696), Eastern Shield (du Bray and others, 1982)	Mean (2327), average granite (Krauskopf, 1967)	Mean (154), this report	Mean (694), Eastern Shield (du Bray and others, 1982)
Fe	1.78	1.50	3.09	8.74	7.60
Mg	.18	.17	.81	.76	1.19
Ca	.55	.96	1.89	2.04	2.55
Ti	.14	.11	.34	.70*	.79*
Mn	295	331	400	2851	1329
Ag	1*	--	.04	2*	--
B	11	5	15	12	8
Ba	305	223	600	192	192
Be	2	2	5	1	1
Bi	10*	25*	.18	17*	21*
Co	1	1	1	16	11
Cr	167	175	4	798	421*
Cu	3	16	10	19	38
La	34	21	40	191*	63*
Mo	1	1	2	4	1
Nb	10	5	20	91	42*
Ni	4	3	.5	27	29
Pb	17	14	20	37	8
Sc	2	2	5	23	16
Sn	21*	.2	3	30*	34*
Sr	79	103	285	149	149
V	20	20	20	176	185
W	--	--	2	217*	90*
Y	22	17	40	20*	62
Zn	321*	282	40	521*	--
Zr	199*	100	180	658*	775*

Table 4.--Threshold concentrations of semiquantitative spectrographic data for rock and sediment samples

	Rock samples					Sediment samples			
			Threshold concentration				Threshold concentration		
Element	Detection limit	No. of unqualified values, this report	This report	du Bray and others (1982)	Jackson and others (1982)	No. of unqualified values, this report	This report (Panned concentrates)	du Bray and others (1982) (Panned concentrates)	Jackson and others (1982)6/ (Sands)
Ag	5	1	54/	54/		2	54/	54/	
B	10	255	201/	301/		110	802/	503/	
Ba	20	288	7001/	10002/		154	3002/	7001/	
Be	1	270	151/	102/		49	32/	52/	
Bi	10	1	104/	103/		17	104/	153/	
Co	5	57	201/	202/		139	701/	301/	
Cr	10	324	3001/	3007/		154	20001/	10002/	
Cu	5	147	152/	1002/	1001/	154	301/	1502/	901/
La	20	257	702/	702/	1731/	139	7001/	3002/	691/
Mo	5	54	103/	152/	44/	81	103/	203/	44/
Nb	30	98	702/	1002/	961/	151	300	5002/	161/
Ni	5	157	202/	702/		154	702/		
Pb	10	285	701/	701/		148	1002/	1002/	
Sc	5	101	152/	152/		147	152/	501/	
Sn	10	24	153/	153/	104/	123	1502/	2003/	104/
Sr	100	146	10001/	7001/		113	2002/	3001/	
V	10	283	1001/	702/		154	2002/	5001/	
W	50	0	504/	504/	504/	16	504/	504/	504/
Y	10	259	1003/	1502/	1991/	150	2002/	3002/	561/
Zn	200	16	2004/	2004/		9	2004/	2004/	
Zr	10	302	7001/	5001/	18201/	17	-- 5/	-- 5/	7001/

Method used to establish threshold:

1/ $\overline{X} + 2S$; $\overline{X} + 1.65S$ (95% probability) for Jackson and others (1982).
2/ Maximum concentration in resolved background population (Sinclair, 1981).
3/ Inspection of frequency histogram.
4/ Any detected value considered anomalous.
5/ Most samples contain in excess of maximum detection limit (1000 ppm); threshold not determined.
6/ -20+60 mesh sands analyzed.

in average granite, generally differ by no more than one spectrographic reporting interval. Agreement is also reasonably good with selected elements in rock samples from the central Hijaz, when allowance is made for the method employed in calculating threshold values (X + 1.65 S or 95 percent probability). The apparent reversal of threshold concentrations, with values for rock samples substantially higher than those for wadi sediment samples, may be the result of large variance in a relatively small population (N. J. Jackson, oral commun., 1983). The similarity of anomaly-defining threshold concentrations (table 4) suggests that attempted regional analysis of geochemically anomalous plutons in the central Shield will reflect real differences in source terranes or dominant geological process rather than artifacts of data treatment.

Further consideration of the geochemical data is limited to potential ore metals (Sn, W, Mo, Cu, Pb, Zn, Be, Y, Nb, Zr) and associated elements (La, Bi) characteristically enriched in the younger felsic plutons of the north-central Shield. Anomalous concentrations of these elements in rock samples are located in figures 5 and 6; anomalous concentrations in wadi sediment samples derived from the plutons are located in figures 6 and 7.

No significant base metal (Cu-Mo, ± Zn, Pb-Ag) anomalies were detected. Low-level, copper enrichment (15 samples) is restricted generally to granodiorite, monzodiorite, or quartz monzonite plutons; mafic minerals in these relatively more melanocratic rocks are the likely source of the anomalies. Note that only one of these values would be anomalous at the threshold concentrations (TC) of du Bray and others (1982) and Jackson and others (1982) (table 4) who report bimodal distributions of overlapping background and anomalous populations not recognized in the present work. Isolated anomalous molybdenum values (1.5-2 times TC) occur in 3 granite plutons, none of which was anomalously enriched in copper. Anomalous lead concentrations averaging 2 to 3 times TC are confined generally to panned concentrates (8 samples) derived from alkali-feldspar granites and muscovite-bearing monzogranites. Zinc concentrations of 1.5 to 2.5 times TC have been determined for 2 samples from both the Jabal Hadb ash Sharar and Jabal Hadb ad Dayahin alkali granites (fig. 6).

Tin occurs in anomalous concentrations (1.5-3 times TC) in one or more rock samples from the muscovite-bearing monzogranites of Jabal Minya and the western part of Jabal Khinzir (fig. 5) as well as the southwestern part of the Jabal Hadb ad Dayahin alkali granite ring structure (fig. 6). Highly anomalous (generally >6 times TC) concentrations of tin (± tungsten) have been detected additionally in panned concentrate samples (fig. 7) from muscovite-bearing monzogranites of Jabal Hadbat Tayma and Jabal Najirah, the

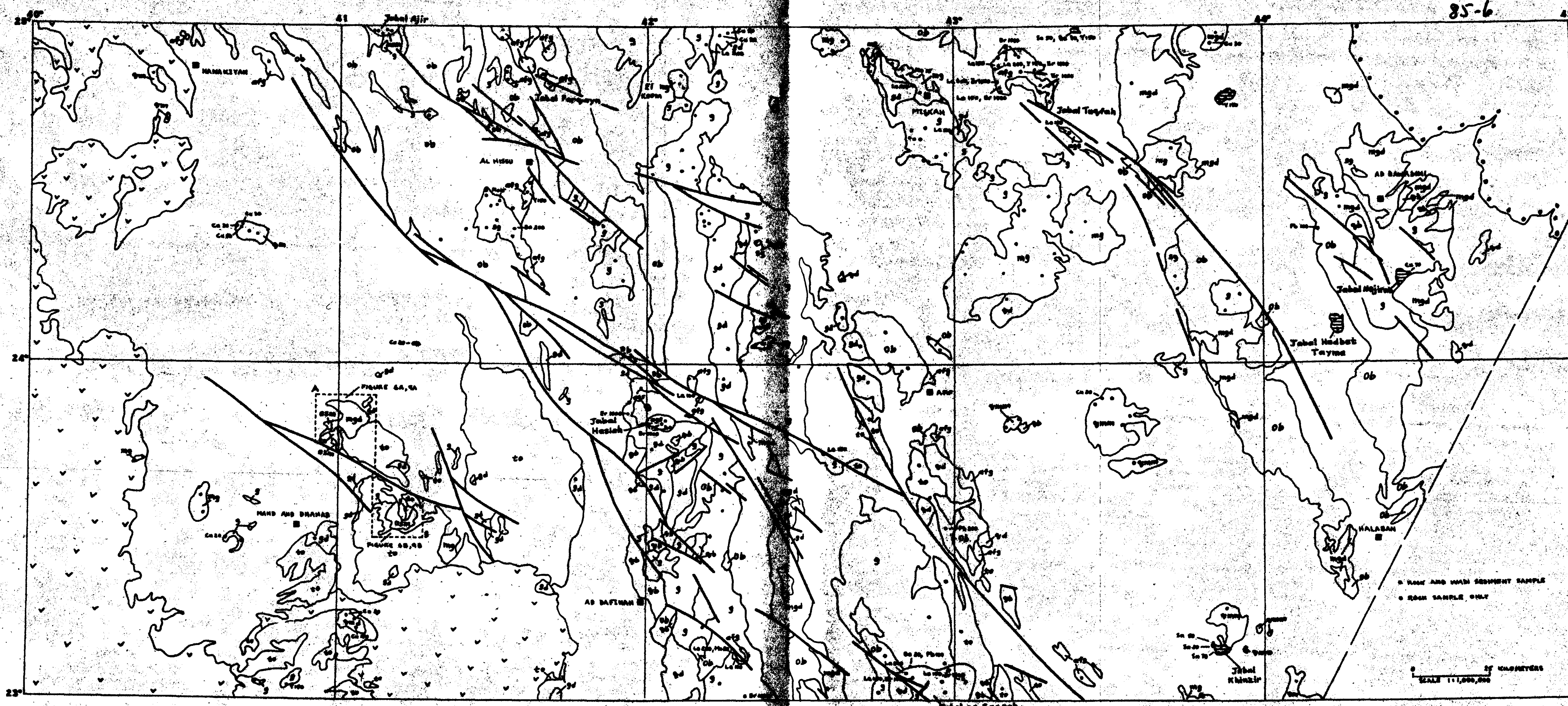


Figure 5.—Map showing sample locations and concentrations of selected elements (in parts per million) in geochemically anomalous samples of felsic plutonic rocks of the north-central Shield. Dashed areas A and B are shown in detail in figure 6, explanation of map units shown in figure 2.

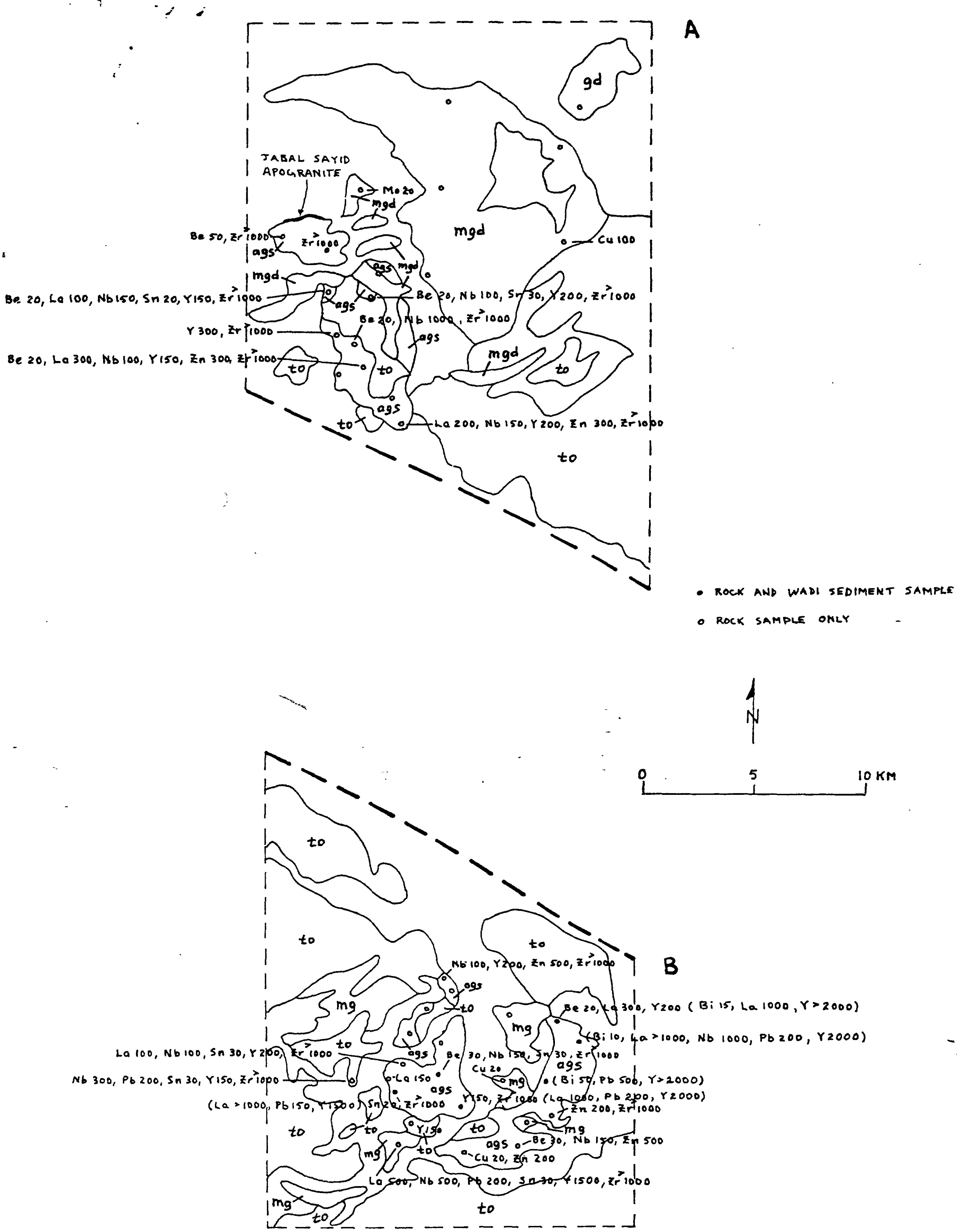


Figure 6.--Maps showing sample locations and concentration of selected elements (in parts per million) in geochemically anomalous samples of felsic plutonic rocks from Jabal Hadb ash Sharar (A) and Jabal Hadb ad Dayahin (B). Patterns for rock type as in figure 2.

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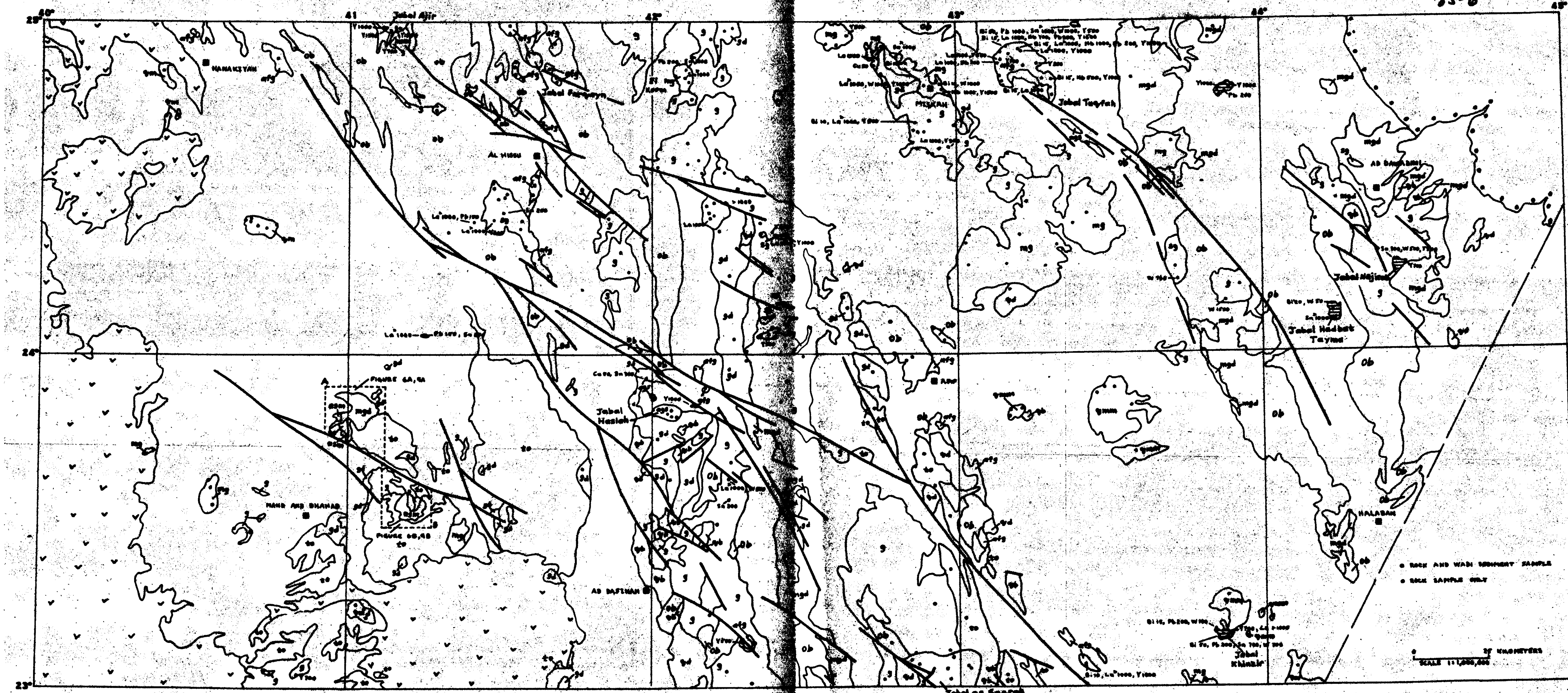

Figure 7.—Map showing sample locations and concentrations of selected elements (in parts per million) in geochemically anomalous panned concentrates of wadi sediment derived from felsic plutons of the north-central Shield. Explanation of map units shown in figure 2.

monzogranite at El Koom, and the monzogranite northwest of Miskah. Low-level anomalous concentrations of tin (1.5-2 times TC) occur also in single samples of syenogranite and alkali-feldspar granite south of Al Hissu, the plug-like syenogranite intrusion of Jabal Furqayn (south), and in the north-trending belts of granodiorite and monzogranite north of Ad Dafinah. Bismuth in near-threshold concentrations is detected in about one-third of the concentrate samples containing anomalous tin or tungsten.

Anomalous concentrations of lanthanum, niobium, zirconium, the radioelements, and the rare-earth elements occur most notably in pegmatitic apogranite at the northern margin of the riebeckite alkali granite at Jabal Hadb ash Sharar (fig. 6A). Samples of the alkali granite from which the apogranite is thought to be a late differentiate (Turkistany and Ramsay, 1982) show a characteristic enrichment in zirconium, niobium, lanthanum, and yttrium ± beryllium, tin, nd zinc. A closely similar anomalous metal suite occurs in the alkali granite ring complex of Jabal Hadb ad Dayahin, about 20 km to the southeast (fig. 6B). The alkali-feldspar granite of Jabal Tuqfah (fig. 5) is the only other pluton in the north-central Shield having a comparable metal suite in rock samples apart from erratic anomalous concentrations of zirconium and (or) lanthanum in the syenogranites of Jabal Haslah and Jabal as Saqrah.

Panned concentrate samples from the alkali granite of Jabal Hadb ad Dayahin contain anomalous concentrations of lanthanum and yttrium ± bismuth and niobium (values in parentheses in fig. 6B). Other plutons for which panned concentrate samples contain lanthanum and (or) yttrium in anomalous concentrations (fig. 7) include several syenogranite ring structures northwest of Afif, a ring structure south of Miskah, the syenogranite south of Al Hissu, and the alkali granite of Jabal Ajir.

Radiometric responses

Total-count gamma radiation measurements, assigned to one of four total-count intervals, were plotted (figs. 8 and 9) as were areas of anomalous aeroradiometric response compiled from 1:100,000-scae aeromagnetic and scintillation counter surveys (AeroService Corporation, 1958) flown at a mean terrane clearance of 150 m (Drysdall, 1979a).

The calculated mean (X) and standard deviation (S) for all readings were 58 and 32, respectively, which compare closely with corresponding values of 50 and 31 reported by du Bray and others (1982). The inability to correct for local and often major topographic effects and variation between scintillometers precluded calculation of a meaningful anomaly threshold. Total counts for 23 samples exceeded X + S, with only 4 of these greater than X + 2 S

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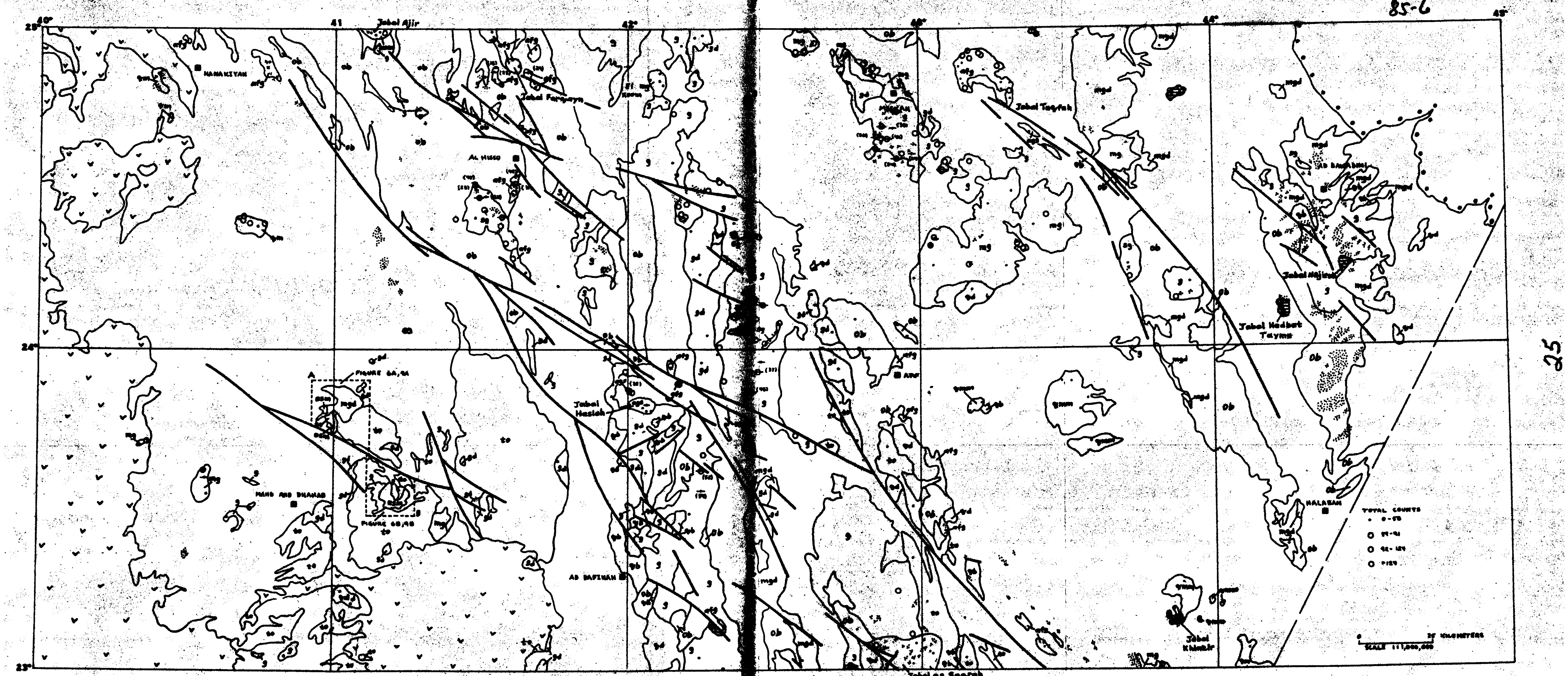

Figure 8.—Total-count scintillometer (gamma ray) responses of felsic plutonic rocks of the north-central Shield. Dashed areas A and B are shown in detail in figure 9, explanation of map units shown in figure 2.

(98 percent probability level). Greater than mean values are most consistently associated with either muscovite-bearing, tin-anomalous monzogranites (Jabal Khinzir, Jabal Minya, and Jabal Hadbat Tayma) or the sodic-mafic alkali granites of Jabal Hadb ash Sharar and Jabal Hadb adh Dayahin (fig. 9). Other plutons giving elevated responses include the alkali-feldspar granites and syenogranites of Jabal Tuqfah, the syenogranite near Jabal Hadb al Hissu, and the granite ring structures south of Miskah and west of Afif.

Splits of each rock sample were analyzed for the radioelements, thorium and uranium, using XRF multichannel spectrometry (Kevex) instrumentation in USGS (Jiddah) facilities (Moore, unpub. data). About one-third of the splits (109) contained detectable thorium (>13 ppm) and 20 of these contained detectable uranium (>8 ppm). Means (X), standard deviations (S), and range of values are:

	X	S	Range
Thorium	32 ppm	27 ppm	15-98 ppm
Uranium	34 ppm	9 ppm	10-52 ppm

Samples containing above-average thorium (symbols crossed with a horizontal bar) and detected uranium (concentrations in parentheses) (fig. 8) are from plutons that include a number of the younger syenogranite and alkali-feldspar granite ring structures or plug-like plutons in the central and northern part of the study area, but none of the tin-anomalous microcline-albite monzogranites in the eastern part. There is a superficial coincidence of aeroradiometric anomalies (exceeding twice regional background) with the above plutons (fig. 8); however many of the former are spurious and reflect lithologic contrasts or terrane clearance effects (Drysdall, 1979a; Jackson and others, 1982) rather than enrichment of radioelements.

DISCUSSION

Felsic plutons for which single samples contain anomalous concentrations of one or two rare elements are scattered throughout the north-central Shield (figs. 5 and 7); for example, the two tungsten-anomalous samples in quadrangle 24/43 D. The significance of these isolated anomalies can not be determined without further sampling and may be more appropriately considered in the regional context of the high-density geochemical sampling program now being conducted by the Riofinex Geological Mission, Jeddah (R. V. Sale, oral commun., 1983). Of greater immediate interest here are plutons enriched in a multi-element suite of rare elements, which also possess favorable features for

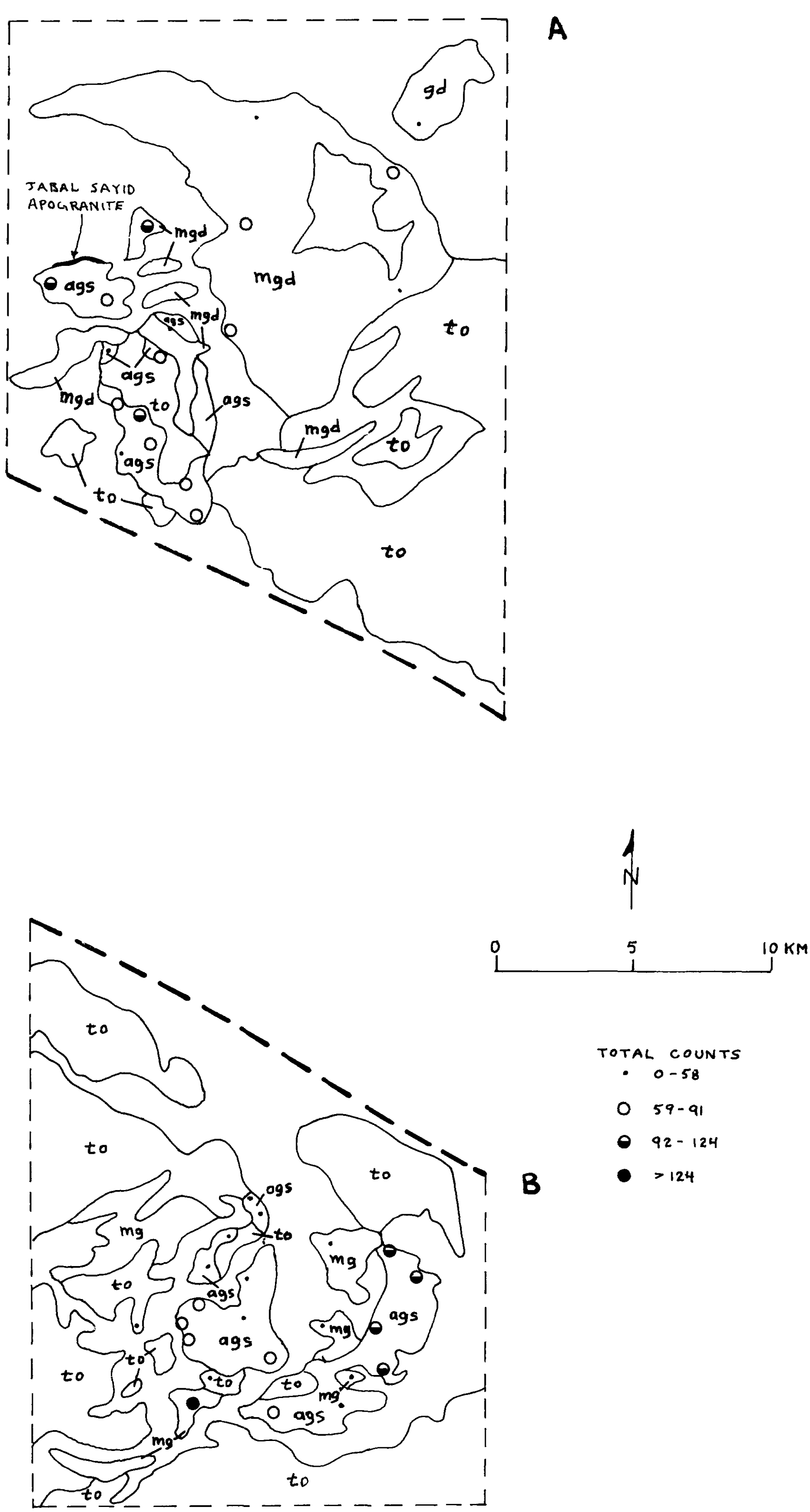

Figure 9.--Total-count scintillometer (gamma ray) responses of felsic plutonic rocks from Jabal Hadb ash Sharar (A) and Jabal Hadb ad Dayahin (B). Patterns for rock type as in figure 2.

mineralization of geologic setting and lithology.

Fourteen Late Proterozoic plutons potentially favorable for rare-lement mineralization have been thus identified in the present petrographic and geochemical assessment (table 5). The plutons are leucocratic granitoids assigned to a major magmatic event that spanned the later stages of the Hijaz orogeny (about 600 Ma to 560 Ma). Most of the targeted plutons are relatively small or not deeply eroded. Two rock types are dominant: subsolvus, muscovite-bearing monzogranite or syenogranite; and hypersolvus alkali-feldspar (microcline perthite) granite commonly containing sodic pyriboles. Medium-grained equigranular to subporphyritic textures prevail. Enrichment in varied suites of granitophile elements is characteristic. Six plutons having tin-tungsten potential and 8 having agpaitic (rare element-radioelement) potential have been identified. All are deemed worthy of follow-up investigation.

Of the targeted plutons in the tin-tungsten or plumasitic group (table 5), highest priority is given to the muscovite-bearing monzogranites of Jabal Minya and Jabal Khinzir that closely resemble the tin-anomalous monzogranite of Jabal Sitarah described by du Bray, in press). The fact that both plutons are well-exposed and contacts with intruded rocks are sharp provides in addition an exceptional opportunity to evaluate emplacement processes as well as internal distribution of rock types and granitophile elements.

In the agpaitic group, the riebeckite alkali granites of Jabal Hadb ad Dayahin and Jabal Tuqfah have the highest potential for rare-element mineralization. The geochemical signature and ring structure of the former are broadly comparable to the nearby ring complex and associated apogranite of Jabal Hadb ash Sharar (fig. 6), which Turkistany and Ramsay (1982) liken to Nb-Ta-Sn-Zr-Y-Th-U mineral prospects in peralkaline microgranites of Jabal Tawlah and Ghurayyah (Drysdall, 1979b). The remaining plutons are moderately enriched in thorium and uranium, but otherwise lack definitive geochemical character.

It should be emphasized that mineralization has not been recognized in any of the plutons listed in table 5 with the exception of quartz-tungsten veins previously described at El Koom. The very ordinary megascopic appearance of the geochemically anomalous felsic plutons noted in prospecting programs in surrounding areas (Ramsay, 1982; Jackson and others, 1982; du Bray, in press) is also a characteristic of geochemically anomalous plutons in the north-central Shield. There is no evidence of pervasive alteration in or adjacent to the plutons. Except for megascopic traces of muscovite or sodic pyriboles, there would be little reason to suspect an enrichment in granitophile elements. Thus an early objective of follow-up investigations must be to seek indications of localized concentrations of the rare elements.

Prior to this study, rare-element mineral occurrences and prospects associated with younger, specialized granites were known chiefly in the northeastern and eastern Arabian Shield (fig. 10; open symbols); fourteen newly identified geochemically anomalous plutons (fig. 10; filled symbols) remove the apparent discontinuity of occurrence in the north-central Shield. Shieldwide, these plutons define a broad arcuate belt concave to the west that conforms generally with the eastern limit of the eposed Proterozoic basement. Agpaitic (Nb-Sn-Zr-Y-Th-U) occurrences, as noted by Elliott (1983), are more common in the north-central and northwestern Shield, whereas Sn-W(-Mo) occurrences are present to the exclusion of agpaitic types in the southeast. A weaker west to east component of variation is also suggested: Jackson and others (1982) did not identify tungsten-tin and plumasitic mineralization in the central Hijaz, but these occur interspersed with agpaitic mineralization in the north-central Shield and become dominant east of long 42°30' E.

RECOMMENDATIONS

Of 14 geochemically anomalous plutons in the north-central Shield having potential for rare-element mineralization (table 5; fig. 10), four are recommended for immediate follow-up investigations: Jabal Minya and Jabal Khinzir (tin-tungsten); and Jabal Hadb ad Dayahin and Jabal Tuqfah (rare-earth and radio-elements). The same methods employed in this reconnaissance assessment are applicable. The nature and extent of mineralization or geochemical enrichment should be established by sampling along systematic traverses; sampling should be accompanied by large-scale mapping of the target plutons, with particular attention given to indirect indications of possible concealed mineralization (such as veining or geochemical "leakage") in or under the intruded rocks. Follow-up investigations of the remaining 10 plutons and scattered anomalies throughout the north-central Shield should be coordinated with the current high-density geochemical sampling program of the Riofinex Geological Mission.

DATA FILE

Geochemical and other data relative to this report are archived in the U.S. Geological Survey Saudi Arabian Mission in data file USGS-DF-04-12.

No entries or updates have been made to the Mineral Occurrence Documentation System (MODS) data bank.

Table 5.--Features of potentially mineralized felsic plutons in the north-central Arabian Shield

[Locality number and name as shown in figure 2. Age from table 1; N.D., not determined. Leaders (--), metal content less than concentration threshold or outside limits of detection]

Locality no. name	Form; dimensions: geologic setting	Rock type	Texture	Age (Ma)	Sample medium[1]	Selected granitophile elements[2] Be	Bi	La	Nb	Sn	W	Y	Zr[4]	Th	U	Radiometric response, total cps	Comments
Tin-tungsten or plumasitic mineral potential[3]																	
1 Jabal Minya	oval plug; 1.5x2 km; intruded at south-eastern margin of of major biotite monzogranite	muscovite-biotite monzogranite	granophyric (porphyritic microgranular)	N.D.	R	2	--	--	--	3.3	--	1.5	--	--	--	128	accessory fluorite and traces of cassiterite; 160 ppm tungsten in concentrate reported by Mytton (1970)
					P	--	5	--	--	6.6	20	2.5	--	--	--	--	
2 Jabal Khinzir	oval stock; 7x3 km; intruded at south-western margin of 576 Ma Ad Darah quartz monzonite	biotite-muscovite albite-microcline monzogranite	medium-grained, inequigranular (seriate)	552±5	R	--	--	--	--	1.5-5	--	--	--	--	--	48-104	accessory fluorite; hosts beryl-microcline-quartz pegmatite (Letalenet and others, 1972a)
					P	--	1-3.3	--	--	4.5	2-3.5	3.5	--	--	--	--	
3 Jabal Hadbat Tayma	oval stock; 7x5 km; intrudes Abt schist	biotite-muscovite monzogranite	medium-grained, hypidiomorphic, equigranular	N.D.	R	--	--	--	--	--	--	--	--	--	--	72-96	
					P	--	2	--	--	6.6	1	--	--	--	--	--	
4 Jabal Najirah	sub-circular stock; 5 km in diameter intrudes composite Dawadimi batholith	biotite (-muscovite) monzogranite	fine-grained, hypidiomorphic equigranular, weakly granophyric	N.D.	R	--	--	--	--	--	--	--	--	--	--	36-56	
					P	--	--	--	--	2	10	1.5-3.5	--	--	--	--	
5 ----	border phase of Dariyah Complex (Beurrier and Villey, 1984)	biotite-amphibole monzogranite	medium-grained, hypidiomorphic equigranular, locally granophyric	N.D.	R	--	--	--	--	--	--	--	--	--	--	34-40	accessory allanite; sodic-amphibole
					P	--	1.5-5	1.5	1.5-3	--	--	2.5-7	--	--	--	--	

Table 5.--Features of potentially mineralized felsic plutons in the north-central Arabian Shield [continued]

Locality no. name	Form; dimensions; geologic setting	Rock type	Texture	Age (Ma)	Sample medium[1]	Selected granitophile elements[2] Be	Bi	La	Nb	Sn	W	Y	Zr[4]	Th	U	Radiometric response, total cps	Comments
Tin-tungsten or plumasitic mineral potential[3]																	
6 El Koom	oval pluton; 9x6 km; oriented inclusions common; intruded by multiple dike swarms	amphibole-biotite monzogranite and granodiorite	fine-grained, hypidiomorphic equigranular	N.D.	R	--	--	--	--	--	--	--	--	--	--	35-40	tungsten potential (wolframite-quartz veins) recognized by Mytton (1970) and Hummel and Ankary (1972)
					P	--	--	--	--	6.6	--	--	--	--	--	--	
Agpaitic mineral potential[3]																	
7 Jabal Hadb ad Dayahin	sub-circular alkali granite ring complex; 8 km in diameter	biotite-riebeckite granite	medium-grained, hypidiomorphic inequigranular to porphyritic	590±10	R	1.5-2	--	1.5-7	1.5-7	2	--	1.5-2	>1.5	--	--	32-176	protolithionite megacrysts in ring dike on western flank; quartz-fluorite veins locally (Radain, 1980)
					P	--	1.5	>1.5	3.3	--	--	7->10	--	--	--	--	
8 Jabal Tuqfah	oval composite pluton; 15x25 km	biotite-riebeckite(?) microcline perthite granite	medium-grained, hypidiomorphic equigranular, granophyric	563±71	R	--	--	2-3	--	--	--	1.5	--	--	--	40-72	
					P	--	--	1.5	1.5-3	--	--	1.5-7	>1.5	--	--	--	
9 Jabal Mazim group	multiple/composite irregular plutons	biotite syenogranite and microcline perthite granite	medium-grained, hypidiomorphic equigranular to seriate, granophyric	N.D.	R	13	--	--	--	--	--	--	--	34-61	28-45	41-140	
					P	--	--	1.5	--	1.5	--	1	--	--	--	--	
10 Jabal Furqayn group	multiple, sub-circular or oval plugs; apopyses of buried pluton(?); 4-6 km in diameter	riebeckite(?) microcline perthite granite	medium-grained, hypidiomorphic equigranular	606±14	R	--	--	--	--	--	--	--	--	44-58	18-29	34-50	unspecified agpaitic mineral potential recognized by Drysdall (1979a)
					P	--	--	--	--	--	--	--	--	--	--	--	

Table 5.--Features of potentially mineralized felsic plutons in the north-central Arabian Shield [continued]

Locality no. name	Form; dimensions; geologic setting	Rock type	Texture	Age (Ma)	Sample medium[1/]	Selected granitophile elements[2/] Be	Bi	La	Nb	Sn	W	Y	Zr[4/]	Th	U	Radiometric response, total cps	Comments
Agpaitic mineral potential[3/]																	
11 Miskah	arcuate, incomplete ring structure	biotite syeno-granite	medium-grained, hypidiomorphic inequigranular	N.D.	R	--	--	1.5	--	--	--	--	--	35-62	24-38	40-128	
					P	--	1	1.5	--	--	--	1.5-2.5	--	--	--	--	
12 Jabal Haslah	oval pluton; 8x5 km; intruded by grano-phyre dikes, plugs	amphibole-biotite syenogranite	medium-grained, hypidiomorphic inequigranular	N.D.	R	--	--	--	--	--	--	--	1.5	44-56	32	40-60	
					P	--	--	--	--	--	--	5	--	--	--	--	
13 Jabal Usay-biyat group	composite ring structures	biotite syenogranite	medium-grained, hypidiomorphic inequigranular, locally grano-phyric	602±9	R	--	--	--	--	--	--	--	--	34-58	37-48	60-96	
					P	--	--	--	--	--	--	1.5-2.5	--	--	--	--	
14 Jabal ad Dira	oval pluton(?); 2x4 km maximum	amphibole monzogranite	medium-grained, porphyritic-microgranular	N.D.	R	--	--	--	--	--	--	--	--	58	34	51	cassiterite in panned concentrates on east & west flanks (Brosset & Conraux, 1975)
					P	--	--	--	--	2	--	--	--	--	--	--	

1/ Sample medium: R=rock, P=panned concentrate
2/ Selected granitophile elements. Range of values in anomalous samples expressed as multiples of threshold concentration (table 4), except for Th and U expressed in parts per million (ppm)
3/ See table 2
4/ Zr content exceeds upper detection limit (1000 ppm) in all panned concentrate samples

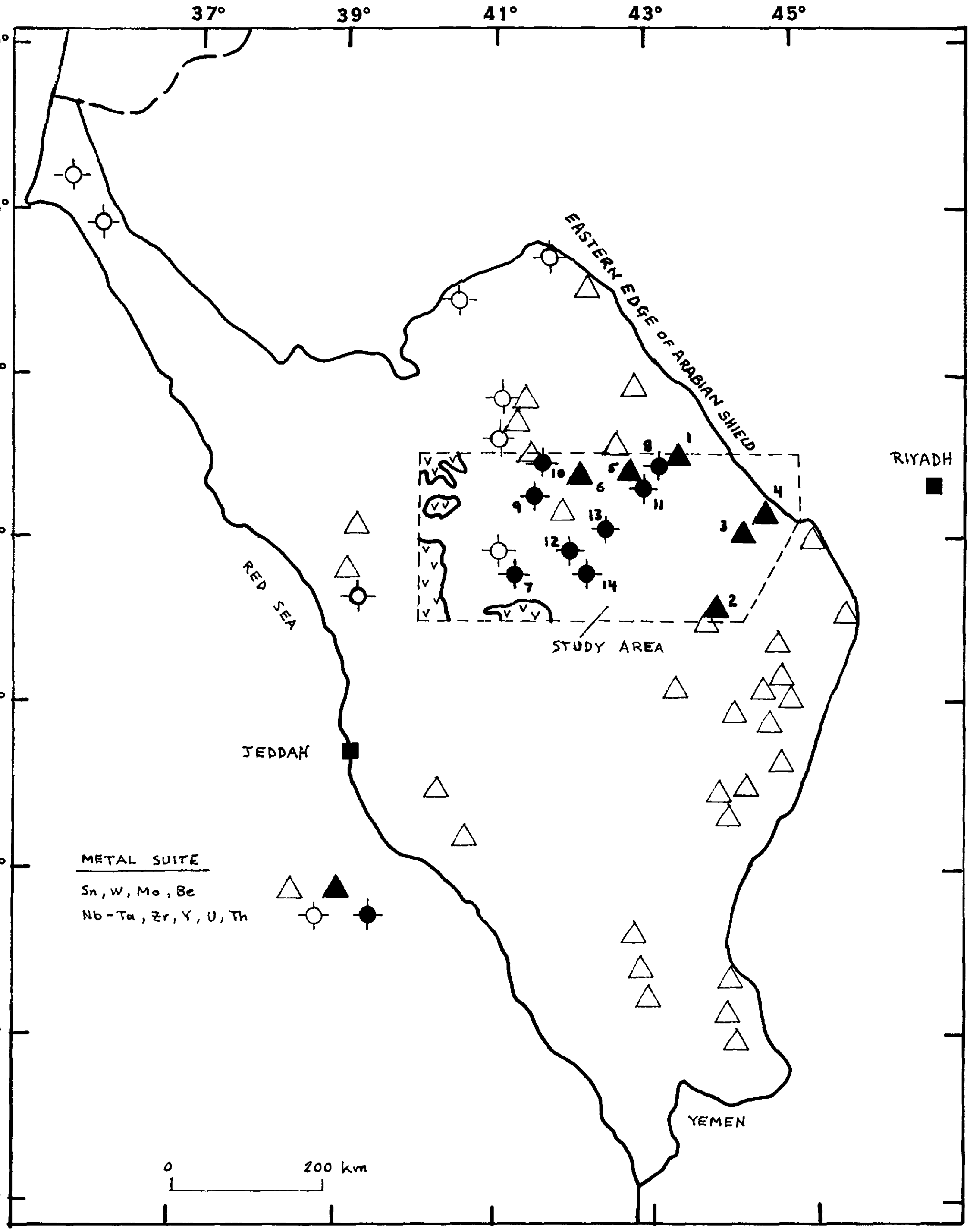

Figure 10.--Map showing Shieldwide mineral occurrences and prospects (open symbols) associated with postorogenic granites, and geochemically anomalous plutons (filled symbols) in the north-central Shield identified in the present study. Pluton location numbers from figure 2. Adapted from Elliott (1983).

APPENDIX

SOURCE GEOLOGIC MAPS USED IN COMPILING FIGURE 2

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