DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Results of a geochemical survey, Wadi Ash Shu'Bah Quadrangle, Sheet 26E, Kingdom of Saudi Arabia

by

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Open-File Report 89-337

Report prepared by the U.S. Geological Survey in cooperation with the Deputy Ministry for Mineral Resources, Saudi Arabia

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

1/ U.S. Geological Survey, Denver, CO

1989

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RESULTS OF A GEOCHEMICAL SURVEY, WADI ASH SHU'BAH QUADRANGLE, SHEET 26E, KINGDOM OF SAUDI ARABIA

BY

WILLIAM R. MILLER AND MARK A. ARNOLD

ABSTRACT

The interpretation of geochemical data of a regional survey of the Wadi ash Shu'bah quadrangle resulted in the selection of areas for follow-up studies. The results of the detailed geochemical studies of these areas, combined with field observation, resulted in the identification of areas of moderate and high mineral resource potential. The most important areas are (1) the Jibal Ba'gham area for tin and tungsten resources associated with the post-Hadn Jufayfah syenogranite; (2) the Murran gossan belt, Aqab gossan area, and Rawdah gossan area for massive-sulfide mineralization associated with Hulayfah-group greenstones; (3) the Rawdat al Ba'ayith area and Jibal Abid area for precious- and base-metal mineralization associated with pre-Hadn intermediate-composition plutons; and (4) the Wadi al Qahad area for skarn and precious- and base-metal mineralization associated with pre-Hadn granodiorite.

The Wadi ash Shu'bah quadrangle (sheet 26E) lies in the north-central part of the late Proterozoic Arabian Shield. Plots showing distributions of single elements and factor scores of the regional geochemical data of wadi concentrates were used to identify areas for follow-up work. Detailed follow-up studies consisted of collection of rocks, wadi concentrates, and wadi sediments. The most useful pathfinder elements for precious- and base-metal mineralization are Pb and Cu for tin and Sn, La, Y, Nb, and Be for tungsten mineralization. R-mode factor analyses of the regional wadi-concentrate data resulted in one factor interpreted as reflecting post-Hadn evolved alkalic-granite lithology and, therefore, tin and tungsten mineralization.

A major problem in the interpretation of the regional data resulted from the incomplete removal of magnetite before analyses. The magnetite can cause anomalous values for Ni, Fe, V, Cu, and Co because of it's ability to incorporate these elements into it's structure during magmatic crystallization. It is essential that samples be prepared and analyzed in a consistant manner so that the resulting data may be as reliable as possible.

INTRODUCTION

GEOGRAPHIC SETTING

The Wadi ash Shu'bah quadrangle (sheet 26E) occupies approximately 16,500 km^2 between lat 26°00' and 27°00' N. and long 40°30' and 42°00' E. in the north-central part of the Arabian Shield (fig. 1). Ha'il, the nearest city with a commercial airport, is located about 60 km north of the quadrangle. Access to the study area is by a paved highway that runs from Al Madinah through the center of the quadrangle to Ha'il. From this highway, secondary paved roads, dirt roads, and desert trails provide access to most areas.

The topography of the study area is characterized by relatively flat peneplains with isolated inselbergs and groups of inselbergs. These peneplanes have an average elevation of 800-900 m and are exstensively covered with thin deposits of grus, aluvium, and eolian material. Jibal Rumman al Humr, located in the northeastern part of the quadrangle, occupies the highest point in the quadrangle with an elevation of about 1,350 m.

Drainages in most of the quadrangle are generally poorly developed and most are partially filled with eolian sand. Drainages associated with prominent mountains are better developed and contain less eolian material. The main drainages in the quadrangle are Wadi ash Shu'bah, which drains from the north-central part of the area to the southeast, and Wadi al Qahad, which drains from the western part of the quadrangle to the southeast. These main drainages supply Wadi ar Rumah, which begins in the southwestern corner of the quadrangle and drains along the southern border of the area to the east. With the exception of the northeastern corner of the quadrangle, which drains northwest toward the Great Nafud by a system of small wadis, all drainages belong to the Wadi ar Rumah drainage basin.

The area has an average annual rainfall of 100 mm (Whitney, 1983), which supports sparse desert-shrub vegetation. The population of the area is sparse, concentrated primarily in small villages and scattered bedouin encampments.

KNOWN MINERAL OCCURRENCES

Quick and Doebrich (1984) briefly discuss the known mineral occurrences for the Wadi ash Shu'bah quadrangle. These occurrences consist of base and precious metals, fluorite, thorium, rare earths, magnesite, and gossans. Many of these locations, particularly the gold occurrences, are associated with ancient workings. Richter and others (1984) describe similar ancient workings in the adjoining Jibal Habashi quadrangle (sheet 26F) and date the last period of mining activity between A.D. 700 and A.D. 800. The locations of these known mineral-occurrence locations are stored in the Mineral Occurrence Documentation System (MODS) and are obtainable through the Office of the Technical Advisor, Saudi Arabian Deputy Ministry for Mineral Resources, Jiddah.

PREVIOUS INVESTIGATIONS

A 1:500,000-scale geologic map of the Northeastern Hijaz quadrangle by Brown and others (1963) includes the Wadi ash Shu'bah quadrangle. More recent geologic mapping by the U.S. Geological Survey has produced six 1:100,000-scale geologic

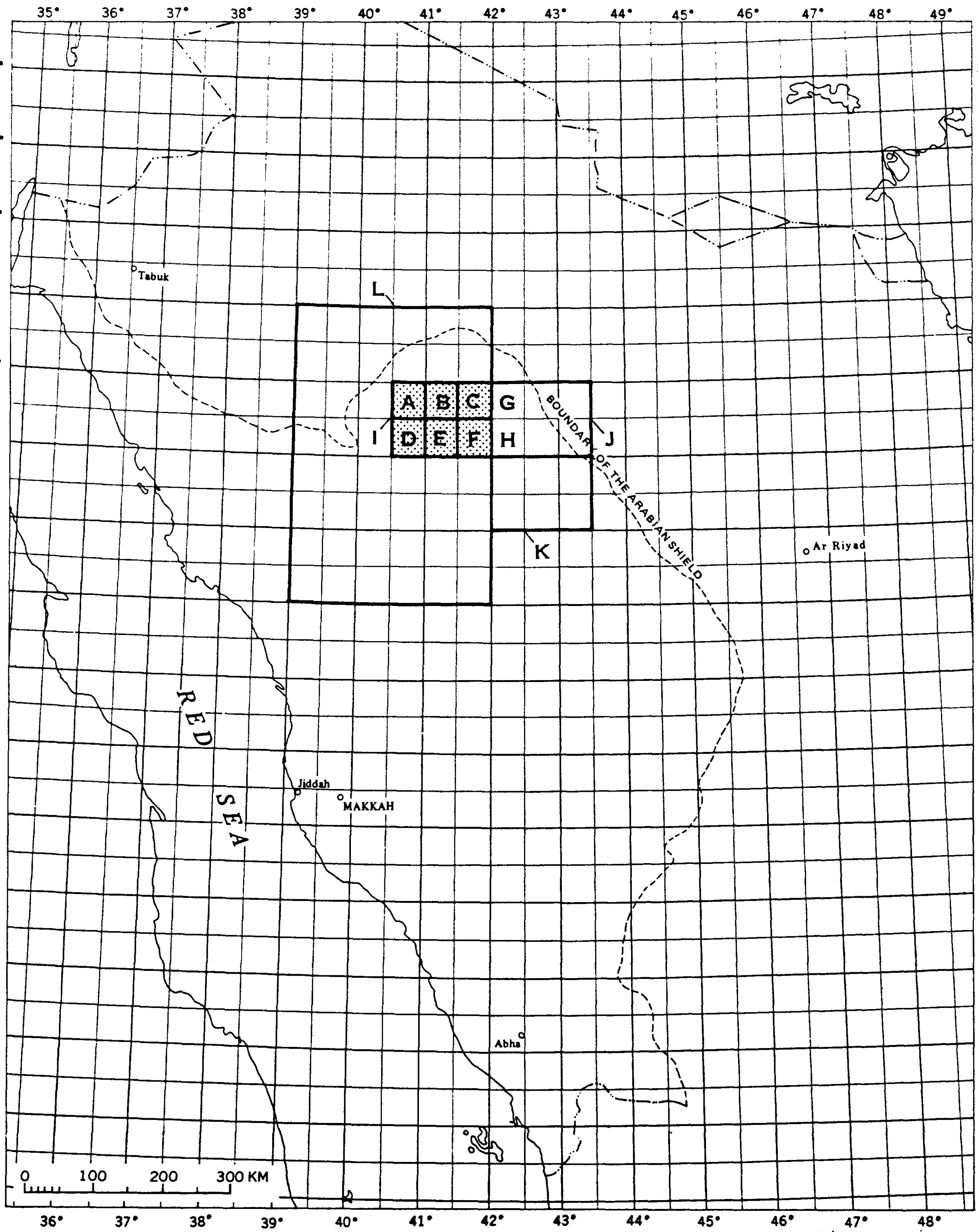


Figure 1.--Index map of western Saudi Arabia showing location of the Wadi ash Shu'bah quadrangle (stippled) and quadrangles referred to in the text; A. Zarghat 26/40B (Quick, 1984a); B. Ghazzalah 26/41 H (Quick, 1983); C. Al Awshaziyah 26/41 B (Leo, 1984); D. Ar Rawdh 26/40 D (O'Neill and Ferris, 1985); E. As Sulaymi 26/41 C (Quick, 1984b); F. Al Ba'ayith 26/41 D (Williams and Simonds, 1985); G. Harrat Hutaymah 26/42 H (Pallister, 1984); H. Samirah 26/42 B (Williams, 1983); I. Wadi ash Shu'bah 26E (Quick and Doebrich, 1984); J. Jabal Habashi 26F (Richter and others, 1984; Allen ad others, 1984); K. Aban al Ahmar 25F (Cole, 1986); L. Northeastern Hijaz (Brown and others, 1963).

maps covering the Wad ash Shu'bah quadrangle. The six quadrangles are the Zarghat, sheet 26/40B (Quick, 1984a), Ar Rawdh, sheet 26/40D (O'Neill and Ferris, 1985), Ghazzalah, sheet 26/41A (Quick, 1983), Al 'Awshaziyah, sheet 26/41B (Leo, 1984), As Sulaymi, sheet 26/41C (Quick, 1984b), and Al Ba'ayith, sheet 26/41D (Williams and Simonds, 1985). A 1:250,000-scale geologic map of the Wadi ash Shu'bah quadrangle has been compiled by Quick and Doebrich (1984).

PRESENT INVESTIGATIONS

The purpose of the investigation was (1) to interpret the regional wadi-concentrate geochemical, data and to select anomalous areas based on the regional geochemical data, and (2) to conduct detailed follow-up geologic and geochemical studies in order to determine the source and economic significance of the geochemical anomalies.

The interpretation of the pre-existing regional geochemical data consisted of producing plots of selected elements, and a discussion of their significance, and an R-mode factor analysis of the data with plots of factor scores and a discussion of their signifcance. Follow-up studies were conducted during 1984 and consisted of visiting anomalous areas identified by the interpretation of the regional geochemical data, examining the rocks, and collecting rock and wadi-sediment samples for later laboratory study for the purpose of evaluation of the mineral resource potential of these areas.

This report will follow the recommendations of Goudarzi (1984) for defining levels of mineral resource potential. Mineral resource potential is defined as the likelihood of the presence of mineral resources in a defined area; it is not a measure of the amount of resources or their profitability. Low mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate an environment where the existence of resources is unlikely. Moderate mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence. High mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resources. In this study, only geochemical and, to a lesser extent, geologic data have been considered.

ACKNOWLEDGMENTS

The authors would like to thank J. E. Quick and J. L. Doebrich of the USGS for their help in understanding the geology of the Wadi ash Shu'bah quadrangle and the northern Arabian Shield. G. L. Selner was helpful with computer manipulation and plotting of the regional geochemical data. R. M. Samater, R. T. Tucker, and J. L. Doebrich provided assistance in collection of rock and wadi-sediment samples. The wadi sediments were panned in the field by Ali Muhammen Jaberti. The heavy-liquid and magnetic separations performed on the panned concentrates were done by members of the USGS Mineralogical Laboratory in Jiddah under the direction of C. R. Thornber. Emission spectrographic and atomic-absorption spectrometric analyses of rocks, wadi sediments, and wadi concentrates were preformed in Jiddah at the DGMR-USGS Chemical Laboratory under the direction of K. J. Curry and in Denver, Colorado at the USGS laboratory by R. T. Hopkins and J. B. McHugh. Discussions of the general geology with D. B. Stoeser, E. A. du Bray, and J. C. Cole, and technical review of this manuscript by J. L. Doebrich are appreciated.

The work on which this report is based was done in accordance with a work agreement between the USGS and the Saudi Arabian Ministry of Petroleum and Mineral Resources, under project 5.21.03.

GEOLOGIC SETTING

The Wadi ash Shu'bah quadrangle, located in the northern Arabian Shield, is a large cratonic area consisting of a wide compositional range of intrusive rocks and several sequences of volcanosedimentary rocks that formed in a magmatic-arc setting from about 738 to 520 Ma (Stoeser and Camp, 1985; Williams and Simonds, 1985; Quick and Doebrich, 1984). The four principal crust-forming episodes are (1) greenstone and quartz diorite and diorite at or prior to 738 Ma (Quick and Doebrich, 1984); (2) granodiorite, tonalite, and monzogranite at about 738 to 635 Ma and volcanosedimentary rocks at about 677 to 600 Ma (Quick and Doebrich, 1984; Williams and Simonds, 1985); (3) volcanic rocks, alkalic granites, and granitoids at about 640 to 580 Ma (Quick and Doebrich, 1984); and (4) gabbro and diabase intrusions and marine sediments interlayered with alkalic basalts at about 520 Ma (O'Neill and Ferris, 1985; Quick and Doebrich, 1984).

Magmatic activity ceased abruptly at about 575 Ma, followed by extensive marine sedimentation over the Arabian Peninsula during the Paleozoic and Mesozoic eras (Williams and Simonds, 1985). Red Sea rifting during early Cenozoic times formed the Ha'il arch in the northern Shield and resulted in the erosion of all but a small part of the post-Proterozoic sediments from the Wadi ash Shu'bah quadrangle (Greenwood, 1973; Williams and Simonds, 1985).

This section briefly describes the geology of the Wadi ash Shu'bah quadrangle and has been generalized and condensed primarily from the 1:250,000-scale geologic compilation by Quick and Doebrich (1984).

HULAYFAH GROUP

The Hulayfah group (fig. 2) consists of greenstones with interbedded silicic-volcanic and associated sedimentary rocks. These are the oldest volcanosedimentary rocks in the Wadi ash Shu'bah quadrangle, dated at about 738 Ma (Quick and Doebrich, 1984).

The greenstones commonly consist of basaltic to andesitic flows and flow breccias with occasional pillow structures. The greenstones are metamorphosed to lower- and middle-greenschist facies. Where proximal to monzogranite and granodiorite intrusions, the greenstones have been metamorphosed to epidote-amphibolite facies (Quick and Doebrich, 1984).

The sedimentary and silicic volcanic rocks of the Hulayfah group are comprised of fine- to coarse-grained greywackes, with interbedded silicic volcanic flows and tuffs ranging in composition from dacite to rhyolite (Quick and Doebrich, 1984).

PRE-HADN INTRUSIVE ROCKS

The pre-Hadn intrusive rocks (fig. 2) consist of six units that range from ultramafic to felsic composition. The oldest unit is composed of ultramafic rock that may predate the Hulayfah group. The monzogranites are younger and clearly post-date the Hulayfah group (Quick and Doebrich, 1984).

The ultramafic rocks are exposed as small outcrops that have been altered to listwaenite and serpentinite. These ultramafic rocks are present in the southeast corner of the quadrangle along the Raha fault (Williams and Simonds, 1985;

Quick and Doebrich, 1984). O'Neill and Ferris (1985) report the presence of similar rocks in the southwestern part of the quadrangle.

Quartz diorite and diorite are in close proximity to the Hulayfah-group greenstones. Quick and Doebrich (1984) suggest that their similarity in appearance and mineralogy to the greenstone indicates that they are the plutonic equivalent of the greenstone. Clasts of quartz diorite and diorite are found in the basal conglomerates of the Hadn and Zarghat formations (Quick and Doebrich, 1984).

Granodiorite and tonalite are found primarily in the south-central part of the quadrangle. This group of rocks is younger than the Hulayfah group and older than the Hadn and Zarghat formations. Locally, diabase and metabasalt xenoliths are present within the granodiorite and tonalite (Quick and Doebrich, 1984).

Quartz monzodiorite is present in the southeast corner of the quadrangle on both sides of Wadi ash Shu'bah. The unit has been eroded to a flat surface and is generally covered with grus and wind-blown sand (Quick and Doebrich, 1984). The quartz monzodiorite is an extension of a large pluton in the adjacent Samirah quadrangle (sheet 26/42C) located to the east. Williams (1983) reports that this large pluton is unconformably overlain by the Hibshi formation and is dated about 646 Ma.

Large areas of poorly exposed gneissic to schistose granodiorite are present in the southeastern part of the quadrangle. Quick and Doebrich (1984) have interpreted these rocks as the deformed equivalents of the granodiorite, tonalite, and quartz monzodiorite and they are considered to be younger than the Hulayfah group. The degree of deformation exhibited in these rocks is probably an expression of their erosion to a deeper level (Quick and Doebrich, 1984).

Monzogranite is present in much of the quadrangle, both as a large batholith in the east and as smaller isolated plutons in the south and west (Quick and Doebrich, 1984). Pallister (1984) mapped the monzogranite as the Kilab monzogranite in the Harrat Hutaymah quadrangle (sheet 26/42 A), located to the east of the Wadi ash Shu'bah quadrangle. Quick and Doebrich (1984) suggest that many of the monzogranite and granodiorite bodies are different facies of one suite of pre-Hadn felsic plutonic rocks. The monzogranites are younger than the Hulayfah group and older than the Hadn formation. In the southwest corner of the quadrangle, O'Neill and Ferris (1985) mapped quartz pegmatites associated with quartz veins intruding the Hulayfah group. On the basis of similarities to the pegmatites found to be associated with monzogranite elsewhere in the quadrangle, Quick and Doebrich (1984) relate the pegmatites to the pre-Hadn monzogranite.

MARAGHAN, HIBSHI, JURDHAWIYAH, AND HADN FORMATIONS

The Maraghan formation (fig. 2), the oldest of the four formations, is present in the southeast corner of the quadrangle and consists of calcareous sandstones, siltstones, and shales. The Maraghan formation is contiguous with the Murdama-group rocks mapped by Williams (1983) in the Samirah quadrangle (sheet 26/42C) and Cole (1984) in the Aban al Ahmar quadrangle (sheet 25F).

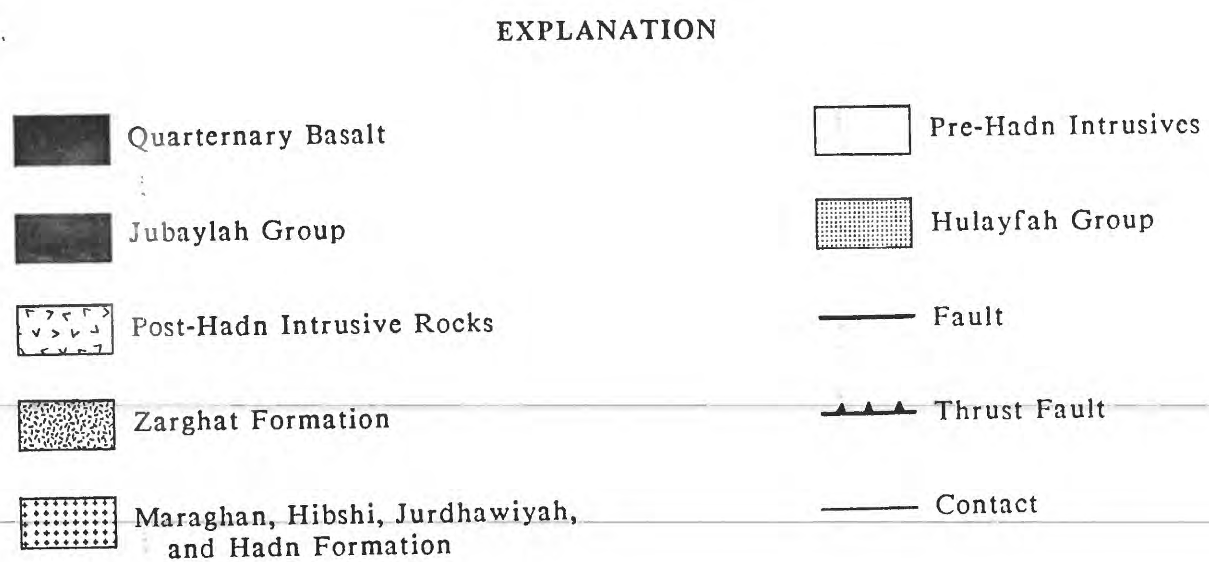
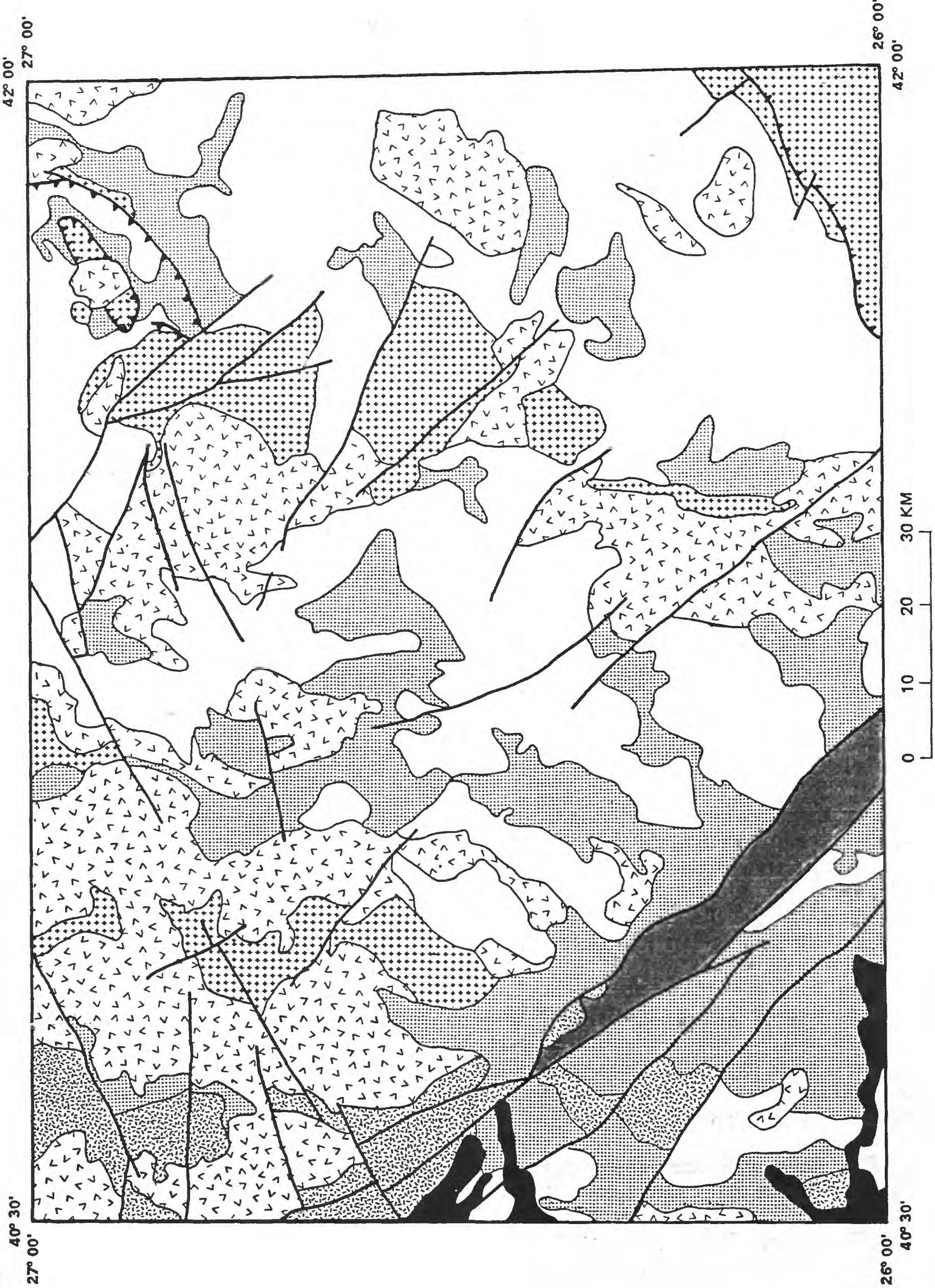


Figure 2.--Generalized geologic map of the Wadi ash Shu'bah quadrangle. Modified from Quick and Doebrich (1984).

B



The Hibshi, Jurdhiyah, and Hadn formations are roughly coeval and represent different facies deposited in seperate basins (Quick and Doebrich, 1984). The Hibshi formation is a narrow band of sediments along the edge of the Raha fault (Williams and Simonds, 1985) in the southeast corner of the quadrangle. It is comprised of basal conglomerate, poorly consolidated sandstone, siltstone, and minor greenstone (Quick and Doebrich, 1984).

The Jurdhawiyah formation crops out in the southeast corner of the quadrangle and consists of allocthonous outcrops of conglomerate and sandstone. These rocks, along with rocks of the Maraghan formation, have been thrust northwest over the Hibshi formation by the Raha fault (Williams and Simonds, 1985).

The Hadn formation consists mostly of silicic volcanic rocks, predominantly rhyodacite to rhyolitic tuff with lesser amounts of rhyolitic and rhyodacitic flows (Quick and Doebrich, 1984). Conglomerate and arkosic sandstone have been mapped as a separate member within the Hadn formation. The conglomerate contains clasts of monzogranite, diorite, and silicic volcanic rocks (Quick and Doebrich, 1984).

POST-HADN INTRUSIVE ROCKS

The post-Hadn intrusive rocks (fig. 2) are divided into two groups. The first group pre-dates the Zarghat formation and the second group is younger than the Zarghat formation. Both groups range in composition from syenogranite to alkalic-feldspar granite (Quick and Doebrich, 1984).

The first group consists of the Ash Shu'bah syenogranite and the Ba'gham granite. The Ash Shu'bah syenogranite is located in the northwest corner of the quadrangle where it forms low pink to white hills and flat-lying, grus-covered plains. This syenogranite contains roof pendents of granodiorite and volcanic rocks, and is unconformably overlain by the Zarghat formation (Quick and Doebrich, 1984).

The Ba'gham granite is located in the north-central part of the quadrangle and forms rugged topography with steep hills and cliffs. These rocks are peralkaline in composition and exhibit gradational contacts with the Ash Shu'bah syenogranite. Quick and Doebrich (1984) suggest that these two units are comagmatic. The Ba'gham granite contains roof pendents of Hadn volcanic rocks and is present as clasts in the conglomerate of the Zarghat formation (Quick and Doebrich, 1984).

The second group consists of several intrusive complexes. The Jufayfah syenogranite in the north-central part of the quadrangle is an extension of a larger pluton in the Al Qsar quadrangle (sheet 27/41C). This syenogranite crops out as numerous tan granitic pinnacles and is younger than the Hadn formation (Quick and Doebrich, 1984).

The Raboud syenogranite intrudes the Kilab monzogranite along Wadi ash Shu'bah in the east-central part of the quadrangle. The syenogranite is eroded to a flat-lying surface and is poorly exposed, except for isolated inselbergs (Quick and Doebrich, 1984). Quick and Doebrich (1984) suggest a post-Hadn age based upon similarities with the other post-Hadn syenogranites.

Several small plutons of quartz syenite and quartz monzonite crop out in the southeastern corner of the quadrangle. On the basis to their fine-grained textures, Quick and Doebrich (1984) differentiate these rocks from the pre-Hadn monzogranites.

A biotite alkalic-feldspar granite is found mostly in the northwest part of the quadrangle. The rock is primarily a coarse-grained, one-feldspar granite; locally it is a two-feldspar granite that intrudes the Hulayfah group and the Hadn and Zarghat formations (Quick and Doebrich,1984).

An arfvedsonite-bearing alkalic granite crops out in the north-central and northwestern parts of the quadrangle. On the basis of mineralogic and textural similarities, Quick and Doebrich (1984) suggest that this unit may be related to the alkalic-feldspar granite that crops out in the northwest part of the quadrangle. This granite intrudes the Zarghat formation.

Two large plutons of alkalic granite, one at Jibal Rumman al Humr in the north-central area and one near As Sulaymi in the south-central region, are interpreted to be coeval, and possibly comagmatic, on the basis of petrographic similarities (Quick and Doebrich, 1984). Both underlie deeply dissected mountain ranges. Stuckless and others (1984) report a Rb-Sr date of 590 Ma from the Jibal Rumman al Humr pluton.

Outcrops of granophyre, felsic dikes, intrusive rhyolite, aplite, gabbro, and diabase are scattered throughout the quadrangle. These rocks are not shown on the generalized geologic map (fig. 2).

ZARGHAT FORMATION

The Zarghat formation (fig. 2) consists of interbedded volcanic and sedimentary rocks that lie unconformably upon the post-Hadn intrusive rocks and contain clasts of peralkaline granite (Quick and Doebrich, 1984).

The Zarghat formation has a basal conglomerate that is poorly sorted with pebble-to-boulder-sized clasts in a matrix of arkosic sandstone and tuffaceous material. The clasts are primarily volcanic rock that was probably derived from the Hadn formation (Quick and Doebrich, 1984). A basalt member is locally interbedded with the basal conglomerate and, in places, overlies the conglomerate. The maximum thickness of the conglomerate is about 100 m (Quick and Doebrich, 1984).

The bulk of the Zarghat formation has been mapped as undivided volcanic and sedimentary rocks. Most of these rocks consist of rhyodacite to dacite tuff, lapilli tuff, and agglomerate, all of which interbedded with volcanic wacke, arenite, breccia, and conglomerate (Quick and Doebrich, 1984).

JIBALAH GROUP

The Jibalah group (fig. 2) consists of marble, calcareous sandstone, shale, and conglomerate interlayered with alkalic basalt deposited in a northwest-trending graben in the southwest part of the quadrangle (O'Neill and Ferris, 1985). Delfour (1977) radiometricaly dated the Jibalah group at about 520 Ma. Quick and Doebrich (1984) note that Jibalah-group sedimentation post-dates all granitic intrusions in the quadrangle.

A small outcrop of Cambrian Siq sandstone was mapped along the northwest border of the quadrangle by Quick (1984a). The Siq sandstone is poorly sorted and contains crossbeds, channel deposits, and graded beds, indicating a fluvial environment (Quick and Doebrich, 1984).

QUATERNARY BASALTS AND SEDIMENTS

Cenozoic basalt flows (fig. 2) are present along the western boundary of the quadrangle. These flows extend eastward from the Harrat Ithnayn and Harrat Khaybar (Quick and Doebrich, 1984).

Much of the quadrangle is covered by terrace and pediment gravel, alluvium, and playa lake deposits.

MAJOR STRUCTURES

Major faulting in the quadrangle is dominated by northwest-trending faults of the Najd fault system. These faults have a complex history of strike-slip and dip-slip movement (Quick and Doebrich, 1984), and were active for an extended period of time. The Zarghat formation is offset left laterally by the Najd fault system.

A group of northeast-trending faults described by Quick (1983) as the Saqf fault system is located in the northwest and north-central parts of the quadrangle and is believed to represent structures conjugate to the Najd fault system (Quick and Doebrich, 1984). Williams and Simonds (1985) describe a southeast-dipping thrust fault in the southeast corner of the quadrangle, which is an extension of the Raha fault system in the Samirah quadrangle (sheet 26/42C) located to the east. Quick and Doebrich (1984) discuss a low-angle thrust and a set of high-angle imbricate thrusts located in the northeast corner of the quadrangle near Jibal Musamma. The low-angle fault is thought to be from a large gravity slide that placed rocks of the Hadn formation over Hulayfah-group rocks (Quick and Doebrich, 1984).

These structures are important because they may have served as conduits for hydrothermal fluids associated with the late-stage emplacement of plutonic rocks.

REGIONAL GEOCHEMICAL SURVEY

TECHNIQUES

A geochemical survey was carried out in the Wadi ash Shu'bah quadrangle by R. M. Samater during 1981 and 1982 as part of a regional geochemical survey of the northern Arabian Shield. The samples were sieved at minus-10 mesh to remove grains larger than 2 mm and then hand-panned to obtain a heavy-mineral concentrate. Magnetite was removed from the concentrate with a hand magnet. The remaining sample was then pulverized to less than 0.064 mm and analyzed by the DGMR-USGS chemical laboratory in Jiddah for 30 elements using a d.c.-arc emission spectrograph. The results of the analyses are reported within a framework made up of six steps per order of magnitude (1, 0.7, 0.5, 0.3, 0.2, 0.15, or multiples of 10 of these numbers) and represent approximate geometric midpoints of the concentration range. The precision was shown to be within one adjoining reporting interval on each side of the reported value 83 percent of the time, and within two adjoining intervals 96 percent of the time (Motooka and Grimes, 1976). The results of the chemical analyses for these samples were interpreted and used as preliminary information for the selection of areas for follow-up geochemical investigations.

The effectiveness of the geochemical survey is dependent on the presence of a mature drainage system and the consistent application of the sampling, preparation, and analytical techniques used. In the Wadi ash Shu'bah quadrangle, the drainage development is generally either immature or buried by eolian material. Some areas of the quadrangle, particularly those underlain by plutons of felsic-to-intermediate-composition that are deeply eroded to a flat surface with poorly developed drainages, were either not covered or not covered adequately by the geochemical survey and are untested as to mineralization.

The sample-preparation techniques were not always consistently applied. The collection and preparation of samples were carried out separately on each of the 1:100,000-scale quadrangles within the quadrangle. There is evidence that the magnetite in samples from two 1:100,000-scale quadrangles was not completely removed. Magnetite is an iron spinel that can incorporate into it's structure elements such as Sc, Cu, Co, and V during crystalization (Deer and others, 1967; Overstreet, 1978; Overstreet and Day, 1985). Plots of the distribution of Fe, Sc, Cu, Co, and V in panned concentrates are shown on figs. 3,[1/] 4, 5, 6, and 7. Most of the anomalous concentrations of these elements fall within quadrangles 26/41A and 26/41B, as do many of the Fe concentrations that were as high as 20 percent, indicating the presence of magnetite in the analysed fraction of samples collected from these two quadrangles. The effect on the results of the geochemical survey is to give elevated and spurious values for these elements in the two 1:100,000-scale quadrangles.

GENERATION OF THE MAPS

Computer-generated point-plot maps showing distribution of elements for the wadi concentrates were prepared using the computer programs within the USGS-STATPAC system (Vantrump and Miesch, 1977). Approximately 10 percent of the samples were classified as anomalous and were divided into four classes at approximately the 99, 97.5, 95, and 90th percentiles. An additional class was

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1/ Figures 3-16 are at the end of the section. See page 22.

added at the 75th percentile in order to show samples with elevated concentrations. This procedure has the advantage of approximately doubling the number of samples for each class.

RESULTS

The results of the chemical analyses for the 1,311 samples collected from the Wadi ash Shu'bah quadrangle is summarized in table 1. The pathfinder elements for base-metal mineralization include Cu, Pb, Mo, and Sn. The maximum values for Cu, Pb, and Mo are generally low, and the range or contrast between maximum and minimum values is generally small. Reasons for this are the dilution of wadi sediments by eolian material and the chemical leaching of shield rocks during the the long period of time that the shield was subjected to weathering. Plots showing the distributions of Cu, Pb, and Mo are shown on figures 5, 8, and 9.

Elements commonly associated with evolved granites include Be, La, Nb, Sn, and Y (table 1). The maximum concentrations and the contrast between maximum and minimum concentrations of these elements generally is greater than that of the base metals (table 1). This is probably caused by the presence of relatively young, evolved plutons exposed in the quadrangle and their active erosion.

Copper

All of the anomalous concentrations of copper (50-70 ppm) are found in the northern part of the quadrangle (fig. 5). Some of the anomalies are caused by incomplete removal of magnetite during sample preparation; as it was discussed earlier, magnetite can contain copper. Most of the highest concentrations are found in Hulayfah-group rocks, some from nearby iron-rich silicious gossans, which are described later. A few scattered low-level copper occurrences (20-30 ppm) are found in the southern part of the quadrangle. These sample sites are mostly located in wadis draining rocks of the Hulayfah group and may be related to massive-sulfide mineralization.

Lead

Anomalous concentrations of lead (50-150 ppm) are found mostly within the core of Jibal Rumman al Humr in the north-central part of the quadrangle and in the northwest corner of sheet 26/41A. Weak lead anomalies (30-50 ppm) are present in the northeast corner of the quadrangle, peripheral to Jibal Salma (fig. 8). These three areas are associated with post-orogenic alkalic granite to alkalic-feldspar granite. One anomalous concentration (70 ppm) is located in the southeastern part of the quadrangle south of the Rawdah gossan area.

Molybdenum

The range of molybdenum values is small (<5-20 ppm) and the maximum concentration is only 20 ppm, probably because the exposed rocks have been leached of much of their molybdenum, which is relatively mobile during chemical weathering. Generally larger concentrations of molybdenum would be expected because of the presence of evolved granites. The most anomalous concentrations (15-20ppm) are located in the northern half and in the southwest corner of the quadrangle (fig. 9), mainly associated with the evolved alkalic granites (fig. 9).

Table 1.--Summary of statistical information from 1311 wadi concentrates, Wadi ash Shu'bah quadrangle.

[Fe, Mg, Ca, and Ti are in percent, all others are in parts per million. Au, Ag, As, Bi, Cd, and Sb were not detected.]

Variable	Number of samples above detection limit	Minimum	Maximum	Geometric mean	Geometric deviation
Fe	1311	0.2	20	5.38	3.34
Mg	1311	.05	5.0	0.48	.560
Ca	1311	.07	10	1.09	1.15
Ti	1311	.07	>1.0	0.65	.303
Mn	1311	50	>5000	663	543
B	206	<10	50	13.5	6.99
Ba	1310	<50	1500	315	171
Be	932	<1.0	20	2.04	1.82
Co	955	<5	70	8.18	6.74
Cr	1309	<10	1500	368	159
Cu	718	<5	70	16.0	10.7
La	816	<20	>1000	59.1	87.4
Mo	486	<5	20	6.73	2.45
Nb	516	<20	500	55.2	56.8
Ni	1274	<5	100	15.1	11.9
Pb	526	<10	150	18.2	15.0
Sc	1014	<5	70	8.36	6.58
Sn	447	<10	300	24.9	37.6
Sr	695	<100	500	172	81.2
V	1311	10	500	76.6	44.7
W	1	<100	100	----	----
Y	1300	<10	1000	62.6	90.2
Zn	1	<1000	1000	----	----
Zr	1311	20	>1000	600	302

Tin

Anomalous concentrations of tin (150-300 ppm) are generally associated with the evolved granites located in the northern part of the quadrangle, primarily within sheets 26/41A and 26/41B (fig. 10). The threshold for anomalous concentrations of tin is much lower (150 ppm) than those used in the Jabal Habashi quadrangle (sheet 26F) and in the Aban al Ahmar quadrangle (sheet 25F), which were 500 ppm and 700 ppm, respectively (Allen and others, 1984; Miller and Arnold, 1986). There are fewer samples with detectable tin in the Wadi ash Shu'bah quadrangle than in the Jabal Habashi and Aban al Ahmar quadrangles. This probably is due to smaller amounts of highly evolved granitic rocks favorable for tin-type mineralization in the Wadi ash Shu'bah quadrangle.

Tin concentrations of 70-150 ppm are associated with the arfvedsonite alkalic-feldspar granite at Jibal Salma in the northeastern corner of the quadrangle (fig. 10). The Jibal Salma pluton has been described by Richter and others (1984) as having potential for tin greisen and tungsten-bearing quartz veins. Because only a small part of the pluton crops out in the quadrangle, the mineral resource potential will not be discussed further in this report.

Wadi-concentrate samples collected over the alkalic granite at Jibal Rumman al Humr (fig. 10) contained 50 ppm tin within the main core of the pluton, indicating moderate resource potential for tin and tungsten in deposits associated with the exposed pluton.

Wadi-concentrate samples collected over the arfvedsonite alkali-feldspar granite at Jibal Uahli located along the northwestern edge of the quadrangle (fig. 10) contained tin concentrations of 20-50 ppm, which are common in evolved alkalic granites in the northern Arabian Shield (Elliott, 1983; Richter and others, 1984).

Wadi samples collected over the peraluminous Ba'gham granite located along the northern edge of the quadrangle (fig. 10) contained tin concentrations of 30-50 ppm within the main pluton, indicating moderate resource potential for tin associated with the exposed pluton.

The highest tin concentrations in the quadrangle (300 ppm) are found in an irregular zone located to the east and south of the Ba'gham granite (fig. 10). These samples are from wadis draining the Hulayfah group and Hadn formation, as well as pre- and post-Hadn intrusive rocks. These same samples also contain anomalous concentrations of Mo and Nb, and significant concentrations of Pb, La, and Y. No greisenized rock or tin-bearing veins were encountered during the regional geologic mapping. One sample collected during the follow-up survey contained angular cassiterite, which indicates a nearby source.

Beryllium

Anomalous concentrations of beryllium (10-20 ppm) are associated with the alkalic granite at Jibal Rumman al Humr and the peralkaline Ba'gham granite located in the north-central part of the quadrangle (Fig. 11).

Lanthanum, Niobium, and Yttrium

Anomalous concentrations of lanthanum, niobium, and yttrium (figs. 12-14) are generally associated with the alkalic post-Hadn granites at Jibal Salma, Jibal Rumman al Humr, the Ba'gham granite, and the areas east and south of the Ba'gham granite discussed above in the section on tin. Weak lanthanum, niobium, and yttrium anomalies are associated with the Kilab monzogranite just north of a post-Hadn syenogranite located along the eastern edge of the quadrangle.

The pluton at As Sulaymi mapped as an alkalic granite is considered by Quick and Doebrich (1984) to be related to the alkalic granite at Jibal Rumman al Humr. Samples collected from wadis draining the As Sulaymi pluton do not contain anomalous concentrations of lanthanum, niobium, and yttrium, indicating the presence of less-evolved rocks; therefore, the geochemistry suggests that the pluton at As Sulaymi may be older and less-evolved then the alkalic granite at Jibal Rumman al Humr.

Tungsten and Zinc

One wadi-concentrate sample collected form the Kilab monzogranite in the northeast corner of the quadrangle contained detectable tungsten (100 ppm). The pluton has been eroded to a flat surface, exposing numerous felsic dikes. The anomalous tungsten is probably associated with one of the dikes and is considered to have low mineral resource potential.

One wadi-concentrate sample collected from volcanic rocks of the Hadn formation located along the east side of Jibal Rumman al Humr in the northeast corner of the quadrangle contained 1,000 ppm zinc. This sample was collected at a large wadi upstream from the village of Ar Ruwadah. The site was resampled during the follow-up survey, but contained no detectable zinc. The source of the zinc is not known but may be cultural contamination.

FACTOR ANALYSIS

Such an extensive amount of data is generated as a result of chemical analyses of the wadi concentrates that a multivariate numerical method was required to reduce the data to a limited number of groups that could be readily interpreted. The technique used is R-mode factor analysis, which is a mathematical technique that identifies natural groupings of elements within the data set. The method attempts to explain variation among a smaller number of relations or factors. End-member compositions (or factors) are calculated that approximately describe the variations within the multielement data. Each factor represents a geochemical control or process. Individual samples can then be described in terms of components of these end-member compositions. Once a factor has been interpreted as reflecting a certain process, each sample can then be evaluated with respect to this factor and the process it represents. The degree to which any given sample relates to each factor is called its factor score. The distribution of these factor scores, particularly for factors interpreted as reflecting geochemical processes related to mineralization, can in turn be plotted on maps and considered with respect to selecting areas for follow-up work.

Factor analysis demonstrates these factors but does not interpret them. The interpretation of these components and the geological significance of the resulting patterns (or plots) are subjective and depend upon the user's knowledge of the local geological and geochemical environments. Similar results based on interpretation of factor analysis can be obtained qualitatively from observation of single-element distributions, but at an investment of more time and without the quantitative estimates of the importance of each element in an association. Once a model is selected by factor analysis, it is helpful to use the single-element distributions to demonstrate the model. Background information on the use of factor analysis applied to geological studies can be found in Davis (1973).

R-MODE FACTOR ANALYSIS OF DATA FROM THE WADI ASD SHU'HAN QUADRANGLE

R-mode factor analysis of data from the Wadi ash Shu'bah quadrangle was carried out by computer using the USGS-STATPAC library system (Van Trump and Miesch, 1977). The basic algorithms for the program were developed following procedures from Rummel (1970). The program extracted principal components that were then rotated according to a varimax solution.

A 10-factor model was selected that accounts for 86 percent of the variation in the geochemical data. The factor loadings are shown on table 2. Factors 6 through 10 were mainly single-element factors and do not add to the interpretation beyond the single-element plots. Factor 2 is interpreted as reflecting evaporative concentration processes associated with playa lakes. Factor 3 is interpreted as reflecting the Zarghat formation. Factor 5 reflects lithologies of intermediate-composition rocks. These factors do not have a direct bearing on the interpretation of the mineral resource potential and, therefore, will not be discussed in this report. Factors 1 and 4 have a direct bearing on the interpretation and will be discussed.

Computer-generated point-plot maps showing the distributions of anomalous values for factor scores were prepared similarly to those of the single-element plots. Ten percent of the samples were classified as anomalous and were divided into four classes at the 99, 97.5, 95, and 90th percentiles. An additional class was added at the 75th percentile in order to show samples with elevated factor scores. This procedure has the advantage of approximately doubling the number of samples for each class.

Factor 1

Factor 1 accounts for 31 percent of the total variation and is represented by significant loadings for Pb, La, Nb, and Y, and less significant but high loadings for Be, Sn, and Mn (table 2). These elements are commonly associated with the younger more evolved alkalic post-Hadn granites (fig. 15). Occurrences of anomalous scores for factor 1 are associated with the alkalic granites at Jibal Rumman al Humr and with the peralkaline Ba'gham granite located in the north-central part of the quadrangle. These rocks are highly evolved granites and have moderate to high mineral resource potential for tin and tungsten. Weakly anomalous factor-1 scores occur in the northeastern corner of the quadrangle along the western side of Jibal Salma. Jibal Salma has been discussed by Allen and others, (1984) and Richter and others (1984) as having high resource potential for tin and tungsten.

Factor 4

Factor 4 accounts for 5 percent of the total variation and is represented by significant loadings for Sc, Cu, Co, V, and Fe (table 2). Factor 4 (fig. 16) is interpreted as reflecting incomplete removal of magnetite during sample preparation. Within the magnetite crystal structure, V and Sc can partially substitute for Fe^{3}, and Co can partially substitute for Fe^{2} during crystallization (Deer, and others, 1966; Wedepohl, 1969-1978). Magnetite can incorporate in it's structure or act as a scavenger for Cu (Overstreet, 1978; Overstreet and Day, 1985). Samples with anomalous iron concentrations of 10 percent or higher (fig. 3) were all collected in the two 1:100,000-scale quadrangles (26/41 A and 26/41 B) in the northeast. Iron concentrations of 10 percent or higher for the majority of the samples is higher for this type of sample than what is normally expected if the magnetite had been completely removed, further indicating the presence of magnetite. Samples containing anomalous Mo and Sn also generally fall within these two quadrangles (figs. 9, 10). Because the evidence is overwhelming that samples from these two 1:100,000-scale quadrangles have been contaminated by incomplete removal of magnetite, any interpretation of the data must take this into account.

Table 2.--Varimax loadings for a ten factor model, Wadi ash Shu'bah quadrangle.

[Significant loadings are underlined.]

	1	2	3	4	5	6	7	8	9	10
Fe	.48	.15	.16	.43	.55	-.04	.11	.02	.08	.13
Mg	-.06	.64	.57	.09	.12	-.04	-.11	-.20	.05	.16
Ca	-.11	.77	.20	.12	.28	-.03	-.11	-.23	.07	.10
Ti	.22	.10	.05	.16	.88	.00	-.07	.07	.10	.01
Mn	.51	.20	-.04	.38	.59	.02	.13	-.02	.03	-.06
B	.08	-.09	-.03	-.02	-.00	.99	.02	.05	.03	.00
Ba	-.02	.89	-.02	.01	.03	-.07	.11	.03	.04	-.12
Be	.71	-.09	-.01	-.11	-.14	.03	.08	.51	-.19	.02
Co	-.02	.35	.36	.72	.19	-.08	-.02	.04	.05	-.02
Cr	-.01	.14	.21	.07	.15	.06	.12	.03	.93	.04
Cu	.41	-.14	-.01	.74	.16	.05	.14	-.11	.16	.03
La	.82	-.17	-.11	.23	.15	.05	.05	.13	-.06	-.08
Mo	.24	-.07	.04	.08	.04	.04	.94	.05	.12	.06
Nb	.81	-.31	-.12	.17	.15	.05	.11	.04	.00	.11
Ni	-.12	.13	.91	.15	.05	.00	.05	-.01	.16	-.03
Pb	.88	.12	.07	.08	.09	.03	.02	-.08	.04	.11
Sc	.39	.14	-.01	.79	.16	.01	.00	-.01	-.07	.09
Sn	.60	-.19	-.05	.18	.10	.02	.15	.01	.11	.66
Sr	-.21	.84	.06	.18	.00	-.08	-.10	.02	.06	-.06
V	-.14	.35	.16	.50	.51	-.04	.08	.21	.12	.33
Y	.77	-.24	-.13	.26	.19	.06	.17	.24	.00	.06
Zr	.38	-.26	-.11	.04	.37	.11	.11	.64	.20	.04

There is moderate correlation of anomalous factor-4 scores with areas underlain by rocks of the Hulayfah group. These anomalous areas are located in the two 1:100,000-scale quadrangles (26/41A and 26/41B) containing samples with the magnetite contamination; therefore, strongly anomalous factor-4 scores probably reflect lithologies of the Hulayfah group effected by contamination due to incomplete removal of magnetite.

DISCUSSION AND SUMMARY

Areas were selected for follow-up work on the basis of the results of the regional geochemical study of wadi concentrates, plots showing the distribution of anomalous concentrations of selected elements, and factor scores. Areas with poorly developed drainages were not evaluated.

Three types of mineralization were revealed by the regional geochemical survey. The first type is base- and(or) precious-metal-bearing quartz veins associated with intrusion of pre-Hadn granodiorite bodies. These mineral occurrences are primarily associated with smaller granodiorite bodies, indicating that the mineralization is associated with the upper parts of these bodies where late-stage hydrothermal fluids would be expected to concentrate. This type of mineralization is discussed in Miller and Arnold (1987) and Cole (1986) for the Aban al Ahmar quadrangle (sheet 25F), located to the southeast of the study area. These occurrences are only weakly detectable by low to moderate values of Pb and Cu in wadi concentrates collected during the regional geochemical survey.

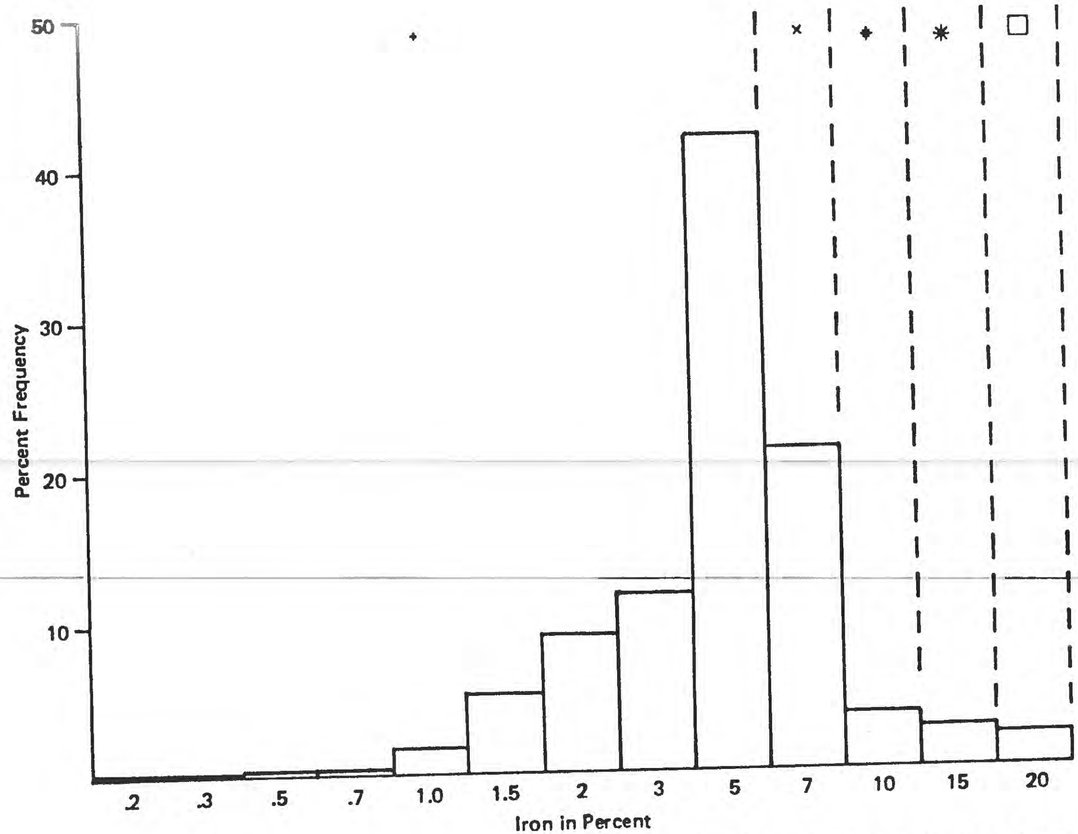
The second type of mineralization involves Sn and related base metals associated with the emplacement of alkalic plutons. This type of mineralization probably occurred during late-stage emplacement of these plutons. This second type of mineralization is reflected by anomalous concentrations of Sn, Be, and, to a lesser extent, Pb, in wadi concentrates. Anomalous factor-1 scores also reflect this type of mineralization. Many of these complexes have been deeply eroded and most of the significant mineralization has been eroded away. Consequently, the areas of highest resource potential for this type of mineralization are the surrounding country rocks where small satellite bodies of the main plutons may contain associated mineralization.

The third type of mineralization involves base and precious metals associated with submarine exhalative-type massive-sulfide mineralization within the Hulayfah group. Several areas of gossanous outcrops were located during the follow-up survey and are discussed later in the text. Massive-sulfide mineralization within the Saudi Arabian Shield has been described by Routhier and Delfour (1979), Jackaman (1972), Blain (1981), and Ryall and Taylor (1981). This type of occurrence is only weakly detectable by low concentrations of copper in the regional wadi-concentrate survey.

Conclusions based on the interpretation of the regional geochemical data regarding the techniques used for the regional geochemical survey of the Wadi ash Shu'bah quadrangle are as follows: (1) in order for a regional geochemical survey to be effective, all samples must be collected, prepared, and analysed in a consistant manner, and (2) to more effectively detect gold mineralization on a regional scale, a minus-80-mesh (<.18 mm) wadi-sediment sample should have been analyzed for gold with a detection limit of 1 ppb.

FIGURES
3-16

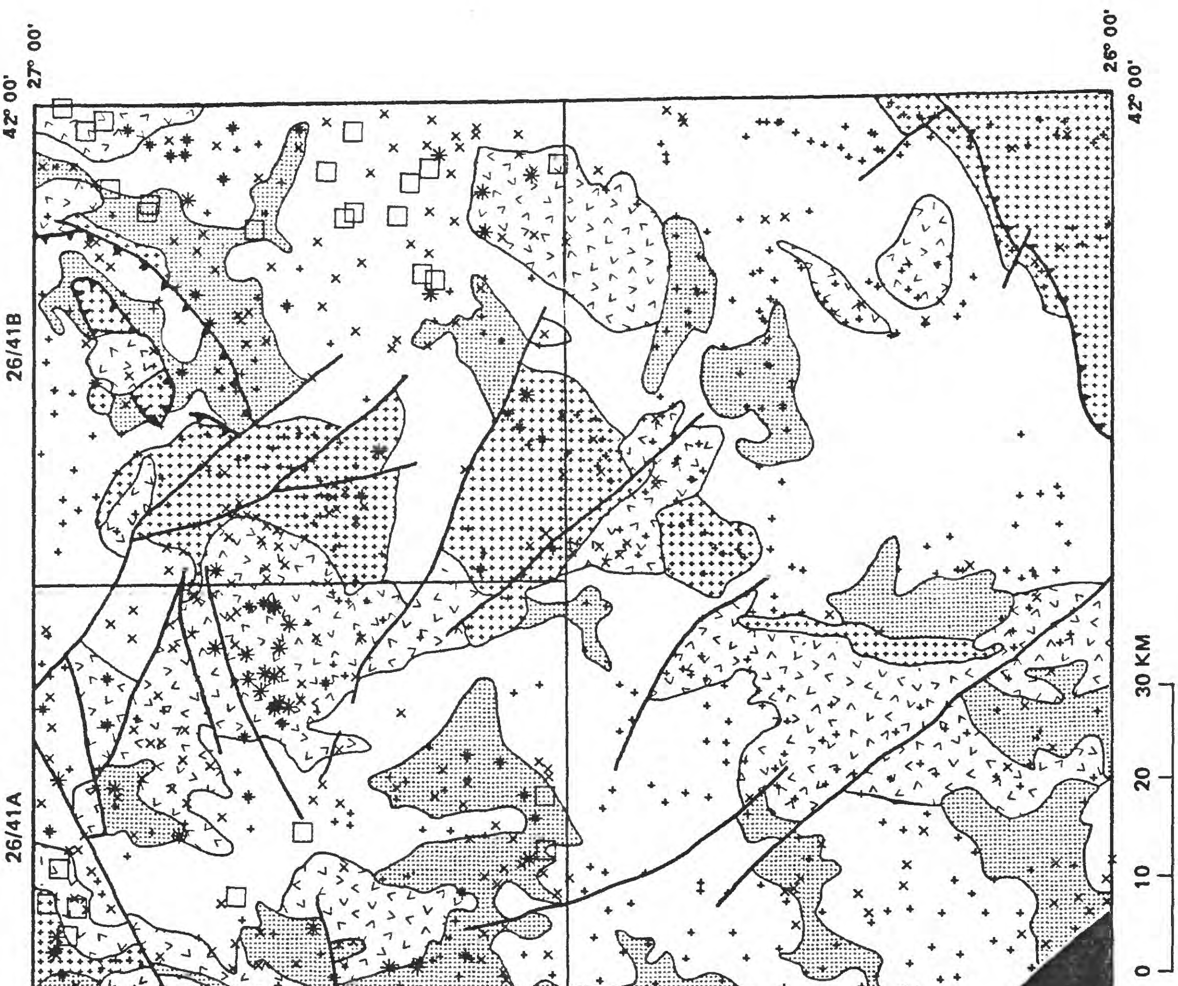
A



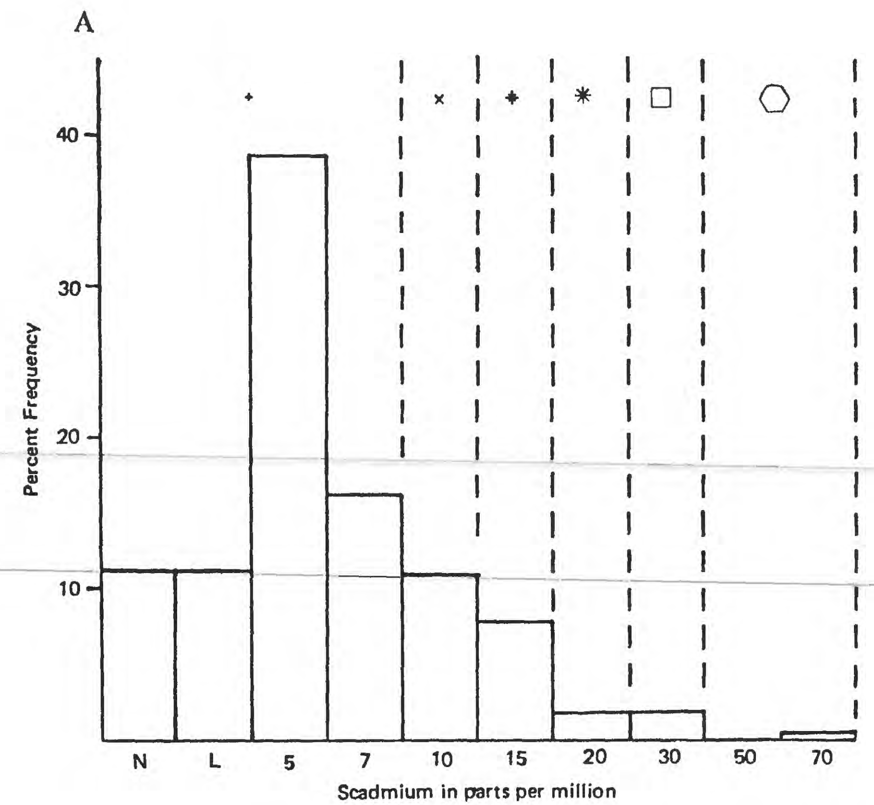
Note: Element-value symbols are shown in red on part B of this figure.

Figure 3.--Histogram (*A*) and distribution (*B*) of iron in wadi concentrates, Wadi ash Shu'bah quadrangle. Geologic map units same as figure 2.

B



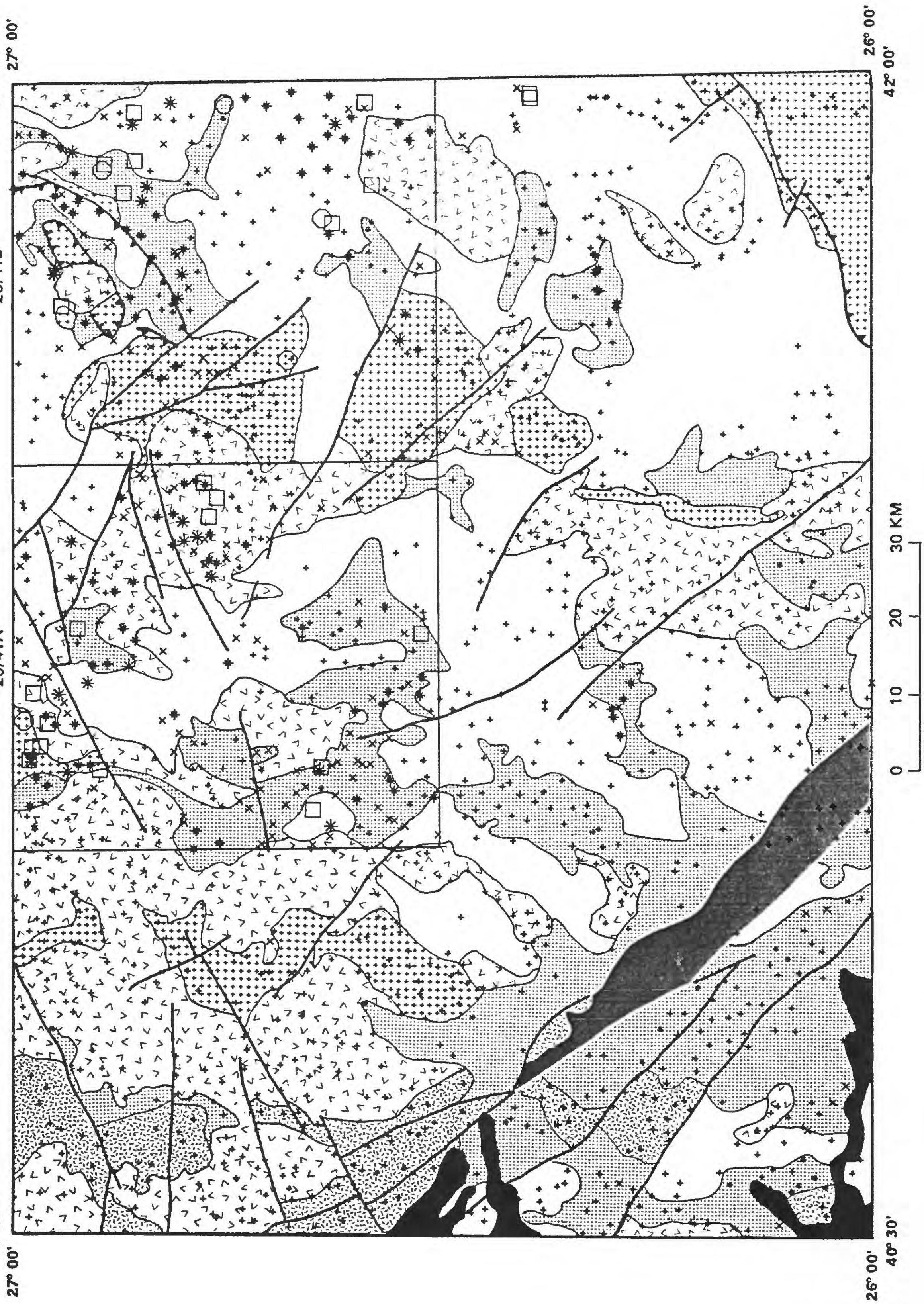
27° 00'
40° 30'
42° 00'
27° 00'
26/41B
26/41A
26° 00'
42° 00'
40° 30'
26° 00'
0
10
20
30 KM



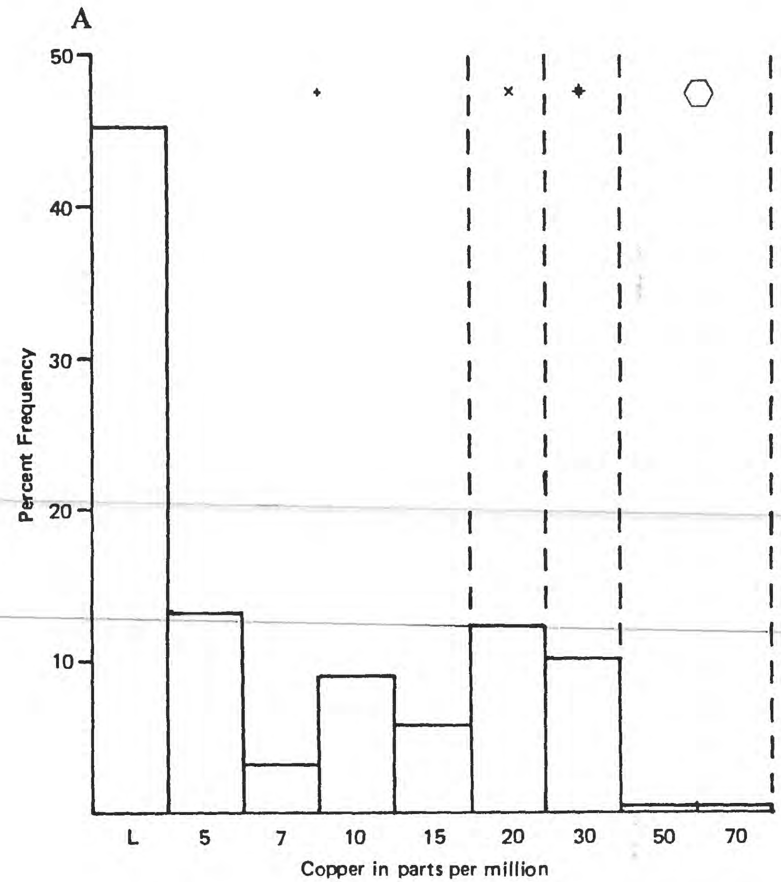
Note: Element-value symbols are shown in red on part B of this figure.

Figure 4.--Histogram (*A*) and distribution (*B*) of scadmium in wadi concentrates, Wadi ash Shu'bah quadrangle. Geologic map units same as figure 2.

B

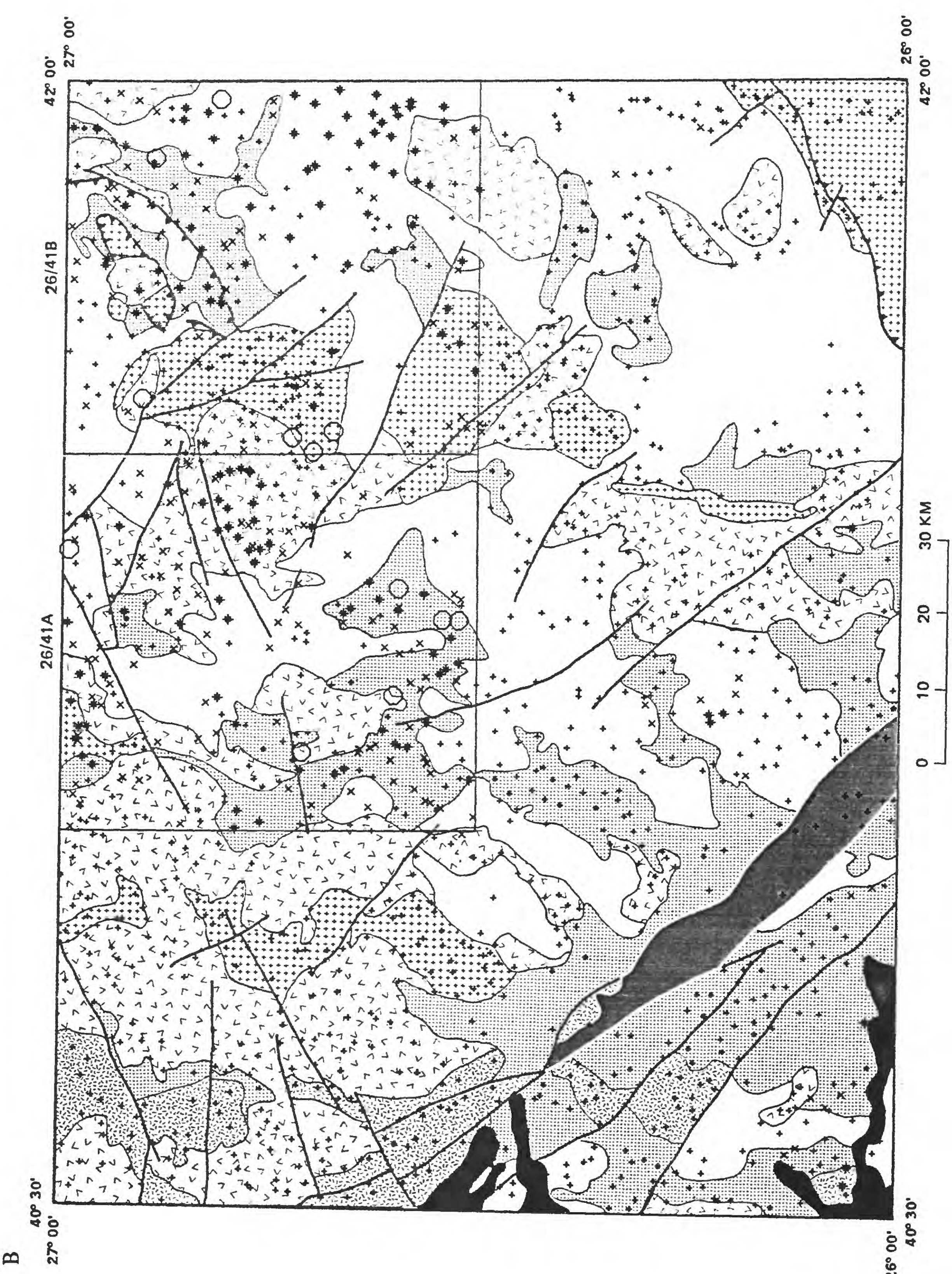


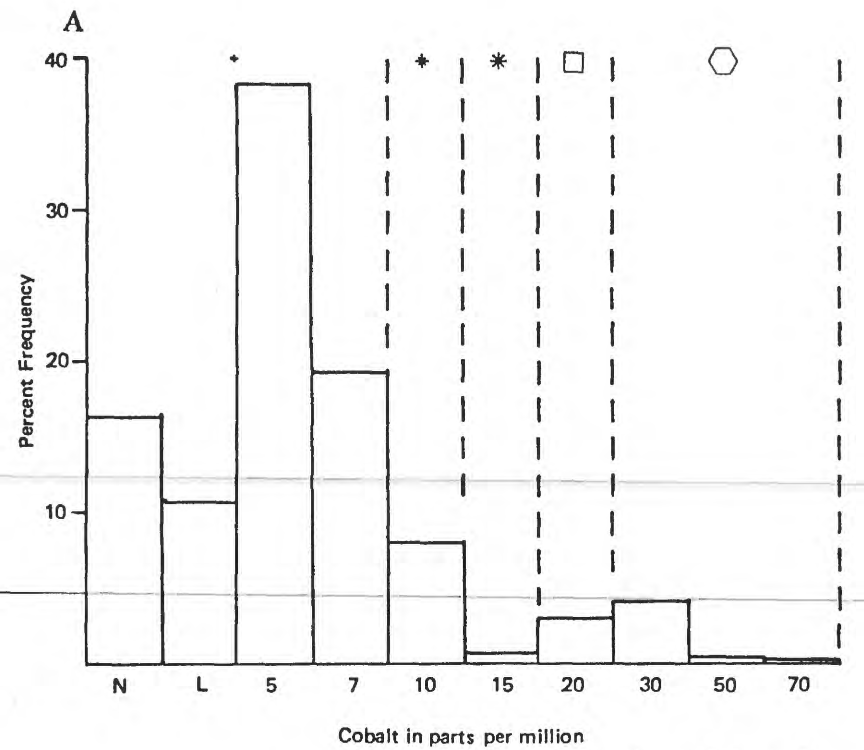
27° 00'
40° 30'
26/41A
26/41B
42° 00'
27° 00'
26° 00'
42° 00'
26° 00'
40° 30'
0
10
20
30 KM



Note: Element-value symbols are shown in red on part B of this figure.

Figure 5.--Histrogram (*A*) and distribution (*B*) of copper in wadi concentrates, Wadi ash Shu'bah quadrangle. Geologic map units same as figure 2.

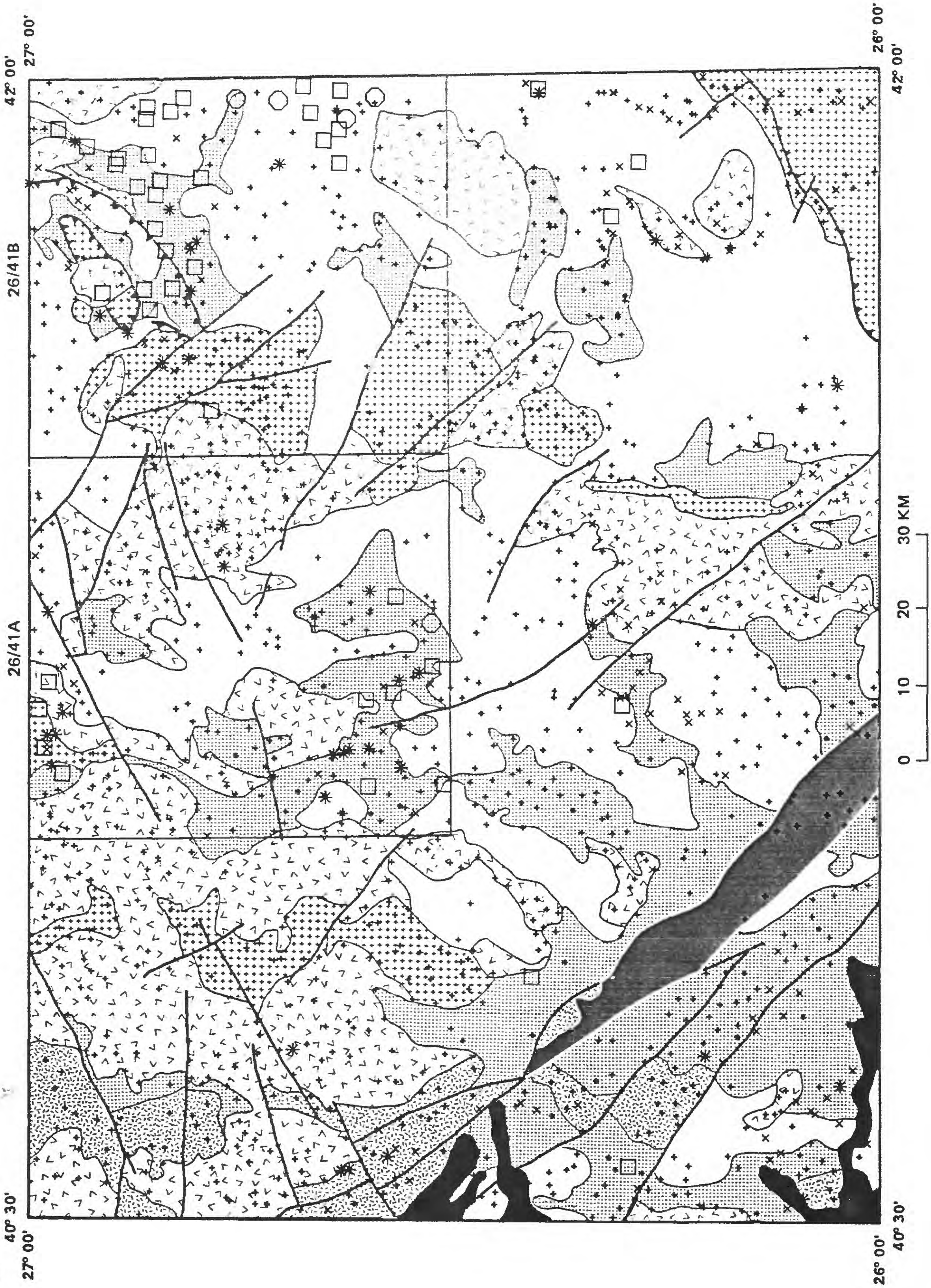

B
27° 00'
40° 30'
26/41A
26/41B
42° 00'
26° 00'
0
10
20
30 KM

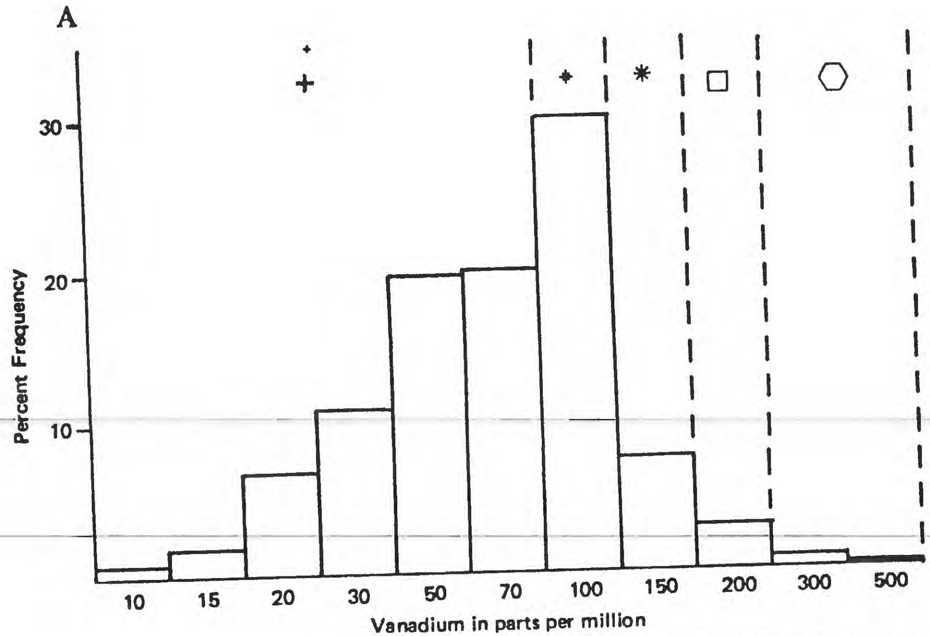


Note: Element-value symbols are shown in red on part B of this figure.

Figure 6.--Histogram (*A*) and distribution (*B*) of cobalt in wadi concentrates, Wadi ash Shu'bah quadrangle. Geologic map units same as figure 2.

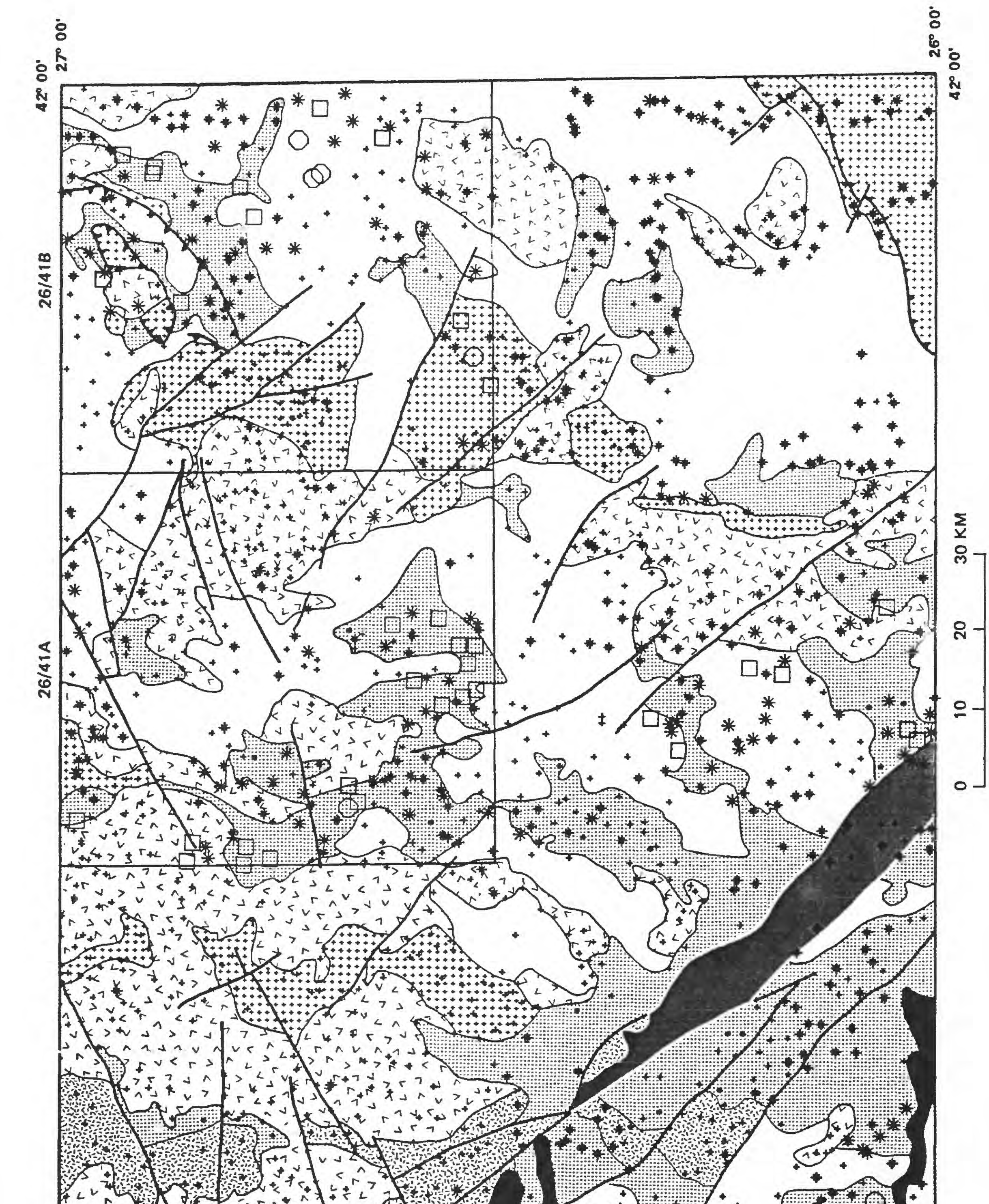
B


42° 00'
27° 00'
26/41B
26/41A
40° 30'
27° 00'
26° 00'
42° 00'
0
10
20
30 KM
26° 00'
40° 30'

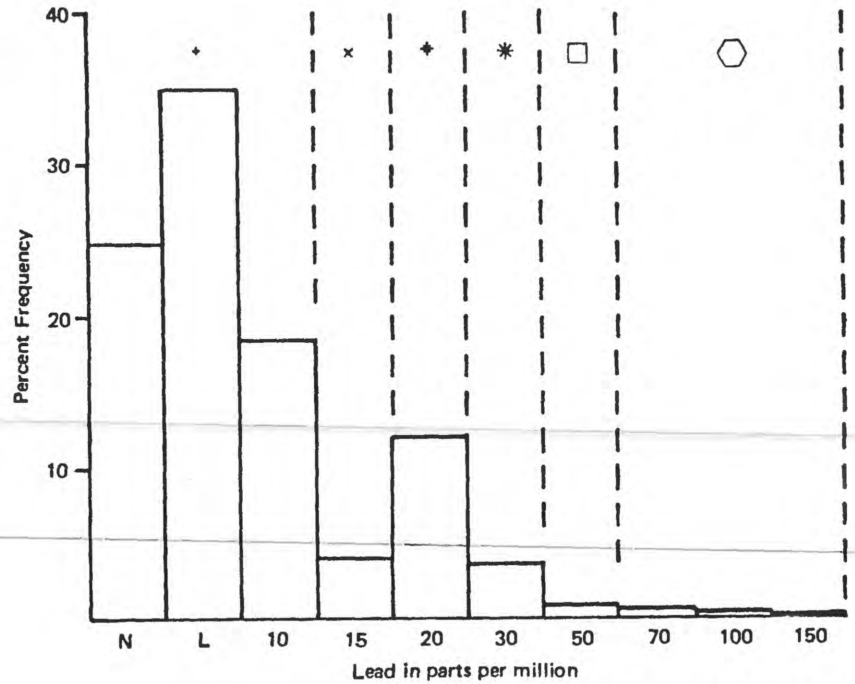


Note: Element-value symbols are shown in red on part B of this figure.

Figure 7.--Histogram (*A*) and distribution (*B*) of vanadium in wadi concentrates, Wadi ash Shu'bah quadrangle. Geologic map units same as figure 2.


B
27° 00'
40° 30'
26° 00'
40° 30'
27° 00'
42° 00'
26° 00'
42° 00'
26/41A
26/41B
0
10
20
30 KM

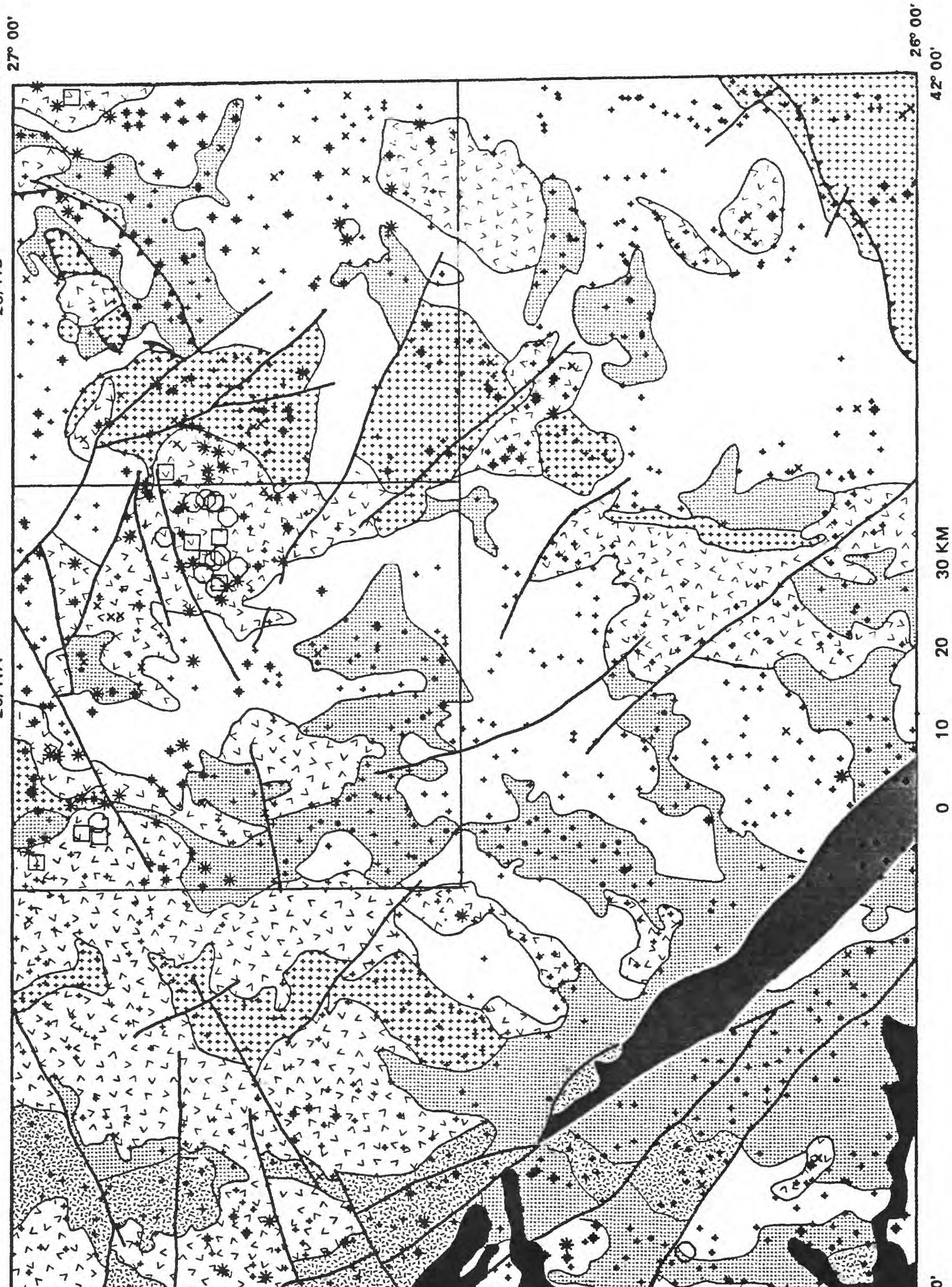
A



Note: Element-value symbols are shown in red on part B of this figure.

Figure 8.--Histogram (*A*) and distribution (*B*) of lead in wadi concentrates, Wadi ash Shu'bah quadrangle. Geologic map units same as figure 2.

B


42° 00'
27° 00'
26/41B
26/41A
40° 30'
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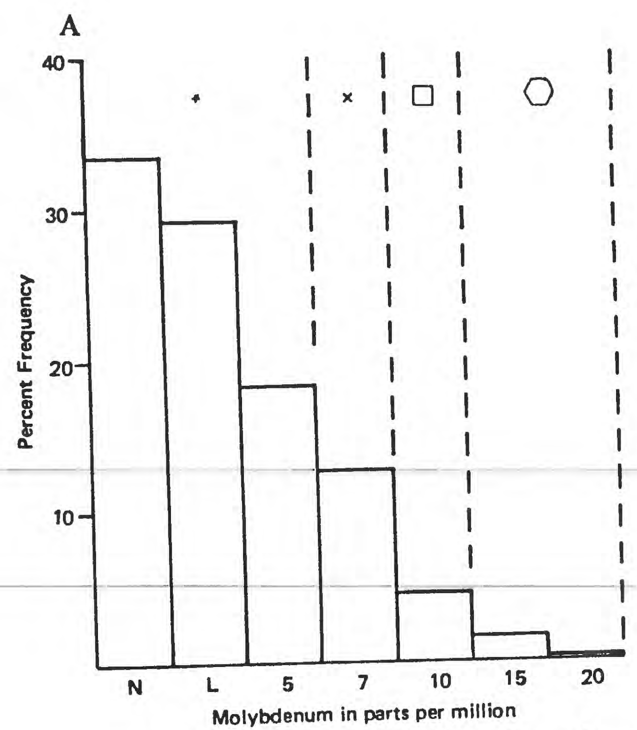
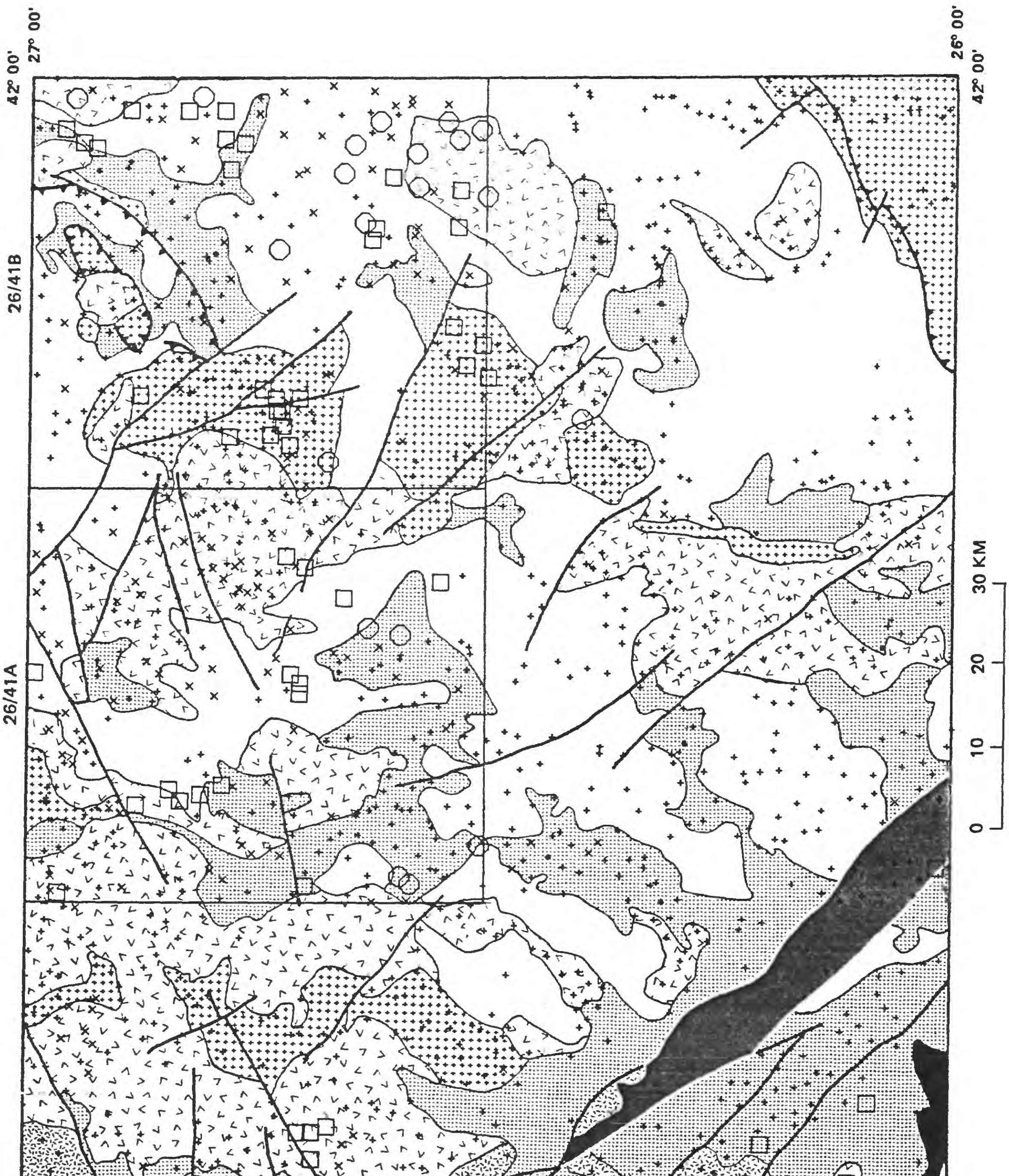


Note: Element-value symbols are shown in red on part B of this figure.

Figure 9.--Histogram (*A*) and distribution (*B*) of molybdenum in wadi concentrates, Wadi ash Shu'bah quadrangle. Geologic map units same as figure 2.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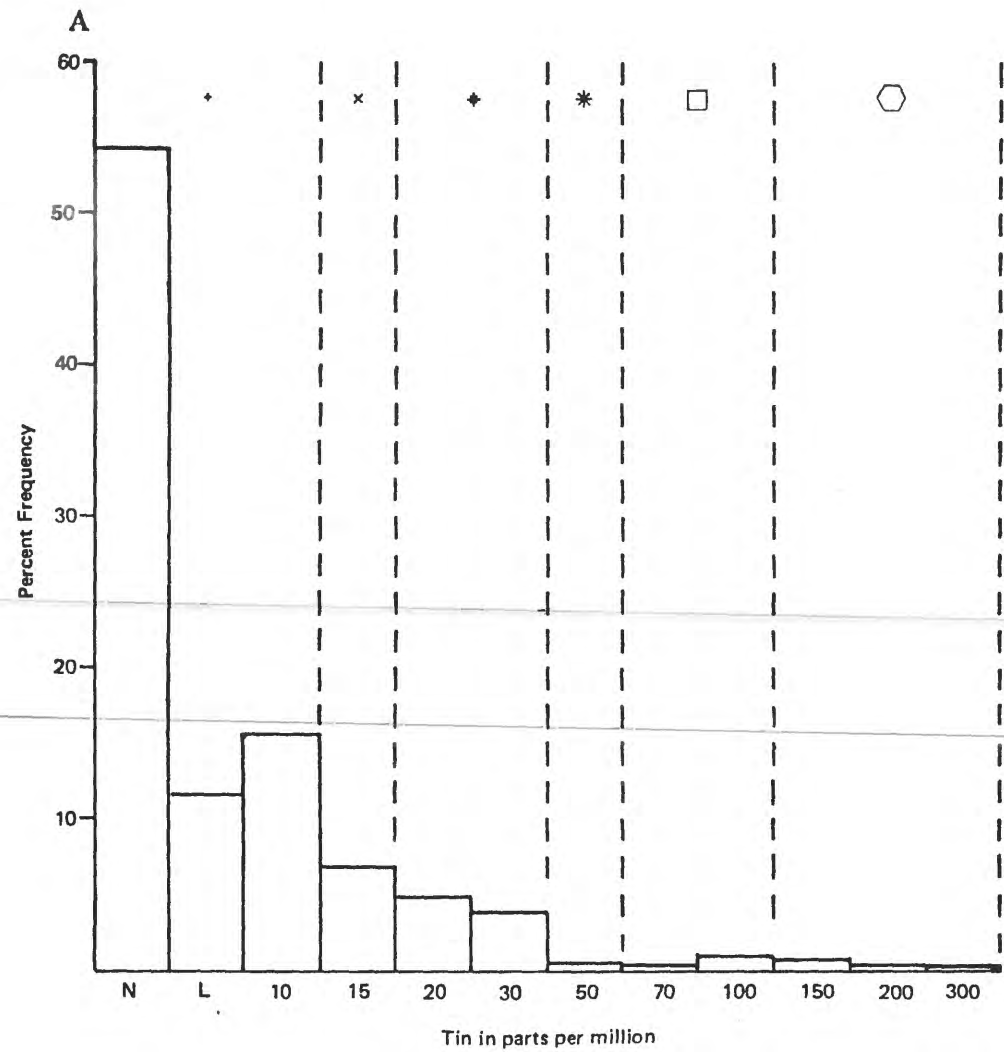
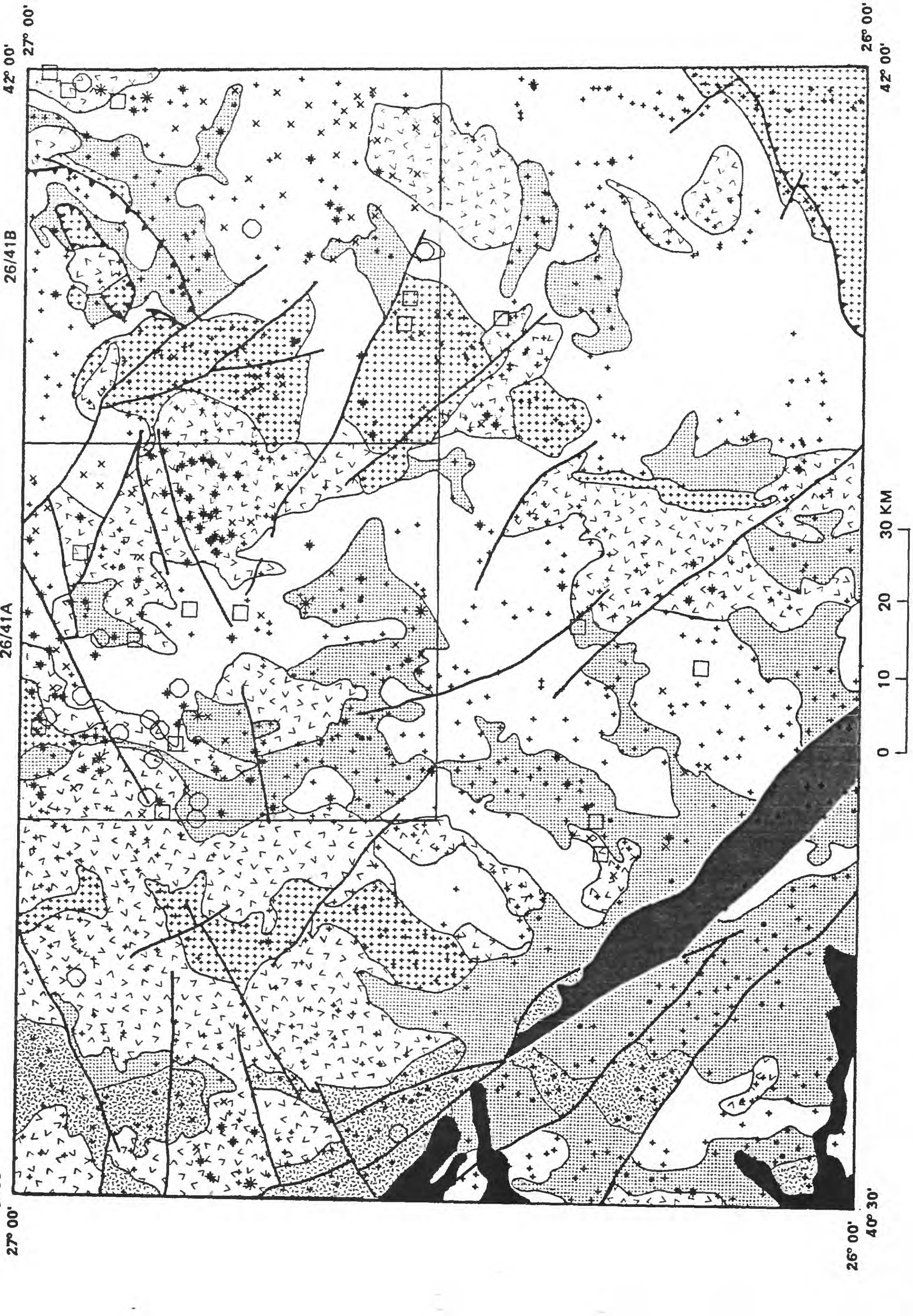


Note: Element-value symbols are shown in red on part B of this figure.

Figure 10.--Histogram (*A*) and distribution (*B*) of tin in wadi concentrates, Wadi ash Shu'bah quadrangle. Geologic map units same as figure 2.

B



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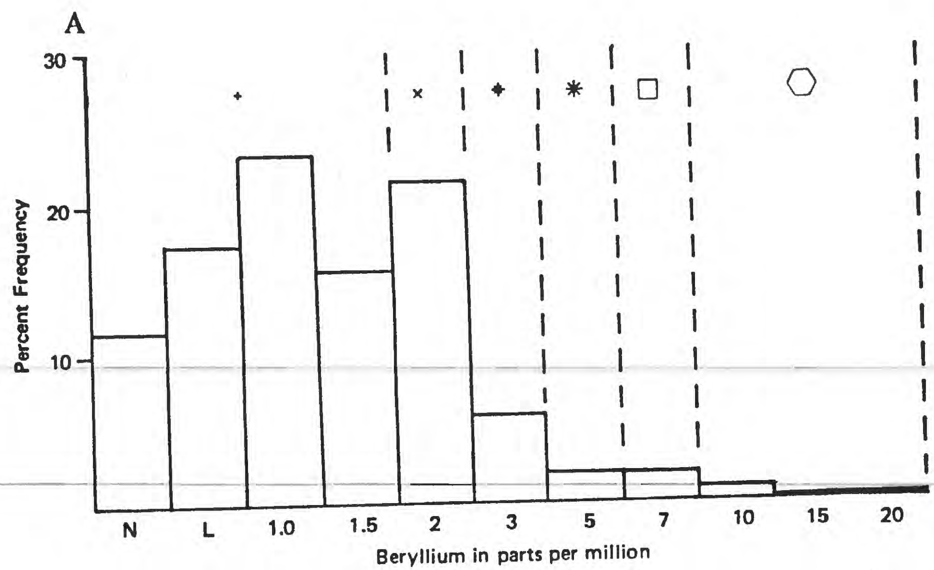
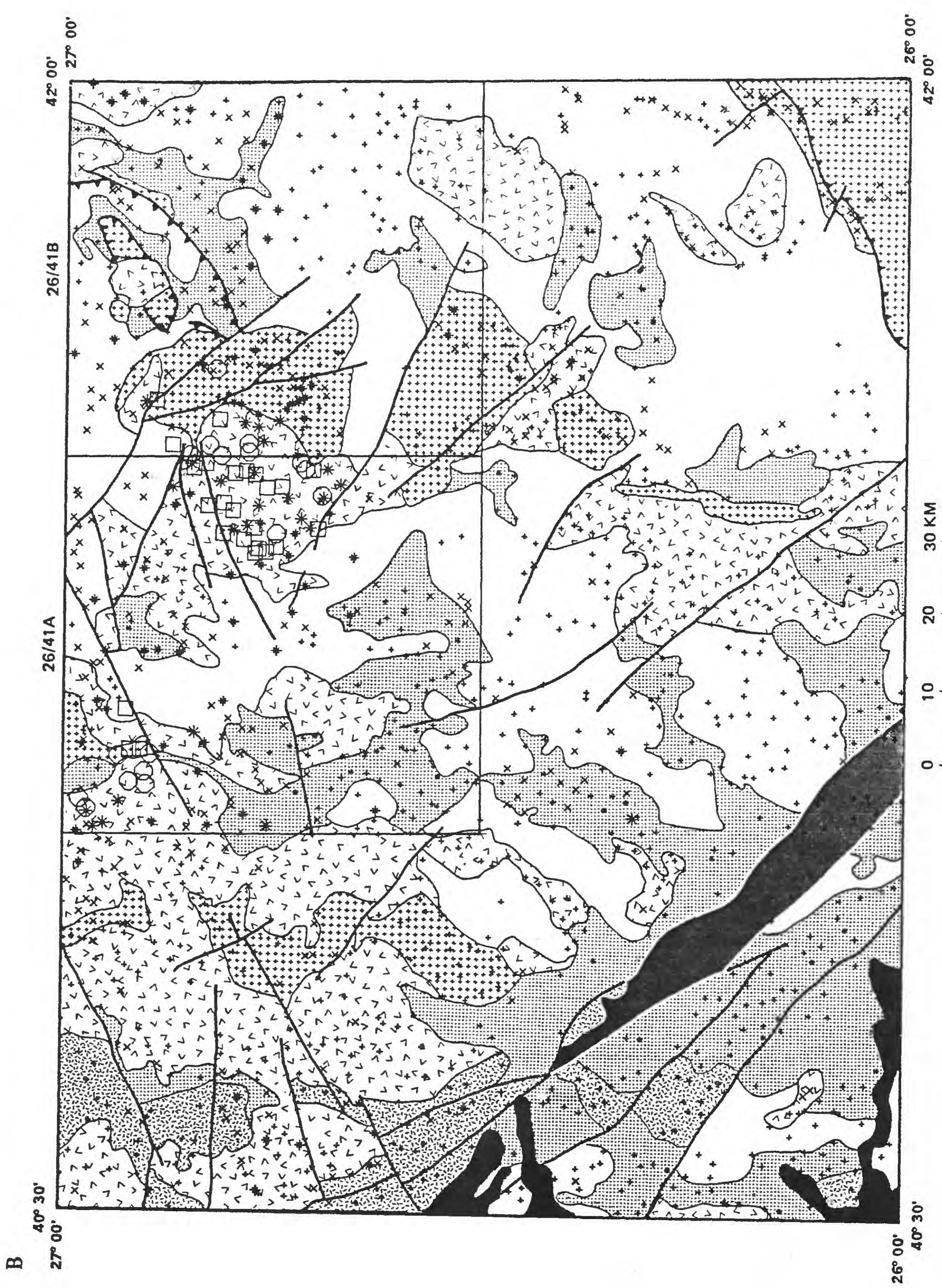


Note: Element-value symbols are shown in red on part B of this figure.

Figure 11.--Histogram (*A*) and distribution (*B*) of beryllium in wadi concentrates, Wadi ash Shu'bah quadrangle. Geologic map units same as figure 2.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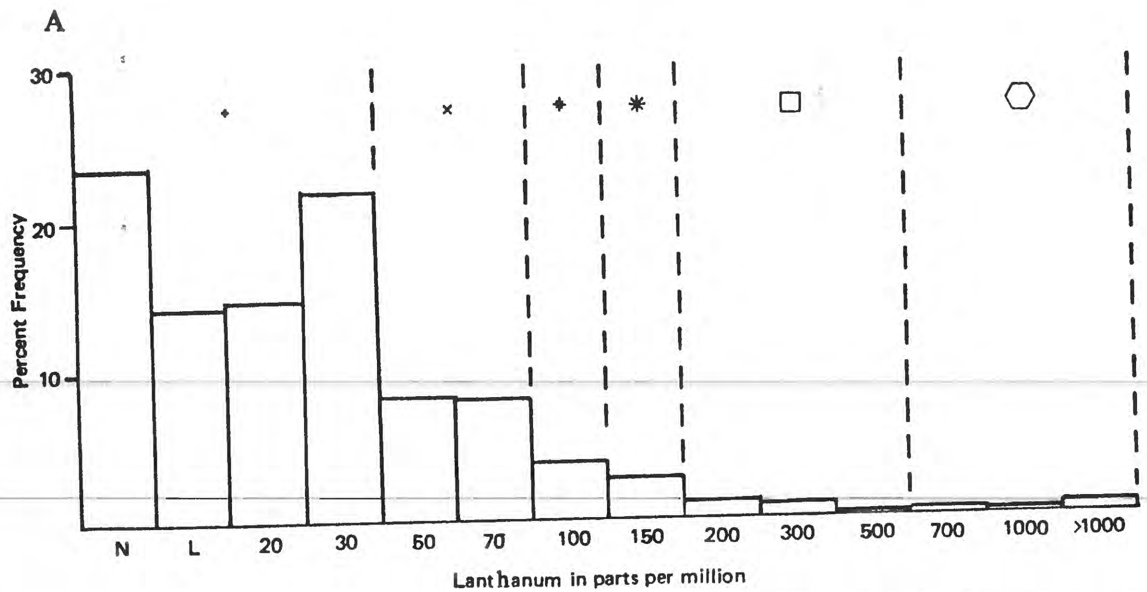
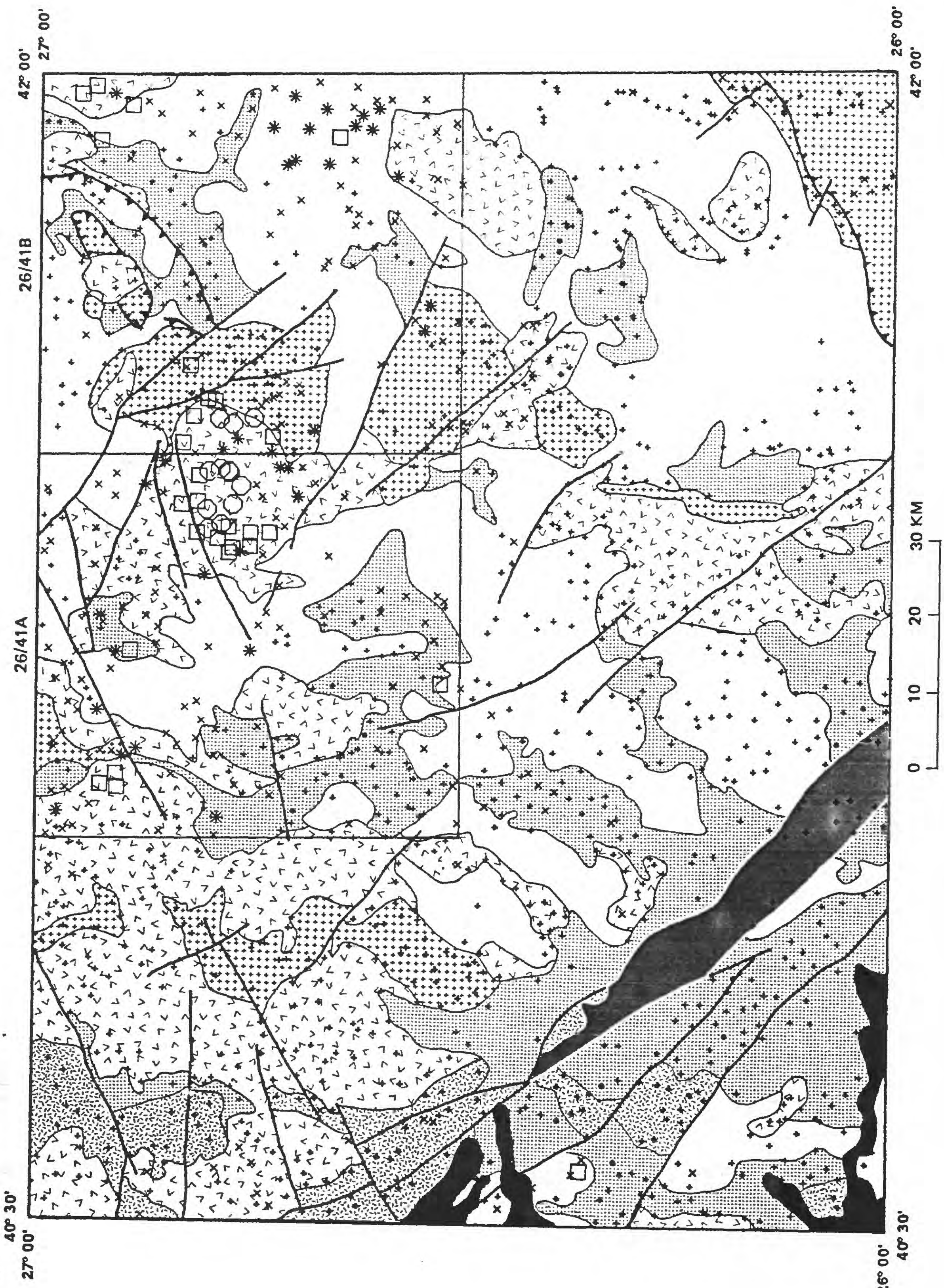


Note: Element-value symbols are shown in red on part B of this figure.

Figure 12.--Histogram (*A*) and distribution (*B*) of lanthanum in wadi concentrates, Wadi ash Shu'bah quadrangle. Geologic map units same as figure 2.

B



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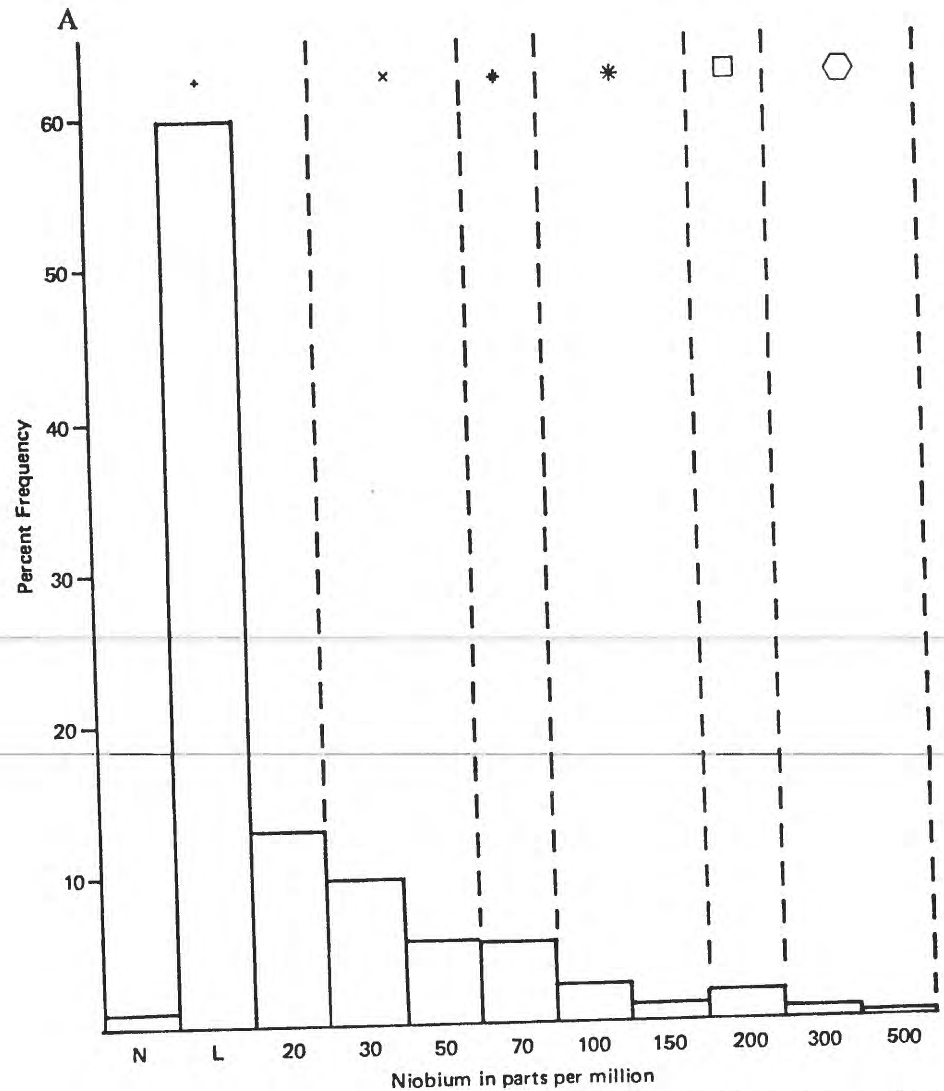
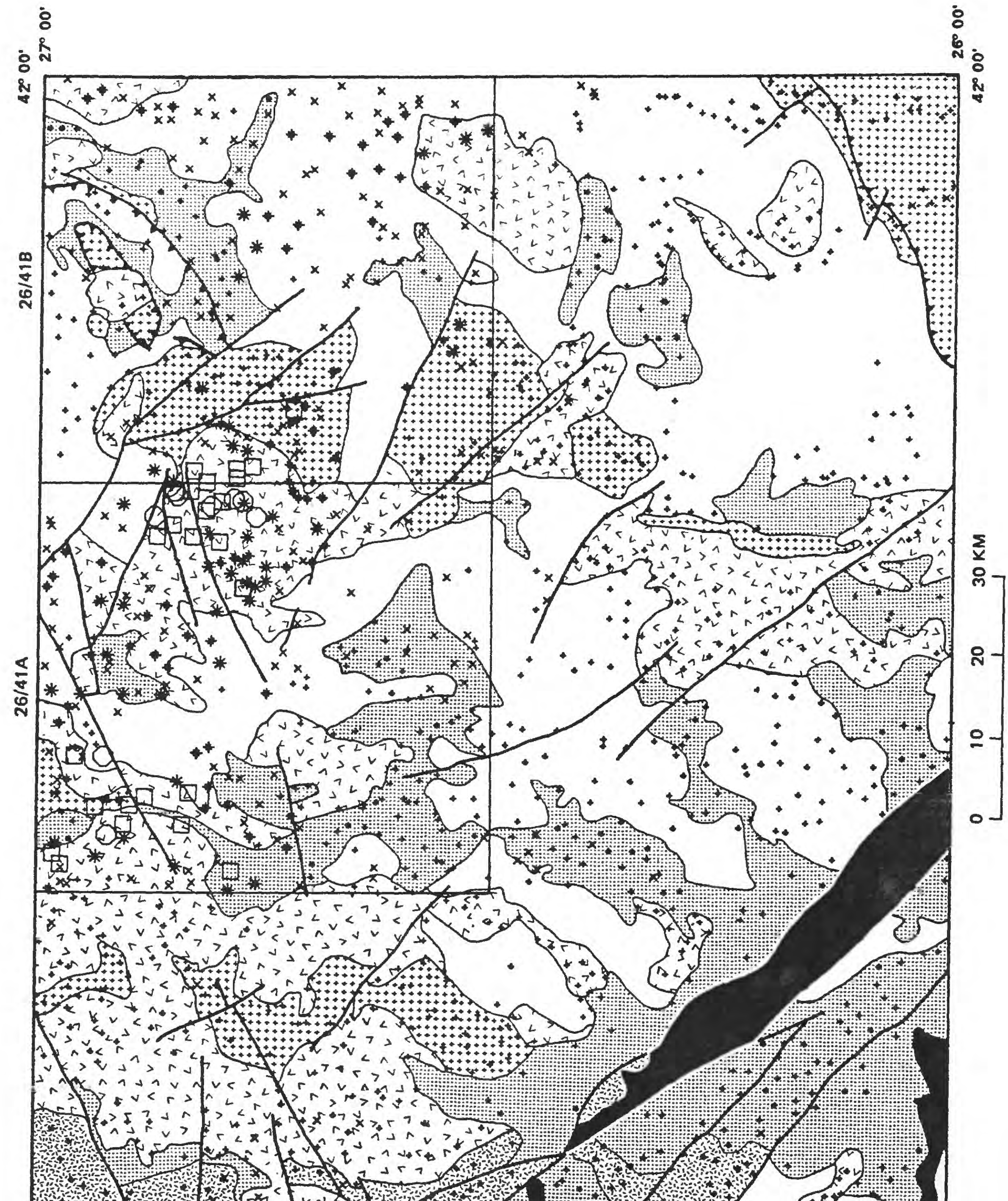


Note: Element-value symbols are shown in red on part B of this figure.

Figure 13.--Histogram (*A*) and distribution (*B*) of niobium in wadi concentrates, Wadi ash Shu'bah quadrangle. Geologic map units same as figure 2.

B



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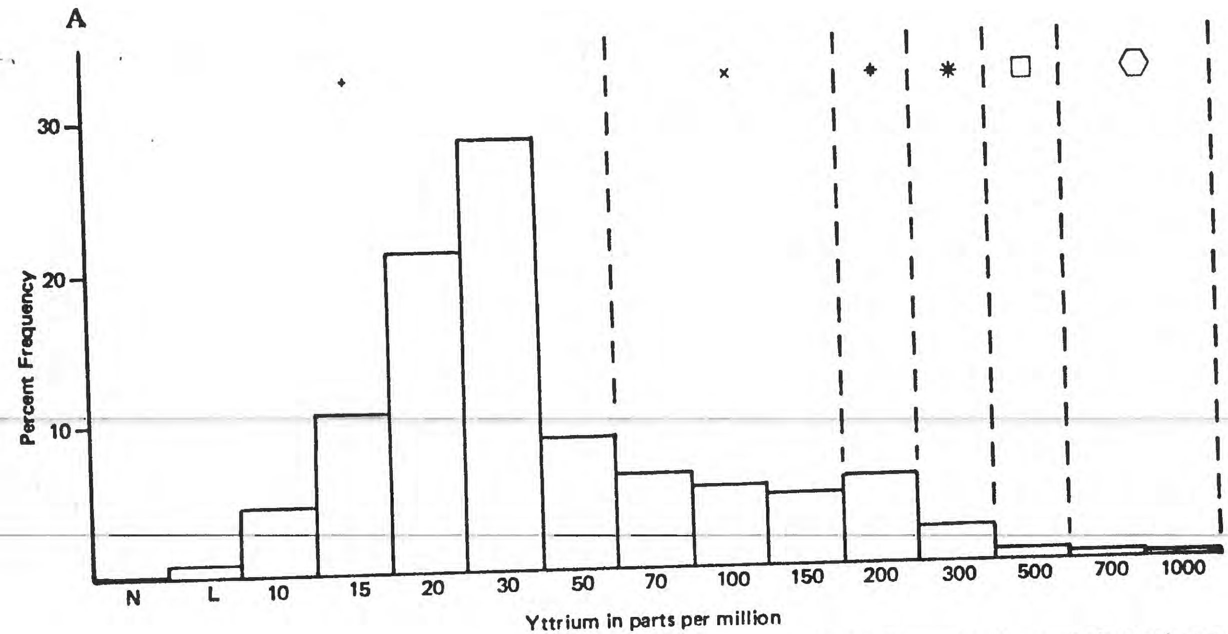
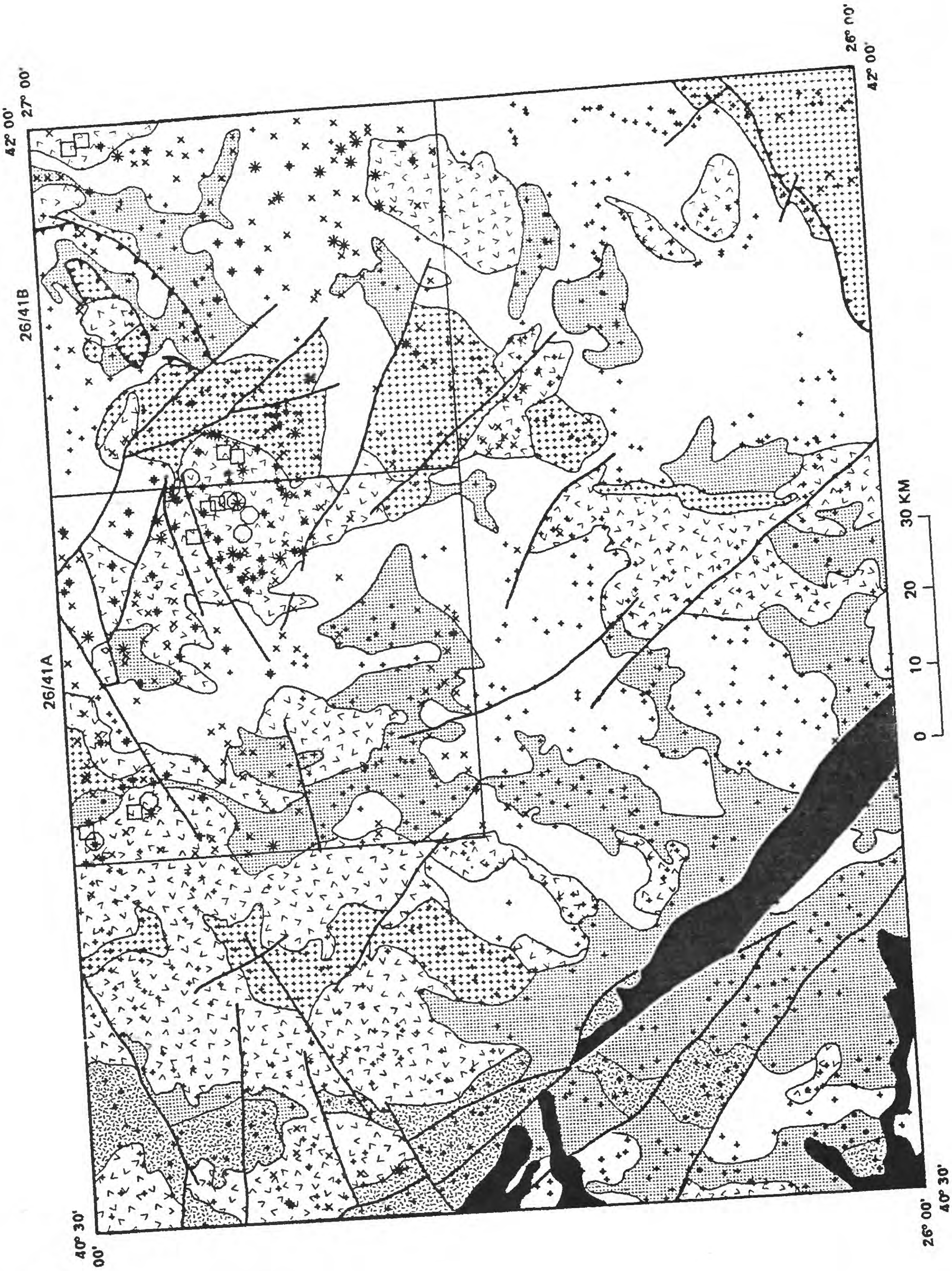


Note: Element-value symbols are shown in red on part B of this figure.

Figure 14.--Histogram (*A*) and distribution (*B*) of yttrium in wadi concentrates, Wadi ash Shu'bah quadrangle. Geologic map units same as figure 2.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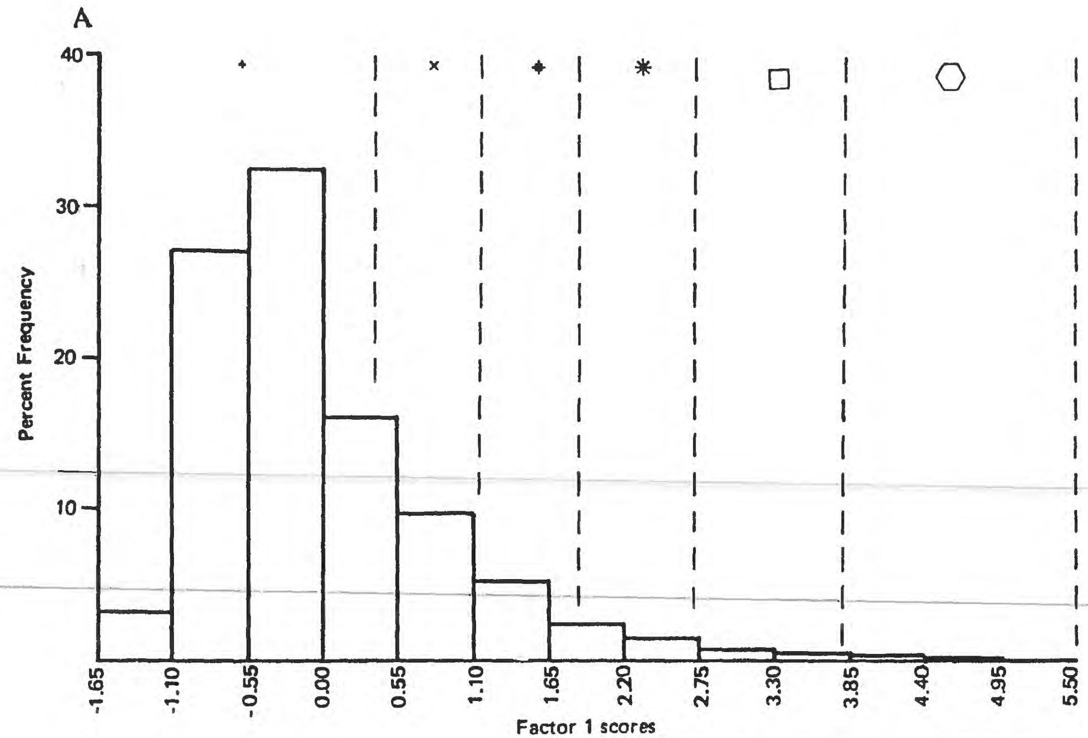
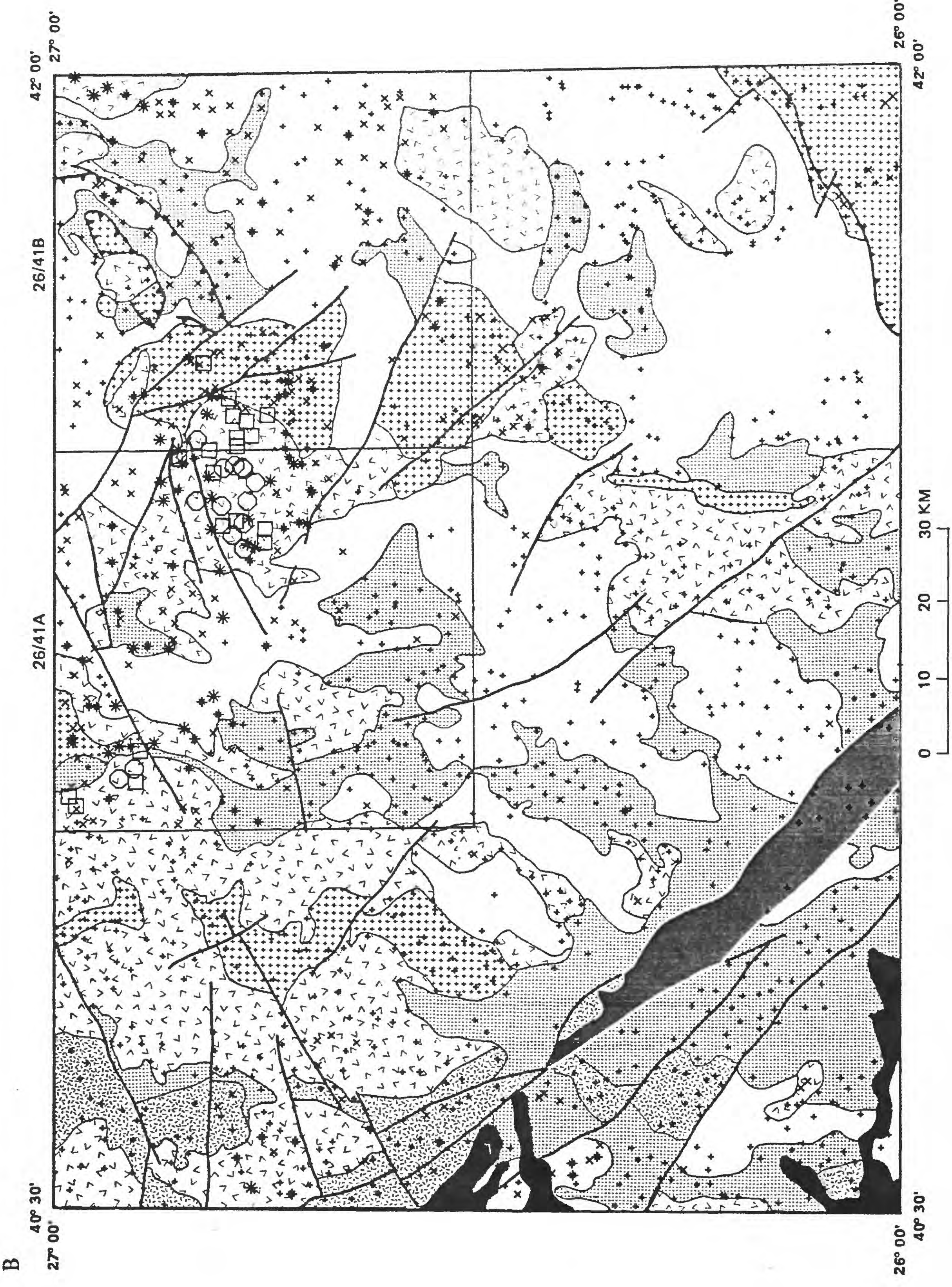


Note: Element-value symbols are shown in red on part B of this figure.

Figure 15.--Histogram (*A*) and distribution (*B*) of factor-1 scores for wadi concentrates, Wadi ash Shu'bah. Geologic map units same as figure 2.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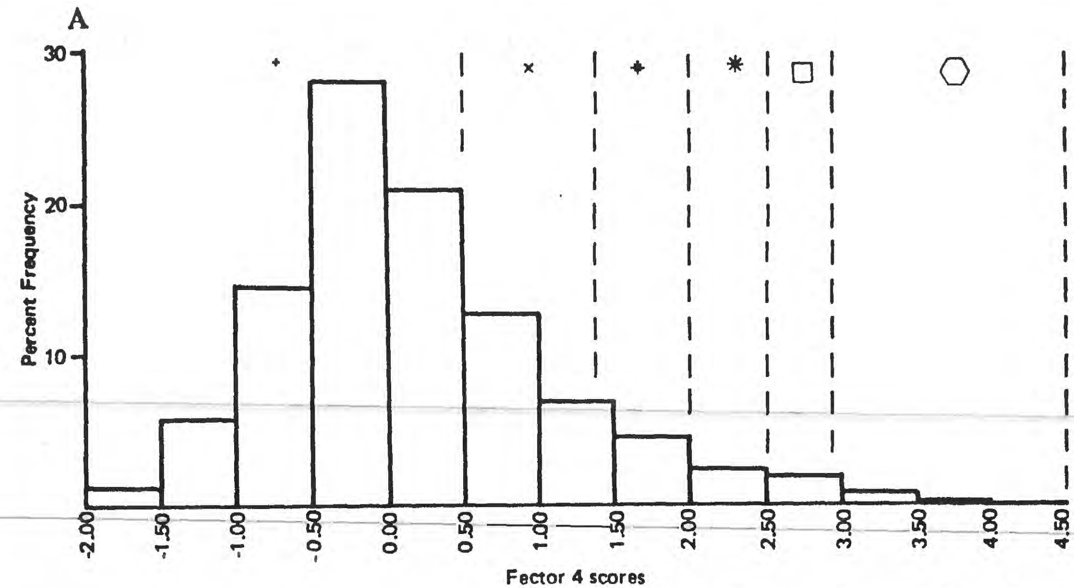
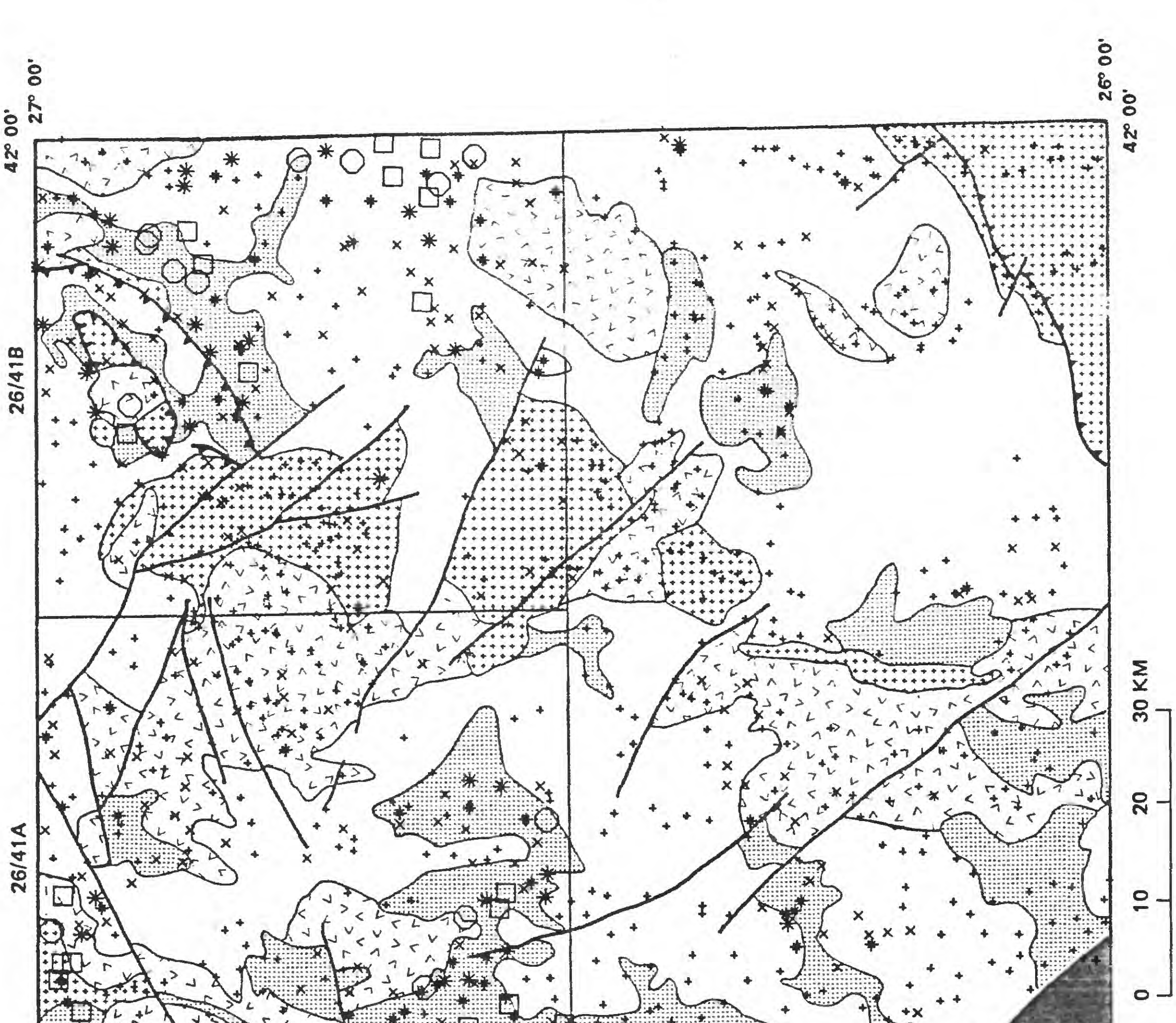


Note: Element-value symbols are shown in red on part B of this figure.

Figure 16.--Histogram (*A*) and distribution (*B*) of factor-4 scores for wadi concentrates, Wadi ash Shu'bah. Geologic map units same as figure 2.

B



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FOLLOW-UP SURVEY

TECHNIQUES

Wadi samples were collected at the sample site by sieving approximately 5 kg of sample through a 2 mm screen. The surface material was first removed before collection of a composited sample. At the field camp, one fraction of this sample was sieved to obtain the -30- to +80-mesh fraction (0.18 to 0.60 mm). This fraction was analysed by atomic absorption spectroscopy for As, Au, Sb, Te, and Zn by the DGMR-USGS chemical laboratory in Jiddah.

The second fraction was hand panned at the field camp to obtain the heavy-mineral wadi concentrates and to eliminate most clay minerals and rock-forming minerals such as quartz, feldspar, and calcite. The wadi concentrates were dried and sieved to -18 mesh (<1.0 mm), and the magnetite removed with a hand magnet. The remaining concentrate was separated into light and heavy fractions using heavy liquids. The light fraction, which contained mainly minerals such as quartz and feldspar, was discarded. The remaining heavy-mineral fraction was separated electromagnetically by an isodynamic separator with a forward and side inclination set at 15 degrees and an ampere setting of 0.2A. The magnetic fraction separated at 0.2A was discarded and the remaining fraction was further separated electromagnetically into a nonmagnetic and magnetic fraction at a setting of 0.6A. The discarded magnetic fraction contained iron-rich magnetic minerals, such as ilmenite, as well as amphiboles and pyroxenes. The nonmagnetic fraction was hand ground to less than 149 micrometers in an agate mortor. This fraction was then analysed with a d.c.-arc emission spectrograph for 31 elements by R. T. Hopkins at the USGS laboratory in Denver, Colorado. The results of the analyses are reported within a framework made up of six steps per order of magnitude (1, 0.7, 0.5, 0.3, 0.2, 0.15, or multiples of 10 of these numbers) and represent approximate geometric midpoints of the concentration range. The precision is shown to be within one adjoining reporting interval on each side of the reported value 83 percent of the time, and within two adjoining intervals 96 percent of the time (Motooka and Grimes, 1976). Mineralogic studies of individual grains from this fraction were conducted using a conventional binocular microscope and x-ray emission spectrography with a scanning electron microscope (SEM) at the USGS laboratory in Denver, Colorado.

Rock samples were collected by compositing chips from an approximately one-m^2 area. Samples of veins were composited from chips collected for one to three meters along strike. All rock samples were pulverized. One split was analysed with a d.c.-arc emission spectrograph for 31 elements, and another split was analysed by atomic absorption spectrography for As, Au, Sb, Te, and Zn. The samples were analysed at the DGMR-USGS laboratory in Jiddah and at the USGS laboratory in Denver, Colorado.

DISCUSSION OF AREAS

The areas located during the follow-up survey that may have economic significance are described below. Figure 17[1/] is an index map of the Wadi ash Shu'bah quadrangle showing the locations of these areas.

1/ Figures 17-27 are at the end of the section. See page 64

Murran Gossan Belt

During the follow-up survey, a discontinuous arc-shaped belt of gossan outcrops approximately 6 km in length was discovered by helicopter (figs. 17, 18, and 19). This belt of outcrops (MODS 3902, 4249, 4250, and 4265) lies approximately 2 km west of the village of Murran. These gossans are hosted by greenstones of the Hulayfah group. Pillow basalts were observed on a small hill just south of the southernmost group of gossan outcrops. The gossan rocks vary in color from a deep hematitic red to limonitic yellow. Their hardness ranges from soft powder to silicious, with silicious parts being more resistant to weathering than the surrounding greenstones. Locally, there are well-developed gypsum crusts formed over parts of the gossan that may have formed from chemical weathering of sulfide minerals associated with the gossans. These gossans are believed to represent submarine exhalative-type massive-sulfide mineralization.

The gossan belt was not readily detected by the regional geochemical survey. Two samples collected from wadis draining the area contained 7 ppm Mo and 20 ppm Cu. During the follow-up survey, nine samples were collected from small wadis to assess the effectiveness of wadi samples to detect this type of occurrence. The wadi concentrates showed only low concentrations of Cu, Pb, Ni, and Cr, while the wadi sediments contained higher concentrations (table 3[1/]). The likley explanation for the higher concentrations of Cu, Zn, and Mo in the wadi sediments compared to wadi concentrates is that the sediments contain iron oxides. Iron oxides act as scavengers of Cu, Zn, and Mo.

Twenty-seven rock samples collected from the gossans contained low concentrations of Cu, Mo, Pb, and Ni (table 4). Analyses of other elements, such as Zn or Au, were not available, but Williams and Simonds (1985) report trace amounts of gold and silver detected by atomic absorption spectrometery from seven rock samples collected from these gossans.

It may be that the length of time that the rocks of the Arabian Shield were exposed to chemical weathering is the reason that few sulfide minerals are presently found at the surface. In their evaluation of gossans in the Kingdom of Saudi Arabia, Ryall and Taylor (1981) report only low concentrations of certain elements in rocks collected from several gossans (table 5). These gossans have been evaluated as having low economic value because of the absence of significant concentrations of base metals.

The economic significance of the Murran gossan belt cannot be adequately evaluated from existing surficial evidence. Subsurface drill-core data is required to adequately evaluate this occurrence. The large size of the occurrence significantly increases the resource potential.

Mishash ar Rafi Shale-Hosted Copper Area

An area of well-developed gypsum crust, similar to those present at the Murran gossan area, was located in the southeast corner of the quadrangle (fig. 17 and 20). A small trench dug by hand through a two-foot-thick gypsum crust encountered calcareous shale of the Maraghan formation. Thin (1-4 cm) interbedded zones of iron oxides and minor sulfides, primarily chalcopyrite, were

1/ Tables 3-15 are at the end of the section. See page 56

observed. Chemical analyses of five rock samples collected from within and near the trench contained low to moderate concentrations of Cr, Cu, Mo, Ni, and Zn (table 6). J. L. Doebrich (written comm., 1985) trenched this area with a backhoe in early 1985 and located a series of oxidation-reduction horizons and additional conformable layers of gypsum that indicate the intensity of chemical weathering. Twenty channel samples were collected from these trenches. Analytical results showed only low concentrations of base metals. Four of these samples contained low concentrations (10-30 ppb) of gold. The median concentration of gold in shales is 4 ppb (Wedepohl, 1969-1978), although Boyle (1979) reports that certain organic-rich shales may contain gold concentrations in excess of the average for normal shales. The gold values of these channel samples are considered to be slightly elevated.

This occurrence cannot be adequately evaluated on the basis of the results of this report. The low trace-element concentrations of the near-surface rocks suggest moderate mineral resource potential. But the presence of the thick gypsum crust at the surface indicates that a considerable amount of sulfide minerals were originally present and that there is a possibility that sulfide minerals exist at depth. Subsurface drilling and(or) deep trenching is needed to adequately evaluate this occurrence.

Rawdat al Ba'ayith Gold Area

One quartz-vein sample collected from a heavily veined area associated with a granodiorite pluton located approximately 3 km southeast of Rawadt al Ba'ayith (figs. 17 adn 21) contained 30 ppm Au, 3 ppm Ag, >1,000 ppm Bi, and 700 ppm Mo. Twelve samples were collected from wadis draining the nearby Raha fault. Chemical analyses of the wadi concentrates from these sites detected only low levels of Cu and Pb at four locations. One wadi-sediment sample (212907) contained 4,400 ppm As (table 7).

J. L. Doebrich (written comm., 1985) conducted follow-up mapping and rock geochemical sampling in early 1985 and reported numerous quartz veins that intrude the Maraghan formation and the granodiorite. Felsite plugs and dikes also locally intrude the Maraghan formation. Doebrich also reported visible pyrite and galena in several of the veins and stockwork veining in the granodiorite. Fifteen of the seventeen composite rock-chip samples collected for 20 to 40 m along the strike of the quartz veins contained detectable gold concentrations that varied from 11 ppb to 8.6 ppm. These 17 samples also contained anomalous concentrations of Ag, As, Bi, Mo, and W. On the basis of the geologic setting and the Au-As-Mo association, Doebrich interprets this area as being similar to the Ar Rahail prospect, located 18 km to the east. Geochemical evidence suggests that this area has moderate resource potential for gold in quartz veins, but subsurface drilling is required to further evaluate its economic significance.

Jibal Abid Copper-Molybbedenum-Gold Area

A group of mineralized ancient workings (MODS 3903) (figs. 17 and 22) were discovered by J. E. Quick and J. L. Doebrich during field work in 1984. The mineralized rocks are found in monzonite to syenogranite and are primarily brecciated quartz veins with abundant malachite staining and well-developed box-work texture. Chemical analyses of the two rock samples collected from the ancient workings contained 3-20 ppm Ag, >20,000 ppm Cu, and >2,000 ppm Mo (table 8). J. L. Doebrich (written comm., 1985) observed considerable visible hexagonal molybdenum crystals at the surface during follow-up work in 1985. He reported areas of pegmatite and quartz breccia containing granite fragments with well-developed stockwork veining, suggesting the presence of a stockwork at depth. Further surficial mapping, sampling, and drilling is required to describe and evaluate the resource potential of this area.

Aqab Gossan Area

A 100 km^2 area of isolated gossans within the Hulayfah group (MODS 3104) was located by helicopter approximately 10 km southwest of Jibal Salma (figs. 17 and 23). Chemical analyses of 10 rock samples collected from the various gossans yielded elevated concentrations of Co, Cu, Mo, Ni, and Ag, and four samples contained weakly anomalous concentrations of As, Cd, Sb, and Au (table 9). Six samples of wadi concentrates and sediments were collected from small wadis draining areas containing gossans. Only weakly anomalous concentrations of Cu, Ni, Cr, and Pb were detected in the wadi concentrates, but slightly higher concentrations of Cu, Zn, As, and Mo were detected in the wadi-sediment samples (table 10). The reason for the higher concentrations of these elements is that wadi sediments contain iron oxides that act as scavengers for Cu, Zn, As, and Mo.

These gossans are associated with the silicic volcanic and greenstone units of the Hulayfah group. The rocks are limonitic yellow to hematitic red, silicious, and commonly layered and brecciated. Some rock samples, primarily those associated with the higher Cu values, contained visible chalcopyrite and bornite. In some areas, thin, well-bedded black carbonaceous shales are interlayered with the greenstones and gossanous rocks. Rock samples from these gossans generally contain higher concentrations of base metals than rock samples from the gossans at Murran discussed earlier in the text. These gossans are probably weathered surficial expressions of submarine exhalative massive-sulfide mineralization. To adequately evaluate the resource potential of this area, more detailed mapping, trenching, and drilling would be required.

A small ancient working (fig. 23), consisting of a pit of about 5 m in diameter located in a saddle between two small hills, was discovered at the northern end of the gossan area. This area is mapped as silicic volcanics of the Hulayfah group by Quick and Doebrich (1984). The country rock near the pit is a white to pale green felsic rock that may intrude the Hulayfah group. A 2-m-wide gabbroic dike is present within the mineralized zone, which is approximately 5 to 10 m wide and is characterized by abundant malachite coatings. Hematitic veins approximately 1 to 2 cm wide were mined within the malachite-stained area. One rock sample (209370) and a nonmagnetic split from soil sample no. 209370S from the pit contained high concentrations of Au, Ag, As, Cu, and Co (Table 9). Detailed follow-up work is required to adequately evaluate the economic significance of this and the surrounding area.

Rawdh Gossan Area

An area containing several gossans was discovered along the southwestern edge of the quadrangle, approximately 20 km northwest of Ar Rawdh (MODS 3900) (figs. 17 and 24). A Pb anomaly detected by the regional geochemical survey approximately 5 km south of the gossan area lead to its discovery. Several gossanous outcrops were observed within Hulayfah group rocks in the area. One gossan contained ancient workings in the form of shallow pits. The gossanous rocks located at the ancient workings are silicified, layered, and brecciated in places with abundant malachite and azurite coatings along fractures. One rock sample (209898) and one slag sample (209294) from the ancient workings contained anomalous concentrations of Ag, Cu, Ni, and Co (table 11). Two other rock samples (209585 and 209810) collected from gossans in the area contained anomalous concentrations of Cu, Ag, and Ni (table 11). Two rock samples collected from chert and marble within nongossanous rocks of the surrounding Hulayfah group contained no anomalous concentrations of elements associated with base or precious minerals (table 11). Three wadi-concentrate and wadi-sediment samples collected from small wadis draining the gossan area contained weakly anomalous concentrations of Cu, Cr, Pb, and Ni (table 12). These gossans are believed to represent massive-sulfide-type mineralization similar to other gossans associated with the Hulayfah group elsewhere in the quadrangle.

An area of ancient workings associated with several 1-m wide quartz veins within the Hulayfah group is located approximately 3 km north of the gossan area. One composited sample (209669) collected from the quartz veins contained anomalous concentrations of Ag, Bi, Mo, Pb, Zn, and a trace of Au (table 11). One wadi-concentrate sample and one wadi-sediment sample collected near the quartz vein area contained weakly anomalous concentrations of Pb and Bi (table 12).

Detailed surface mapping, geochemical sampling, and trenching is needed to fully evaluate the economic significance of this area.

Rijlat al Ashgar Quartz Vein Area

An area containing several quartz veins averaging 1 m in width and trending northwest discontinuously for 1 to 2 km was located approximately 10 km southeast of the Jibal Abid Cu-Mo area in the southeastern part of the quadrangle (MODS 3897) (figs. 17 and 25). The veins are present in pre-Hadn quartz diorite to diorite and may be associated with the emplacement of these plutons. Fifteen composited samples of vein material were collected. Several samples contained anomalous concentrations of Bi, Mo, and W (table 13). One sample analyzed for Au contained only 0.002 ppm (table 13). Most of the samples of vein material that contained anomalous concentrations of metal consisted of hematite-rich material found along the margins of these veins. Based on the small amounts of mineralization, these quartz veins are believed to have only moderate resource potential.

Wadi al Qahad Skarn Area

An area containing scattered ancient workings was discovered by helicopter 42 km west of the Rijlat al Asgar area (figs. 17 and 26). The ancient workings consist of several pits and trenches located in greenstone containing small quartz veins and iron-oxide stringers, and in garnetiferous skarn in limestone within the greenstone. Six rock samples collected from in and around the ancient workings contained low concentrations of Au, Ag, Mo, Bi, and moderate concentrations of Cu. Thirteen wadi-concentrate and wadi-sediment samples were collected from small wadis draining the area. These samples contained anomalous concentrations of Sn, Sb, Bi, and As (table 14). The tin is thought to be associated with the skarn. No scheelite was detected by short-wave untraviolet light. The cassiterite from the wadi concentrates consists of small, angular, black to transparent red grains. Wadi concentrates containing anomalous antimony and bismuth were collected from small wadis located north of the ancient workings and skarn, indicating possible undetected mineralization (table 14 and fig. 26). Wadi sediments containing anomalous arsenic and zinc were collected from small wadis located south and east of the ancient workings. Wadi concentrate 209984 also contained 70 ppm Be, which may be related to skarn mineralization.

Two types of mineralization are present in this area: (1) precious- and base-metal-bearing quartz veins within the greenstone and (2) skarn mineralization within carbonate beds in the greenstone. Both types of mineralization are associated with the intrusion of the granodiorite.

Detailed mapping and rock geochemical sampling are required to further evaluate the economic significance of this area.

Jibal Ba'gham Area

Anomalous concentrations of tin and factor-1 scores are found to the south and east of Jibal Ba'gham (MODS 3156) (figs. 10 and 15). The Jibal Ba'gham area is located near the village of Saqf in the north-central part of the quadrangle (figs. 17 and 27). A follow-up wadi-concentrate geochemical survey was conducted to further evaluate the mineral resource potential of the area.

Seven wadi-concentrate samples collected during the follow-up survey contained anomalous concentrations of Be, La, Nb, Pb, Sn, Y, Th, and W (table 15). Microscope studies of grains from the wadi concentrates identified cassiterite as the tin-bearing mineral and monazite as the yttrium- and thorium-bearing mineral. The cassiterite is translucent red to amber colored and is similar to cassiterite observed at the Wadi al Qahad skarn area. This cassiterite differs from that observed in the Aban al Ahmar quadrangle, which is often associated with peraluminous granites and is black and submetallic in appearence.

Sample 209371, which is from a small wadi draining the Hadn formation, Banana greenstone, and hornblende-quartz diorite, contained small scheelite grains along with angular cassiterite grains. The Banana greenstone, which is a member of the Hulayfah group, may contain limestone lenses (Quick and Doebrich, 1984); therefore, the possibility exists for skarn mineralization. Samples 209089 and 209284 come from a larger wadi that drains several rock units from a large area. The cassiterite grains are rounded to subangular, indicating grain transport over a greater distance than that of sample 209371. Samples 209089, 209284, 209371, and 209632 contain tin concentrations of 500 to >2,000 ppm. These samples were all collected from wadis draining older rocks surrounding the Jufayfah syenogranite (fig. 27). This lecocratic hornblende-biotite-bearing granite may contain a peraluminous phase (D. B. Stoeser, personal comm.). The Jufayfah syenogranite is probably the source of the anomalous tin concentrations and may host tin and tungsten deposits associated with greisen, stockwork, or skarn mineralization. Erosion has probably removed any significant mineralization that may have been present in the upper part of the pluton, but there may be mineralization present in the surrounding country rocks associated with the main pluton or unexposed satellite bodies of the main pluton.

Wadi-concentrate samples 209111, 209180, and 209297, which are from wadis draining the main Ba'gham granite, contain tin concentrations of 150 to 300 ppm, indicating that the Ba'gham granite (fig. 27) probably does not host significant tin mineralization. Peralkaline granites in the Arabian Shield have been described as containing high concentrations of tin (Elliott, 1983; Cole, 1986), but not in economic concentrations. The peralkaline Ba'gham granite contains high concentrations of thorium and rare-earth elements in areas with associated radiometric anomalies (Quick, 1983) and should be considered as having potential for rare-earth deposits. Detailed mapping and geochemical sampling is required to further evaluate this area.

Kilab Monzogranite Area

Interpretation of the regional wadi-concentrate data identified an area containing anomalous concentrations of La, Nb, Y, Mo, and Sn in the southern part of the Kilab Monzogranite (figs. 9, 10, 12, 13, 14, and 17). The Kilab monzogranite is probably not the source of these anomalous concentrations because concentrates collected from wadis draining this monzogranite do not normally carry elevated concentrations of these elements. The source of the La, Nb, Y, Mo, and Sn may be a burried alkalic post-Hadn granite similar to the one in the Nubayah area located to the southeast in the Aban al Ahmar quadrangle (Miller and Arnold, 1986). No follow-up samples were collected from this area. This area is considered to have moderate resource potential for tin and tungsten. Detailed mapping and geochemical sampling is required to further evaluate the area.

Table 3.--Chemical analyses of wadi samples from the Murran gossan belt area.

[Wadi concentrates by emission spectrography and wadi sediments by atomic absorption. Fe in percent, all other values are in parts per million; N=not detected.]

Wadi concentrate						Wadi sediment			
Sample	Fe	Cr	Cu	Ni	Pb	Sample	Cu	Zn	Mo
209049	1.5	100	10	30	70	212049	232	234	7
209446	1.5	100	N	15	70	212446	164	232	8
209448	1.5	100	N	15	50	212448	260	342	16
209568	0.7	50	N	10	20	212568	112	380	10
209839	0.7	70	10	10	30	212839	236	378	8
209868	0.5	70	N	30	50	212868	270	342	10
209904	1.0	100	10	20	50	212904	232	342	10
209983	0.7	100	10	30	50	212983	196	284	10

Table 4.--Chemical analyses by emission spectrography of gossan samples from the Murran gossan belt.

[Fe in percent, all others in parts per million; N=not detected.]

Sample	Fe	Mn	Ba	Cr	Cu	Mo	Ni	Pb
209020	2.0	1000	2000	300	10	<10	7	10
209091	>20	150	1500	50	50	20	7	<10
209108	20	200	500	30	50	<10	5	30
209109	15	100	200	500	10	20	10	N
209125	20	50	150	300	30	20	<5	<10
209127	3.0	200	500	500	10	15	7	N
209204	0.7	1000	2000	200	<10	N	<5	10
209227	>20	200	1000	300	20	50	10	15
209279	10	150	200	30	20	<10	5	30
209287	>20	100	500	200	70	30	7	<10
209332	5	200	300	500	15	15	10	N
209352	5	2000	1500	200	<10	<10	N	<10
209359	20	300	70	150	15	50	10	<10
209408	20	70	700	200	15	20	7	10
209467	2.0	150	1000	100	<10	<10	10	10
209490	3.0	2000	2000	150	20	N	15	N
209502	>20	150	700	50	70	20	15	10
209503	15	50	100	200	10	10	10	<10
209531	20	100	1500	50	50	20	7	<10
209565	20	200	500	70	50	<10	7	<10
209618	20	100	200	200	30	15	7	<10
209699	20	200	300	70	20	N	7	<10
209779	10	150	1000	200	15	30	10	<10
209825	>20	150	1000	70	10	20	<7	<10
209841	>20	300	150	30	50	N	7	<10
209858	>20	70	N	70	30	N	N	N
209889	15	200	1500	500	10	15	7	<10
Minimum	0.7	50	0	30	<10	0	<5	0
Maximum	>20	2000	2000	500	70	50	15	30

Table 5.--Arithmatic mean values for selected gossans in the Kingdom of Saudi Arabia (Ryall and Taylor, 1981).

[Fe values in percent, all other values in parts per million.]

Gossan	Fe%	Cu	Mo	Pb	Co	Mn	Zn	Ba
Wadi Wassat	30	17	18	6	20	100	16	550
Khomfut	35	59	120	2	60	150	55	120
Nuhum	31	34	16	7	25	140	21	420
Girwash	19	19	11	9	16	43	29	64

Table 6.--Chemical analyses by emmison spectrography of rocks from the Mishash ar Rafi area.

[Fe values in percent, all other values in parts per million; N=not detected.]

Sample	Discription	Fe	Co	Cr	Cu	Mo	Ni	Pb	V	Zn
209105	Quartz vein	10	N	30	50	N	5	30	70	N
209225	Shale	20	20	200	100	20	70	10	300	200
209355	Shale	3	15	70	70	N	100	20	150	N
209451	Silicious hematitic layer in shale	5	7	70	20	10	15	N	30	N
209536	Silicious hematitic layer in shale	10	30	70	50	15	50	15	100	N
209824	Shale	5	7	300	20	N	50	N	150	N

Table 7.--Chemical analyses of wadi samples of the Rawdat al Ba'ayith gold Area.

[Wadi concentrates by emission spectrography and wadi sediments by atomic absorption. All values are in parts per million; N=not detected.]

Wadi Concentrates			Wadi Sediments				
Sample	Cu	Pb	Sample	Cu	Zn	As	Mo
209115	N	50	212115	140	360	55	6
209141	N	70	212141	160	396	88	8
209144	10	50	212144	179	370	44	7
209166	20	50	212166	192	392	15	8
209217	N	70	212217	165	294	10	10
209258	N	70	212258	174	300	10	10
209407	N	300	212407	182	323	10	12
209795	N	70	212795	250	340	15	10
209880	N	50	212880	168	410	10	12
209907	N	70	212907	350	320	4400	10
209961	N	70	212961	164	356	13	7
209968	10	100	212968	140	364	10	8

Table 8.--Chemical analyses of rocks from the Jibal Abid area.

[All results are in parts per million; [--]=not analyzed.]

	Emission Spectrography						
Sample	Ag	Bi	Cu	Mo	Pb	Sb	Sn
209579	20	30	20,000	>2,000	50	300	50
209637	3	150	>20,000	>2,000	30	300	150

	Atomic Absorption					
Sample	Au	As	Zn	Cd	Bi	Sb
209579	--	160	110	0.4	19	140
209637	0.8	40	10	0.7	68	104

Table 9.--Chemical analyses of rocks from the Aqab gossan area.

[Fe values in percent, all other values in parts per million; N=not detected; [--]=not analyzed.

Gossans

	Emission Spectrography									Atomic Absorption					
Samples	Fe	Ag	Co	Cr	Cu	Mo	Ni	Pb	V	Au	As	Zn	Cd	Bi	Sb
209126	3	N	5	30	30	15	30	N	30	--	30	5	0.5	N	N
209201	0.15	N	N	100	5	N	5	N	N	--	--	--	--	--	--
209242	0.5	N	N	300	5	5	7	N	10	--	--	--	--	--	--
209252	15	N	N	100	50	7	15	30	500	--	200	15	0.7	N	28
209432	3	0.7	N	30	20	10	5	N	70	.002	460	110	0.3	1.0	N
209670	>20	N	200	50	500	N	200	10	30	--	--	--	--	--	--
209737	>20	N	20	50	150	N	50	N	70	--	--	--	--	--	--
209799	20	N	5	300	20	70	20	10	500	--	--	--	--	--	--
209856	5	N	5	200	30	5	70	N	70	--	10	25	0.7	N	12
209985	>20	N	150	20	200	N	150	30	50	.002	30	40	1.4	4.0	N

Ancient workings

		Emission Spectrography									Atomic Absorption					
Site Number	Discription	Fe	Ag	As	Co	Cr	Cu	Ni	Pb	Zn	Au	As	Zn	Cd	Bi	Sb
209370	Mineralized pit	10	30	10,000	1000	200	>20,000	150	30	300	6.4	>2,000	220	2.0	2.0	6.0
209377	Gabbroic dike	10	N	N	7	200	20	N	10	N	--	--	--	--	--	--

Soil concentrates

	Emission Spectrography						Atomic Absorption				
Sample	Au	Ag	As	Co	Cu	Pb	Ag	Cu	Zn	Mo	As
209370S	>1,000	3,000	5,000	200	7,000	70	11	6,993	1,470	18	80,000

Table 10.--Chemical analyses of wadi samples from the Aqab gossan area.

[All values are in parts per million; N=not detected.]

-------Emission Spectrography---					--------Atomic Absorption--------				
Wadi Concentrate	Cr	Cu	Ni	Pb	Wadi Sediment	Cu	Zn	As	Mo
209161	70	10	20	50	212161	159	344	10	5
209195	100	N	15	70	212195	214	460	80	7
209292	100	10	30	70	212292	118	340	130	5
209452	300	20	20	70	212452	430	355	10,000	10
209900	200	20	30	50	212900	157	356	205	8
209926	100	10	15	70	212926	160	320	10	20
209970	70	10	15	50	212970	144	126	140	10
209991	100	10	30	70	212991	138	415	13	6

Table 11.--Chemical analyses of rocks from the Rawdh gossan aera.

[Fe values in percent, all other values are in parts per million; N=not detected; [--]=not analyzed.]

		-------------------Emission Spectrography---------------------									
Sample	Discription	Fe	Ag	Bi	Co	Cr	Cu	Mo	Ni	Pb	Zn
209223	Chert	3	N	N	N	50	20	10	15	N	N
209294	Slag	15	N	N	500	700	>20,000	N	1,500	10	N
209585	Gossan	15	N	N	50	700	5,000	N	200	10	N
209669	Quartz vein	5	150	>1,000	5	50	30	150	7	3,000	700
209810	Gossan	5	20	10	70	30	3,000	N	150	50	N
209896	Marble	2	N	N	5	70	15	5	5	10	N
209898	Prospect	20	30	N	300	300	>20,000	N	2,000	10	N

		-------Atomic Absorption---------					
Sample	Discription	As	Zn	Cd	Bi	Sb	Au
209223	Chert	30	10	0.1	N	N	N/A
209294	Slag	--	--	--	--	--	--
209585	Gossan	--	--	--	--	--	--
209669	Quartz vein	N	450	1.0	630	2.0	.06
209810	Gossan	110	20	0.6	3	N	N/A
209896	Marble	--	--	--	--	--	--
209898	Prospect	--	--	--	--	--	--

Table 12.--Chemical analyses of Wadi samples from the Rawdh gossan area.

[All values in parts per million; N=not detected.]

	----Emission Spectrography----						---Atomic Absorption---			
Wadi Concentrate	Bi	Cr	Cu	Ni	Pb	Wadi Sediment	Cu	Zn	As	Mo
209149	N	50	15	20	30	212149	292	388	14	60
209466	N	150	200	30	50	212466	270	336	10	14
209672	300	100	10	15	200	212672	122	308	10	5
209694	N	70	10	15	30	212694	490	248	55	7

Table 13.--Chemical analyses of rocks from the Rijlat al Ashgar quartz vein area.

[Fe in percent, all other values in parts per million; N=not detected; [--]=not analyzed.]

	-----Emission Spectrography-----									
Sample	Fe	Bi	Co	Cr	Cu	Mo	Ni	Pb	W	Sb
209044	>20	50	500	30	100	1,000	150	20	100	N
209047	1.5	N	N	10	5	N	5	30	N	N
209061	0.7	N	N	500	7	N	10	20	N	N
209174	1.5	N	20	200	70	7	70	10	50	N
209190	1.5	N	N	300	5	5	5	10	N	N
209244	1.5	N	N	15	5	N	10	N	N	N
209291	0.5	N	N	300	10	N	7	N	N	N
209362	1.0	N	N	200	5	5	5	15	N	N
209393	>20	15	100	300	70	1,500	50	10	500	N
209527	1.0	N	N	300	5	50	15	N	N	N
209581	2.0	N	5	200	15	5	5	10	N	N
209641	2.0	N	10	N	150	50	20	30	N	100
209678	1.5	N	20	200	150	50	20	N	N	N
209861	20	10	200	N	30	1,500	150	70	N	N
209998	10	1,000	N	50	100	500	5	150	2,000	N

	-----Atomic Absorption-----					
Sample	As	Zn	Cd	Bi	Sb	Au
209044	110	10	0.1	36	N	--
209047	N	20	N	N	N	--
209061	--	--	--	--	--	--
209174	--	--	--	--	--	--
209190	--	--	--	--	--	--
209244	N	15	0.1	18	N	--
209291	--	--	--	--	--	--
209362	--	--	--	--	--	--
209393	--	--	--	--	--	--
209527	--	--	--	--	--	--
209581	--	--	--	--	--	--
209641	10	40	0.2	3	52	0.002
209678	--	--	--	--	--	--
209861	70	5	0.1	7	N	--
209998	60	5	0.2	600	2.0	--

Table 14.--Chemical analyses of wadi samples from the Wadi al Qahad skarn area.

[Wadi concentrates by emission spectrography and wadi sediments by atomic absorption. Fe in percent, all other values are in parts per million; N=not detected.]

Wadi concentrate					Wadi sediment				
Sample	Bi	Pb	Sb	Sn	Sample	Cu	Zn	Mo	As
209072	N	50	N	1000	212072	147	281	5	75
209106	200	50	<200	1500	212106	157	273	9	15
209122	N	20	N	300	212122	129	264	8	15
209232	N	<20	N	300	212232	118	218	12	13
209233	N	30	N	30	212233	171	326	9	75
209301	N	50	N	300	212301	106	329	7	<10
209594	N	70	200	300	212594	113	223	8	<10
209645	N	20	N	20	212645	140	344	6	75
209658	N	100	N	2000	212658	169	327	8	375
209818	N	50	N	70	212818	172	300	8	210
209842	N	70	N	150	212842	163	360	7	55
209967	70	50	700	700	212967	120	267	12	15
209984	N	70	N	1000	212984	113	215	6	270

Table 15.--Chemical analyses by emission spectrography of wadi concentrates from the Jibal Ba'gham area.

[All values in parts per million; N=not detected.]

Sample	Be	La	Nb	Pb	Sn	Y	Th	W
209089	15	500	50	200	>2000	5000	500	N
209111	70	300	50	150	300	5000	<200	N
209180	100	1000	50	500	150	5000	700	N
209284	15	150	50	70	>2000	1500	N	N
209297	70	700	100	500	200	5000	500	N
209371	15	100	<50	100	1500	3000	200	150
209632	7	100	N	150	500	3000	N	N

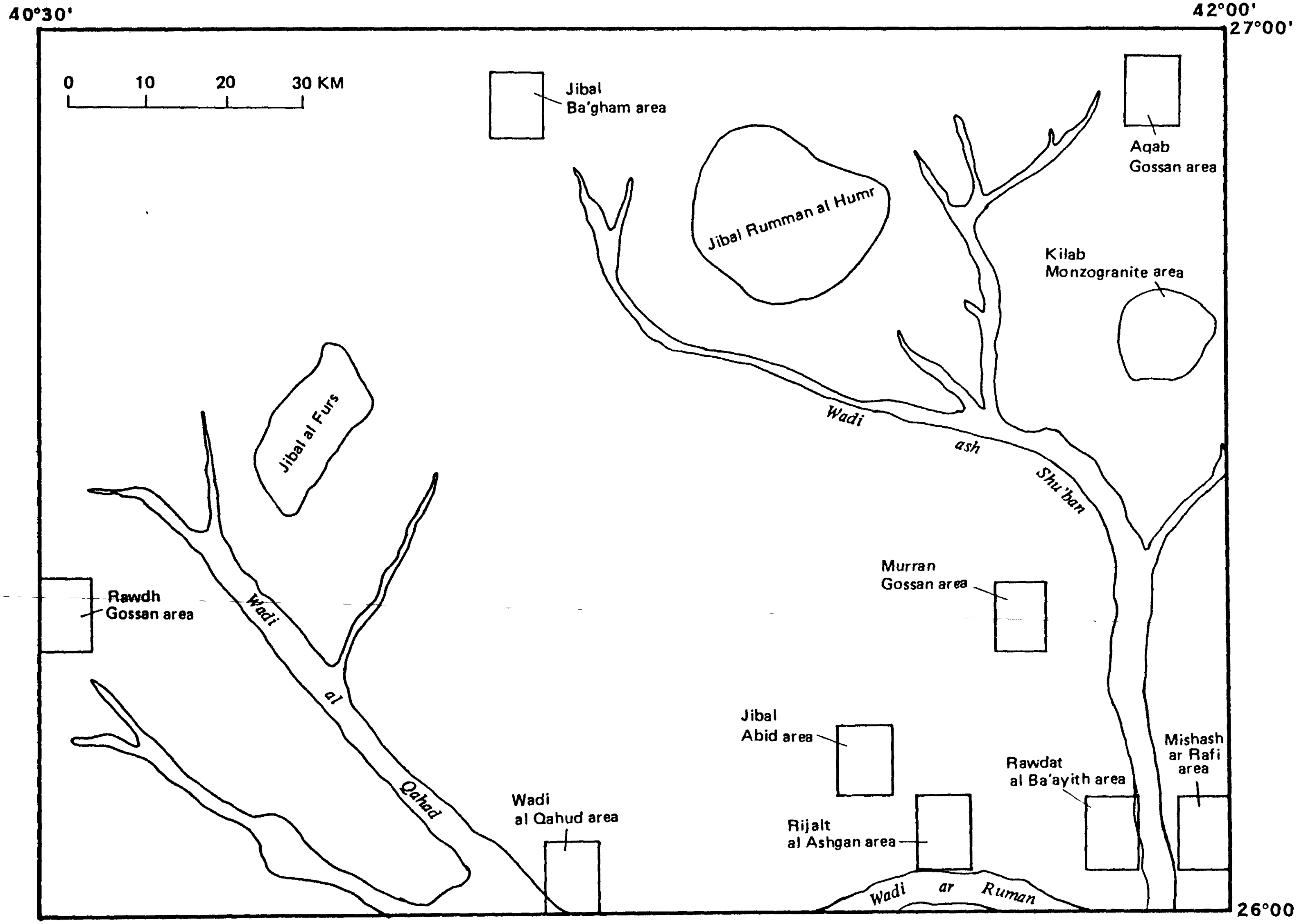
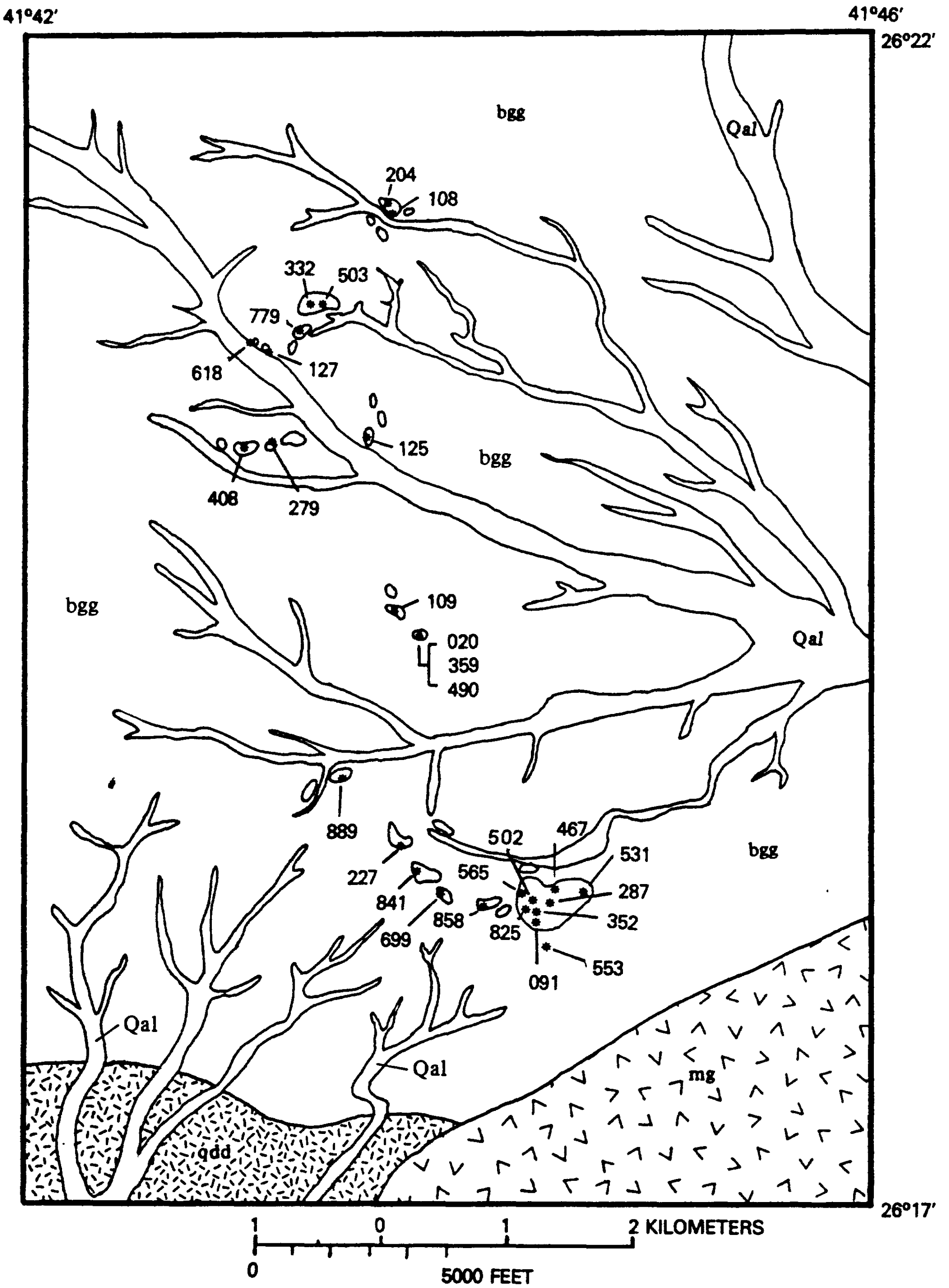


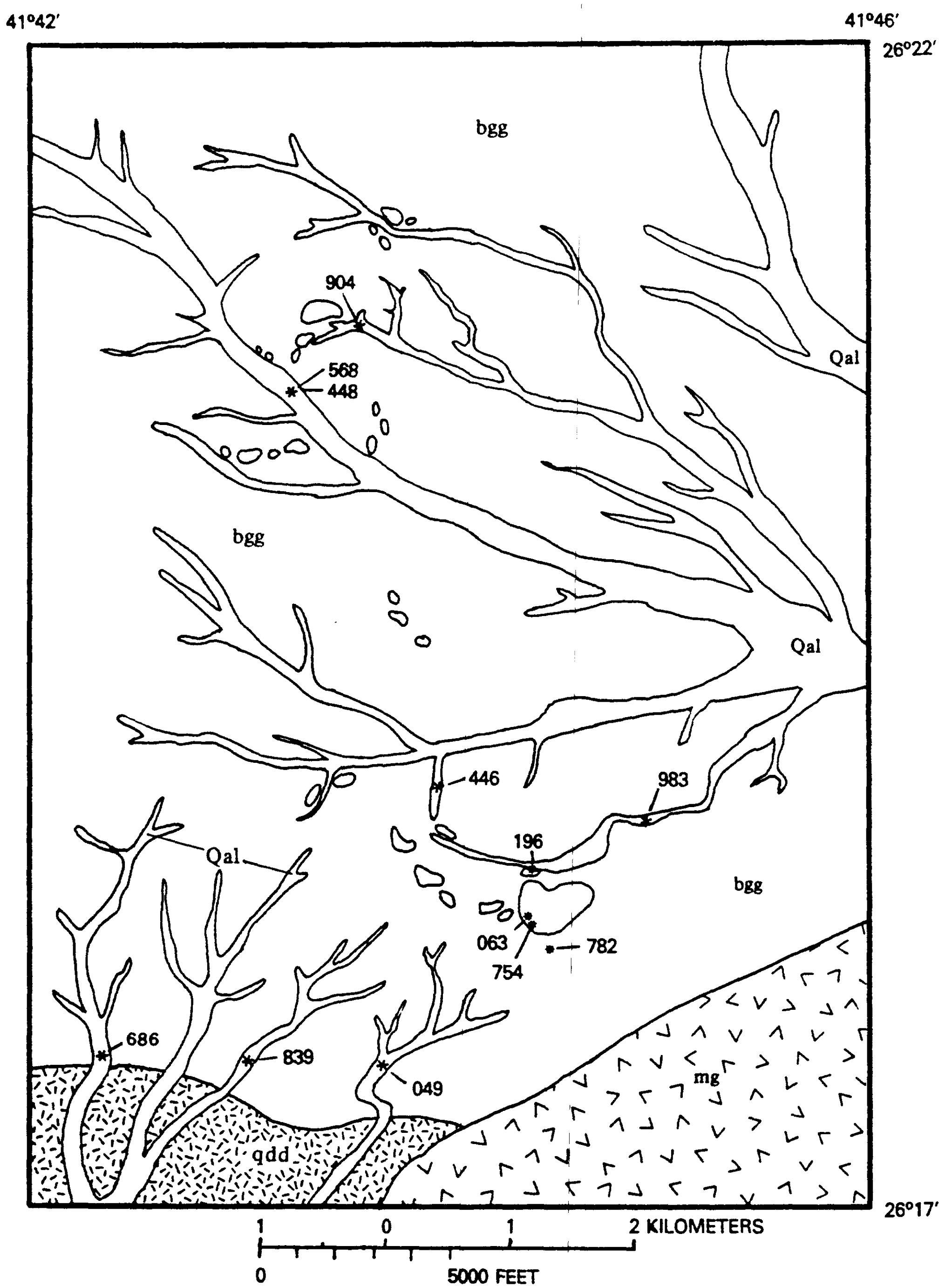
Figure 17.--Index map of the Wadi ash Shu'bah quadrangle, showing locations of detailed study areas.



EXPLANATION

Qal — Quaternary alluvium	qdd — Pre-Hadn quartz diorite and diorite
UNCONFORMITY	Gossan
bgg — Hulayfah group gneissic greenstone	Contact
mg — Pre-Hadn monzogranite	+ 102 Rock sample with site number

Figure 18.--Geologic map of the Murran gossan belt showing rock-sample sites. Modified from Quick and Doebrich (1984), see table 4.



EXPLANATION

Qal - Quaternary alluvium

UNCONFORMITY

bgg Hulayfah group gneissic greenstone

mg Pre - Hadn monzogranite

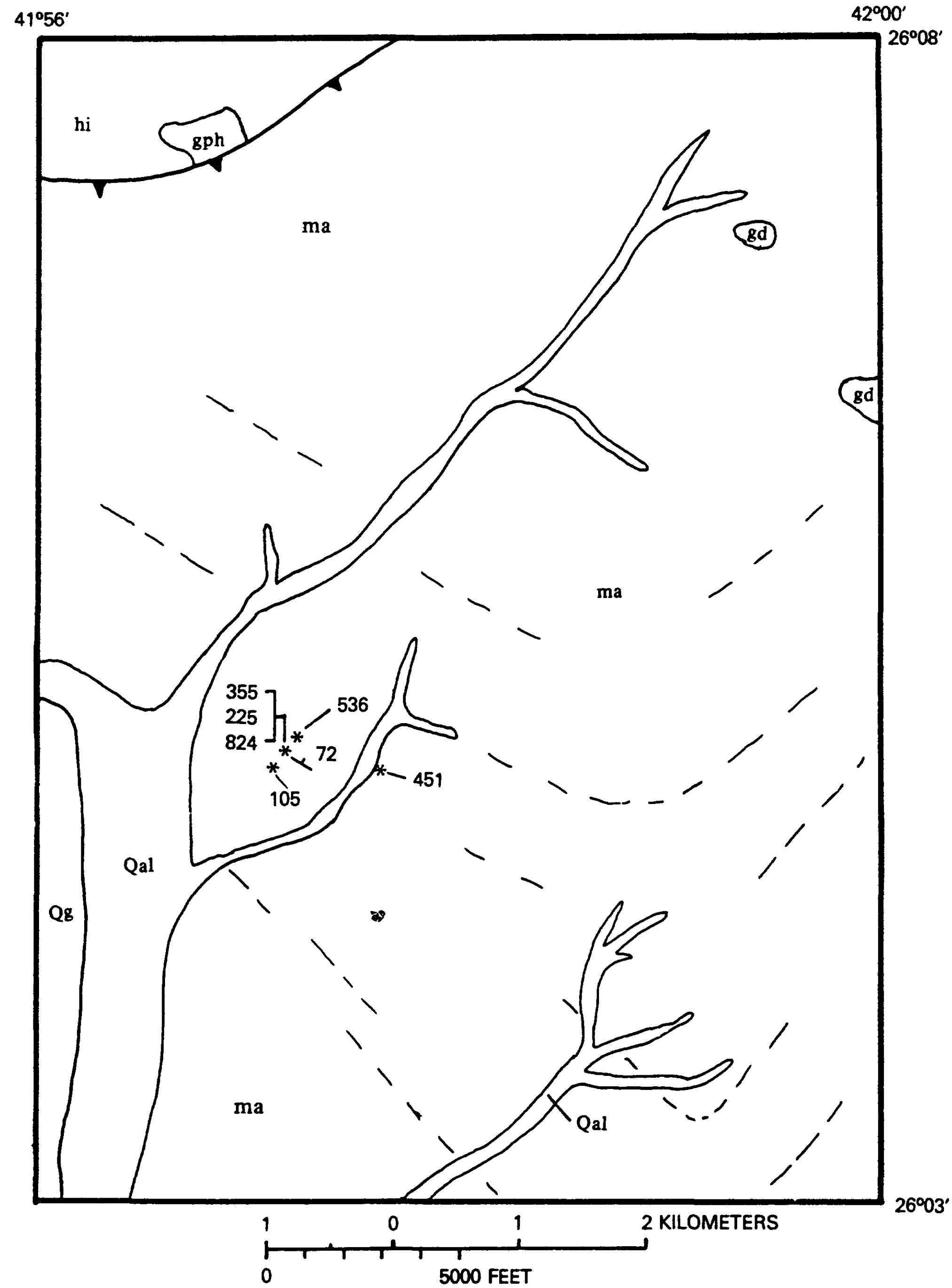
qdd Pre -Hadn quartz diorite and diorite

Gossan

Contact

*307 Wadi sample with site number

Figure 19.--Geologic map of the Murran gossan belt showing wadi-sample sites. Modified from Quick and Doebrich (1984), see table 3.



EXPLANATION

Qal	Alluvium
Qg	Sheet Gravels
UNCONFORMITY	
gph	Granophyre
gd	Granodiorite
hi	Hibshi Formation
UNCONFORMITY	
ma	Maraghan Formation
———	Contact
*122	

Figure 20.--Geologic map of the Mishash ar Rafi shale area showing rock-sample sites. Modified from Williams and Simonds (1985), see table 6.

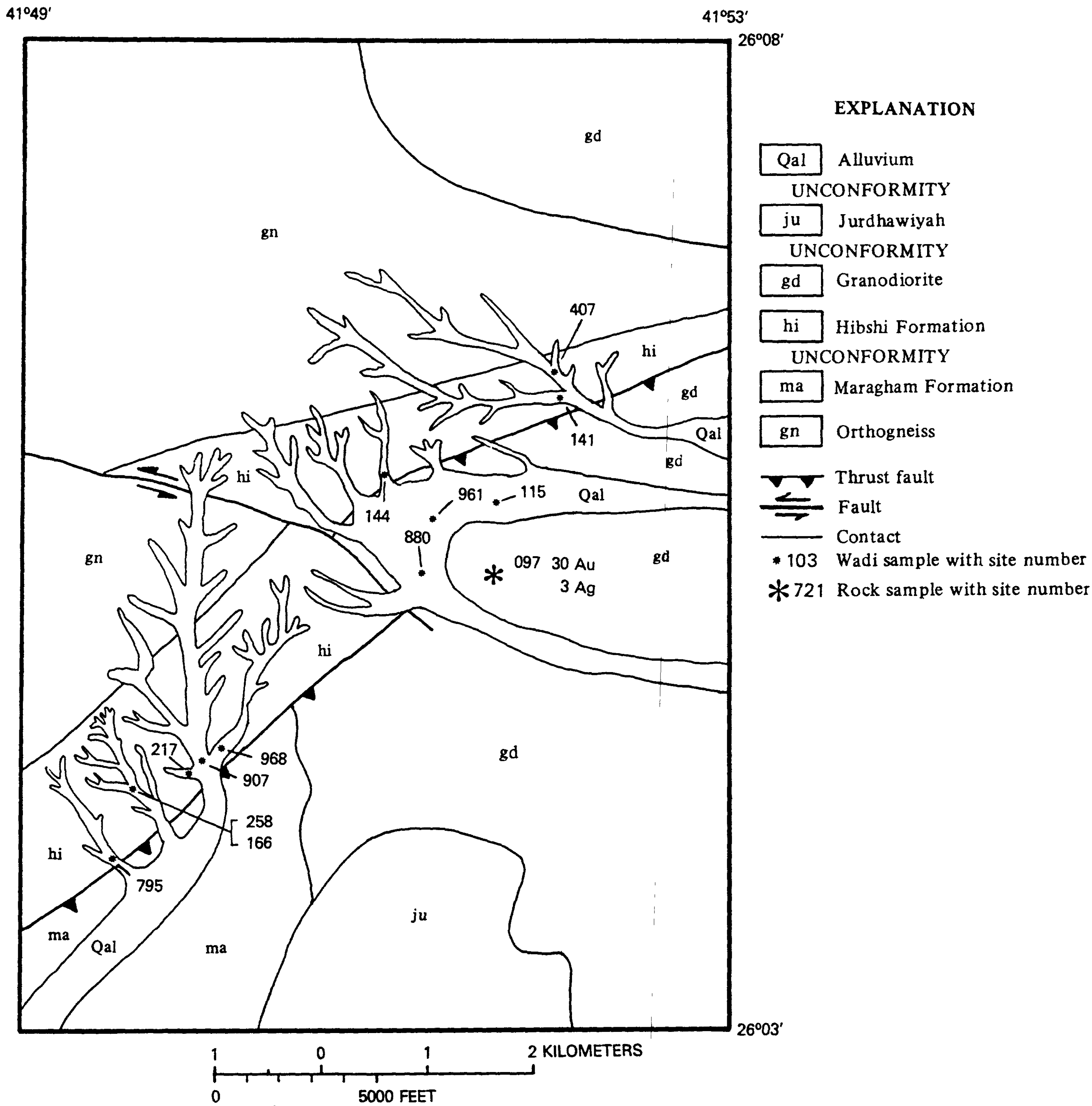


Figure 21.--Geologic map of the Rawdat al Ba'ayith gold area showing sample sites. Modified from Williams and Simonds (1985), see table 7.

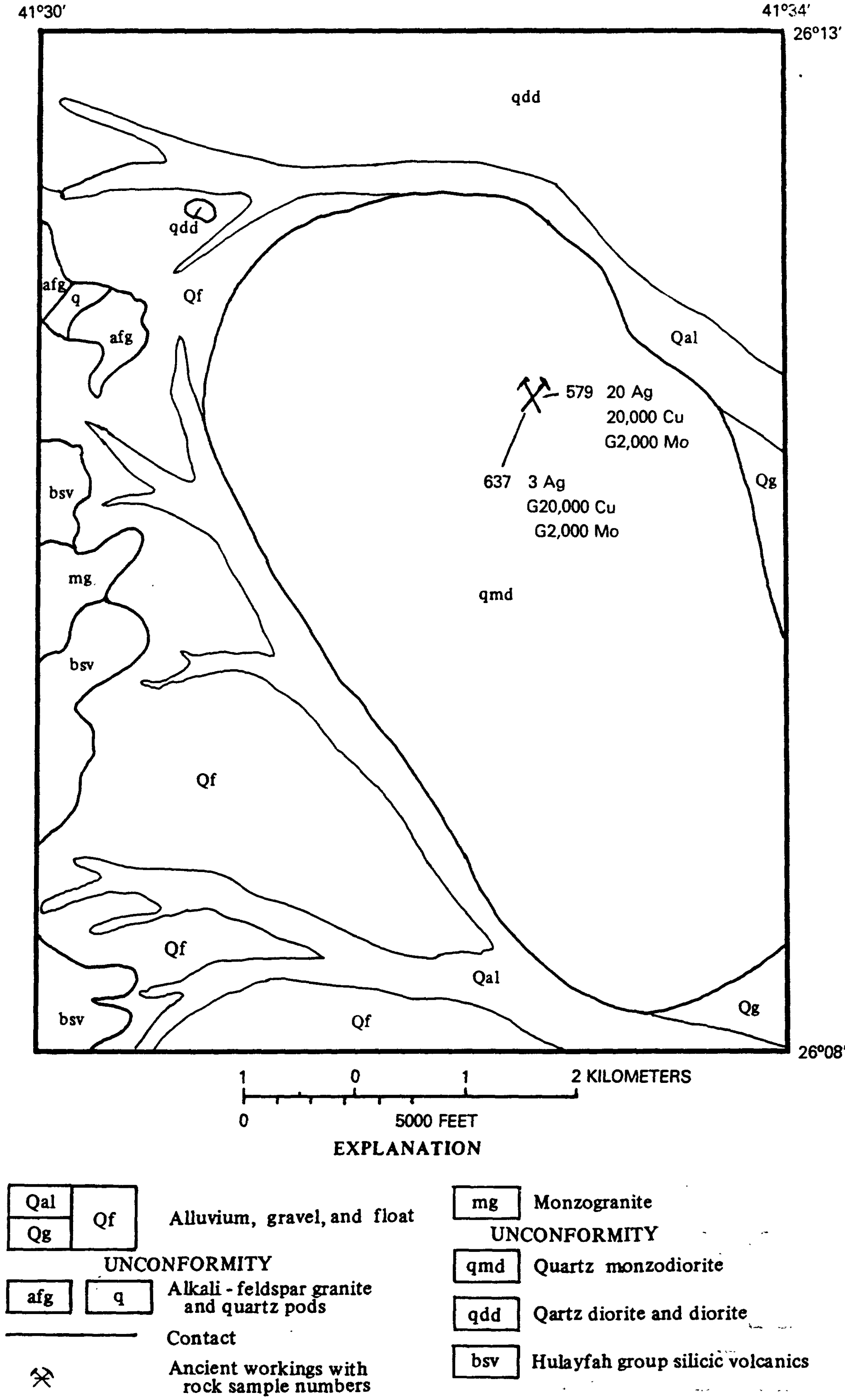
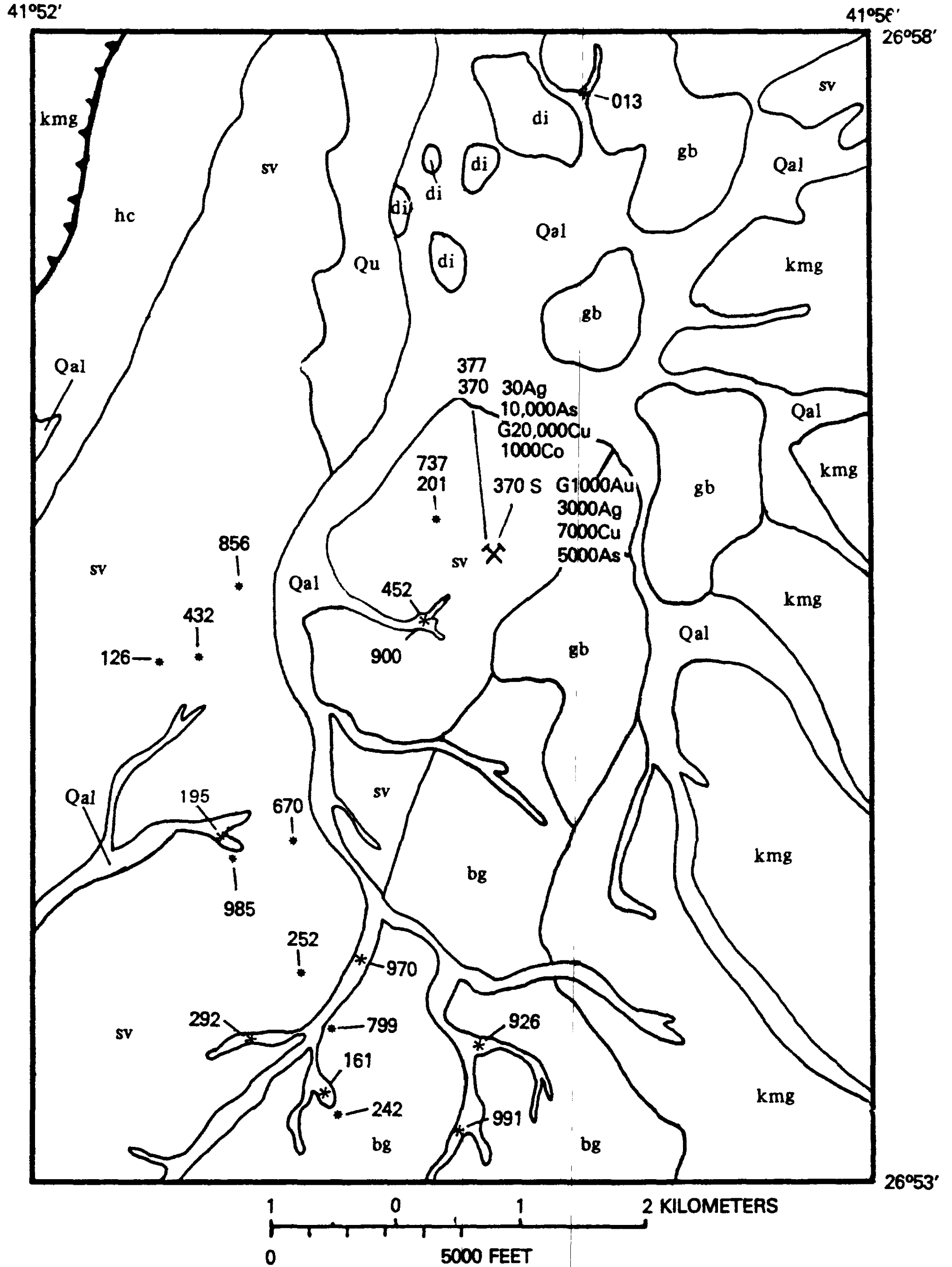


Figure 22.--Geologic map of the Jibal Abid Cu-Mo-Ag area showing sample sites. Modified from Williams and Simonds (1985), see table 8.



EXPLANATION

Qal	Qu	Alluvium and undivided Quaternary deposits

UNCONFORMITY

gb	di	Gabbro and diabase

UNCONFORMITY

hc	Hadn formation conglomerate

Contact

Thrust fault

kmg	Kilab monzogranite

bg	sv	Hulayfah group greenstone and silicic volcanics

Ancient working

• 307 Rock sample with site number

* 249 Wadi sample with site number

✱ 3705 Soil sample with site number

Figure 23.--Geologic map of the Aqab gossan area showing sample sites. Modified from Quick and Doebrich (1984), see tables 9 and 10.

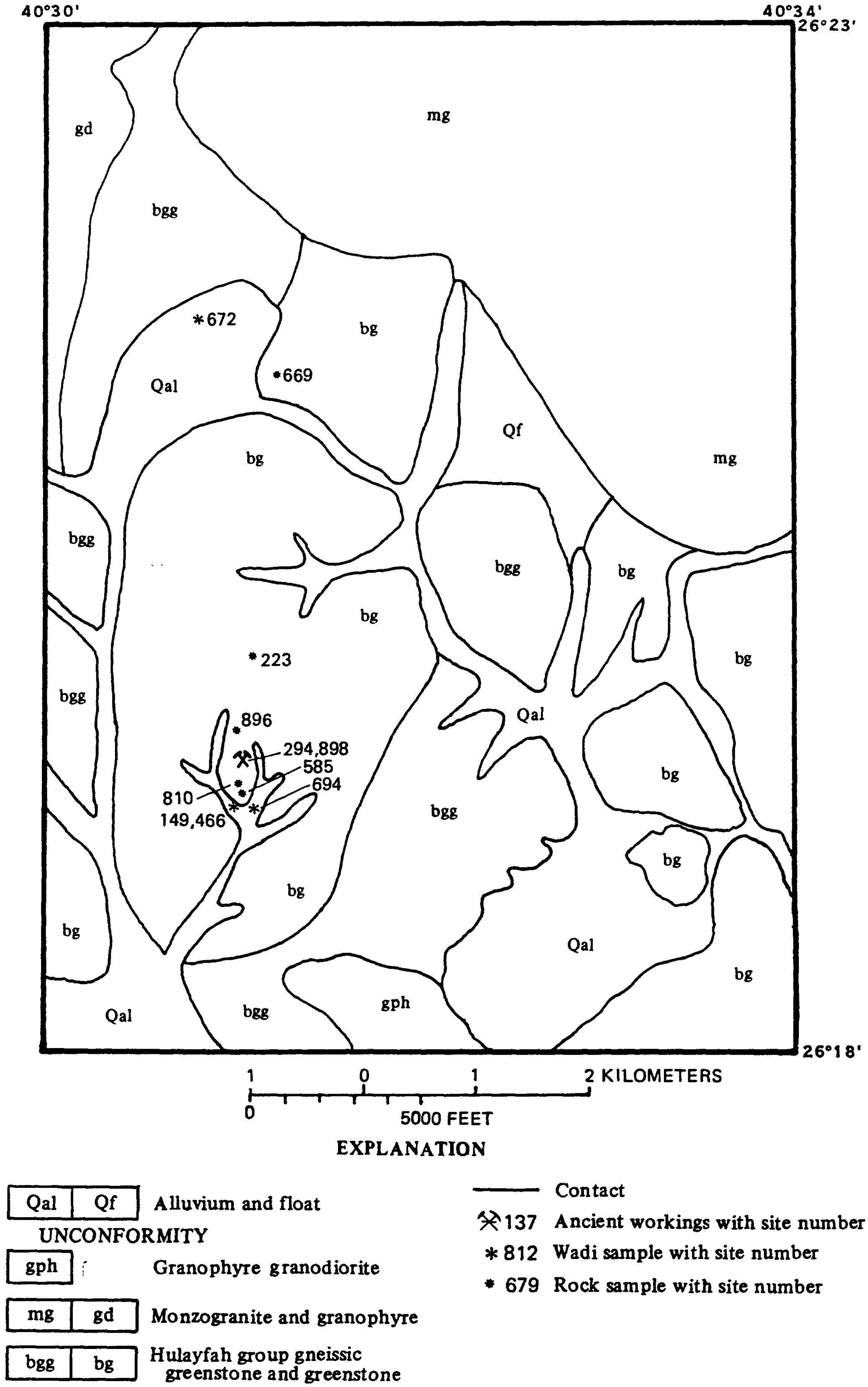


Figure 24.--Geologic map of the Rawdh gossan area showing sample sites. Modified from Quick and Doebrich (1984), see tables 11 and 12.

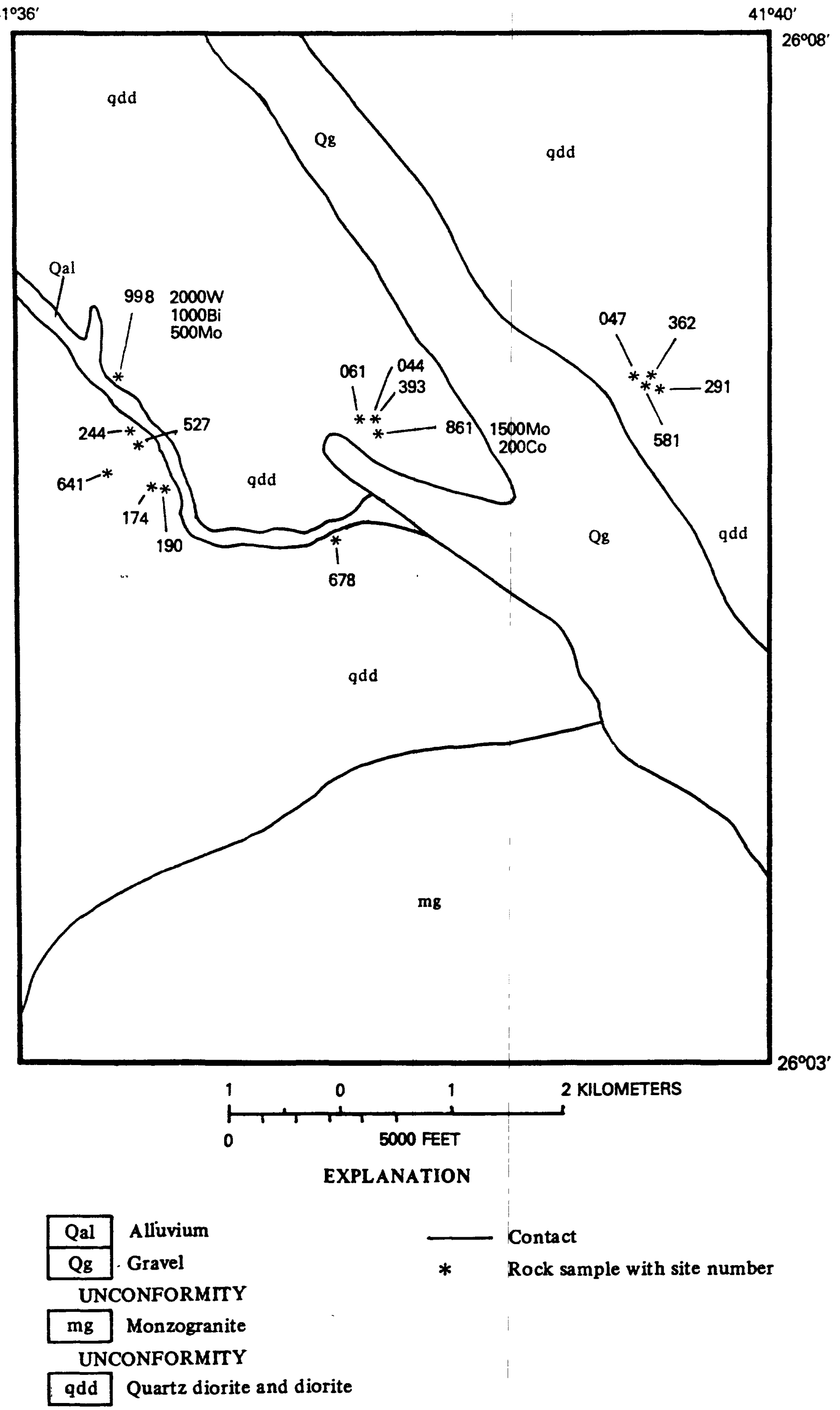
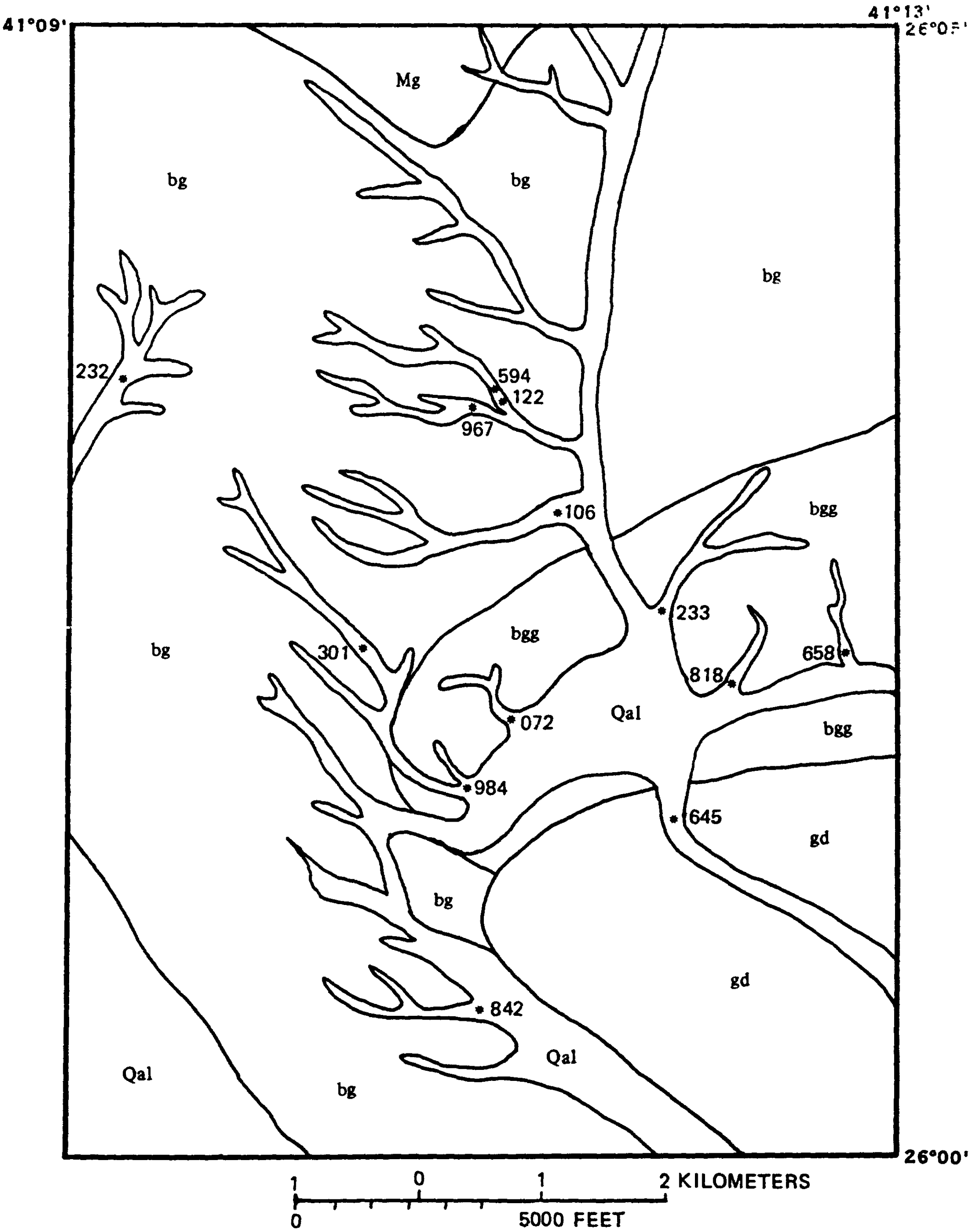


Figure 25.--Geologic map of the Rijalt al Aspar quartz vein area showing sample sites. Modified from Williams and Simonds (1984), see table 13.

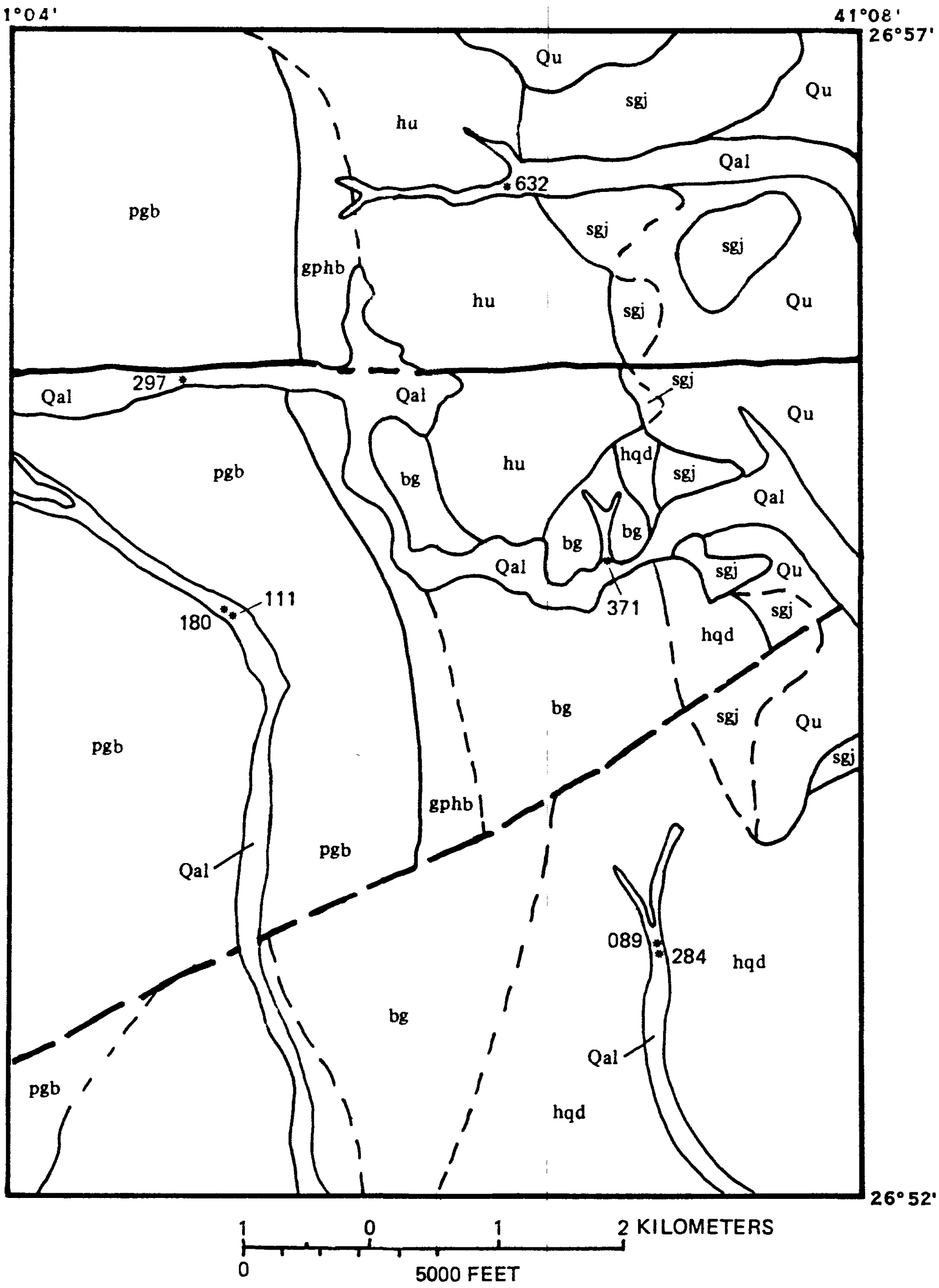


EXPLANATION

Qal	Quaternary alluvium
UNCONFORMITY	
Mg	Pre-Hadn monzogranite
gd	Pre-Hadn granodiorite
bgg | bg	Hulayfah group gneissic greenstone and greenstone

———	Contact
⚒	Ancient workings
* 233	Wadi sample with site number

Figure 26.--Geologic map of the Wadi al Qahad skarn area showing wadi-sample sites. Modified from Quick and Doebrich (1984), see table 14.



EXPLANATION

Qal / Qu	Quaternary alluvium and undifferentiated deposits
gphb	Ba'gham porphyritic granophyre
pgb	Ba'gham granite
sgj	Jufayfah syenogranite
hu	Hadn formation
sgm	Magnetite syenogranite
hqd / bg	hqd - Hornblende quartz diorite bg - Banana greenstone
(heavy line)	Fault, dashed where inferred
(line)	Contact, dashed where inferred
* 111	Wadi sample with site number

Figure 27.--Geologic map of the Jibal Ba'gham area showing wadi-sample sites. Modified from Quick (1983).

SUMMARY AND CONCLUSIONS

Areas within the Wadi ash Shu'bah quadrangle are assigned moderate or high mineral resource potential (fig. 28) on the basis of the results of the regional and follow-up geochemical surveys. Four genetically distinct types of mineralization can be identified within the quadrangle. The first type is base-metal with minor precious-metal mineralization within the Hulayfah group. The surface expression for this type of mineralization is typified by silicious iron-rich gossans and is believed to represent submarine exhalative-type massive-sulfide mineralization. The gossans are leached of any sulfide minerals at the surface, but may contain occasional malachite and azurite coatings. None of the rocks collected from gossans contained high concentrations of metals. This may be due to chemical leaching of shield rocks during the time that these rocks were subjected to chemical weathering. Although the gossans are not readily detectable from the wadi-sediment geochemical surveys, they can be identified from the air during helicopter reconnaissance.

Within the Wadi ash Shu'bah quadrangle, massive-sulfide mineralization associated with the Hulayfah group has the highest resource potential of any deposit types. In order to adequately evaluate gossans, such as those of the Murran gossan belt, drilling below the zone of chemical weathering is necessary. Gossans have a high resource potential for base and precious metals.

The second type of mineralization found in the quadrangle is associated with the emplacement of pre-Hadn intermediate-composition plutons (fig. 28). This type of mineralization consists of base and precious metals associated with quartz veins. The ancient gold and base-metal workings are often associated with this type of occurrence. The mineralization is usually associated with small monzogranite to granodiorite plutonic bodies, indicating that the veins are present in the upper part of the pluton where late-stage hydrothermal fluids would tend to accumulate during emplacement. Generally, the larger and more deeply eroded plutons no longer contain associated mineralization. The small volume of mineralized veins indicate moderate resource potential for most of these occurrences. The Jibal Abid and Rawdat al Ba'ayith areas may be associated with more extensive stockworks and so have high resource potential.

The third type of mineralization is skarn mineralization associated with the emplacement of pre-Hadn intermediate-composition plutons into Hulayfah-group greenstones containing limestone beds. The Wadi al Qahad area is the only known example of this type of mineralization in the quadrangle and consists of tin and base metals associated with skarn.

The fourth type of mineralization found in the quadrangle is tin and tungsten mineralization associated with late-stage emplacement of post-orogenic alkalic granites (fig. 28). No mineral occurrences of this type were identified during this survey, but areas of resource potential were identified. The Silsilah tin prospect in the Jabal Habashi quadrangle (sheet 26F) (du Bray, 1984) and the Baid al Jimalah West tungsten prospect in the Aban al Ahmar quadrangle (sheet 25F) (Cole and others, 1981) are good examples of this type of mineralization. Both prospects are located within the upper parts of young post-orogenic alkalic granites similar to those present within the Wadi ash Shu'bah quadrangle.

Low to moderate potential for tin and tungsten resources, associated with alkalic granite plutons.

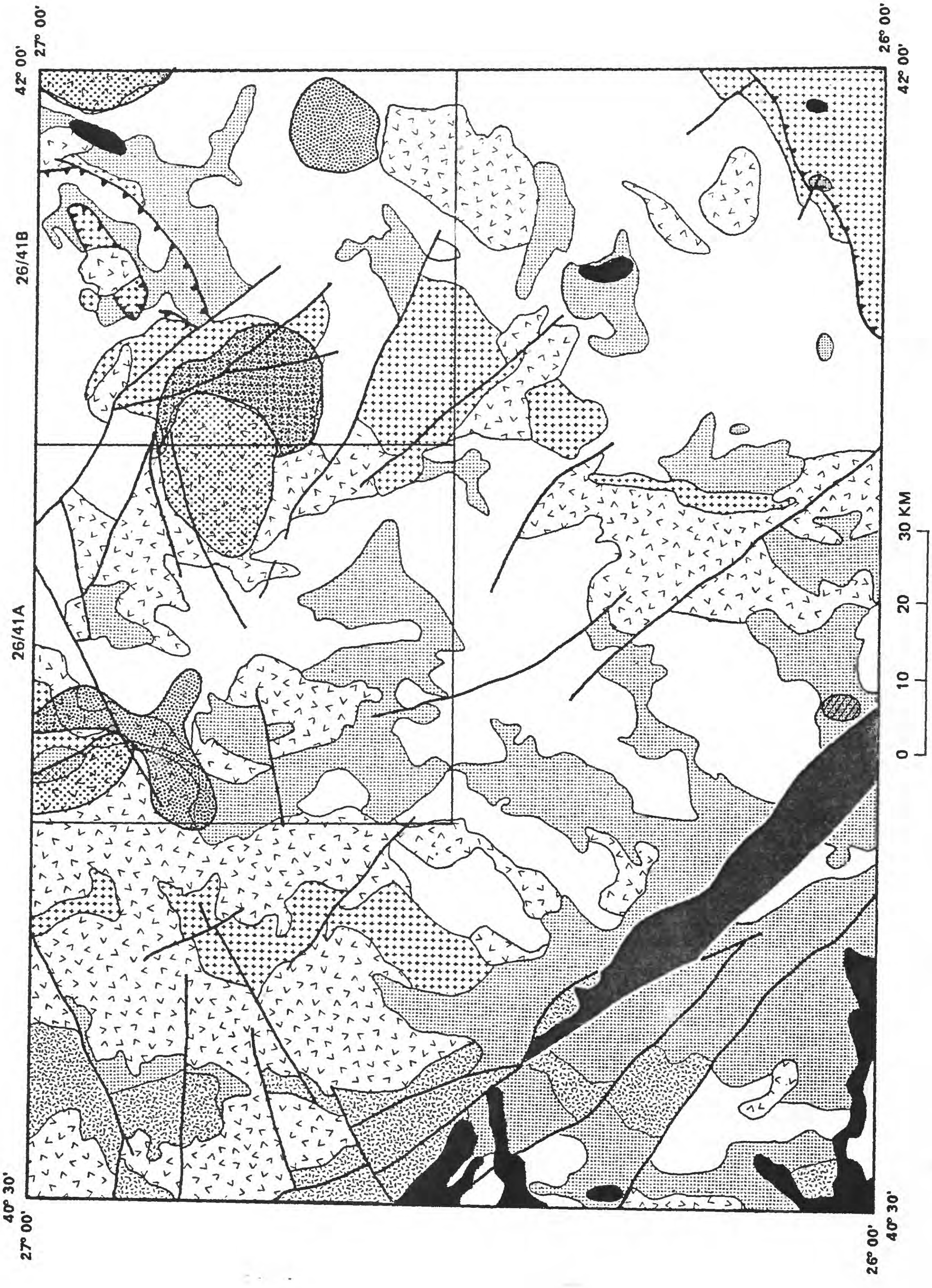
Low to moderate potential for tin and tungsten resources, associated with possible unexposed alkalic granites.

Moderate to high potential for massive sulfide-type resources.

Moderate to high potential for base- and precious-metal resources, associated with pre-Hadn intermediate plutons.

Moderate potential for tin resources in skarn deposits associated with pre-Hadn intermediate plutons.

Figure 28.--Mineral favorability map based on regional and follow-up geochemistry, Wadi ash Shubah quadrangle. Geologic map units same as figure 2.



42° 00'
27° 00'
26/41B
26/41A
40° 30'
27° 00'
26° 00'
42° 00'
26° 00'
40° 30'
0
10
20
30 KM

The alkalic granites in the Wadi ash Shu'bah quadrangle are generally deeply eroded, and so any associated mineralization has been removed; therefore, the country rock surrounding these evolved plutons at Jibal Salma, Jibal Rumman al Humr, and the Ba'gham granite are considered to have moderate to high resource potential for tin and tungsten. In addition, the area south and east of the Ba'gham granite and the area within the Kilab monzogranite are considered to have moderate resource potential for tin and tungsten (fig. 28). This conclusion is based upon moderate concentrations of La, Nb, Y, and Sn thought to be associated with shallow alkalic plutons that have not been exposed or are only partially exposed at the surface.

The occurrence of La, Y, and Nb within the alkalic-granites of the quadrangle indicates moderate potential for rare-earth elements in veins and pegmatites. Rare-earth and thorium minerals are associated with the Ba'gham granite (Quick and Doebrich, 1984).

DATA STORAGE

DATA FILE

Field and laboratory contributing to this report are stored in Data File USGS-DF-06-10 in the Jeddah office of the U.S. Geological Survey Mission. This Data File contains:

Field notes
Sample location maps
Single element and factor plots

MINERAL OCCURRENCE DOCUMENTATION SYSTEM

The following new mineral localities were established in the Wadi ash Shu'bah quadrangle and entered into the MODS (Mineral Occurrence Data System) system:

Mishash ar Rafi	Cu, Au	10/86
Rawdat al Ba'ayith	Au	10/86
Rijlat al Ahsgar	Bi, Mo, W	10/86

Bibliographies for mineral occurrences in the Wadi ash Shu'bah quadrangle were updated for the following localities:

3104	Aqab	Au, Ag	10/86
3156	Jibal Ba'gham	REE, Sn	10/86
3897	Wadi al Qahad	Sn	10/86
3900	Rawdh	Pb, Ag	10/86
3903	Jabal Abid	Cu, Mo, Ag	10/86
3902, 4249,	Murran	Au, base metals	10/86

REFERENCES CITED

Allen, M. S., Tidball, R. R., Samater, R., and Selner, G.L., 1984, Interpretation of geochemical data from panned concentrates of wadi sediments using R-mode factor analysis, Jabal Habashi quadrangle, sheet 26F, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-04-45, 51 p. Also USGS OPen-File Report 85-5.

Blain, C. F., 1981, Geochemistry of the gossans at Wadi Wassat, Kingdom of Saudi Arabia: Saudi Arabian Directorate General for Mineral Resources Miscellaneous Document 25 (IR 359), 71 p. On file in the Jiddah office of the U.S. Geological Survey Saudi Arabian Mission.

Boyle, R. W., 1979, The geochemistry of gold and its deposits: Geological Survey of Canada Bulletin 280, 584 p.

Brown, G. F., Layne, N. M., Goudarzi, G. H., and MacLean, W. H., 1963, Geologic map of the Northeastern Hijaz quadrangle, Kingdom of Saudi Arabia: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-205A, scale 1:500,000 (Reprinted 1979, Saudi Arabian Directorate General of Mineral Resources Geologic Map GM-205-A, scale 1:500,000).

Cole, J. C., Smith, C. W., and Fenton, M. F., 1981, preliminary investigation of the Baid al Jimalah tungsten deposit, Kingdom of Saudi Arabia: U.S. Geological Survey Saudi Arabian Mission Technical Record 20 (Interagency Report 377), 26 p. Also USGS Open-File Report 81-1223.

Cole, J. C., 1986, Geology of the Aban al Ahmar quadrangle, sheet 25F, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-04-9, 87 p., scale 1:250,000. On file in the Jiddah office of the U.S. Geological Survey Saudi Arabian Mission.

Davis, J. C., 1973, Statistical and data analysis in geology: John Wiley & Sons, Inc., New York, 550p.

Deer, W. A., Howie, R. A., and Zussman, J., 1967, An Introduction to the Rock-Forming Minerals: John Wiley and Sons, New York, 528 p.

Delfour, Jacques, 1977, Geology of the Nuqrah quadrangle, sheet 25E, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Geologic Map GM-28, 32 p., scale 1:250,000.

du Bray, E. A., 1984, Geology of the Silsilah ring complex, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Technical Record USGS-TR-04-19, 78 p. Also USGS Open-File Report 85-253.

Elliot, J. E., 1983, Peralkaline and peraluminous granites and related mineral deposits of the Arabian Shield, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-03-56, 37 p. Also USGS Open-File Report 83-389.

Greenwood, W. R., 1973, The Ha'il arch -- a key to the Arabian Shield during the evolution of the Red Sea rift: Saudi Arabian Directorate General of Mineral Resources Bulletin 7, 5 p.

Goudarzi, G. H., 1984, Guide to preparation of mineral survey reports on public lands: U. S. Geological Survey Open-File Report 84-787, 37 p.

Jackaman, Barry, 1972, Genetic and environmental factors controlling the formation of the massive sulphide deposits of the Wadi Bidah and Wadi Wassat, Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Technical Record TR-1972-1, 244 p.

Leo, G. W., 1984, Reconnaissance geology of the Al 'Awshaziyah quadrangle, sheet 26/41B, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-04-33, 29 p., scale 1:100,000. Also USGS Open-File Report 84-390.

Miller, W. R., and Arnold, M. A., 1987, Results of a geochemical survey, Aban al Ahmar quadrangle, sheet 25F, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry of Natural Resources Technical Record USGS-TR-07-3, 76 p. Also USGS Open-File Report 88-605.

Motooka, J. M., and Grimes, D. J., 1976, Analytical precision of one-sixth order semiquantitative spectrographic analyses: U. S. Geological Survey Circular 738, 25 p.

O'Neill, J. M., and Ferris, D. C., 1985, Reconnaissance geology of the Ar Rawd quadrangle, sheet 26/40D, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-05-3, 24p., scale 1:100,000. Also USGS Open-File Report 85-659.

Overstreet, W. C., 1978, A geological and geochemical reconnaissance of the Tathlith one-degree quadrangle, sheet 19/43, Kingdom of Saudi Arabia: U. S. Geological Survey Saudi Arabian Project Report SA(IR)-230, 132 p. Also USGS Open-File Report 78-1072.

Overstreet, W. C., and Day, G. W., 1985, Review of the use of magnetic concentrates in geochemical exploration: Saudi Arabian Deputy Ministry for Mineral Resources Technical Record USGS-TR-05-4, 38 p. Also USGS Open-File Report 85-541.

Pallister, J. S., 1984, Reconnaissance geology of the Harrat Hutaymah quadrangle, sheet 26/42C, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-04-46, 77 p., scale 1:100,00. Also USGS Open-File Report 85-125

Quick, J. E., 1983, Reconnaissance geology of the Ghazzalah quadrangle, sheet 26/41A, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-03-91, 44 p., scale 1:100,000. Also USGS Open-File Report 83-331.

Quick, J. E., 1984a, Reconnaissance geology of the Zarghat quadrangle, sheet 26/40B, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-04-28, 379 p., scale 1:100,000. Also USGS OPen-File Report 84-794.

Quick, J. E., 1984b [1985], Reconnaissance geology of the As Sulaymi quadrangle, sheet 26/41C, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-05-4, 20 p., scale 1:100,000. Also USGS OPen-File report 85-619.

Quick, J. E., and Doebrich, J. C., 1984, Reconnaisannce geology of the Wadi ash Shu'bah quadrangle, sheet 26E, Kingdom of Saudi Arabia, with a Geographic map compiled by Jack D. Turner: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-04-11, 36 p., scale 1:250,000. Also USGS Open-File Report 87-501.

Richter, D. H., Allen, M. S., duBray, E. A., Klienkopf, M. D., Pallister, J. S., Raines, G. L., Smith, C. W., and Williams, P. L., 1984, Metallic-Mineral assessment of the Jabal Habashi quadrangle, sheet 26F, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Technical Record USGS-TR-04-8, scale 1:250,000.

Routhier, P., and Delfour, J., 1979, Lithology of massive sulfide deposits associated with acid volcanism and its application to the search for such deposits in the precambrian of Saudi Arabia: Saudi Arabian Directorate General for Mineral Resources Mineral Resources Bulletin 18, 61 p.

Ryall, W. R., and Taylor, G. F., 1981, Gossan evaluation manual for use in the Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Technical Report RF-TR-01-3, 146 p.

Rummel, R. J., 1970, Applied factor analysis: Northwestern University Press, Evanston, 617 p.

Stoeser, D. B., and Camp, V. E., 1985, Pan-African mircroplate accretion of the Arabian Shield: Geological Society of America Bulletin, v. 96, p. 817-826.

Stuckless, J. S., Hedge, C. E., Wenner, D. B., Nkomo, I. T., 1984, Isotopic studies of postorogenic granites from the northeastern Arabian Shield, Kingdom of Saudi Arabia: Unpublished data on file in the Jiddah office of the U.S. Geological Survey Saudi Arabian Mission.

Vantrump, G., Jr., and Miesch, A. T., 1977, The U.S. Geological Survey RASS-STATPAC system for managment and statistical reduction of geochemical data: Computors & Geosciences, v. 3, p. 475-488.

Wedepohl, K. H., ed., 1969-1978, Handbook of Geochemistry: Vols. 1-4, Springer-Verlag, Berlin.

Whitney, J. W., 1983, Erosional history and surficial geology of western Saudi Arabia: U.S. Geological Survey Saudi Arabian Mission Technical Record USGS-TR-04-1, 90 p. On file in the Jiddah office of the U.S. Geological Survey Saudi Arabian Mission.

Williams, P. L., 1983, Reconnaissance geology of the Samirah quadrangle, sheet 26/42C, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-04-3, 33 p., scale 1:100,000. Also USGS Open-File Report 84-383.

Williams, P. L., and Simonds, F. W., 1985, Reconnaissance geology of the Al Ba'ayith quadrangle, sheet 26/41D, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-file Report USGS-OF-05-18, 38 p., scale 1:100,000. Also USGS OPen-File Report 85-617.