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THE MINERAL RESOURCE POTENTIAL OF THE HARRAT NAWASIF, SHEET 21/42 C, RANYAH, SHEET 21/42 D, AND JABAL DALFA, SHEET 21/43 C, QUADRANGLES, KINGDOM OF SAUDI ARABIA

by

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ABSTRACT

Areas with mineral resource potential in the Harrat Nawasif, Ranyah, and Jabal Dalfa quadrangles in the central Precambrian Shield of Saudi Arabia have been identified by reconnaissance rock geochemistry and inspection of ancient prospects.

Locally anomalous areas in perthitic, alkalic granite terrane in the Ranyah quadrangle possibly contain niobium, zirconium, thorium, fluorite, rare-earth, tin, molybdenum, or copper mineralization. The reconnaissance rock geochemical survey in layered volcanic and volcaniclastic terrane in the Jabal Dalfa quadrangle identified a zinc anomaly in quartzite and a nickel-copper zone that is an extension of the Jabal Judayr prospect, where a low-grade nickel-copper sulfide deposit is known. The Precambrian terrane in the Harrat Nawasif quadrangle has no known mineral resource potential.

INTRODUCTION

Purpose and location

This report describes the results of a study to determine the mineral resource potential of the Precambrian terrane of the Harrat Nawasif, sheet 21/42 C, Ranyah, sheet 21/42 D, and Jabal Dalfa, sheet 21/43 C, quadrangles. These quadrangles are located within lat 21°00' N. and 21°30' N., and long 42°00' E. and 43°30' E. about 380 km east of Jiddah (fig. 1).

Previous mineral exploration

The Jabal Dalfa quadrangle (Greene, 1982, 1983) includes the northern part of the Jabal Ishmas-Wadi Tathlith gold belt, studied by Worl (1979, 1980). The gold deposits are within or adjacent to quartz veins or zones of quartz-rich breccia that cut greenschist-facies metavolcanic and volcaniclastic rocks. Greene (1982, 1983) after Worl (1979), describes and estimates the resource potential of four of the ancient gold mines in the Jabal Dalfa quadrangle. The Directorate General of Mineral Resources (DGMR) has completed a drilling program

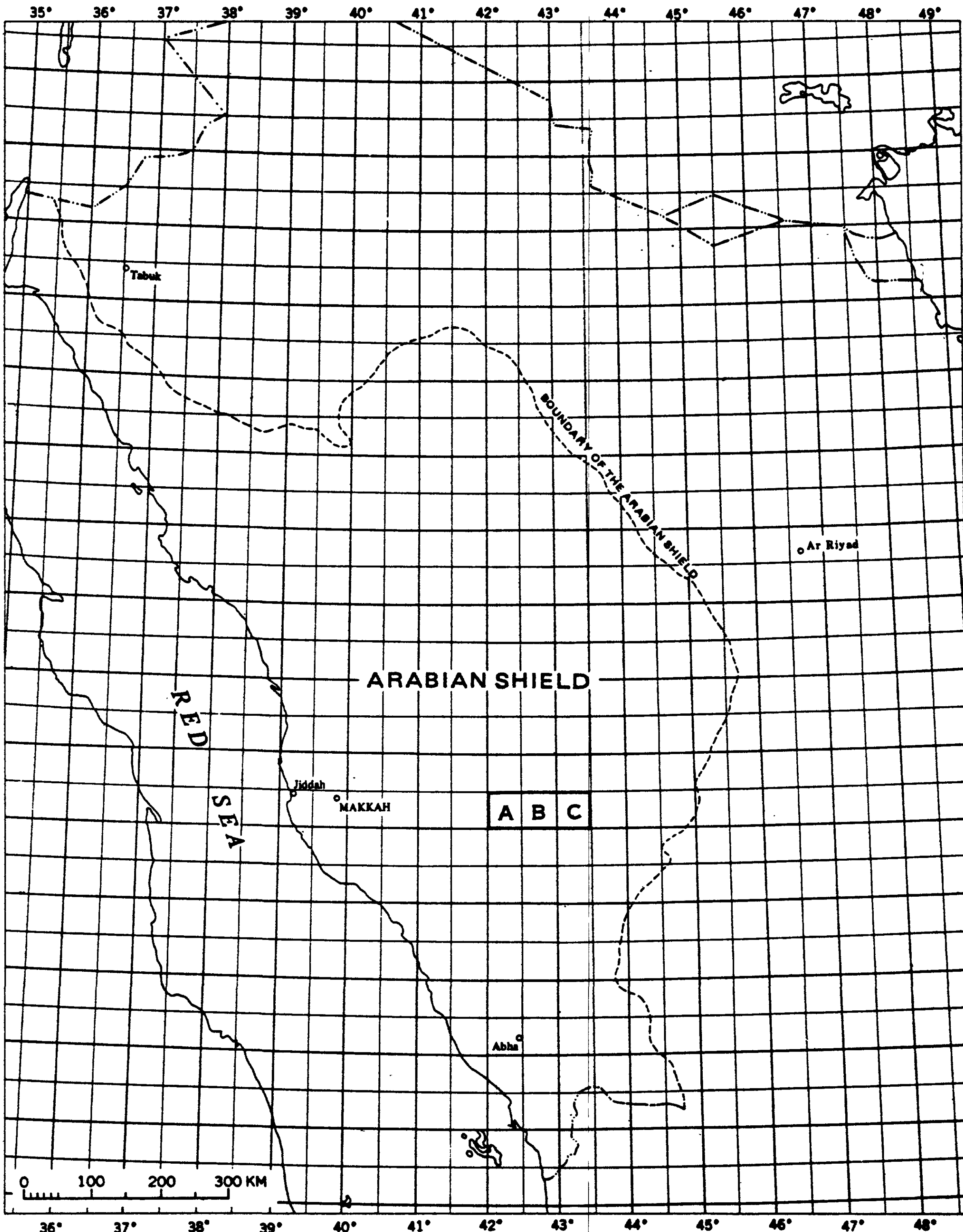

Figure 1.--Index map of western Saudi Arabia showing the location of the study area: A--Harrat Nawasif (Greene, in press); B--Ranyah (Greene, in press); C--Jabal Dalfa (Greene, 1982, 1983).

at the most northerly of these deposits, the Jabal Umm Matirah gold prospect (D. Hackett, written commun., 1982)

In the southeastern corner of the Jabal Dalfa quadrangle, the Jabal Judayr nickel-copper prospect consists of gossanous ultramafic and mafic rock. Gonzalez (1970), Puffett and others(1975, 1976), and Hadley (1976) reported mapping, surface geochemical sampling, geophysical studies, and drilling conducted at this prospect.

Greene (in press) reported anomalous metal values in a suite of 181 granitic rocks collected from granitic plutons in the Ranyah quadrangle. Whitlow(1966, 1971) and Theobald(1970, 1971) reported the results of reconnaissance wadi-sediment geochemical surveys in the Harrat Nawasif, Ranyah, and Jabal Dalfa quadrangles. The results of these rock and wadi-sediment surveys influenced the planning of geochemical work in this program.

Present study

The present study is based on the results of reconnaissance geologic mapping by Greene(in press, in press, 1982, 1983)and rock geochemistry programs reported in the literature. Samples for reconnaissance geochemical analyses were selected from rocks collected by Greene and additional rock samples were collected by the author. Known locations of mineralization have been evaluated by field inspection or by referral to published evaluations. Low-level helicopter traverses were used to search for areas of alteration.

An X-ray fluorescence spectrometer was used to determine the molybdenum, rubidium, strontium, yttrium, niobium, zirconium, and thorium contents of rock samples. These analyses were performed by the author and by F. Elsass and A. H. El Bazli. Copper, lead, zinc, gold, silver, cobalt, and nickel were measured by standard atomic-absorption methods; chromium was determined colorimetrically by the U.S. Geological Survey (USGS)/DGMR laboratory in Jiddah under the direction of K. J. Curry.

This investigation was performed in accordance with a work agreement between the Saudi Arabian Ministry of Petroleum and Mineral Resources and the USGS. The assistance of K. J. Curry, F. Elsass, G. I. Selner (USGS computer center), and A. H. El Bazli is gratefully acknowledged.

Data storage

Mineral localities referred to in this report are recorded in the Mineral Occurrence Documentation System (MODS) data bank and identified by a unique five-digit locality number (MODS xxxxx). The Jabal Silli West ancient prospect has been entered in MODS as file 02732 to mini-MODS standard. Data from geologic samples are recorded in the Rock Analysis Storage System (RASS) data bank and each sample is identified by a unique six-digit number (RASS yyyyyy). Inquiries regarding either bank may be made through the Office of the Technical Advisor, Deputy Ministry for Mineral Resources, Jiddah, Saudi Arabia. No base data files have been established for this report.

PRECAMBRIAN GEOLOGY OF THE JABAL DALFA QUADRANGLE

The following discussion of Precambrian geology of the Jabal Dalfa quadrangle is adapted from Greene (1982, 1983) who mapped the quadrangle at the scale of 1:100,000. Subsequent geochemical studies reported here are based on his observations of geology and geochemistry.

Metavolcanic and metasedimentary rocks

A complex of serpentinite, amphibolite, metabasalt, and andesite containing minor beds and lenses of carbonate rock (serpentinite, and metavolcanic and carbonate rocks, sbc) crops out at the west-central border of the quadrangle. A similar unit, serpentinite, marble, and metabasalt (smb), crops out about 33 km to the east. Several small areas near the southeastern corner of the quadrangle are underlain by anthophyllite-carbonate rock and serpentine-carbonate rock (ultramafic-carbonate rocks, umc).

Metabasaltic flow rock is exposed in three areas. The prominent Jabal Dalfa in the middle of the quadrangle is composed of metabasalt and amphibolite (metabasalt of Jabal Dalfa, mbd). Amphibolite (am) also crops out in the northwestern corner of the quadrangle. Serpentinite, talc schist, metabasalt, and meta-andesite have been extensively intruded by metagabbro, granite, and metavolcanic and ultramafic rocks (ggvu) in the southeastern corner.

Metabasalt and meta-andesite flow rocks are mixed in three areas. Metabasalt and meta-andesite flow rock and tuff at the west-central border extend into the Ranyah quadrangle (metabasalt and meta-andesite of Rawdah, bar). An extensive area in the central part of the Jabal Dalfa quadrangle is underlain by fine-grained metabasalt and meta-andesite flow rock and fragmental rocks of similar composition (metabasalt and meta-andesite of central belt, mbac). In the southeast, an extensive unit of serpentinite with interlayered marble and metabasalt (smb) is adjacent to granite and gabbro to the east. Metabasalt and meta-andesite of Umm Shat (mbas) underlie the area to the west.

At the western edge of the Umm Shat unit, felsic volcanic rock crops out in several areas. The rock is mostly dacite flow rock and tuff with some rhyodacite, andesite, and marble (dacite and dacite tuff, ds). This rock seems to represent the culmination of a differentiation cycle that began by producing mafic to ultramafic volcanic rock and gradually produced more felsic flow rock and pyroclastic rock.

In the northeastern section of the quadrangle, the Arfan formation that Hadley (1976) established in the adjacent Bir Juqjuq quadrangle has been divided into eight informal units. A narrow belt of predominantly fine-grained or brecciated metabasalt with subordinate meta-andesite and minor carbonate rock and serpentinite (bcas) is at the southwestern edge of the exposed formation. A volcanic sandstone, conglomerate, and meta-andesite unit (scg) is immediately to the northeast. The sandstone consists of medium- to coarse-grained, angular andesite to dacite rock fragments (80 to 90 percent), and quartz and plagioclase (5 to 10 percent), in a matrix of quartz, chlorite, and opaque minerals. The sandstone grades into conglomerate of similar composition containing pebbles as large as 10 mm in diameter. Adjacent to this unit are meta-andesite (ma), metabasalt (mba), and metaquartzose sandstone and serpentinite (sss). The metadacite and meta-andesite (mda) of Jabal Umm Matirah are in contact with the sandstone and serpentinite. Several thin units of pyroxenite (px), metadacite and meta-andesite (adm), and feldspathic sandstone and conglomerate (cgg) are within the intrusive gneiss in the extreme northeastern corner of the quadrangle.

Mixed rocks

Map units of combined volcanic layered and intrusive rock include a small outcrop of meta-andesite and diorite (mad) in the southwestern corner of the Jabal Dalfa quadrangle, and metabasalt and intrusive granite, granodiorite, and tonalite gneiss (metabasalt of Jabal Dalfa and gneiss of Shaib Hadhaq, mg) in the northern and western parts of the quadrangle.

Ten km south of Jabal Silli, a large mass of intrusive granite, granodiorite, and tonalite gneiss has engulfed layers of metabasalt, marble, and plagioclase-pyroxene granofels (metavolcanic and granitic rocks of Urayyiq, vgu). Jabal Silli itself is underlain by a complex of predominantly metabasalt and amphibolite, with minor meta-andesite and rhyodacite, and rhyolite intruded by gabbro and pyroxenite (metavolcanic and intrusive complex of Jabal Silli, bjs). The distribution of the felsic rock may be more widespread than merely the single outcrop located near the eastern end of the jabal. The gabbro and pyroxenite intrusions seem to be intimately intermixed with the volcanic rock and all were probably formed at the same time. A very small outcrop of basaltic tuff is just east of Jabal Silli.

Plutonic rocks

Both metamorphosed and unmetamorphosed plutonic rocks were mapped in the Jabal Dalfa quadrangle. Interlayered hornblende- and plagioclase-rich gneisses (hornblende-plagioclase gneiss and plagioclase-quartz gneiss, gnh) that are the metamorphic equivalents of mafic tonalite, quartz diorite, and diorite and a tonalite gneiss (gnt) crop out in the extreme northeastern corner of the quadrangle. Small areas each of quartz diorite gneiss (qdg) and potassium feldspar-plagioclase-quartz augen gneiss (gn) are near the east-central border. The granite, granodiorite, and tonalite gneiss (gneiss of Shaib Hadhaq, gbh) in the southwestern quarter of the quadrangle correlates with a unit of mixed gneiss and basalt in the Ranyah quadrangle to the west.

In the extreme southeastern corner of the quadrangle, a small mass of tonalite, quartz diorite, and granodiorite (toq) is adjacent to a larger mass of two-mica granite (bg) containing potassium feldspar and plagioclase. Another two-mica granite (of Jabal Hadad, gh) is 11 km to the west and a small area of tonalite (toq) is 5 km to the northwest. One granite body (granite of Jabal ash Shayal, gs) is 5 km south of Jabal Silli and another is 3 km southwest of Jabal Dalfa (granite of Jabal Dalfa southwest, gsw). A small exposure of granodiorite (gd) is in the north-central part of the quadrangle.

Alkali-feldspar granite (ag) crops out 13 km northeast of Jabal Silli. A small exposure of quartz syenite (sy) is 10 km north of Jabal Dalfa.

Gabbro (gab) occurs in two areas of substantial size. One body of gabbro is northwest of Jabal Dalfa and the other is in the southwest where it extends into the Ranyah quadrangle. Both bodies appear to be layered, especially the latter, which seems to be partially funnel shaped.

PRECAMBRIAN GEOLOGY OF THE RANYAH AND HARRAT NAWASIF QUADRANGLES

The following discussion of Precambrian geology of the Ranyah and Harrat Nawasif quadrangles is adapted from Greene (in press, in press) who mapped the quadrangles at a scale of 1:100,000. Subsequent geochemical studies reported here are based on his observations of geology and geochemistry.

Metavolcanic and metasedimentary rocks

Three small areas near the southwestern corner of the Ranyah quadrangle are underlain by dark metasiltstone (ms) composed of quartz, feldspars, and clay minerals. Four small areas near the northwestern corner of the quadrangle consist of metabasalt and calc-silicate granulite grading to biotite-chlorite schist (granulite, schist, and metabasalt, gsb). The parent rock of these metasedimentary rocks was calcareous sandstone and siltstone.

The east-central and south-central portions of the Ranyah quadrangle are extensive areas of metabasalt and meta-andesite tuffs and flow rock (metabasalt and meta-andesite of Rawdah, bar), and at one locality (lat 21°10' N., long 42°56' E.) is a distinctive chert, chert breccia, and chert pebble conglomerate (ch). Locally, a shard texture suggests that the chert was a silicic ash-fall deposit. Several large gabbroic intrusive bodies (gab) seem to be genetically related to the metabasalt and meta-andesite. The large gabbroic mass in the south-central part of the quadrangle appears to be layered and dish shaped. Jabal Silli at the east-central border and extending into the Jabal Dalfa quadrangle is underlain by a complex of volcanic and possibly intrusive rock. In the Ranyah quadrangle, only metabasalt crops out at Jabal Silli (bjs) and it predominates as the Jabal extends to the east, where minor felsic volcanic and ultramafic rock crops out. West and south of Jabal Silli, two small areas are underlain by serpentinite, metabasalt, amphibolite, pyroxenite, and minor carbonate lenses (sbc).

Rhyolite flow rock is distributed throughout the unit of felsic volcanic rocks (of Al Khaniq, fvk) widely exposed in the central part of the Ranyah quadrangle. Rhyolite tuff (ash flow and ash fall) and breccia were found only in a small area at lat 21°14'0" to 21°15'5" N. and long 20°44' to 20°46' E. Dacite and andesite are also widely distributed and are the predominant rock north of lat 21°15'5" N. Field observations in one locality indicate that the felsic volcanic rock erupted soon after the metabasalt (bar) and that their relationship is conformable.

An area near the southeastern corner of the Harrat Nawasif quadrangle is underlain by locally porphyritic metabasalt and meta-andesite (mba). This rock is probably correlative with the granulite, schist, and metabasalt (gsb) of the Ranyah quadrangle and with metabasalt in the gneiss and metabasalt of Shaib Hadhaq (gbh) in the western part of Ranyah quadrangle.

Rhyolite (ry), including some tuff breccia, crops out in several small areas in the southeastern part of the Harrat Nawasif quadrangle. The rhyolite may be comagmatic with the perthite granite (grs and grf) described in the section that follows on plutonic rocks.

Mixed rocks

Intrusive granitic rock containing local residual blocks of older metabasalt and minor intrusive gabbro and felsic dikes underlies nearly all of the western half and the northeastern quarter of the Ranyah quadrangle and extends into the Harrat Nawasif quadrangle. Gneiss and metabasalt of Shaib Hadhaq (gbh) includes mostly granite and tonalite, some granodiorite, and minor amounts of alkali feldspar granite, syenite, and monzonite. The metabasalt in relatively minor amounts is interlayered with the gneiss and distributed uniformly throughout the outcrop area. Apparently, a granitic magma engulfed a terrane of metabasalt and minor metasedimentary rock. The tonalite, including the distinctive biotite tonalite (tb) gneiss in the far northwestern corner of the quadrangle, may be metasomatized volcanic rock. Tonalite (to) crops out in several small areas near the southeastern corner of the Harrat Nawasif quadrangle where it intrudes layered metabasalt and meta-andesite.

Near the southeastern corner of the Ranyah quadrangle, underlying metabasalt and gneissic granitic rock (volcanic and granitic rocks of Urayyiq, vgu) is similar to the gneiss and metabasalt of Shaib Hadhaq (gbh), except that the proportion of interlayered metabasalt is much greater (50 percent, or more) in the former. A thin, finely banded gneiss interpreted to be a metamorphosed felsic volcanic rock with a compositional range of rhyolite through andesite crops out at lat 21°05' N. long 42°56' E.

Plutonic rocks

Perthite granite of Kwar Barahah (grb) forms a prominent mountain range across the central part of the Ranyah quadrangle. This composite pluton is the northern extension of the red, fine- to coarse-grained, perthitic syenogranite of Jabal Kor in the Wadi al Miyah quadrangle (Schmidt, in press). Most of the granite is coarse grained and perthitic feldspar is ubiquitous. Only a few outcrops are porphyritic, having perthite megacrysts. Some granite, especially near the edges of the mountain range and near the contact with the felsic volcanic rock (fvk), is fine to medium grained. Coarser grained granite intrudes fine-grained granite throughout the quadrangle, and both types of granite intrude the felsic volcanic rock. This formation suggests a batholith that has intruded its own chill margin and its overlying, comagmatic, volcanic rock. The presence of sodium-rich amphibole in some of the granite suggests that it should be designated as alkalic granite (Stoeser and Elliott, 1980). According to C. R. Ramsay (DGMR, oral commun., 1981), approximately the northern half of the pluton is alkalic granite. The rock containing substantial plagioclase does not contain sodium-rich amphibole; therefore, it is metaluminous (calc-alkalic) granite.

In the northeastern quarter of the quadrangle, a small range of hills is composed of slightly perthitic granite (granite of Ar Ruzayzah, grr) that may be related to the perthite granite of Kwar Barahah (grb). This granite does not contain sodium-rich amphibole. A small area of porphyritic granite of Kwar Barahah (pgr) containing potassium feldspar phenocrysts is surrounded by the perthite granite at the southern border of the quadrangle.

A mass of perthite granite (perthite granite of Jabal Suily, grs) of various colors and textures crops out in the southwestern corner of the Ranyah quadrangle and in the Harrat Nawasif and Wadi al Miyah quadrangles. A medium- to very coarse grained, red perthite granite may be the most abundant variety. A second variety contains yellowish-gray to pink, very coarse grained perthite. A third variety is distinctively porphyritic, containing phenocrysts of perthite, plagioclase, and plagioclase-rimmed perthite (Rapakivi texture). This granite, containing locally distinctive blue amphibole, is slightly alkalic. Closely related to this granite is a fine-grained perthite granite (grf). Pink porphyritic granite (gpp) in the Ranyah quadrangle extends a short distance into the Harrat Nawasif quadrangle.

MINERALIZATION IN THE JABAL DALFA QUADRANGLE

Gold

The Jabal Dalfa quadrangle contains four known gold-quartz deposits of the northern part of the Jabal Ishmas-Wadi Tathlith gold belt (Worl, 1979, 1980). Gold is within or next to quartz veins or zones of quartz-rich breccia that commonly cut greenschist-facies metavolcanic and volcaniclastic rocks. The four deposits are known as Jabal Dalfa, Jabal Umm Matirah, Chaim, and Jabal Silli.

Worl (1979) described the Jabal Silli gold deposit (MODS 01451; lat 21°12'56" N., long 43°08'02" E.) as a group of widely scattered small pits in poorly exposed quartz veins that are each less than 20 m long. Gold was not detected in two grab samples that he collected. The author found this prospect to be two short, linear groups of shallow pits and very low mounds of rock fragments in granitic terrane. One group of mounds consists entirely of quartz fragments, whereas the second group is composed primarily of fine-grained mafic dike-rock fragments containing a trace of quartz. Two composite samples of quartz float, a sample of dike rock, and a sample of granitic country rock were collected. The two samples of quartz (170082, 170083) contain 3.6 and 2.0 parts per million (ppm) gold, 6.0 and 1.2 ppm silver, 5 and 15 ppm copper, 25 and 20 ppm zinc, and 75 and 45 ppm lead, respectively. The gold, silver, copper, lead, and zinc contents of the sample of granitic rock (170084) were less than 0.05, 1.1, 5, 20, and 40 ppm, respectively. The gold, silver, copper, and zinc contents of the sample of dike rock (170085) were 0.10, 1.5, 45, and 180 ppm, respectively.

A previously undescribed prospect, Jabal Silli West (MODS 02732; lat 21°13'24" N., long 43°02'11" E.), is a single large pit about 20 m across in a quartz vein that cuts altered (carbonate) basaltic rock. Two samples of altered mafic volcanic rock and one of quartz float were collected from the pit. The two samples of volcanic rock (161904, 161906) contain less than 0.05 ppm gold, 1.9 ppm silver, 90 ppm copper, and 15 ppm zinc. The composite sample of quartz (161905) contains 8.0 ppm gold, less than 0.5 ppm silver, and 90 ppm copper.

A large area of old prospect pits centered at lat 21°09'07" N. and long 43°13'01" E. just to the west of Jabal Dalfa is the Jabal Dalfa Group (MODS 01444) described by Worl (1979). He estimated a resource potential of about 370,000 tons of rock containing 15 to 21 grams per ton (g/t) of gold, based on twelve dump samples containing 0.16 to 26 g/t gold (5.3 g/t average). This author visited three prominent pits in a shear zone 300 m long at lat 21°09'40" N. and long 43°22'50" E. The country rock is severely sheared granitic rock and the waste dumps consist mostly of quartz fragments and a trace of fine-grained ferruginous dike rock. A large composite sample of quartz (161949) contains 0.2 ppm gold and 0.5 ppm silver. A sample of ferruginous rock (161950) contains 1.3 ppm gold and 0.8 ppm silver.

The Jabal Umm Matirah gold deposit (MODS 01172, lat 21°23'30" N., long 43°29'30" E.) is the most northern of 38 known deposits that occur along the Jabal Ishmas-Wadi Tathlith regional fault zone (Worl, 1979, 1980). The ancient mine workings consist of pits and trenches along parallel quartz veins that are 100 to 500 m long (Hadley, 1976). Grab samples from dumps of the two southern quartz veins range in grade from 0.6 to 16 ppm gold. Worl (1979) reported analyses of 24 samples of outcrop and dumps. His samples contain from 0 to 22 ppm gold (3.5 ppm average) and from 0 to 2.6 ppm silver (0.5 ppm average).

Ten holes were drilled by the DGMR to test this prospect (D. Hackett, written commun., 1982). Three gold-bearing quartz veins exposed at the surface are in shear zones that cut slightly metamorphosed volcanic rock, ranging from basalt to rhyolite, and volcanic sandstone and conglomerate. Hydrothermally altered host rock and vein quartz contain abundant pyrite and arsenopyrite, but Hackett did not observe gold as reported by Hadley (1976) and Worl (1979).

Drilling defined two minor gold-bearing quartz veins and nine hydrothermal zones bearing gold; one major zone is the subsurface projection of the main line of ancient workings. The main zone of alteration is about 3 m wide, 400 m long, and contains a quartz vein with an average width of 1.3 m. Alteration products are silica, arsenopyrite, and pyrite and there is a positive correlation between gold and sulfide content and the width of alteration. Available data suggest that hydrothermal activity along fractures in the Jabal Ishmas-Wadi Tathlith fault zone caused silicification and the introduction of gold. More silica, sulfide minerals, and minor gold were introduced during a second phase of hydrothermal activity. Jabal Umm Matirah seems to be a typical example of epigenetic gold deposits found in intermediate to mafic volcanic host rocks.

Hackett's (written commun., 1982) estimate of the gold resource in the main zone of mineralization, assuming that free gold is present, is 300,000 metric tons with a grade of 7.3 ppm gold. Mining dilution and loss during milling would reduce the reserves to 240,000 tons of 5.8 ppm gold. This resource was far below the minimum requirement of the Riofinex Geological Mission when the price of gold was $600 per ounce.

The Chaim deposit (Worl, 1979; MODS 01440; lat 21°04'10" N., long 43°14'20" E.) consists of quartz veins in a zone of breccia that is 5 m wide over a distance of 1 km. Worl's estimate of the resource potential is 120,000 tons of ore containing 9 to 12 g/t of gold with an additional 8,000 tons of dump rock containing 3 g/t of gold.

Three km southeast of the Chaim deposit are a few small pits, two of which have been trenched by a bulldozer. One composite sample of quartz chips (161952) contains negligible base and precious metals.

Nickel

An area of very low hills underlain by serpentinite, pyroxenite, and gabbro in the southeastern part of the quadrangle is locally referred to as Jabal Judayr (MODS 00897, lat 21°04' N., long 43°29' E.). The discovery of nickeliferous gossans that cap some of these rocks led to magnetic, gravity, electromagnetic-Turam, and self-potential surveys. Subsequent diamond drilling revealed pyrrhotite-pyrite-bearing pyroxenite and gabbro. Detailed descriptions of the exploration are reported by Gonzalez (1970), Puffett and others (1975, 1976) and Hadley (1976).

Gossanous material from Jabal Judayr was reported to contain as much as 1,700 ppm nickel and 485 ppm copper (Puffett and others, (1975, 1976). Seven rock samples, including two ferruginous samples, collected by the author each contain 1,400 ppm nickel and 600 ppm copper or less (table 1). The

Table 1.--Trace element contents of metavolcanic and metasedimentary rocks containing anomalous copper in the Jabal Dalfa and Ranyah quadrangles

[All data are in parts per million. Values for copper, zinc, nickel, and cobalt were determined by atomic absorption analysis; values for chromium were determined colorimetrically. Sample locations are shown and unit symbols are explained on plates 1 and 2. Leaders indicate not detected in anomalous amounts]

Sample number	Rock unit	Quadrangle	Cu	Zn	Ni	Co	Cr
157326	mbac	Jabal Dalfa	205	60	<10	15	288
157327	mbac	Jabal Dalfa	210	55	15	20	375
157390	ggvu	Jabal Dalfa	350	30	200	185	1,000
157406	umc	Jabal Dalfa	250	35	750	150	750
157408	ggvu	Jabal Dalfa	400	30	850	210	1,240
157409	ggvu	Jabal Dalfa	600	30	1,400	350	2,460
157436	bjs	Jabal Dalfa	250	30	15	20	250
157971	ggvu	Jabal Dalfa	250	20	-	-	-
157976	smb	Jabal Dalfa	225	110	-	-	-
161619	bar	Ranyah	250	55	30	25	-
161938	mbac	Jabal Dalfa	200	10	-	-	-
161973	ggvu	Jabal Dalfa	600	30	1,000	240	630
161976	ggvu	Jabal Dalfa	300	25	750	160	410

highest values of nickel, copper, and chromium recorded for samples of pyrrhotized core from two holes drilled to test the gossan are 4325 ppm, 1000 ppm, and 1500 ppm, respectively, and the average nickel content is 0.24 percent (Puffett and others, 1975). Drilling defined the mineralized zone as 8.5 million metric tons of rock with a grade too low to justify further exploration.

REGIONAL ROCK GEOCHEMISTRY

Plutonic terrane

Plutonic terrane in the Harrat Nawasif, Ranyah, and Jabal Dalfa quadrangles was surveyed to determine the potential for copper-molybdenum, tin-tungsten, and yttrium-niobium-thorium-rare earth mineralization. The block-averaging method was used to evaluate gold, silver, copper, lead, zinc, rubidium, strontium, yttrium, niobium, zirconium, molybdenum, and thorium rock geochemistry data.

According to the central-limit theory, the frequency distribution of means of a trace element variable of samples collected from nonoverlapping blocks of ground (block averages) will tend toward normality if the variable has a random spatial distribution throughout the surveyed area (Chork and Govett, 1979). The frequency distribution of block averages for a mineralized plutonic terrane, however, will be skewed or polymodal, depending upon the size and position of the blocks in relation to the proportion of anomalous samples, the size of the anomalous zone, and the number of anomalous zones. The averaging process tends to reduce the effect of sampling errors and minor local trace element fluctuations, thereby eliminating insignificant anomalies.

The quadrangles were divided into a series of nonoverlapping blocks, each 3 km on a side, and the mean value for each of the trace elements was calculated for each block. Histograms were constructed for the variables and anomalous values were identified by inspection of skewed or bimodal distributions. The sample numbers of all samples containing anomalous values are plotted on plates 1 and 2 and clusters of anomalous samples are outlined as areas with potential for mineralization. The analyses of samples used to define the five anomalous areas in the Ranyah quadrangle are shown in table 2 along with the analyses of eight other anomalous samples that are geographically isolated from each other and unrelated.

Area A includes perthite granite (grb) and a small area of comagmatic felsic volcanic rock (fvk) in the southeastern quarter of the Ranyah quadrangle. Fourteen rock samples contain anomalous values of rubidium, yttrium, niobium, zirconium, molybdenum, thorium, and the Rb/Sr ratio. Area A coin-

Table 2.--Anomalous analyses of plutonic rocks in the Ranyah quadrangle defined by area

[All data are in parts per million. Values for copper, lead, and zinc were determined by atomic absorption analysis; all others were determined by X-ray fluorescence spectrometry. Sample locations are shown on plate 1. Leaders indicate not detected in anomalous amounts]

Sample number	Rb	Rb/Sr	Y	Nb	Zr	Mo	Th	Cu	Zn	Cu/Zn	Pb	Sn
					Area A							
157226	154	-	-	27	-	-	-	-	-	-	-	-
157227	170	-	116	33	-	-	-	-	-	-	-	-
161021	-	-	-	-	-	32	-	-	-	-	-	-
161543	148	-	-	26	-	31	-	-	-	-	-	-
161544	-	-	-	24	-	27	-	-	-	-	-	-
161552	-	-	-	25	-	24	36	-	-	-	-	-
161554	-	-	131	37	1,202	38	-	-	-	-	-	-
161557	157	-	-	-	-	13	30	-	-	-	-	-
161558	147	-	105	34	-	22	-	-	-	-	-	-
161564	177	16	-	39	-	27	36	-	-	-	-	-
161573	145	-	-	29	-	17	-	-	-	-	-	-
161816	-	-	-	-	-	33	-	-	-	-	-	-
161818	-	-	157	46	1,115	44	30	-	-	-	-	-
161819	100	5.9	-	-	-	22	-	-	-	-	-	-
					Area B							
161507	-	-	-	29	-	30	-	-	-	-	-	-
161508	-	-	-	32	-	17	-	-	-	-	-	-
161509	-	-	-	25	-	21	-	-	-	-	-	-
					Area C							
161019	155	-	172	57	2,492	-	-	-	-	-	-	-
161510	-	-	-	-	-	-	-	-	-	-	630	-
161511	-	-	135	41	1,330	52	-	-	-	-	-	-
					Area D							
161628	-	-	-	38	-	-	33	-	-	-	-	-
161629	-	-	-	32	-	-	33	-	-	-	-	-
161627	-	-	-	-	-	-	-	-	145	-	-	-

Table 2.--Anomalous analyses of plutonic rocks in the Ranyah quadrangle defined by area-Continued

Sample number	Rb	Rb/Sr	Y	Nb	Zr	Mo	Th	Cu	Zn	Cu/Zn	Pb	Sn
						Area E						
161043	186	-	152	37	-	-	-	-	-	-	-	-
161633	-	-	-	23	-	-	33	-	-	-	-	-
138109	-	-	-	-	-	-	-	-	-	-	300	70
						Other samples						
157241	-	-	-	-	-	26	76	-	-	-	-	-
157249	-	-	-	-	-	-	-	100	-	5	-	-
161023	-	-	-	-	-	39	-	-	-	-	-	-
161548	-	-	-	-	-	32	-	-	-	-	-	-
161595	-	-	-	-	-	30	-	-	-	-	-	-
161673	-	-	-	-	-	40	-	-	-	-	-	-
161707	-	-	-	-	-	30	-	-	-	-	-	-
161830	-	-	-	-	-	27	61	-	-	-	-	-

cides with the most intense airborne radiometric anomaly in the region. Greene (in press, written commun., 1981) collected three rock samples for emission spectrometric analysis from area A that are anomalous in tin and molybdenum. These samples are 138177 (15 ppm molybdenum), 138059 (20 ppm molybdenum), and 138103 (70 ppm tin).

Area B, defined by three samples of perthite granite (grb), is to the southeast of area A. The samples contain anomalous niobium and molybdenum. Further south, area C contains three samples of perthite granite that are anomalous in rubidium, yttrium, niobium, zirconium, molybdenum, and lead. Theobald(1970, 1971) reported anomalous molybdenum in heavy mineral pan concentrates from wadi sediments from an area including areas B and C. Whitlow(1966, 1971) recommended exploration in these two areas on the basis of anomalous zinc and molybdenum in magnetite from wadi sediments. Theobald(1970, 1971) also found anomalous tin in the 30- to 80-mesh fraction of wadi sediments from an area that includes areas A, B, and C.

Area D is defined by three samples of perthite granite (grb) and felsic volcanic rocks (fvk) near the middle of the Ranyah quadrangle. The samples contain anomalous zinc, niobium, and thorium. A few kilometers to the northeast, two samples of area E contain anomalous rubidium, yttrium, niobium, and thorium. Areas D and E are each adjacent to a radiometric anomaly and are in the area outlined by Theobald (1970, 1971)that contains anomalous molybdenum in pan concentrates from wadi sediments and anomalous tin in the 30-to 80-mesh fraction of wadi sediments. A rock sample (138109) collected by Greene (in press) from area E contains 70 ppm tin, 300 ppm lead, and 1500 ppm chromium.

Plate 1 shows the location and table 2 shows the analyses of eight unrelated plutonic rock samples that contain anomalous molybdenum and thorium (157241, 161830), molybdenum (161023, 161548, 161595, 161673, 161707), and copper (157249).

Metavolcanic and metasedimentary terrane

Low level helicopter traverses were flown over volcanic terrane in the Harrat Nawasif, Ranyah, and Jabal Dalfa quadrangles to locate zones of alteration indicated by discoloration or bleaching. Three hundred and eighty-six samples were collected for trace element analysis. Three percent of these samples are considered anomalous in zinc (120 ppm or greater) and four percent are anomalous in copper (200 ppm or greater), according to frequency distribution plots of the data. The sample numbers of anomalous samples are plotted on plates 1 and 2 and the results of analyses are listed in tables 1 and 3.

Table 3.--Trace element contents of metavolcanic and metasedimentary rocks containing anomalous zinc in the Jabal Dalfa and Ranyah quadrangles

[All data are in parts per million. Values for copper, zinc, nickel, and cobalt were determined by atomic absorption analysis; values for chromium were determined colorimetrically. Sample locations are shown and unit symbols are explained on plates 1 and 2. Leaders indicate not detected in anomalous amounts]

Sample number	Rock unit	Quadrangle	Cu	Zn	Ni	Co	Cr
157208	fvk	Ranyah	5	350	25	0	220
157342	smb	Jabal Dalfa	30	160	100	45	144
157485	sis	Jabal Dalfa	5	120	10	30	60
157962	sss	Jabal Dalfa	15	180	-	-	-
157964	sss	Jabal Dalfa	70	350	-	-	-
161523	fvk	Ranyah	20	125	10	0	-
161561	fvk	Ranyah	10	120	-	-	-
161575	fvk	Ranyah	10	130	15	10	-
161579	fvk	Ranyah	10	135	10	10	-
161591	fvk	Ranyah	15	125	15	20	-
161604	fvk	Ranyah	15	120	<10	<10	-
161627	fvk	Ranyah	5	145	10	10	-

Eight of the 12 samples that are anomalous in zinc are from the felsic volcanic rocks of Al Khaniq (fvk) in the Ranyah quadrangle (pl. 1, table 3). The amount of zinc ranges from 120 ppm in several of the samples to 350 ppm in sample 157208. A second sample (161598) taken from the same location as sample 157208 does not contain significant base metals.

Two samples (157962 and 157964, pl. 2, table 3) collected from the metaquartzose sandstone and serpentinite unit (sss) in the northeastern corner of the Jabal Dalfa quadrangle have zinc contents of 180 and 350 ppm, respectively. These are two of the three highest zinc values in the region. The remaining two samples containing anomalous zinc (157342 and 157485) are from the serpentinite, marble, and metabasalt unit (smb) and the siltstone and sandstone unit (sis), respectively.

Seven of 13 samples that are anomalous in copper are from the metagabbro, granite, and metavolcanic and ultramafic rocks (ggvu) and the ultramafic-carbonate rocks (umc) in the southeastern corner of the Jabal Dalfa quadrangle (pl. 2, table 1). This area is the site of the Jabal Judayr nickel prospect. The copper content of these samples ranges from 250 to 600 ppm, and the values for nickel and chromium are as high as 1,400 and 2,460 ppm, respectively. All samples are from mafic or ultramafic metavolcanic rocks with the exception of samples 161973 and 161976, which are from ferruginous (perhaps gossanous) rocks.

Sample 161938 is a felsic volcanic rock from the metabasalt and meta-andesite of central belt (mbac) of the Jabal Dalfa quadrangle (pl. 2). Trace disseminated pyrite is in the sample and the copper content is 200 ppm. The remaining samples are from mafic metavolcanic areas.

CONCLUSIONS

The reconnaissance geochemical survey, conducted to determine whether rocks of the Harrat Nawasif, Ranyah, and Jabal Dalfa quadrangles are potential sources for metals, has defined five anomalous areas in the perthite granite of the central part of the Ranyah quadrangle. The most significant, area A (pl. 1, table 2), is anomalous in molybdenum, tin, thorium, niobium, yttrium, rubidium, zirconium, and the Rb/Sr ratio and coincides with the strongest airborne radiometric anomaly in the region. The other four anomalous areas are geochemically similar to area A but they are smaller and only two, areas D and E, are associated with radiometric anomalies. Independent geological and geochemical study by C. R. Ramsay (oral commun., 1982) confirms the potential importance of these anomalous areas. Eight unrelated samples of plutonic rock from the Ranyah quadrangle contain anomalous molybdenum, thorium, or copper (pl. 1, table 2).

The anomalous areas defined by rock geochemistry are potential sites of molybdenum, tin, copper, yttrium, niobium, zirconium, thorium, and rare earth mineralization. Detailed wadi sediment surveys in these anomalous areas and analyses of heavy mineral concentrates will either reduce the size of the areas for later detailed mapping or eliminate them from further consideration.

Zinc values of 120 to 350 ppm for samples from the felsic volcanic rocks unit (fvk, pl. 1, table 3) in the central part of the Ranyah quadrangle are believed to represent a high zinc background rather than significant mineralization. Additional exploration effort is not recommended for this rock unit.

The two samples of fine-grained metaquartzose sandstone (157962 and 157964, pl. 2, table 3) that contain anomalous zinc are from a wide, intensively sheared zone that includes the Jabal Umm Matirah ancient mine. Additional sampling should be done along strike from these samples to confirm their anomalous character and to establish the extension of any mineralization.

A linear zone of anomalous copper and nickel has been defined by rock samples from the metagabbro, granite, and metavolcanic and ultramafic rocks (ggvu) and ultramafic-carbonate rocks (umc) in the southeastern corner of the Jabal Dalfa quadrangle (pl. 2, table 1). This anomalous zone is 10 km long and far exceeds the area of the included small Jabal Judayr nickel prospect that was explored geophysically and tested by two drill holes. Although the metal content of the samples is not high, the area contains enough ferruginous float to encourage further work to assure that the area has been adequately tested. An induced polarization survey is recommended to locate massive and disseminated nickel and copper sulfides. This geophysical technique has been used extensively and successfully in the nickel-bearing ultramafic rock of western Australia (Woodall and Travis, 1970).

The seven remaining sites from which samples containing anomalous copper or zinc were collected should be investigated to determine the reasons for the anomalies.

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