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PRELIMINARY REPORT ON THE ANCIENT MINES AND MINERAL OCCURRENCES IN NORTHEASTERN HIJAZ QUADRANGLE 205 AND THE SOUTHWEST PART OF WADI AR RIMAH QUADRANGLE 206 SAUDI ARABIA

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PREFACE

In 1963, in response to a request from the Ministry of Petroleum and Mineral Resources, the Saudi Arabian Government and the U. S. Geological Survey, U. S. Department of the Interior, with the approval of the U. S. Department of State, undertook a joint and cooperative effort to map and evaluate the mineral potential of central and western Saudi Arabia. The results of this program are being released in USGS open files in the United States and are also available in the Library of the Ministry of Petroleum and Mineral Resources. Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian government agencies. The Government of Saudi Arabia makes this information available to interested persons, and has set up a liberal mining code which is included in "Mineral Resources of Saudi Arabia, a Guide for Investment and Development," published in 1965 as Bulletin 1 of the Ministry of Petroleum and Mineral Resources, Directorate General of Mineral Resources, Jiddah, Saudi Arabia.

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Summary

The current reconnaissance mineral survey of the Precambrian Arabian Shield in Northeastern Hijaz Quadrangle 205 and the southwest part of Wadi ar Rimah Quadrangle 206 encompasses areas of Precambrian rocks aggregating 84,000 square kilometers (33,000 square miles). To date, fieldwork and preliminary evaluation of results have been completed in 80% of the total Shield area, all in the eastern part of the quadrangle; field work in the rest of the Shield will be done by April 1966.

Numerous mineral deposits and occurrences of epigenetic, syngenetic, and metamorphic origin have been identified and investigated during the survey, but none has been determined on present evidence to be of economic size and grade. Massive magnetic deposits possess the greatest mineral potential.

Small, massive magnetite deposits occur in marble beds along and near the contacts of granitic bodies just south of Hulayfah. Although too small to be of economic value, they represent epigenetic mineralizing processess which could have produced much larger deposits. The deposits are composed mainly of magnetite and, thus, can be detected by magnetic geophysical techniques. The known deposits are located in an area covered by an aeromagnetic survey and it should be examined for evidence indicating other exposed or buried deposits.

Deposits representing two periods of hydrothermal mineralization are present in Quadrangle 205. Those of the first are strongly localized along contacts of older granitic masses which were intruded syntectonically during the orogeny which produced the northward-trending folds with which they are closely associated. Deposits of a younger period of mineralization occur along a number of northwest-striking wrench faults and in minor features and structures associated with them.

Although many deposits can readily be attributed to one of the periods of mineralization, some cannot because the field evidence is incomplete and contradictory. Numerous gold-quartz veins, including all of the ancient gold mines, are strongly localized along contacts of older syntectonic granitic bodies and are thought be be genetically related to them. Similarly, fluorite deposits occur in

wrench-fault zones and in faults subsidiary to them and are thought to have formed during the deformation which produced the wrench faults. However, all of the copper deposits and a group of quartz-sulfide-fluorite veins possess features which are characteristic of both periods of mineralization and deformation; it is possible that they represent the effects of both periods.

Results of the current reconnaissance mineral survey in Quadrangle 205 indicate sufficient mineral potential to warrant additional investigations. Future work should be concentrated largely in the Shield area lying south of Wadi ar Rimah and should be done at 1:50,000 or larger scales. Emphasis in future geologic work should be on differentiating and correlating granitic rocks, delineating and interpreting structures of the wrench-fault system, and on economic studies of the mineral deposits associated with these features. The following mineral districts and areas are listed in order of overall mineral potential and should be worked in this order to realize that potential and achieve the geologic objectives requisite to it.

1. An Nimahr - Nugrah
2. Musaynah - Ar Rhodah
3. As Safra - Al Hasan
4. Mawan - Sokhaybrah - (Al Habla)
5. An Nagab - Al Kurayziah.

Introduction

Upon arrival in Jiddah on February 11, 1964, C. L. Hummel assumed responsibility for a reconnaissance mineral survey of the Precambrian Shield areas in Northeastern Hijaz Quadrangle 205. Fieldwork was started the following month; to date, five field trips, aggregating 26 weeks, have been made in the quadrangle.

1. March 13 - April 11, 1964		4 weeks
2. October 22 - December 9, 1964		7 weeks
3. February 24 - April 2, 1965		5 weeks
4. May 2 - June 10, 1965		6 weeks
5. November 28 - December 23, 1965		4 weeks
	Total	26 weeks

Another trip of about one month will be made before April 1966 in order to complete the survey.

Ministry Geologist, Hashim Hakim, was associated with the mineral survey in Quadrangle 205 from the beginning until the end of the field trip on April 2, 1965. During this period, he did short, independent fieldwork in the Musaynah and Nugrah districts.

Ministry Geologist, Abdullah Ankary, made an independent mineral survey under the general direction of J. W. Mytton (USGS) of the southwest corner of Wadi Ar Rimah Quadrangle 206 comprising the western half of Photomosaic Sheet 96 (JN) and all of Photomosaic Sheet 103 (JS). The fieldwork was done during two trips totalling 10 weeks.

1. February 21 - March 27, 1965		5 weeks
2. May 12 - June 17, 1965		5 weeks
	Total	10 weeks

Hummel assumed responsibility for this area when Ankary went to school in the United States in the Fall of 1965 and will prepare a joint report based on the results of his own and Ankary's work in it.

Quadrangle 205 encompasses a total area of 130,000 square kilometers (50,000 square miles), of which Precambrian Shield areas make up 76,000 square kilometers (30,000 square miles), about 60%. In the rest of the quadrangle, the Precambrian Shield is covered by younger rocks and deposits - by sedimentary rocks of Paleozoic age and recent eolian deposits (nefud) in the northern and northern-most parts of the quadrangle and by extensive lava fields (harrat) of Tertiary and Quaternary age throughout the west-central portion. The northward-trending lava fields divide the Shield in the quadrangle into two unequal parts; by far the larger proportion (64,000 square kilometers, 25,000 square miles) lies east of the lava fields, of which a little less than half lies north of Wadi ar Rimah and a little more than half south of it. Of the remaining 12,000 square kilometers (4,500 square miles) of Shield area located west of the lava fields, most (9,000 square kilometers, 3,400 square miles) lies around Medina in the southwest corner of the quadrangle and the rest (2,600 square kilometers, 1,000 square miles) occurs just north of Khaybar.

The Precambrian Shield extends eastward into Quadrangle 206 and is exposed throughout Photomosaic Sheet 103 (JS) and the western half of Photomosaic Sheet 96 (JN), except for small areas where it is covered by eolian deposits. The total Shield area represented in these sheets is about 8,000 square kilometers (3,100 square miles).

Field work of the reconnaissance mineral survey has been completed in all of the Shield lying east of the lava in Quadrangle 205 and in the southwest corner of Quadrangle 206. This comprises all of French Mineral Survey Area I in these quadrangles, which includes about one-half of the Shield in Quadrangle 205.

Objectives

The immediate objectives of the current survey in Quadrangle 205 have been to make a reconnaissance-scale (1:100,000) search for mineral deposits and to develop additional information at larger scales about any deposits or areas which possessed potential for early economic exploitation. The ultimate purpose of the survey is to determine the mode of origin and economic potential of all mineral occurrences found during the survey; to this end, and to the extent that circumstances permitted, geological studies were made to establish the plutonic, tectonic, stratigraphic, and metallogenic associations and relationships of all the deposits. Mapping of rock units at the same scale as the mineral survey has been a secondary objective throughout.

Three general lines of inquiry have been followed in the field investigations of the mineral survey.

1. Recover and locate all ancient mining, smelting, and prospecting sites.
2. Examine all geologic features of the Shield with which mineral deposits might be associated.
3. Search in reconnaissance fashion for all kinds of mineral deposits throughout all parts of all exposed Shield areas.

As they do everywhere on the Arabian Shield, ancient mines, smelter sites, and prospects occur sporadically throughout the portion present in Quadrangle 205. Beyond being the best possible evidence of potentially economic mineral deposits, these ancient workings are proof that the Shield has been extensively and probably thoroughly prospected for numerous precious and base metals, and for smelting fluxes such as fluorite. In the absence of any formal record, these workings can be located only with the help of others --- of Ministry guides for known deposits and of local Bedouins for any others. A thorough canvass for information about ancient workings among these wide-ranging and knowledgeable people of the desert has been one of the principal field methods of the present mineral survey.

The Geologic Map of the Northeastern Hijaz by Glen F. Brown, Newton Layne, Gus H. Goudarzi, and Wallace M. MacLean (1963), has been the main guide to general geologic features with which mineral deposits might be associated. The 1:100,000 scale photomosaic series has provided the necessary intermediate map base between the scale of this geologic map and the scale of the survey (1:100,000 scale and larger). Used in conjunction with stereoscopic studies of 1:60,000-scale aerial photographs from which it was made, this series has proved entirely adequate for the map needs of the survey - for, both locating, delineating, and examining geologic features in the field and for representing them in reports.

Finally, every part of the Shield has been visited and all geologic elements which might be associated with or related to mineral deposits have been examined. Principal reliance for this purpose has been on visual observation of the vast expanses of rock surface everywhere present in the desert; accordingly, traverse routes have been especially planned to permit as much as possible of these exposures to be examined for signs of mineralization. Necessarily, large Shield areas with little or no relief and more or less covered by wind-blown and wash material have received little attention. To be examined in the same degree as the higher-standing areas would have required systematic traverses (that is, along bearings or on grids) which limitations of time precluded. As a result, visual observations of these areas extend little beyond the sparse traverse routes made across them to examine features indicated by other phases of the mineral survey - reports of ancient mines, studies of aerial photographs, etc.

Methods

A wide-ranging network of daily traverses by vehicle was the main field method employed to survey the extensive Shield areas in Quadrangle 205. Individual traverses ranging from 50 to 200 kilometers were designed to prosecute concurrently the three major field objectives of the survey, that is, to locate and investigate all ancient workings, to examine all previously selected geological targets, and to observe as much exposed bedrock as possible.

In addition to the regular ore assay facilities of the Directorate of Mineral Resources in Jiddah, a laboratory was established there by the USGS and designed to determine very small (trace) amounts of many elements, mainly by emission spectrometric and wet chemical methods. Services of both facilities were available to support field activities as required; for trace analysis determinations, wet methods were available from the start of the work, whereas spectrometric determinations could be made only during the last year.

Trace analysis services permitted consideration of a number of geochemical prospecting techniques to support the mineral survey, especially of those based on samples of alluvial and other detrital materials derived from mineral deposits. However, it was soon learned that the practical limit for detection of even the most abundant constituents of known deposits in these materials was about one kilometer from their sources. Sampling at one-or two-kilometer intervals was thus necessary to obtain meaningful areal geochemical prospecting results. Limitations of time and personnel to collect sufficient samples and of laboratory facilities to process them -- coupled with an inadequate knowledge of the geology to interpret the results -- effectively obviated general use of systematic areal geochemical prospecting techniques. As a consequence, trace analyses, generally, were utilized of materials and in ways which were directly related to potential or actual mineralization.

Three general types of geologic materials have been collected for which trace element determinations have been obtained. Samples, mainly from dumps and tailings, have been collected from all of the ancient workings. The major elements being obvious from the nature of the workings or megascopic mineralogy, the immediate purpose of trace analyses of these has been to determine the chemistry of the minor elements in the deposits, their relationship to the major ones, and the immediate economic implications of these.

Of highest priority in this connection has been to ascertain whether silver occurs in any of the base metal deposits and especially in any which contain appreciable amounts of lead. Beyond providing information about the chemistry of each deposit, the results from all of the deposits are expected to provide the basis for determining the geochemistry of the mineralization, or mineralizations, which gave rise to them, and the relationship of these to other plutonic, stratigraphic or metamorphic elements and events.

A second group of samples comprises residual and wash material from numerous epigenetic and syngenetic geologic deposits such as pegmatites, veins, altered rocks, fault breccias, etc. Again, the objects of trace analyses of these was, first, to determine any indications of economic mineralization and, thereafter, from similar samples of many of the same kinds of deposits, to determine their geochemistry and possible geochemical affiliation with other deposits.

The last group of samples consisted of wadi sediments. By far the most of these were collected in wadis from places at distances no greater than a kilometer or two from the bedrock sources of actual or suspected mineral deposits. For known deposits, the purpose was to determine their geochemical character as manifested in wadi sediments; for other geologic features such as faults, skarn zones, etc., the object was to establish whether metallization was associated with them.

Finally, some sediment samples were collected from numerous large wadis draining extensive areas of the Shield and many of the rock units making it up. The purpose of these was to determine regional levels of concentration of the elements for use as background to determine anomalous concentrations of any of them in any other samples.

Reports

The results of the mineral survey will be presented in three ways. The first of these is to be a series of preliminary mineral survey maps comprising all or most of the 1:100,000-scale photomosaic sheets in Quadrangle 205. On these will be shown the locations of all ancient mining and smelting sites, mineral occurrences, etc., and, in addition, to the extent that field information permits, all other relevant geologic features, structures, rock units, etc. A written report will accompany each or groups of these preliminary maps describing the features shown and appraising their economic potential.

From this series, a number will be chosen which cover areas of particular interest or mineral potential. The maps of these will be prepared for color printing and the text accompanying them will cover the geology of the mineral deposits and rock units more thoroughly.

Lastly, the same information as is represented on the 1:100,000-scale sheets will be compiled on a 1:500,000-scale map. In addition to descriptions and evaluations of individual mineral deposits and districts, the text will contain recommendations for future investigations in those parts of the Shield areas which are considered to be particularly promising.

General geology

Although it is complicated, the geology of the Precambrian Shield areas in Quadrangle 205 is not inordinately complex. Most of the rocks making up the Shield are metamorphosed in some degree, but nearly all of them still possess enough of their original character to be correlated on it rather than on present metamorphic form. Clearly recognizable metasedimentary rocks, layered metavolcanic rocks, and granitic and metagranitic plutonic rocks are by far the most common rock types. Despite this, several factors make it difficult to establish and correlate stratigraphic units.

Foremost of these factors are the variable effects of metamorphism on the same kinds of rocks at different places, and on different rock types at the same place. Thus, dynamic effects may predominate at one place and thermal effects at another, and both may vary in grade. Conversely, different rock types in the same area may respond differently to the same metamorphic conditions and lead readily to the erroneous conclusion that rocks represented in subjacent but isolated exposures have been metamorphosed to different grades and, therefore, must be uncomformable.

A second confusing factor is the similarity of rock types of different ages. This is true of both the plutonic igneous rocks and of the layered rock sequences. Most of the former are in the range between granodiorite and granite and very similar in appearance and mineralogic composition; as a consequence, detailed studies would be required to differentiate and map the granite masses of different ages which may be present in the Shield. Similarly, the layered rock units of different ages include similar rock sequences, notably of silicic volcanic rocks. This precludes any "quick and dirty" correlation on lithology alone and requires, instead, detailed studies of both the volcanic rocks and the sedimentary or metasedimentary rocks with which they are interlayered.

The character of the exposures is another cause of confusion. Typically, these are in the form of high-standing, isolated hills and mountain masses. Although the rocks composing them are very well exposed, their relations with the surrounding low-lying rocks are obscured by the debris derived from them which extends away on all sides. Together with the other factors, this frequently leads to the intuitive impression that the rocks making up the mountains and hills are outliers of younger rocks resting unconformably on older, perhaps basement rocks. Again, all too often, the high-standing rocks tend to be volcanic rocks with the result that they can easily be miscorrelated and their relations with other units can be misinterpreted as well.

Like the stratigraphy, the structural geology of the Shield in Quadrangle 205 does not seem to be overly complex, but it may be more complicated than is indicated by present evidence. The three major systems of structures are readily apparent; northward-trending fold belts, northwestward-striking wrench fault zones, and eastward-striking fractures and dike swarms. Smaller order structures include those which have formed through deformation of the former by the latter, and some which are the result of dynamic-intrusive processes, ring-dikes, etc. and the effects of these on previously existing structures. Although no large thrust-faults or overturned folds have been identified in the quadrangle, apparently gently folded metasedimentary rocks have been found at several places which contain small-scale structures indicating much greater structural complexity, perhaps of Alpine character.

Stratigraphy

As portrayed on the geologic map of Northeastern Hijaz Quadrangle 205 (Brown and others, 1963), rocks of Precambrian age making up the Arabian Shield form most of the bedrock exposed in Quadrangle 205; everywhere else in it they are unconformably overlain and thinly covered by younger rocks and deposits - by sedimentary rocks of early Paleozoic age and modern eolian deposits in the northwest and northernmost parts of the quadrangle, and by basaltic and andesitic lava fields (harrat) in a broad belt extending northward through the west-central part of the quadrangle. Small exposures of nearly flat-lying sandstone of Cambrian (?) age also occur at numerous places on the Shield.

As abridged from the legends of the 1:500,000 scale geologic map of Northeastern Hijaz Quadrangle 205 and the 1:2,000,000-scale Geologic Map of the Arabian Peninsula (Anon., 1963) the following rock units are represented in the Shield areas in Quadrangle 205.

Dikes, mostly rhyolite or diabase (no letter symbol)

rtp - Igneous plugs, including some fine-grained thorium-rich red granite.

sr - Flows, tuffs, and breccias, some welded; horizontal to gently folded with least folding in uppermost beds. Red and green tuffaceous slate or shale interbedded in flows.

gp - Peralkaline granite. Generally in circular plugs, stocks, and ring dikes; more abundant accessory minerals are xenotime, thorite, and fluorite; unmetamorphosed but sheared in places near major wrench faults. Isotopic age 535 $\pm$ m.y.

fa - Fatima formation. Arkose, red slate and siltstone, tuffaceous wacke, conglomerate, sandstone, and thin limestone members containing stromatolitic structures. Typically little metamorphosed and showing ripple marks, rain-splatter marks, and worm(?) borings. Includes some porphyritic rhyolite and andesite sills and flows of the Shammar Rhyolite, sr, in upper part.

fm - Brown, tan, dark blue, and black marble; detrital, crossbedded, locally cherty in lower part; commonly sheared, folded and thrust over and along wrench fault zones. (Present locally, but not shown on geologic maps of Quadrangle 205).

sc - Schistose rocks, mostly confined to large shear zones and increasing in volume towards northwest as fault zones join.

mu - Murdama formation. Slate, schist, phyllite, conglomerate, and quartzite; gently to intensely folded and sheared, dominantly siliceous, moderately metamorphosed clastic rocks.

hi - Hibshi formation. Conglomerate, red ripple-marked slate, wacke, and arkose; welded agglomerate at top. Age relationship not clear as formation rests disconformably on gray granite; may be equivalent to basal Murdama or Fatima Formations.

gm - Gray biotite-hornblende granite; at places including a red facies of isotopic age about 670 m.y.

fh - Diorite; hornblende-feldspar contact or xenolithic rocks.

ha - Halaban formation. Andesite, typically felsitic.

hc - Haliban formation. Clastic facies; composed of agglomerate, conglomerate, quartzite, and graywacke; locally includes interbedded marble, rhyolite.

hd - Epidotized hornblende-plagioclase rock resembling igneous rocks occurring as the intrusive phase of the Haliban petrogenic cycle.

gr - Gray and pink, hornblende granite, generally massive, weathers into bornhardts. Some included rocks have isotopic age 700-750 m.y.

gn - Granite gneiss, gn; gray, many inclusions and xenoliths. Weathers into pits and caves; quartz shows strain shadows. Synkinematic intrusive, isotopic age 1000 ± m.y. where sampled.

dg - Granodiorite and diorite, gneissic; many amphibolite xenoliths; darker phases of gn.

gb - Mafic rocks; all of questionable age relationships. Gabbro gb.

gs - Chlorite schist. Schist of indeterminate age but derived mostly from basic igneous flow rocks. (Shown on 1:500,000-scale geologic map of Quadrangle 205 but not on 1:2,000,000-scale Geologic map of Arabian Peninsula).

As indicated in the descriptions, many of these units are composed of similar rocks and some may be the same as others, or closely related to them. Only two layered rock units lying east of the lava, have been recognized during the current work in the Shield, and all of the granitic plutonic rocks have been included in two general groups. Both layered units include sedimentary and volcanic rocks and, perhaps, hypabyssal equivalents of the latter. All of the older layered rocks are thought to belong to the Haliban unit and all of the younger ones to the Shammar unit. In general, a group of younger granitic rocks includes only those now mapped as gp and rtp; (Brown and others, 1963); the group designated as "older granitic rocks" includes all of the others.

Haliban formation.

The Haliban formation was established and named by G. F. Brown on the basis of exposures in Jabal Haliban in the northwestern part of Quadrangle 211 and has been subdivided and mapped nearly everywhere on the Shield as predominently sedimentary (hc) and andesitic volcanic sequences (ha). The Haliban formation is the oldest and most extensively distributed unit on the Shield in Quadrangle 205. It is exposed in large areas throughout the region east of the lava fields and is everywhere intruded by all of the granitic rocks. Accordingly no parts of the Shield have been identified which can be characterized as "basement" relative to everything else.

No sections of the Haliban formation have been measured in Quadrangle 205, nor have any thicknesses been computed for it. As indicated earlier, it is intruded by granitic masses throughout the area east of the central lava fields, and so is the oldest rock unit in the Shield there. It is unconformably overlain by sporadic occurrences of Shammar layered rocks and sparse outcrops of sedimentary rocks of early Paleozoic age.

The Haliban formation is composed of several kinds of layered sedimentary and volcanic rock sequences which are moderately to strongly folded and variously metamorphosed. The main rock types are calcareous and argillaceous metasedimentary rocks, metawacke clastic rocks, and meta-andesitic and matarhyolitic pyroclastic and flow rocks. Although all of these have been found interlayered together, each also predominates and can be mapped separately locally. Some of these are formations in their own right, and when sufficient work has been done to establish this, the Haliban unit will probably become a stritigraphic group.

The Haliban formation in Quadrangle 205 also includes some minor rock types which are of special interest or significance. One of these is bedded jasper which occurs with marble beds in some calcareous sequences beds of jasper are associated with two of the principal replacement copper deposits (Musaynah and An Nimahr) and are significant for any possible genetic relationship.

Also present in the Haliban formation are numerous metadioritic masses, some quite large and discrete. Elsewhere, these have been mapped as "hd" and interpreted as intrusive phases of the Haliban; if so, they are of great importance as critical elements in the petrogenic cycle which produced them.

Finally, a number of rock sequences which have been mapped as separate units previously (Brown and others, 1963) are now regarded as metamorphic variations of parts of the Haliban unit and are included with it. These include the northwestward-striking belt of "sc" (sericite-chlorite schist) rocks located northeast of Al Hanakiyah and a number of small exposures of rocks shown as "fh" (hornblende-feldspar contact xenolithic rocks). The former are thought to be somewhat more dynamically metamorphosed equivalents of some of the Haliban rocks, and the latter to represent Haliban rocks metamorphosed to above average thermal grade, usually amphibolites. In addition to these, all of the rocks previously mapped as the Murdama formation (mu), and many others mapped as Shammar (sr) are now considered to belong to the Haliban formation instead.

The general character and structure of the rocks of the Haliban formation in Quadrangle 205 indicate that they have been deposited and deformed along a northward-trending eugeosyncline. Sedimentary rocks of marine origin are most abundant; of these, wacke-type clastic rocks predominate and indicate conditions of rapid, undifferentiated accumulation. Pyroclastic and flow rocks of andesitic and rhyolitic composition are interlayered with the marine sedimentary rocks in such a way as to attest to concurrent submarine vulcanism and sedimentation. In an environment of accumulation characterized by these events, and probably by tectonic activity too, local -- even angular -- unconformities and "cannibalized" clastic products may be expected.

Beyond this, the Haliban formation may represent but one aspect of a much larger and more complicated cycle of orogeny. It is everywhere regionally metamorphosed to some degree and intruded by granitic masses; features and structures which indicate syntectonic intrusion -- linear fold cores, abundant Haliban --like inclusions and xenoliths, migmatite margins, autometamorphosed zones, etc. -- abound in and around these latter. Together, they may constitute effects of the terminal stages of an orogeny which produced an extensive, northward-trending mountain chain of which only the roots remain in the present Arabian Shield.

Shammar rhyolite.

No type locality is known for the Shammar rhyolite and the geographic name assigned to it includes a very large part of the Shield extending south of Hail.

Although widespread, individual exposures of the formation tend to be isolated; with the additional complications of variety of lithology and similarity of lithology to some of the silicic volcanic sequences in the Haliban formation, correlation of these exposures is difficult, at best, and probably impossible without detailed studies.

Despite the lack of specific correlations, tentative lithologic correlation has been made of many occurrences of the Shammar rhyolite as mapped by Brown and others (1963) and of several other units which are represented separately. These latter include the following units which are shown on the Geologic map of Northeastern Hijaz Quadrangle (Brown and others, 1963) and, in addition, the Farida marble (fm) which is not.

rtp - fine-grained red granite
fa - Fatima formation
fm - Farida marble
hi - Hibshi formation

The possible relationship of all of these units, and of the Shammar rhyolite, are clearly implied in previous descripitions of them (see above). As mapped before, they include arkosic sandstone and conglomerate, thin-bedded siliceous shale and limestone, and rhyolitic pyroclastic and flow rocks; all of the units contain one or more of these rock types in common with others. Somewhat more doubtfully affiliated with these rocks is the fine-grained, red to red-orange, hornblende granite which crops out in numerous, isolated exposures. In addition to this similarity of exposure, the granite is like the other units in being unmetamorphosed and, generally, only gently to moderately folded.

A singular, and significant, feature of the Shammar rhyolite and its related units is the disproportion of their exposures along northwest-striking wrench-fault zones -- so much so that they constitute one of the criteria by which these structures can be recognized and delineated. Of the two possible interpretations -- whether they were deposited or only preferentially preserved in them -- the latter seems the most likely. Rocks of the Shammar unit also occur away from the wrench-faults and the character of those in them indicates that they once extended laterally well beyond their present limits. This preferential preservation of Shammar rocks in the wrench-fault zones indicates that graben-like down-dropping took place on them along with compressional and shear actions as now manifested by folds (in part overturned) and drag effects in these rocks.

Excluding some doubtful occurrences consisting of rhyolitic volcanic rocks interlayered with wacke-type clastic rocks which are now mapped as Shammar but which probably belong to the Haliban formation, all of the rocks now assigned to the Shammar formation appear to have formed under terrestrial and shallow marine or lacustrine conditions. The origin of the fine-grained granite is uncertain but it may represent the hypobyssal equivalent of some of the Shammar rhyolitic pyroclastic and flow rocks.

Plutonic igneous rocks.

Both silicic and mafic plutonic rocks are present in the Shield east of the lava fields, but the former are most abundant, by far. Excluding the metadiorite rocks which are integrally associated with the Haliban formation, most of the mafic plutonic rocks are of gabbroic composition. These occur in a few, widely-separated, small masses; none are as large as those depicted on the Geologic Map of Northeastern Hijaz (Brown and others, 1963).

Granitic rocks make up about one-half of the Shield in the eastern part of Quadrangle 205. Although it is virtually certain that granites of several ages are represented, perhaps along the lines of the three-fold subdivision of them shown on the present geologic map (Brown and others, 1963) only two general groups of granitic rocks have been distinguished during the present work. They are an older group and a younger group.

Older granitic rocks:-- Older granitic rocks include all of those mapped as gn and gm on the present geologic map of Quadrangle 205. Most of the older granitic rocks are exposed in extensive tracts characterized by general low relief and sparse, steep-sided hills and clusters of hills (inselberg, bornhardt) which are cut by numerous dikes and dike swarms. The older granitic rocks are usually gray, medium-grained, erratically porphyritic, and contain biotite and hornblende; in addition, they are locally reddened, sheared, and gneissic. No petrographic studies have been made of the older granitic rocks, but on field evidence they appear to vary in composition from granite to granodiorite; the variation is small and might be due to local effects of rocks assimilated during intrusion, notably calcareous ones.

Everywhere throughout the area east of the lava fields, the older granitic rocks intrude the Haliban formation, making it the oldest unit in the Shield there. Generally, this is manifested only by the higher thermal grade of the Haliban rocks along seemingly accordant contacts, suggesting a passive, permissive mode of intrusion; however, at many places, apophysitic dikes and magmatic stope features extend from the granite and attest to the dynamic character of the intrusion, at least locally.

Many of the older granitic bodies have characteristics which indicate that they were intruded syntectonically during the deformation which produced the northward-trending fold belts in the Haliban rocks. That the folding in belts in the Haliban rocks and intrusion of some of the older granitic rocks took place concurrently is indicated by numerous belts of older granitic rocks and groups of elongated granitic plutons, all aligned northward parallel to the northward-trending folds in the Haliban rocks. This, together with the sparse to abundant, angular and round, dark-colored, Haliban-like xenoliths in these granitic bodies, constitutes the principal evidence of their syntectonic origin. If, as seems likely, the folding and syntectonic intrusion of the older granite are concommitant, both might be parts of a single cycle of orogeny of which the Haliban formation and the granite may also be elements; if so, the former represents an earlier, eugeosynclinal phase and the latter, a later metamorphic-intrusive phase.

In addition to their stratigraphic importance in the geology of the Shield, the older granitic rocks have a special significance in the current mineral survey: all of the gold deposits, and all but a few of the copper deposits, occur in them and in the Haliban rocks along their contacts with each other.

Younger granitic rocks:-- Many relatively small granitic plutons mapped as "gp" on the present geologic map of Quadrangle 205 (Brown and others, 1963), and numerous, still smaller ones shown as "rtp", are included in the group herein designated younger granitic rocks. They occur throughout the Shield east of the central lava belt where they are exposed as prominent, high-standing, circular plugs, stocks, and ring dikes. Most of the younger granitic rocks are medium to coarse-grained, non-porphyritic, contain biotite, and have a distinctive reddish color.

Nearly all of the younger granitic masses have dynamic intrusive contacts with their adjoining wall rocks, characterized by prominent, stoped contacts and apophysitic dikes. They intrude and are clearly younger than the Haliban formation but their relationship with the Shammar rhyolite has not been established. This is because they have not been found together, for sure. The younger granitic rocks clearly intrude sequences containing abundant rhyolitic volcanic rocks, but confusion arises because it is not known whether these belong to the Haliban or Shammar units. Until the stratigraphy of these is known better, their relative ages with respect to the granitic rocks cannot be determined.

The younger granitic rocks are not known to be associated with any tectonic activity, however, one gp stock in Photomosaic Sheet 103 has been truncated and offset across a northwest-striking wrench-fault.

No mineral deposits are related to the younger granitic rocks but a few barren pegmatites are associated with them.

Unconsolidated deposits.

Extensive areas throughout Quadrangle 205 are more or less covered by a variety of unconsolidated deposits, mainly wadi sediments, eolian sand, and fan and outwash debris. These have little or no economic value themselves, nor do their several modes of origin afford much, if any, chance for concentrating anything from bedrock sources into secondary deposits which might have. However, well-rounded and well-sorted terrace gravels are present at many places and were clearly once far more extensive than now. They appear to represent a period of rainfall and alluviation reflecting conditions of climate and erosion far different from the arid regime which prevails now. The terrace deposits everywhere stand above the levels of present wadis and are incised by them. They have not been found anywhere under modern unconsolidated deposits, which everywhere rest on bedrock.

The terrace gravels are of economic interest for any placers which they may contain, notably any containing gold. The character of thse gravels indicates that they formed under conditions which could have produced placers in them. For this reason, they deserve to be examined and tested wherever they have been derived from or occur in auriferous bedrock areas.

Structural geology

The three major systems of structures in the eastern part of the Arabian Shield in Quadrangle 205 can be readily discerned. They comprise a series of northward-trending folds and foldbelts, a group of northwestward-striking wrench faults, and abundant eastward-striking fractures, dikes, and dike swarms. The first of these is older and represents but one aspect of a complex cycle of orogeny; the last two are younger and may have formed together. Mineralization accompanied both periods of deformation.

Older structures.

The older fold structures are closely associated with syntectonic granitic rocks and metamorphic effects; all of these are thought to be elements representing stages of a single, major orogeny. Effects of the older deformation are present mainly, perhaps only, in the oldest rocks of the Shield, that is in those of the Haliban formation and the older granitic rocks. The most obvious of these occur in the former; they consist of numerous northward-trending, tight but still open folds and generally moderate metamorphic effects. Although the older granitic rocks intrude the Haliban formation, both possess syntectonic characteristics which indicate strongly that they are orogenically related.

The principal evidence for syntectonic relationship of the folds and the older granitic rocks includes the distribution and configuration of the older granitic bodies, internal features of them, and metamorphic effects in the Haliban rocks.

The older granitic rocks constitute one-half of the eastern part of the Shield and almost certainly join at no great depth to form a single, enormous batholith. The shape of the upper surface of this batholith is highly irregular as now manifested by the manner in which it is exposed. The largest exposures of the older granitic rocks also constitute the largest proportion of their total exposure. These consist of large, stock-like masses which are joined by numerous smaller bodies. It is these latter which exhibit the most marked syntectonic character. They are localized in northward-trending fold belts in the Haliban rocks where they are exposed in numerous, linear granitic belts and aligned groups of small, elongate plutons, all with orientations parallel to the trend of the folds. In addition, all of the smaller plutonic masses, and many of the larger ones, contain sparse to abundant, mostly angular, dark-colored, Haliban-like xenoliths.

Finally, metamorphic effects in the Haliban rocks vary directly with distance, laterally and vertically, from contacts with older granitic rocks. The highest grade rocks, usually amphibolites, occur along the contacts of the largest bodies and in erosional outliers on top of them (often shown as fh)on the present geologic map of Quadrangle 205 (Brown and others, 1963). Elsewhere, much lower metamorphic effects prevail; however, even around contacts of the smallest, older granitic plutons, they are appreciably higher grade than away from them. This close relationship of regional and contact metamorphic effects strongly suggests that the Haliban rocks were being folded regionally metamorphosed, and syntectonically intruded by granitic rocks at the same time, and that these latter, in addition, effected contact metamorphic effects above the regional grade through local, exothermic crystallization reactions. Together with the predominantly submarine-volcanic rock composition of the Haliban formation, the effects of deformation and metamorphism are thought to be the major elements of a cycle of orogeny. The earliest stages of the orogeny, comprising formation, and sedimentation and vulcanism, in a eugeosyncline, are represented by the Haliban unit, whereas the latter stages of deformation and syntectonic intrusion are represented by the folds and older granitic masses. In this context the present Arabian Shield constitutes the eroded roots of a northward-trending mountain system.

Younger structures.

A system of younger structures includes several major northwest-striking wrench fault zones, many small folds and faults in Shammar rocks which are preferentially preserved along them, and a number of reverse-S flexures which represent distortion of older, northward-trending folds and fold belts across them. Eastward-striking fractures and dikes which occur in great numbers throughout the Shield east of the lava fields may also belong to the same group.

Minor mineral deposits are associated with several of the younger structures, and some of the major deposits may also be associated with them.

Northwest-trending wrench faults:-- One minor and three major wrench fault zones are present in the eastern part of the Shield in Quadrangle 205; all but part of one of these occur in the portion of the region lying south of Wadi ar Rimah. The wrench fault zones are from one to ten kilometers wide and are manifested by many left-lateral faults, numerous isolated and deformed occurrences of younger, layered rocks of the Shammar formation, and a number of distorted older structures. The wrench-faults are not single, large, transcurrent faults but, instead, are made up of many small ones. All are vertical and strike between west-northwest and north-northwest with a resulting, general trend of northwest. The relative movement wherever identified is invariably left-lateral, that is, north side west and south side east. Large, silicified breccia veins have formed along some of these faults and a few of these veins are metallized; a carbonate breccia vein has been found along one of the faults.

Relatively small, isolated exposures of rocks belonging to the Shammar formation occur intermittently in the wrench-fault zones. These comprise fine-grained, red granite, rhyolitic volcanic rocks, arkosic sandstone and conglomerate, and thin-bedded siliceous and calcareous rocks, including chert and limestone. They are not obviously metamorphosed but they have been profusely folded and faulted. They once clearly extended beyond their present limits and, so, were not deposited in the wrench fault zones but, rather, were preferentially preserved in them. This attests to a graben-like downdropping movement along the wrench faults in conjunction with compressional and shearing actions which are now represented by faults and folds, some overturned, in the same rocks.

The last of the major, younger structures is a number of reverse-S. flexures in the Haliban rocks; these are the result of left lateral movements on the wrench fault zones and represent the effect of large-scale drag across them on the older, northward-trending folds and fold belts in the Haliban rocks. Locally, these flexures are marked by similar effects on other accordant features in the Haliban rocks, notably on marble beds and metasegregarion quartz zones.

Generally, the wrench fault zones are not well marked physiographically, although individual, minor structures and features along them often are. However, portions of two of the major wrench fault zones are strongly manifested in the modern topography, both by wadis. The present course of Wadi Asmarah, one of the principal headwater tributaries of Wadi ar Rimah, is the topographic expression of the northwest end of the northmost wrench fault zone, and the northwest-trending portion of Wadi al Jarir located southwest of Afif marks the central part of the southernmost wrench fault zone in Quadrangle 205.

Eastward-striking fractures and dikes:-- Strong, eastward-striking, vertical fractures and lineaments are present throughout the eastern part of the Shield in Quadrangle 205; however, the rhyolite dikes having the same altitude which are closely associated with them tend to occur in swarms at intervals throughout the length of the Shield. Prominent belts of these dikes pass through Al Jufayfah and Jabal Rughayghith about 75 kilometers southwest of Hail, through Jibal al Kashabah 30 kilometers east of Hanakiyah, and through the As Safra mining district.

The dikes cut all of the rocks in the Shield except the gp granite, which seems to be younger. Striking evidence of this is present in excellent exposures along As Silf in the central part of Jabal Aja just west of Qufar where a younger granite (gp)? has intruded and selectively stoped into an older, gneissic granite containing numerous, eastward-striking rhyolite dikes; these latter were preserved almost entire, and with little or no change distortion of altitude, as pseudo-dikes in the younger granite.

If, as seems likely, the gp granitic rocks with an isotopic age of 535± m.y. (Brown, and others, 1963) are the youngest rocks in the Shield, it is clear that all of the other units represented in it are of Precambrian age. The older, northward-trending folds and the elongated, syntectonic granite bodies genetically associated with them which are intruded by gp granitic bodies are also safely of Precambrian age. However, the age of the younger wrench-fault structures is less certain. Although probably of Precambrian age, lineaments which seem to be extensions of the wrench faults occur in the sedimentary rocks north of Khaybar and indicate that movements have taken place on them at least as late as the early Paleozoic age which has been reckoned for these rocks.

Mineral deposits

The ancient mines and mineral occurrences in Quadrangle 205 have been classified according to the following inferred modes of origin and are described briefly thereafter:

I. EPIGENITIC: Magmatic; contact-metasomatic.
   - A. Pegmatites and pegmatitic veins.
   - B. Contact-metasomatic; massive iron deposits.

II. EPIGENITIC: Hydrothermal alteration and mineralization; ancient mines and smelter sites.
   - A. Hydrothermal deposits; ancient mines.
     1. Ancient mines; concordant replacement and discordant filling-type depotis.
     2. Small quartz veins with sparse sulfides and (or) fluorite.
     3. Barren, silicified fault breccia veins.
     4. Mineralized, silicified fault breccia veins, containing sulfides.
     5. Quartz veins of doubtful origin; usually isolated.
   - B. Hydrothermal alteration, including bleached zones, serpentine, and jasperoid.
   - C. Ancient copper smelting sites without ancient mines.

III. <u>SYNGENETIC</u>: Sedimentary, regional metamorphic.

A. Metallic deposits.

1. Bedded jasper with varying amounts of disseminated iron oxides; small beds of hematite and jaspilite.
2. Silicified nodules and irregular, siliceous replacement zones in marble; usually iron-stained and contain disseminated pyrite.

B. Non-metallic deposits.

1. Metamorphic segregation quartz veins.
2. Thin-bedded, siliceous rocks.
3. Bedded and nodular magnesite deposits.
4. Bedded talc deposit.

IV. <u>SUBAERIAL:</u> Residual and detrital deposits.

Epigenetic deposits

<u>Magmatic; pegmatites.</u>

Pegmatites are not abundant in the portion of the Arabian Shield lying east of the lava belt, having been found during the present mineral survey only sparsely in Jabal Aja west of Hail and in moderate numbers in Jabal Tuwalah west of Nugrah. On present evidence, only the latter deserve any further investigation to determine economic potential.

The pegmatites in Jabal Tuwalah are localized in the single, large granitic pluton which makes up most of the jabal. Although this indicates a genetic relationship, not enough is known about this granite, or about those around it in which pegmatites are absent, to state this definitely. Nor does it rule out a possible relationship with the northwest-trending wrench-fault zones, one of which passes just south of Jabal Tuwalah.

The pegmatites range in physical character from nearly perfect, lens-shaped masses with well-defined zones to tabular, vein-like bodies which are unzoned. All of the pegmatites are small, none exceeding a few tens of meters long and a few meters wide.

Where best developed, the pegmatites consist of a central core composed almost entirely of very-coarse quartz crystals in a subradiating, stellate aggregate surrounded by a border zone containing abundant, well-developed crystals of pink potash feldspar (orthoclase) and hematite. The border zones weather more readily than the quartz cores, which remain to mark the pegmatites and can be seen easily from great distances in the field and on aerial photographs.

In vein-like bodies and less well-developed pods, the pegmatites are unzoned or the zones are poorly developed; instead, they are composed of coarse, irregular aggregates of pink feldspar, hematite, and quartz. Sulfides, including those of copper and lead, have been identified in some of these and suggest a possible relationship with many small, sulfide-bearing quartz veins which occur with the pegmatites throughout Jabal Tuwalah.

No commodities of economic importance have been identified in the pegmatites; this, together with their small size, precludes any need for further, early investigation of them.

Contact metasomatic; massive iron deposits.

Larger and smaller granitic plutons are abundant throughout the eastern portion of the Arabian Shield in Quadrangle 205 and well-exposed intrusive contacts are common there. Although metamorphic effects are associated with many of these, they are almost entirely thermal in character - of regional scale in the case of the gn granite relative to rocks of the Haliban unit, and local in the case of the gp granite against rocks of both Haliban formation and older granitic rocks. Additive metamorphic effects, that is, those involving metasomatic replacement of country rocks, are thus the exception and not the rule in Quadrangle 205, however, a few occurrences have been found.

By far the most important contact metasomatic deposits are located just south of Hulayfah, at field stations 2862 and 2866. Small replacement deposits of massive magnetite in marble of the Haliban unit are present at both places; however, the field relations of only the one at Station 2866 are clear. At this locality, a northward-striking bed of marble has been intruded by a small granite pluton (gp?)

and a small deposit comprising numerous, irregular-shaped masses of massive magnetite and small magnetite veins is present in the marble along the contact with the granite. Sparse blebs of a peculiar yellow-green alteration mineral are the only other metasomatic effects associated with the deposits. This alteration occurs in the same marble bed a kilometer or two south of the deposit (at Field Station 2868), which suggests that the iron mineralization may also extend in that direction.

Nearly identical, massive magnetite deposits and alteration effects are present in a marble bed at Field Station 2862, however, they are not localized along a contact with a granitic mass. If one is associated with the deposit it must be at depth, probably the same one which is exposed just north of the deposit. From the similarity of the iron deposits and alteration at both places and the presence of one along a granite contact and the proximity of the other to one, it seems certain that both are true contact or subjacent metasomatic replacement deposits.

Although both iron deposits are far too small to be of economic importance, they represent a style of mineralization which could produce much larger deposits. For this reason, the area containing them should be given high priority for additional work. Deposits of this sort are most easily detected by magnetic geophysical techniques; fortunately, the known deposits occur in an area over which an aeromagnetic survey has been made. Accordingly, the first step in any additional investigation should be to identify and correlate the magnetic results from the known deposits, then to seek similar anomalies for leads to other deposits which may be exposed or buried elsewhere in the area.

Hydrothermal deposits.

Epigentic hydrothermal deposits are abundant in the eastern part of the Shield in Quadrangle 205, but are localized almost entirely in the southern half of it; similar types of deposits occur in the southwest corner of Quadrangle 206. All of the ancient workings are on deposits which are thought to be of hydrothermal origin; these deposits comprise both accordant-replacement and discordant-filling types, and in many of them, both types are present. Other hydrothermal deposits include small sulfide and fluorite-bearing quartz veins and large, silicified fault breccia veins. Most of the former are localized in and around Jabal Tuwalah where they are closely associated with pegmatites and may be genetically related to them. Nearly all of the silicified breccia veins occur along minor, northwest-striking faults in the wrench-fault zones. No significant metallization is associated with these; however, sulfides have been found in a few silicified fault breccia veins which strike other than northwest.

One of the major objectives of the current mineral survey of the Shield areas in Quadrangle 205 has been to establish the interrelationships of all of the hydrothermal deposits and to determine their relations to the major tectonic and plutonic elements of the Shield. The most important of these elements include the older, northward-trending folds and syntectonic granitic rocks, the younger, northwest-striking wrench fault zones, and the younger, granitic plutonic rocks. Concerning these, the following tentative conclusions have been reached on present evidence.

1. The gold deposits are genetically related to some of the older granitic rocks and to the northward-trending folds which are related to them syntectonically. The hydrothermal mineralization which formed the deposits accompanied the deformation which produced the folds and the intrusion of the granitic rocks.
2. Many silicified breccia and quartz veins, some containing base metal sulfides and fluorite, occur in or near minor northwest-striking faults in the northwest-striking wrench fault zones. The hydrothermal mineralization which produced them accompanied the deformation which produced the wrench faults and may have produced some of the base metal deposits, or remineralized some of the older gold deposits.
3. No significant hydrothermal mineralization accompanied intrusion of the younger granitic rocks.

The conclusion that the gold deposits and older granitic rocks are genetically related is based entirely on their close areal association. Although this is most obvious for the deposits worked in ancient mines, many others have been found during the current mineral survey for which it is equally true. Most of them occur within a kilometer or two of the intrusive contacts in marginal parts of older granite masses or in subjacent parts of the Haliban country rocks. For the few, apparently isolated, deposits farther than this from exposed contacts, similar proximity to those of buried masses can be safely inferred from metamorphic effects at the surface. As indicated earlier, little has been done on the petrology of the older granitic rocks. Until enough is known about them to correlate the numerous bodies with which the gold deposits are associated, the conclusion as to their genetic relationship must remain tentative.

Several occurrences of fluoritized limestone and chert, and of many large, silicified fault breccia veins and small fluorite veins on minor subsidiary faults in the northwest-striking wrench fault zones, constitute the main evidence that hydrothermal mineralization accompanied the deformation which produced the wrench faults. That metallization may have accompanied hydrothermal mineralization during the wrench fault deformation is indicated by the following indirect evidence. Gold and base metal deposits of the Ar Rhodah, Jazzabat al Ufar, Al Musamah, and Nugrah districts occur along and near the same wrench fault zone, the northernmost in Quadrangle 205; the first two districts are located about 75 kilometers northwest of the last two. In the Nugrah district, fluoritized limestone (at F.S.3061) and chert (at F.S.18169) occur in the wrench fault zone while just south of the zone, prominent, northwest-striking quartz vein-faults intersect both of the principal accordant-replacement, base metal deposits of the district (North and South Nugrah) in which fluorite is a minor constituent. Similarly, fluoritized chert is present along the same wrench fault zone in the Ar Rhodah district (F.S.2818) which, in addition, contains base metal sulfides; the same sulfides are present in all of the other known deposits of the district and fluorite is an abundant gangue mineral in the largest of these, the accordant-replacement copper deposit at Field Station 2811. Although no mineralization has been found in the wrench fault zone just south of Jabal Tuwalah (50 kilometers west of Nugrah), several large silicified fault breccia veins and numerous, small sulfide-bearing quartz veins with sparse sulfides occur within a few kilometers just north of it. All of these have the same attitude as the northwest-striking, vertical wrench fault, and the fractures and minor faults which they are in are almost certainly subsidiary structures of the wrench fault system.

Finally, although the gp granite masses and their surrounding country rocks have provided some of the most obvious targets in the present mineral survey, they have proved to be uniformly unmineralized. The few mineral deposits which are associated with them, such as the small, sulfide-fluorite-quartz veins at field stations 2486 and 2489 in the Ar Rhodah district, are thought to have formed as a result of the hydrothermal mineralization which accompanied the wrench-fault deformation.

The effects of the two periods of hydrothermal mineralization are obvious in some deposits, but they have not been distinguished in many others, nor have their relationships with each other and with the structures genetically related to them. However, for purposes of discussion they can be readily characterized as ancient gold, base metal, and fluorite mines; fluorite-sulfide-quartz veins; and silicified fault breccia veins.

Ancient mine and smelter sites:-- Beyond determining the gross geologic (tectonic, stratigraphic, plutonic) relationships of the mineral deposits in Quadrangle 205, it has been a lesser objective to establish the limits and essential features of all of the mineralized areas in the quadrangle in order to delineate mineral districts which represent more or less discrete loci of single periods of mineralization. So thoroughly was the country once prospected that these districts can everywhere be characterized by the ancient mines which they contain. Nearly all of these occur south of Wadi ar Rimah, in the southern half of the eastern part of the Shield in Quadrangle 205. They can be readily subdivided into gold, copper, and fluorite mines and grouped as major and minor workings of numerous districts in which these commodities were mined.

The name of the principal workings in each district and the one assigned to the district is underlined in each group of mines below.

GOLD MINES

Quadrangle 205

1. Al Musamah
2. Sokhaybrah
   a. West
   b. East
3. Mawan
   a. Um Zarib
   b. Bulgah
   c. F.S. 18304
   d. Subhah?
4. Shohaib
   a. Al Obaid
   b. Enaizat
   c. F.S. 18673
5. Thurb (North)
   a. South ?

Quadrangle 206

6. El Khom
   a. West
   b. F.S. 18678
   c. East
9. Ash Shumta
   a. South
   b. Al Boharah
10. Akliyah
   a. Derahn
   b. Arahiyah
   c. F.S. 18607
11. Al Hasan
   a. South

COPPER MINES

Quadrangle 205

1. Ar Rhodah
   a. Jazzabat al Ufar
   b. F.S. 2505
2. Musaynah
   a. North
   b. South
   c. East
3. An Numahr
4. Nugrah
   a. North
   b. South
   c. F.S. 3052
5. Subhah
6. Thurb (South)
7. As Safra
   a. North
   b. South

Quadrangle 206

8. El Abdt

FLOURITE MINES

Quadrangle 205

1. An Nabab
   a. F.S. 2737
   b. F.S. 2739
   c. F.S. 2740

Gold deposits:-- All of the ancient gold mines in Quadrangle 205 lie east of longitude 41°15'E., they appear to belong to a belt of gold deposits which continues eastward at least to longitude 43°00'E., and extends from latitude 23°30'N. in the south to latitudes 26°30'N., and perhaps to 27°00'N., in the north. Although mainly localized in deposits in this belt, gold is also a constituent of some of the copper deposits outside it. The fact that most of the gold deposits also contain sulfides of several metals, including copper, suggests that all of the deposits may be genetically related, but this can only be conjectured on present evidence.

All of the deposits which have been mined for gold, and many more like them which contain gold but have not been mined, consist of one or more quartz veins which vary in size from less than a meter to several meters wide and from less than one hundred to several hundreds of meters long. The veins are usually vertical or steeply dipping and, if several are present, they are parallel. The veins are more or less fractured and contain sparse to moderate amounts of base metal sulfides; although visible in vein material they are manifested as anomalous concentrations of base metals only barely in residual and wash material from the veins and very rarely in detrital material (talus, wadi sediment, etc.) from it at distances greater than a few hundred meters.

In addition to sparse base metal sulfides, the veins contain moderately abundant to very abundant pyrite, which imparts the most distinctive physical characteristics to them. The pyrite, mostly weathered to hematite, occurs as irregular-shaped, sometimes sizeable, filling clusters in fractures and as isolated cubes in the quartz or coating fractures and walls of the veins. Sparse, enhedral crystals of pink feldspar are often associated with the pyrite, especially on vein wall surfaces, and add materially to their distinctive physical aspect.

From the nature of the milling methods at the ancient mines, it is clear that most of the gold obtained from them was free in the veins. Blebs of free gold have also been observed in pyrite (or hematite pseudomorphs after it), however, tellurides have not been identified. Low content of silver as determined by assays of vein material an- by emission spectrography of mine dump material indicates that the fineness of gold is high, however, analyses of the gold alone are needed to confirm this.

Tungsten is usually present in the gold-quartz deposits as sparse to moderately abundant scheelite, but in some of the veins in the El Khom district (F.S.18679), it occurs as moderately abundant wolframite (Ankary, 1965a, 1965b). The physical similarity of the wolframite-quartz veins to numerous gold-quartz veins which are present in nearby ancient gold mines attests to their probable genetic relationship. Like the gold-quartz veins, the wolframite-quartz veins appear to be too small to be of economic value, however, they deserve more detailed examination to establish this.

All of the deposits worked in ancient gold mines and many others like them which were found during the current mineral survey, are closely associated areally with older granite bodies and are thought to be genetically related to them. They occur in marginal parts of these granitic bodies or in subjacent parts of the country rocks, always within a few kilometers of the contact. The granitic masses usually possess marked syntectonic features and have intrusive contacts, as indicated by higher than average thermal metamorphic effects in the country rocks and, at a few places, by dynamic intrusive features such as apophysitic dikes.

Most of the deposits in all of the gold districts consist of moderately to well-defined quartz veins or suites of parallel veins, but in a few places, notably at Mawan and Al Habla, they are localized along fractures which also contain andesitic and silicic dikes. No detailed studies have been made of these deposits and the inter-relationships of the dikes, veins, and granitic rocks have not been determined.

Systematic sampling and quantitative valuation of individual deposits were beyond the scope of the current reconnaissance mineral survey; however, qualitative evaluations on intrinsic geologic grounds were made. Because most of the gold deposits are far too small to be of economic interest, these evaluations were concerned mainly with geologic factors affecting volume, notably structural control features. On considerations of volume, there is little question that the best economic lode gold possibilities are in the Al Habla, Ash Shumta, and El Khom districts. At all of these places, especially the first, some of the known deposits are on strongly developed faults and fractures having considerable continuity in surface exposures and the potential for persistence in depth. Systematic investigation of these districts at 1:25,000 and larger scales should reveal whether any of these possess workable grade and tonnage.

Copper deposits:-- Although they were exploited for copper, the ancient copper mines are, in fact, base metal deposits. Sulfides of copper, lead, and zinc are the most abundant constituents, but nearly all of them also contain silver, gold and molybdenum.

All of the copper deposits are mainly accordant, bedded-replacement types, but small, filling type quartz veins which transect these are present in some deposits, notably in those of the Musaynah district. Individual deposits comprise conformable, siliceous-base metal replacement zones a meter or so to several tens of meters thick and a hundred to several hundreds of meters long. Being bedding replacement deposits, they have the same altitude as that of the rocks they replace; in all known deposits, these belong to the Haliban formation which strike uniformily northward and dip moderately to steeply toward the east and west.

Most copper districts comprise numerous individual bedded replacement deposits which occur intermittently for several kilometers in the same general sequence of Haliban rocks and are aligned northward. In most districts, these sequences are calcarious and contain abundant marble beds and lenses, as at Nugrah and As Safra; but at a few places, although they have the same general replacement character as those in calcareous sequences, the copper deposits are in noncalcareous rocks, such as the An Nimahr deposit, which is in tuffaceous shales.

Field evidence concerning the larger geologic aspects of the copper deposits is contradictory and no final conclusion has been reached about them. The gross stratigraphic localization of the deposits, mainly in calcareous sequnces of the Haliban formation, together with the association of bedded jasper beds with two of them (Musaynah, An Nimahr), and of copper sulfides and anomalies with a few jasper beds elsewhere (F.S.2782, F.S.2942), suggests that they may be of syngenetic-metamorphic origin. Contrarily, the Nugrah district lies just south of a well-defined wrench-fault zone and the two main accordant-replacement deposits of the district (North and South Nugrah) are intersected by northwest-striking fault veins which are subsidiary structures of the wrench-fault system. Finally nearly all of the copper deposits are located within a short distance (laterally or vertically) of contacts with granitic bodies; many of these bodies are either the same as those with which some of the gold deposits are associated or they possess similar syntectonic features. The possibility that all of the deposits, whether exploited for gold or copper, formed during a single period of auriferous-siliceous-base metal hydrothermal mineralization is indicated strongly by the overlapping mineralogic and chemical composition of the two suites of deposits: Sparse base metal sulfides and abundant pyrite are present in all of the gold deposits and all of the base metal deposits also contain gold.

Fluorite deposits:-- Fluorite occurs widely as a minor constituent of many kinds of hydrothermal deposits, but it has only been mined in the An Nagab district in Jabal Kurayziah. There, the fluorite occurs in numerous small to moderately large, shattered quartz veins; a few of these were mined, probably to provide flux for the copper smelting operations at Musaynah, Al Huwayit, and Al Hayit.

The fluorite deposits are clearly related to the siliceous-fluorite hydrothermal mineralization which accompanied the wrench-fault deformation. Numerous small fluorite veins occur in minor faults of the wrench-fault system at F.S.2763, just north of the An Nagab district, and in finely fractured, thin-bedded limestone and chert calcareous and siliceous rocks at field stations 2818, 3061, and 18169; all of those have been preferentially preserved along the same northernmost wrench fault zone.

Fluorite-sulfide-quartz veins:-- Small fluorite and sulfide-bearing quartz veins from a few to a few tens of centimeters thick and several hundreds of meters long, and vein material from them are present at several places in the eastern part of Quadrangle 205. Most of the veins occur in granitic rocks, often in great numbers, and the vein material is present as debris in wadis draining them. When first encountered, these veins were thought to be of magmatic segregation origin, however, in light of their regional relationships, they are now thought to be genetically related to the hydrothermal mineralization associated with the wrench-fault deformation.

The three principal occurrences of these veins are at Jabal Wasmah 30 kilometers north of Hulayfah, at field stations 2875-2877 20 kilometers southeast of Hulayfah, and in Jabal Tuwalah 20 kilometers north of Bir Arja. The areal association of two of these localities - Jabal Wasmah and Jabal Tuwalah - adjacent to wrench-fault zones, and of the first of these adjoining the Jazzabat al Ufar district, together with physical character and composition of the veins, is the principal field evidence for concluding that they are genetically related to the other hydrothermal mineral deposits.

Compositional affinities of the veins in Jabal Wasmah and deposits of the Jazzabat al Ufar district are very strong. Fluorite, and the sulfides and weathered products of copper and lead have been identified in the veins and in most of the deposits of the district, including the replacement deposits in the Haliban rocks at Ar Rhodah (Field Station 2811) and in thin bedded Shammar rocks in the Wadi Asmarah wrench-fault zone at Field Station 2818.

The physical habit of the quartz veins in Jabal Tuwalah relative to the adjacent northwest-trending wrench-fault zone is striking. Single veins and swarms of parallel veins are vertical and strike northwestward and, at two places, (field stations 2921 and 2952), they occur near and have the same attitude as silicified fault breccia veins.

Although the fluorite-sulfide-quartz veins at field stations 2875-2877 are very similar to those in Jabal Wasmah and, Jabal Tuwalah, they are not obviously associated with any wrench-fault structures and their attitude differs from the veins at these places in striking eastward instead of northwestward. This is the same as the attitude of numerous, prominent lineaments and rhyolite dikes and, as suggested earlier, may constitute the tension features which might have formed concurrently with the wrench-faults.

One of the isolated occurrences of the sulfide-quartz veins, at Field Station 18012, merits special mention. These occur along the wrench-fault zone which passes through Hanakiyah; they differ from the others found elsewhere in being the only ones found in other than granitic rocks, in this case in sandstone of the Shammar unit.

Silicified fault breccia veins:-- Silicified breccia veins are sufficiently abundant in the eastern part of Quadrangle 205 to be mapped as separate mineral occurrences. Being very large, up to several kilometers long, they constitute almost the only possibility of large volume-low grade epigenetic mineral deposits in the area. For this reason, they were inspected and sampled wherever encountered.

By far the greatest numbers of the silicified breccia veins have formed along northwest-striking vertical, strike-slip faults within the wrench-faults zones and are thus, like the faults, features of the wrench-fault system. This being so, most of them are present in the part of the area south of Wadi ar Rimah where they are further localized in and along the wrench-fault zones.

No significant metallic mineralization has been found in any (2759-60?) of the northwest-striking fault breccia veins, although a few are strongly iron stained. By themselves, they constitute the most spectacular evidence for the genetic relationship of mineralization with the wrench-faulting, yet they cannot represent more than a barren quartz stage of it. Such additional attention as they deserve should be in conjunction with a much broader investigation of all features of the wrench-fault system.

The remaining silicified breccia veins strike other than northwest, but are otherwise similar to those which do; they include the only deposits of this type in which sulfides have been identified. These are located at Field Stations 18288, 18289, and 18290, just southeast of the Bulgah and Mawan districts.

Hydrothermal alteration.

Several kinds of alteration which are thought to be of hydrothermal origin are sparse but widespread in the Shield in the eastern part of Quadrangle 205. These include bleached rocks, jasperoid, and serpentine. Only jasperoid and a yellow-green mineral which occurs in some of the bleached marble zones are closely enough associated with known mineral deposits to assume a genetic relationship.

Bleached rocks:-- Bleached zones in rocks of several kinds have been found during the present mineral survey. They are present in granitic rocks at Field Station 2587 (25 kilometers northwest of Ghazzalah), in felsic rhyolite rocks at Field Stations 2403 (3 kilometers north of Al Awshazyah) and 2482 (45 kilometers northeast of Hulayfah), in marble at Field Stations 2868 (15 kilometers southeast of Hulayfah) and 18060 (45 kilometers west of Jabal Mawan), and in metasedimentary rocks at Field Station 18163 (40 kilometers east of Nugrah).

Only the bleaching in marble is now known to be associated with potentially economic mineralization. The bleached marble at Field Station 2868, which is located about one kilometer south and in the same marble bed that contains the massive iron deposit at Field Station 2866, contains the same yellow-green mineral (not identified) which is present in the marble with the massive iron deposit at Field Station 2862. The same association of this mineral in bleached marble occurs at Field Station 18060 and is similarly present along the contact of a small granitic body. The implications of the possible genetic relationship of this alteration and the contact-metasomatic massive iron deposits is considerable: it is that the massive iron deposits, like the alteration, may occur far beyond the limits of the known deposits south of Hulayfah.

Jasperoid:-- Jasperoid alteration is present both in mineral districts where it seems definitely to have formed with the other hydrothermal deposits, and at other places with no obvious relationship to them. In the Musaynah district, jasperoid occurs as a gangue mineral in the copper deposits and as sporadic, small altered deposits in marble throughout the district. Conversely, in Jabal al Furs (field stations 2498-2500, and 2555, 50 kilometers north of Hulayfah), it makes up irregular but extensive altered zones in pyroclastic rocks, but neither occurs near known hydrothermal mineral deposits or contains anomalous amounts of any metallic elements.

Syngentic deposits

Information has been developed during the current mineral survey about a number of widespread geologic features in Quadrangle 205 which both possess characteristics of epigentic mineral deposits and have implications for syngenetic ones. These are associated with both layered rock units and are either sedimentary rocks, as in the case of the Shammar unit or metamorphic equivalents and derivatives of sedimentary rocks and sequences, as in the case of the Haliban unit. Some of these deposits, such as bedded jasper, are little changed from their original sedimentary form, but others, such as metasegregation quartz masses, are the result of a total metamorphic reconstitution and compositional differentiation of the original sedimentary rocks and rock sequences.

Metallic deposits.

Bedded jasper-hematite rocks:-- Lenticular beds of jasper are widely distributed in the area south of Wadi ar Rimah where they crop out as numerous, elongate deposits in well-defined belts marking lithologic horizons in the layered rock sequences. Individual deposits are as much as two kilometers long and a few tens of meters thick. All of the jasper deposits occur in rocks of the Haliban unit which, being of marine origin, is the most likely place for them.

The bedded jasper deposits are of interest in the context of the present mineral survey for the iron and copper associated with some of them. Of these, iron as hematite is the invariable associate of the jasper and, undoubtedly, was deposited with it. Hematite is present as layers (jaspilite) and disseminations in the jasper and is sufficiently abundant in some deposits to yield assays of 30% iron from specially picked samples.

The association of copper with the jasper deposits is more irregular and may be fortuitous. The most significant occurrences of copper with jasper are in the Musyanah district and at Field Stations 2780 and 2942, respectively, about 30 kilometers southwest and southeast of it. Copper and hematitie-jasper deposits occur together throughout the Musaynah district, notably at Field Stations 2873 in the southern part and 3038 in the northern part. Two characteristics of the mineralization in the Musaynah district are significant in this connection. It has been controlled to a large degree by primary layering in the Haliban sedimentary and volcanic rocks and, as a consequence, has yielded mainly replacement deposits which are concordant with them. Bedded jasper being one of these, it is not surprising that some copper mineralization should have been deposited in them/

A further coincidence is the presence of jasper as a gangue mineral in some of the northeast-striking vein copper deposits. This indicates that it may also occur much more widely in the district as an alteration product. Much more detailed work than was possible during the durrent survey would be needed to solve the prolem, but there is little doubt that the district deserves it.

At the other two localities cited, copper minerals were found with the jasper at Station 2942, and that at station 2780 was found to contain an anomalous amount of copper (as determined by emission spectrometry). As in the Musaynah district, the association of the copper and jasper may be fortuitous. In all cases, the deposits are also closely associated with structures of the wrench-fault system. If it has excercised the structural control of the copper mineralization, the association of copper and bedded jasper deposits is fortuitous, wheras the association of copper and jasper as a gangue or alteration mineral is a genetic one.

Silicified and pyritized marble:-- Small silicified masses and nodules in marble beds in the Haliban unit are common throughout the area south of Wadi ar Rimah. When first observed near some of the ancient mines, they were thought to be related to the epigenetic mineralization of these districts. They were encountered subsequently at great distances from and were found to have characteristics which clearly marked them as of syngenetic origin.

The silicified bodies occur sporadically in marble lenses and beds cropping out in well-defined belts in the Haliban metasedimentary sequences. This general habit of occurrence, together with the absence of the silicified bodies in some marble belts, suggests strongly that they have formed in response to some peculiarity of composition of the original limestone beds from which they were derived, or to some later differential effect of regional metamorphism arising from the same factor.

Most of the silicified masses, nodules, and small vein-like bodies are dense and blue but many are iron stained. In all cases observed, this was due to small amounts of disseminated pyrite. The silicified bodies are not thought to have any economic potential.

Non-metallic deposits.

Metamorphic segregation quartz masses:-- At numerous places in the area south of Wadi ar Rimah, quartz occurs in great abundance as smaller and larger masses in the country rocks, and as profuse eluvial and alluvial debris derived from them. Most of this quartz occurs in well-defined belts in the Haliban unit but it is also present in some ill-defined or irregular-shaped areas. Where best developed and most abundant, the quartz is closely associated with calcareous sequences of the Haliban unit in fold belts. In these cases, it seems clear that the quartz is the result of differentiation, mobilization, and deposition of the siliceous material of the original sequence in response to deformation, and thermal and hydrothermal activity associated with regional metamorphism, the latter probably involving and assisted by the role of dissolved carbonate material and perhaps other mineralizing agents.

By far the most of the quartz comes from smaller and larger concordant pods and lenses in the metasediments, but much is also derived from small veins and veinlets, some of which join accordant bodies.

Sparse carbonate, silicate, and metallic minerals, including iron and copper sulfides and magnetite, are present in the quartz, however, it has no economic potential and requires no additional work.

Thin-bedded siliceous rocks and magnesite:-- Younger layered rocks of the Shammar rhyolite occur widely but in small exposures in the eastern part of Quadrangle 205. They are largely localized in wrench fault zones and are clearly outliers of far more extensive deposits which have been preferentially preserved in them. The exposures include chert, limestone, siliceous and tuffaceous shales, arkosic sandstone and conglomerate, and rhyolitic pyroclastic and flow rocks.

The Shammar rocks are of interest economically for two mineral commodities, magnesite and manganese, which have been found in them already, and for some potential they may have for syngenetic gold deposits. Magnesite has been found as small beds and lenses in thin-bedded calcareous and siliceous rocks at Zarghat (F.S.2518) and at F.S.2818, about 30 kilometers southeast of this. At Zarghat, magnesite also occurs as large nodular masses of remarkable purity. Both occurrences are too small to be of economic interest, however, additional work is warranted to seek larger deposits

Small manganese nodules up to a few centimeters in diameter are interbedded with a thick section of cherty rocks at F.S. 2796, about 20 kilometers north of Al Hayit; the deposits are too small to be of interest. Ancient flint workings are also present.

Finally, because they were derived, in part, from auiferous bedrocks of the Haliban formation, the sandstones and conglomerates of the Shammar unit deserve to be examined and tested for any gold placers, which they might contain.

Future investigations

Of the total Shield area lying east of the lava in Quadrangle 205 (64,000 square kilometers, 25,000 square miles), only one-third (25,000 square kilometers, 10,000 square miles) warrants additional investigation. Nearly all of this part of the Shield is located south of Wadi ar Rimah; it encompasses all of the mineral districts and ancient mines and most of the other mineral occurrences.

Two general bases for further work in Quadrangle 205 are possible - areal and topical: the first consists of additional, larger-scale studies of all aspects of the geology, and the latter of special studies of those aspects most directly related to mineral deposits. Included in topical investigations would be such things as detailed studies of known mines and mineral occurrences, studies to determine structural control or plutonic relationships of epigenetic mineral deposits, and stratigraphic studies for syngenetic and detrital deposits. On the basis of the results of the current reconnaissance mineral survey, additional work is recommended on the basis of areal investigations at 1:50,000 and larger scale, with emphasis on detailed studies of the mineral districts and structures of the wrench-fault system associated with them.

Areas recommended for further work are shown on the enclosed 1:2,000,000 scale map and numbers in order of priority of mineral potential and proposed work. These are:

1. An Nimahr - Nugrah.
2. Musaynah - Ar Rhodah
3. As Safra - Al Hasan
4. Mawan - Sokhaybrah - (Al Habla)
5. An Nagab - Al Kurayziah

This order has been chosen because the results from it would provide the basis for earliest evaluation and realization of the best mineral potential and solution of the general problems of genesis and control of the mineralization. Thus, from the earliest stage would come knowledge of the character and relationships of two major wrench-fault zones and five mineral districts associated with them and, in addition, information concerning the possible plutonic association of some of the deposits of these districts.

References

Anon., 1963, Geologic map of the Arabian Peninsula (compiled by U. S. Geological Survey and Arabian American Oil Company): U. S. Geological Survey Misc. Geol. Inv. Map I-270A.

Bramkamp, R. A., Ramirez, L. F., Brown, G. F., and Pocock, A.E., 1963, Geologic map of the Wadi ar Rimah Quadrangle, Kingdom of Saudi Arabia: U. S. Geological Survey Misc. Geol. Inv. Map I-206A.

Brown, G. F., Layne, Newton, Goudarzi, G. H., and MacLean, W.H., 1963, Geologic map of the Northeastern Hijaz Quadrangle, Kingdom of Saudi Arabia: U. S. Geological Survey Misc. Geol. Inv. Map I-205A.

Ankary, A. O., 1965a, Short report on the El Koom-Ashumta area, Saudi Arabia: Saudi Arabia Directorate Gen. Min. Res. Rept. 5, 2 p.

Ankary, A. O., 1965b, The occurrence of tungsten in the southwestern portion of the Wadi ar Rimah quadrangle, Saudi Arabia: Saudi Arabia Directorate Gen. Min. Res. Rept. 11, 2 p.

MAP SYMBOLS - MINERAL DEPOSITS

Note: Numbers with symbols indicate field stations and sample sites. All stations located with respect to shaded relief features on geologic and geographic maps of Quadrangle 205. (I-205A and I-205B, Glen F. Brown, et, al, 1383 A.H., 1963 A.D.)

<u>EPIGENETIC</u> - Magmatic, contact-metasomatic

Pegmatites and pegmatitic veins

simple, unzoned

zoned; mainly with stellate quartz cores and border zones rich in pink feldspar and hematite; some contain sparse Cu and Pb sulfides.

Contact-metasomatic deposits

Fe mainly massive magnetite

<u>EPIGENETIC</u> - Hydrothermal alteration and mineralization; includes ancient mines, smelter sites, and doubtful mineral occurrences.

Hydrothermal deposits and ancient mines

<u>Cu</u> ancient mine; vein and (or) replacement deposit; underlined field station number indicates ancient workings; principal constituents shown by element symbols; commodity mined underlined.

concordant mineral deposit; mainly of disseminated, replacement character; symbol used in conjunction with the one for ancient mine (above).

discordant mineral deposit; mainly cross-cutting, filling-type quartz veins; symbol used in conjunction with the one for ancient mine (above).

Cu mainly small quartz veins with sparse sulfides and fluorite; principal constituents indicated by element symbols.

barren, silicified fault breccia vein

barren, silicified fault breccia vein, strikes northwestward; occurs mainly in northwest-trending wrench-fault zones.

Cu mineralized, silicified, fault breccia vein, contains sulfides; principal constituents indicated by element symbols.

quartz veins with sparse to moderately abundant pink feldspar.

doubtful or unevaluated mineral occurrence; usually isolated, apparently barren quartz vein

Hydrothermal alteration:

$\otimes_b$ bleached

$\otimes_s$ serpentine; mainly after Glen F. Brown, ef. al., 1383 AH, 1963 AD

$\otimes_j$ jasper

other

Ancient copper smelter site without ancient mine

slag, moderately to very abundant

single or sparse pieces of slag, probably transported.

SYNGENETIC - Sedimentary, regional metamorphic

Metallic

bedded jasper with varying amounts of disseminated iron oxides,

silicified nodules and irregular siliceous replacement masses in marble; usually iron-stained and containing disseminated pyrite.

small beds of hematite; probably similar to jasper-hematite beds.

Non-metallic

abundant metamorphic segregation quartz; usually associated with calcareous meta-sedimentary rocks; contains sparse carbonate, silicate, and metallic minerals.

thin bedded siliceous rocks, including chert, flint, and jasper.

$_{Mg}$ bedded magnesite

$_{T}$ bedded talc deposit

GEOLOGIC AND GEOGRAPHIC EXPLANATION

Contact; dashed where approximately located

Fault; dashed where approximately located, queried where probable. Arrows indicate location of field evidence for relative horizontal movement.

Fault or lineament from aerial photographs.

Center line of wrench-fault zones, approximately located; queried where doubtful or weakly developed.

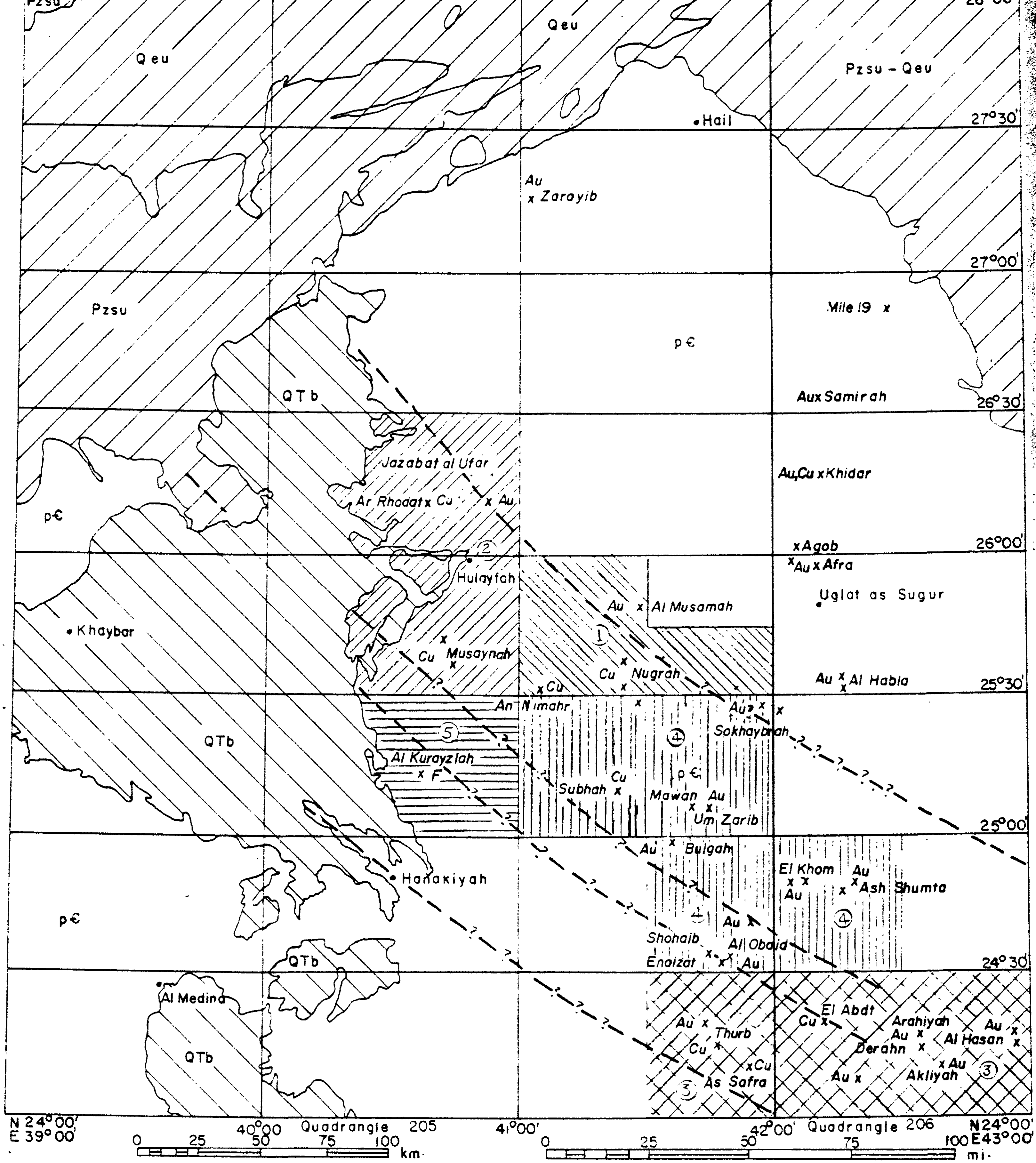
Trend lines, showing layering in layered rocks and foliation in metamorphic rocks.

MAWAN (A20)	Name of ancient mine and number of low-level, aerial photographic survey (1:12,500 scale).
2983	Field station and number of sample from station.

Boundary of French mineral survey area.

Hulayfah airborne magnetic-scintillation survey area.

Hulayfah (78)	Number and geographic name of 1:100,000 scale photomosaic sheet of area.



x Musaynoh-Ancient mine Scale 1 2,000,000 Au-gold, Cu-copper, F-fluorite

NORTHEASTERN HIJAZ QUADRANGLE 205 AND WESTERN PART OF WADI AR R.MAH QUADRANGLE 206

Qeu-Quaternary eolian/alluvial deposits, undivided - Pzsu-Paleozoic sedimentary rocks, undivided

QTb-Quaternary-Tertiary basaltic lava (harrat) p€-Precambrian rocks, undivided (Arabian Shield).

SAMPLE DATA

70-168

CONTENT† OF ELEMENTS (ppm) IN SAMPLES FROM QUADRANGLE 205-6[redacted]. SILICIFIED FAULT BRECCIA VEINS

Number	Type"	Size°	Ag	As	Au*	B	Ba	Be	Bi	Cd	Co	Cr	Cu	Ga	Ge	Hg	La	Mn	Mo	Nb	Ni	Pb	Sb	Sc	Sn	Sr	Te	Ti	U	V	W	Y	Zn	Zr
Min. detect. content'			1		1	10	20	2	20	50	5	5	10	10	20		20	20	2	50	5	10	200	10	10	50		20		20	50	10	100	20
2507																																		
2759	R/W	<32				30	700				20	300	20	15				700	5		20	20		15		300		2000		50		15		30
2759																																		
2759	RV		1			30	100				20	30	150	10				500	15		20					50		500		50				10
2760	R/W	<32				30	300				10	200	10	15				700	5		30	30		15		150		1500		70		15		50
2869																																		
2953	R/W	<32				30	70				10	70	10	30				200			20	15		<10		100		500		50		20		30
2954																																		
18202	R/W	<32				15	500				20	70	15	10				500			15	15		10		200		5000		100		15		100
18288	R/W	<32				15	500				30	150	10	10				500			20	15		10		200		7000		100		15		100
18289	R/W	<32				15	700				10	50	15	10				500			30	10		10		200		3000		100		20		70
18290	R/W	<32				15	500				30	150	10	10			30	500			20	15		15		200		7000		100		20		150
18343	R/W	<32				20	500				30	150	10	15			70	700			30	10		15		150		5000		100		20		100
18344	R/W	<32				20	700				30	150	10	10			50	700			20	10		15		150		5000		100		20		70
18345	R/W	<32				20	1000				30	200	10	15				500			30	10		15		700		5000		100		15		70
18363	R/W	<32				20	500				30	150	10	10			20	700			30	10		15		150		7000		100		20		100
18367	R/W	<32				30	500				15	70	15	15				500			50	10		10		150		7000		100		20		100
18374	R/W	<32				20	300				10	500	15	10				500			50	10		10		200		5000		100		10		70
18384	R/W	<32				30	500				30	150	15	10				700			30	15		15		150		7000		150		15		100
18442	R/W	<32				30	500				10	70	50	10			20	500			50	10		15		300		5000		150		20		100
18427	R/W	<32				20	300				15	150	20	15				500			50	15		10		200		5000		100		20		100
18589*	R/W	<32				20	200				20	70	30	10				300			50	10		10		200		3000		100		15		100
18646	R/W	<32				30	300				15	70	20	10				200			50			10		200		2000		50		10		70
18651	R/W	<32				20	300				10	50	20	15				300			30	20				200		2000		50		10		70
18655	R/W	<32				20	300				10	50	20	15			100	200			50	10		15		300		2000		70		20		150
18656	R/W	<32				15	500				10	50	20	15				200			20	10		10		200		2000		50		15		100
18659	R/W	<32				15	500				15	50	50	10				300			30	10		10		2000		1500		50		10		70
Background																																		

† All determinations by emission spectrometry (Analyst: C.E. Thompson) unless indicated otherwise: a-assay results converted to ppm; f-fluorescence; r-radiometric; x-X-ray spectrometry; w-wet chemical methods; v-vapor detection. * carbonate fault breccia vein

" R-rock: RA-altered rock; RP-pegmatite; RV-vein material; S-soil sample; R/W-residual and wash material; AD-dump and pit material from ancient mine; AT-tailings from

SAMPLE DATA

70-168

CONTENT† OF ELEMENTS (ppm) IN SAMPLES FROM QUADRANGLE 205 [redacted] SAMPLES FROM ANCIENT MINE WORKINGS 1/6

Number	Type"	Size°	Ag	As	Au*	B	Ba	Be	Bi	Cd	Co	Cr	Cu	Ga	Ge	Hg	La	Mn	Mo	Nb	Ni	Pb	Sb	Sc	Sn	Sr	Te	Ti	U	V	W	Y	Zn	Zr
Min. detect. content'			1		1	10	20	2	20	50	5	5	10	10	20		20	20	2	50	5	10	200	10	10	50		20		20	50	10	100	20
ZURAYIB	(?)																																	
18689	R/W	<32				30	200				10	50	20	10				200	3		15	10		10		700		1500		50		10		100
SAMIRAH	(Au)*																																	
18685	AD	<32				20	500				30	100	150	15				500			20			15		300		3000		100		15		100
[illegible]T	AT	<32	1			15	500				20	100	100	15				300			30	300		10		300		3000		100		15		100
2463																																		
[illegible]	(Au,Cu)																																	
2505																																		
2505	RV					<10	50					5	20	<10				100			<5	50				200		50		20		<10	100	<20
2505																																		
2505																																		
2507½																																		
2507½																																		
2507																																		
2811	AD	<32				30	500				15	200	70	15				500			20	15		10		200		1500		50		15		30
2811																																		
2815	R/W	<32				20	300				10	100	20	15				300			15	300		<10		200		700		50		<[illegible]		20
2815																																		
2841	AD	<32				20	500				15	150	20	15				700			30	15		10		200		3000		70		10		50
2841																																		
[illegible]	(Cu)*																																	
2052	AD					70	700				20	200	1000	20				500	2		30	20		20		300		2000		100		15		100
2052																																		
2873	AD	<32				20	200	2			10	200	50	30				500			30	200		10		200		1000		50		50	200	70
2873																																		
3022																																		
3022																																		
3037																																		
3037																																		
[illegible]	(Cu)*																																	
2034	R/W	<32				20	200				10	150	10	10				500	2		20	20		10		150		1500		50		20		30
2034																																		
2034																																		
2035	AD	<32	3			20	500				20	100	1000	10				700	15		15	3000	200	15		150		1000		100		15	1500	100
2035																																		
2035																																		
2038½	AD	<32	10			15	1000				30	150	1000	10				700	30		30	200		20		100		3000		200		15	3000	70
2038½	AD		7			20	1000				20	200	700	10				500	15		50	2000		15		200		1500		100		10	2000	70
2090 (3039)	AD	<32				15	300				20	100	500	10			30	300	50		10	10		15		200		5000		70		20	700	100
Background																																		

† All determinations by emission spectrometry (Analyst: C.E. Thompson) unless indicated otherwise: a-assay results converted to ppm; f-fluorescence; r-radiometric; x-X-ray spectrometry; w-wet chemical methods; v-vapor detection. * (Au) - gold (Cu) - copper

" R-rock; RA-altered rock; RP-pegmatite; RV-vein material; S-soil sample; R/W-residual and wash material; AD-dump and pit material from ancient mine; AT-tailings from

SAMPLE DATA

CONTENT† OF ELEMENTS (ppm) IN SAMPLES FROM QUADRANGLE 205 [redacted] SAMPLES FROM ANCIENT MINE WORKINGS 2/6

Number	Type"	Size°	Ag	As	Au*	B	Ba	Be	Bi	Cd	Co	Cr	Cu	Ga	Ge	Hg	La	Mn	Mo	Nb	Ni	Pb	Sb	Sc	Sn	Sr	Te	Ti	U	V	W	Y	Zn	Zr
Min. detect. content'			1		1	10	20	2	20	50	5	5	10	10	20		20	20	2	50	5	10	200	10	10	50		20		20	50	10	100	20
2090																																		
2090																																		
3052	AD	<32				15	500				20	100	50	15				500			70	15		15		200		5000		70		20		150
3052																																		
3052																																		
3059	AD	<32				15	300				20	100	500	10			30	300			50	10		15		200		5000		70		20	700	100
3059																																		
3059																																		
[illegible] NIMARS	(Cu)*																																	
2176	AD	<32	1			20	150				10	100	70	15				100	100		10	2000		10		200		1500		300		15	2000	50
2976																																		
2976																																		
AL [illegible]	(Au)*																																	
[illegible]	R/W	<32	1			30	500				10	100	50	15				500	3		15	1000		10		200		700		50		[illegible]	200	20
2191½																																		
2191½																																		
[illegible]	R/W	<32				20	300				10	150	20	15				500	2		15	70		10		300		1500		50		10		30
[illegible]																																		
[illegible]																																		
AL HABLA	(Au)*																																	
13683	AD	<32				20	500				20	200	50	15				500			70	200		15		300		3000		100		20		100
13683																																		
13683																																		
SOK HAYRR[illegible]	(Au)*																																	
2013	AD	<32				15	700				10	150	10	10				500			20	15		15		300		1500		50		10		70
2013																																		
2015	AD	<32				20	700				15	200	15	10				500	5		30	15		10		200		2000		50		15		100
2015																																		
18212	AD	<32				20	500				20	150	50	10				500	2		20	30		10		150		5000		100		10		100
18212																																		
18213	AD	<32				20	500				30	200	10	10				500	2		30	50		15		150		5000		100		10		100
18213																																		
18214	AD	<32	1			15	500				30	100	10	10				300	3		20	200		10		150		5000		100		15		150
18214																																		
½ 18215T	AD	<32				15	500				20	100	10	10				300			20	10		10		200		2000		100		10		100
18215T																																		
2/6 18215T	AD	<32	2			15	300				20	100	20	10				300	10		15	70		10		200		[illegible]		100		10		70
18215T																																		
MAWAN	(Au)*																																	
2025	R/W					15	500				15	10	[illegible]	10				700			15	15		10		200		1500		100		10		70
2025																																		
18123	AD	<32				15	500				30	150	10	10				500	<2		15	50		15		150		5000		100		15		70
Background																																		

† All determinations by emission spectrometry (Analyst: C.E. Thompson) unless indicated otherwise: a-assay results converted to ppm; f-fluorescence; r-radiometric; x-X-ray spectrometry; w-wet chemical methods; v-vapor detection. * (Au) - gold (Cu) - copper

" R-rock; RA-altered rock; RP-pegmatite; RV-vein material; S-soil sample; R/W-residual and wash material; AD-dump and pit material from ancient mine; AT-tailings from ancient mine; AS-slag; HWS-head wadi or fan sediment; WS-wadi sediment; K-khabra sediment. Letters after the foregoing indicate magnetite (M), panned concentrate (P)

SAMPLE DATA

CONTENT† OF ELEMENTS (ppm) IN SAMPLES FROM QUADRANGLE 205 [redacted] SAMPLES FROM ANCIENT MINE WORKINGS 3/6 70-168

Number	Type"	Size°	Ag	As	Au[a]	B	Ba	Be	Bi	Cd	Co	Cr	Cu	Ga	Ge	Hg	La	Mn	Mo	Nb	Ni	Pb	Sb	Sc	Sn	Sr	Te	Ti	U	V	W	Y	Zn	Zr
Min. detect. content'			1		1	10	20	2	20	50	5	5	10	10	20		20	20	2	50	5	10	200	10	10	50		20		20	50	10	100	20
18123																																		
181[illegible]																																		
1812[illegible]	AD	<32	1			20	500				30	150	15	10				700	7		10	200		15		150		3000		100		15		150
UM ZAG[illegible]	(Au)*																																	
1812	AD	<32				20	500				30	50	15	15				700			20	70		15		200		5000		100		20		100
18126																																		
18127	AD	<32	1			15	500				30	150	10	10				500	2		10	70		15		150		5000		100		15		100
18127																																		
18127																																		
18129	AD	<32	1			15	500				30	200	10	10			50	500	5		15	100		15		150		5000		100		20		300
18129																																		
S[illegible] H	(Cu)*																																	
2027	AD					15	500				15	100	150	10				700	5		20	100		15		200		2000		100		10	500	150
2027																																		
18130	AD	<32				15	500				30	50	10	10				500			30	15		10		150		3000		70		15		[illegible]
18139	AD	<32				15	200				30	200	20	10				700	2		30	15		20		150		5000		100		15		70
18139																																		
AN NAGAB	(F)*																																	
2737	AD	<32				20	200				15	150	10	20				500			20	20		10		200		2000		50		15		70
2737																																		
2739	R/W					20	300				15	20	10	20				100			20	20		10		200		2000		30		15		50
273[illegible]																																		
274[illegible]	R/W					20	500				20	200	15	20				500			20	20		15		300		2000		50		15		70
274[illegible]																																		
BU[illegible]AH	(Au)*																																	
18256	R/W	<32				15	500				30	7	10	10				500			20	15		10		150		500		100		15		150
18256																																		
18257A	AD	<32				20	700				10	70	70	10				500	5		30	15		10		200		2000		70		15		100
18257 A																																		
18257B	R/W	<32				15	500				7	150	20	10				300			30	10		10		150		3000		100		15		100
18257B																																		
SH[illegible]AIB	(Au)*																																	
18346	AD	<32	3			15	2000				[illegible]	70	150	15				700	20		15	1500		20		200		5000		150		15	1500	70
18[illegible]46																																		
18346T	AD	<32				10	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]				500			[illegible]	100		10		[illegible]		[illegible]		100		15		100
18346T																																		
EN[illegible]T	(Au)*																																	
18421	AD	<32				20	300				50	100	20	15				700			20	500		15		[illegible]		5000		100		15	150	100
18421																																		
18422	AD	<32				20	50			150	30	500	15	10				500			50	150		15		150		500		150		15	150	100
18422																																		
18422T	AD	<32				10	300				15	10	50	10				500			20	300		10		200		3000		150		15		100
18422T																																		
Background																																		

† All determinations by emission spectrometry (Analyst: C.E. Thompson) unless indicated otherwise: a-assay results converted to ppm; f-fluorescence; r-radiometric; x-X-ray spectrometry; w-wet chemical methods; v-vapor detection. * (Au)-gold (Cu)-copper (F)-fluorite

" R-rock; RA-altered rock; RP-pegmatite; RV-vein material; S-soil sample; R/W-residual and wash material; AD-dump and pit material from ancient mine; AT-tailings from

SAMPLE DATA

CONTENT† OF ELEMENTS (ppm) IN SAMPLES FROM QUADRANGLE 205-6 [redacted] SAMPLES FROM ANCIENT MINE WORKINGS 4/6

70-168

Number	Type"	Size°	Ag	As	Au*	B	Ba	Be	Bi	Cd	Co	Cr	Cu	Ga	Ge	Hg	La	Mn	Mo	Nb	Ni	Pb	Sb	Sc	Sn	Sr	Te	Ti	U	V	W	Y	Zn	Zr
Min. detect. content'			1		1	10	20	2	20	50	5	5	10	10	20		20	20	2	50	5	10	200	10	10	50		20		20	50	10	100	20
AL DURD	(Au,Cu)																																	
18423	AD	<32				15	300				50	100	20	10				700	2		20	50		15		100		5000		150		15		100
18423T	AD	<32	1			15	500				15	70	100	10				500			20	1000		10		200		3000		150		20		100
18423T																																		
AS SAFRA	(Cu)*																																	
18378	AD	<32	2			10	500		100		30	30	>10000	10				700	2		15	30		10		150		3000		100		15		70
18378																																		
18378																																		
18379	AD	<32	2			10	500		30		30	50	>10000	10				700	7		15	500		10		150		3000		100		15	700	70
18379																																		
18379																																		
THURB	(Au,Cu)																																	
18398	AD	<32				20	300				15	100	100	10				700			30	70		10		200		5000		150		20		100
18398																																		
18399	AD	<32				20	700				50	150	15	10				500			30	15		15		150		3000		70		15		100
18399																																		
18400	R/W	<32				20	500				50	150	15	10				700			30	10		15		100		7000		150		20		100
18400																																		
EL KHOM	(Au)*																																	
18673	AD	<32				20	500				20	70	30	15				500			50	15		10		200		3000		70		20		100
18673																																		
18673																																		
18673	AT	<32				15	500				20	100	30	10				300			30	20		10		300		2000		70		20		70
18674	AD	<32				20	500				20	100	20	10				300	2		30	20		10		200		3000		70		20		200
18674																																		
18674																																		
18675	AD	<32				15	500				20	70	100	15				500			50	10		10		200		5000		100		30		100
18675																																		
18675																																		
18676	AT	<32				15	500				20	70	200	15				300			30	20		10		200		5000		70		30	100	100
18676																																		
18678	AD	<32				20	500				20	100	200	10				500			30	1000		20		300		3000		100		20	100	100
18678																																		
18678																																		
18678T	AT	<32	2			20	500				20	200	200	10				300			70	1000		15		300		2000		70		10		100
18678T																																		
18679	R/W	<32				20	500				15	200	20	10				500			50	20		15		300		3000		50		20		100
18679																																		
18680	AD	<32	2			20	500				15	100	200	10				300	15		30	1500		10		300		3000		100		15	150	100
18680																																		
18680																																		
18680T	AT		1½			20	500				10	70	100	10				200			20	500		10		300		2000		100		10		100
18680T																																		
Background																																		

† All determinations by emission spectrometry (Analyst: C.E. Thompson) unless indicated otherwise: a-assay results converted to ppm; f-fluorescence; r-radiometric; x-X-ray spectrometry; w-wet chemical methods; v-vapor detection. * (Au) - gold (Cu) - copper

" R-rock; RA-altered rock; RP-pegmatite; RV-vein material; S-soil sample; R/W-residual and wash material; AD-dump and pit material from ancient mine; AT-tailings from

SAMPLE DATA

CONTENT† OF ELEMENTS (ppm) IN SAMPLES FROM QUADRANGLE 206 [redacted] SAMPLES FROM ANCIENT MINE WORKINGS 5/6

70-168

Number	Type"	Size°	Ag	As	Au^a	B	Ba	Be	Bi	Cd	Co	Cr	Cu	Ga	Ge	Hg	La	Mn	Mo	Nb	Ni	Pb	Sb	Sc	Sn	Sr	Te	Ti	U	V	W	Y	Zn	Zr
Min. detect. content'			1		1	10	20	2	20	50	5	5	10	10	20		20	20	2	50	5	10	200	10	10	50		20		20	50	10	100	20
ASH SHUMTA	(Au)*																																	
18661 T	AT	<32	1½			15	500				20	50	100	10				300			20	150		10		300		2000		70		10		70
18661 T																																		
18662	AD	<32	1			15	300				20	70	200	10				300			30	300		10		200		2000		100		15		100
18662																																		
18662																																		
18668	AD	<32				15	300				20	100	30	10				300			70	300		15		200		2000		100		15		150
18668																																		
18668																																		
AL BoHARAH	(Au)*																																	
18660	AD	<32				15	300				20	150	50	10				300			150			10		200		1500		50		10		150
18660																																		
18660																																		
18660 T	AT	<32				15	500				20	100	30	10				300			50	20		10		200		2000		50		10		100
18660 T																																		
EL ABDT	(Cu)*																																	
18658	AD	<32	50			15	300				50	70	>10000	10				500			150	10		10		200		1500		70		15		100
18658																																		
18658																																		
ARAHIYAH	(Au)*																																	
18642	AD	<32				15	500				15	50	10	10				300			70	200		10		300		3000		70		15		100
18642																																		
18642																																		
18645	AD	<32				20	500				20	50	30	10				300			20	100		15		300		2000		70		20		100
18645																																		
18645																																		
18645 T	AT	<32				15	300				10	50	20	10				150			20	150		10		300		1500		70		10		
18645 T																																		
DE RAHN	(Au)*																																	
18643	AD	<32				15	300				20	50	30	10				300			20	15		10		200		3000		70		15		100
18643																																		
18643																																		
AKLIYAH	(Au)*																																	
18633	R/W	<32				20	300				20	150	150	10				300			70	30		10		200		2000		70		15		100
18633																																		
18633																																		
18634	AD	<32				20	500				20	30	200	15				200			20	20		10		200		1500		50		20		100
18634																																		
18634																																		
18635	AD	<32				20	500				20	50	30	15				300			30	15		10		200		3000		70		20		100
18635																																		
18635																																		
18636 T	AT	<32				15	300				20	100	50	10				300			30	15		10		300		3000		70		15		100
18636 T																																		
Background																																		

† All determinations by emission spectrometry (Analyst: C.E. Thompson) unless indicated otherwise: a-assay results (> .1oz./ton, 3ppm); f-fluorescence; r-radiometric; x-X-ray spectrometry; w-wet chemical methods; v-vapor detection. *(Au) - gold (Cu) - copper

" R-rock; RA-altered rock; RP-pegmatite; RV-vein material; S-soil sample; R/W-residual and wash material; AD-dump and pit material from ancient mine; AT-tailings from

SAMPLE DATA

CONTENT† OF ELEMENTS (ppm) IN SAMPLES FROM QUADRANGLE 206 [redacted] SAMPLES FROM ANCIENT MINE WORKINGS 6/6

70-168

Number	Type"	Size°	Ag	As	Au°	B	Ba	Be	Bi	Cd	Co	Cr	Cu	Ga	Ge	Hg	La	Mn	Mo	Nb	Ni	Pb	Sb	Sc	Sn	Sr	Te	Ti	U	V	W	Y	Zn	Zr
Min. detect. content'			1		1	10	20	2	20	50	5	5	10	10	20		20	20	2	50	5	10	200	10	10	50		20		20	50	10	100	20
AL HASAN	(Cu)*																																	
18627	R/W	<32				15	500				10	50	10	10				200			20	10		10		200		2000		50		10		100
18627																																		
18627																																		
18628	AD	<32				30	700				70	50	30	5				200			30	70		10		200		1500		50		20		100
18628																																		
18628																																		
18629	AD	<32				20	500				20	70	70	15				300			30	30		10		200		3,000		70		20		100
18629																																		
18629																																		
18607	AD	<32				20	500				15	30	30	10				300			20	10		10		300		2000		100		15		70
18607																																		
18607																																		
18619	AD	<32				15	500				15	50	30	10				300			50	15		10		300		2000		70		10		50
18619	(Au)*																																	
18619																																		
Background																																		

† All determinations by emission spectrometry (Analyst: C.E. Thompson) unless indicated otherwise: a-assay results (> .1oz./ton, 3ppm); f-fluorescence; r-radiometric; x-X-ray spectrometry; w-wet chemical methods; v-vapor detection. * (Au) gold

" R-rock; RA-altered rock; RP-pegmatite; RV-vein material; S-soil sample; R/W-residual and wash material; AD-dump and pit material from ancient mine; AT ...

SAMPLE DATA

CONTENT† OF ELEMENTS (ppm) IN SAMPLES FROM QUADRANGLE 205 [redacted] SAMPLES FROM BEDDED JASPER DEPOSITS

70-168

Number	Type"	Size°	Ag	As	Au	B	Ba	Be	Bi	Cd	Co	Cr	Cu	Ga	Ge	Hg	La	Mn	Mo	Nb	Ni	Pb	Sb	Sc	Sn	Sr	Te	Ti	U	V	W	Y	Zn	Zr
			1		1	10	20	2	20	50	5	5	10	10	20		20	20	2	50	5	10	200	10	10	50		20		20	50	10	100	20
2781	R/W	<32				20	500				50	70	50	20				500	3		70	15		10		200		2000		150		20		100
2781																																		
2782	R					20	30				20	20	150					500	10		20					50		70		100				10
2782																																		
2782	R/W	<32				15	700	2			20	50	10	20			30	300	7		20	20		10	10	100		2000		50		50		300
2782																																		
2782																																		
2788																																		
2795	R		1			30	300				7	30	30	10			20	300	7		10	15			10	30		100		70			100	10
2795																																		
2795	R/W					30	300				10	200	15	10				500			20	20		10		200		1500		50		10		50
2795																																		
2795M																																		
2873																																		
2942																																		
2986																																		
3021																																		
3023																																		
3027																																		
3038																																		
18108	R/W	<32				20	500				30	200	10	10				700	2		20	10		20		150		3000		70		15		100
18109	R/W	<32				20	500				30	100	10	10				500	5		20	10		15		150		5000		70		15		100
18110	R/W	<32				30	500				30	70	20	10				700	5		70	10		10		300		7000		100		15		150
18112	R/W	<32				15	500				30	200	10	10			30	500	2		20	10		15		150		5000		70		20		100
18260	R/W	<32				50	300				15	200	50	15				300			70	10		15		200		3000		100		20		100
18275	R/W	<32				20	700				20	700	30	15				700	3		100	10		10		200		5000		150		10		100
18275S	R/W	<32				10	300				7	30	10	10				200			20	<10		<10		300		1500		50		<10		50
18376	R/W	<32				15	500				30	150	10	10				700			30	10		15		150		7000		100		20		100

† All determinations by emission spectrometry (Analyst: C.E. Thompson) unless indicated otherwise: a-assay results converted to ppm; f-fluorescence; r-radiometric; x-X-ray spectrometry; w-wet chemical methods; v-vapor detection.

" R-rock; RA-altered rock; RP-pegmatite; RV-vein material; S-soil sample; R/W-residual and wash material; AD-dump and pit material from ancient mine; AT-tailings from ... letters after the foregoing indicate magnetite (M), panned concentrate (P)

SAMPLE DATA

CONTENT† OF ELEMENTS (ppm) IN SAMPLES FROM QUADRANGLE 205 PHOTOMOSAIC SHEET

70-168

Number	Type"	Size°	Ag	As	Au[a]	B	Ba	Be	Bi	Cd	Co	Cr	Cu	Ga	Ge	Hg	La	Mn	Mo	Nb	Ni	Pb	Sb	Sc	Sn	Sr	Te	Ti	U	V	W	Y	Zn	Zr
Min. detect. content=			1		1	10	20	2	20	50	5	5	10	10	20		20	20	2	50	5	10	200	10	10	50		20		20	50	10	100	20
2322*																																		
2323*																																		
2350	HWS	< > 32-80				10	1000				20	50	15	20				300			30	10		10		500		3000		70		20		100
2356																																		
2375*																																		
2376*																																		
2413																																		
2745	R/W	<32				20	300				20	300	15	20				500	2		50	10		20		200		2000		50		15		30
2746	R/W	<32				50	700				20	200	30	20				700			20	15		20		70		2000		50		15		50
2834	R/W	<32				20	500				10	150	50	20				500			20	15		10		200		2000		70		15		15
2852	R/W	<32				30	500				15	200	20	10				500	3		50	20		15		300		2000		70		10		50
2854	R/W	<32				20	200				10	150	20	10				500			50	20		15		300		1500		50		20		50
2936	R/W	<32				20	200				15	150	30	10				500			50	10		20		150		2000		50		15		30
2958	R/W	<32				30	200				15	150	20	20				500			30	15		15		200		2000		50		15		30
2961	R/W	<32				30	500				15	300	20	15				700			50	15		20		200		1500		50		10		30
2962	R/W	<32				20	200				15	150	50	20				500	3		20	20		10		200		2000		50		10		20
2963*	R/W	<32				20	300				10	150	15	15				500			20	20		10		200		1500		50		10		20
2972	R/W	<32				20	200				10	300	15	10				500			30	20		10		200		1000		50		10		30
2973						50	300				10	200	20	10				700			30	<10		30		200		2000		70		15		30
2974	HWS	< > 32-80				20	500				30	150	30	15				500	3		100	10		10		200		2000		150		10		70
2980	R/W	<32				20	200				10	150	15	10				500			15	50		<10		200		1000		50		10	150	20
18023	R/W	<32				20	500				30	200	10	10			20	700			50	20		20		150		5000		100		15		100
18046	R/W	<32				15	500				20	500	15	10				500	2		30	10		10		100		5000		70		15		100
18067*	R/W	<32				20	500				20	100	10	10			20	500	2		20	50		15		150		3000		70		20		150
18089																																		
18090	R/W	<32				100	500				30	500	15	10				500	2		30	10		20		150		5000		100		15		70
18091	R/W	<32				15	500				50	150	15	10				700	2		50	<10		20		150		7000		100		15		70
18100	R/W	<32				15	500				30	150	10	10				500	2		20	10		20		100		3000		70		15		100
18155																																		
18157	R/W	<32				20	500				20	150	10	10				500			20	10		10		100		5000		70		10		100
18158	R/W	<32				20	500				30	100	15	10				500			30	15		10		200		3000		70		15		100
18159						70	300				20	100	10	<10				200	2		20	10		10		3000		3000		50		10		70
18160	WS	< > 32-80				20	500				20	50	10	10				500			10	10		10		700		3000		70		50		100
18166	R/W	<32				20	700				20	150	10	10				500	3		30	15		15		150		5000		70		15		100
18167	R/W	<32				20	500				20	200	20	10			20	500	3		50	15		15		100		5000		70		15		100
18180	WS					15	700				20	150	10	10				500	2		20	10		15		150		5000		70		20		70
18182½						15	500				20	150	10	10				700			20	15		10		150		5000		100		15		100
18182½	WS	<32				20	500				20	150	10	10				500			50	10		10		200		5000		100		15		100
18183	WS	< > 32-80				20	500				30	200	15	10				500			30	10		15		200		3000		100		10		100
18191	R/W	<32				15	500				20	150	10	10				700	2		30	15		10		70		5000		100		15		100
18192	R/W	<32				15	500				20	100	<10	10				500			20	15		10		200		5000		70		15		100
18236	R/W	<32				20	700				20	100	10	10				500			20	15		15		200		5000		100		20		100
18237	WS	<32				20	700				7	100	15	10				300			50	10		10		200		3000		100		10		100
18238	WS	<32				15	700				20	100	<10	10				500			20	10		10		200		5000		100		10		70
Background																																		

† All determinations by emission spectrometry (Analyst: C.E. Thompson) unless indicated otherwise: a-assay results converted to ppm; f-fluorescence; r-radiometric; x-X-ray spectrometry; w-wet chemical methods; v-vapor detection.

* - quartz - feldspar - (hematite) veins

" R-rock; RA-altered rock; RP-pegmatite; RV-vein material; S-soil sample; R/W-residual and wash material; AD-dump and pit material from ancient mine; AT-tailings from