DEPARTMENT OF THE INTERIOR
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Preliminary report on the gold deposits at Al Habla, Kingdom of Saudi Arabia

with a section on Geologic setting and igneous controls of mineralization,

by James C. Cole

By

C. W. Smith[1/], R. M. Samater, M. A. Hussain, M. A. Basheer, and V. A. Trent[2/]

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

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ON THE GOLD DEPOSITS AT AL HABLA,

KINGDOM OF SAUDI ARABIA

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ABSTRACT

The Al Habla area encompasses a zone approximately 7 by 12 km where ancient miners worked gold-bearing quartz veins. Most of the workings are trenches following vein systems, which ordinarily are adjacent to felsic dikes in granite, and preliminary studies have shown that there are more than 6 km of this type of ancient workings in the area. Only isolated outcrops of veins are exposed, and in most places they are obscured by mining debris, sand, and gravel. In addition, large areas surrounding known vein systems are covered by a veneer of alluvium.

Detailed, methodical sampling of quartz from all known ancient dumps in the region resulted in mean gold assays of 7.8 ppm at Al Habla, 5.8 ppm at Southeast Al Habla, and 8.4 ppm at Al Madraba. However, trenches excavated for this study across ancient workings did not reach the bottoms of the more intensely mined vein systems.

Fractures in granite that allowed for the passage of felsic magma were also sites of gold and quartz deposition and in most of the area dikes and gold-bearing quartz veins are found close together. Most of the gold in the Al Habla area is probably in a free state in quartz; at least some of the gold is in visible particles, and in most places it is associated with pyrite and minor, finely crystalline galena and sphalerite.

Further studies, including more trenching and detailed mapping, are recommended.

INTRODUCTION

The Al Habla area, located at lat. 25°33'30" N., long 42°16'00" E. (fig. 1), is in a region where ancient erosion surfaces have formed vast peneplains of flat to gently undulating topography interspersed by solitary mountains, or small mountain ranges. A main tributary of the Wadi ar Rimah drains the region, and one of the better landmarks in the area is flat-topped Jabal Tamiyah, which is 28 km west-northwest (fig. 1). The village of Uqlat as Suqur, on the Buraydah-Al Madinah highway, is about 35 km north over easily traversible desert tracks.

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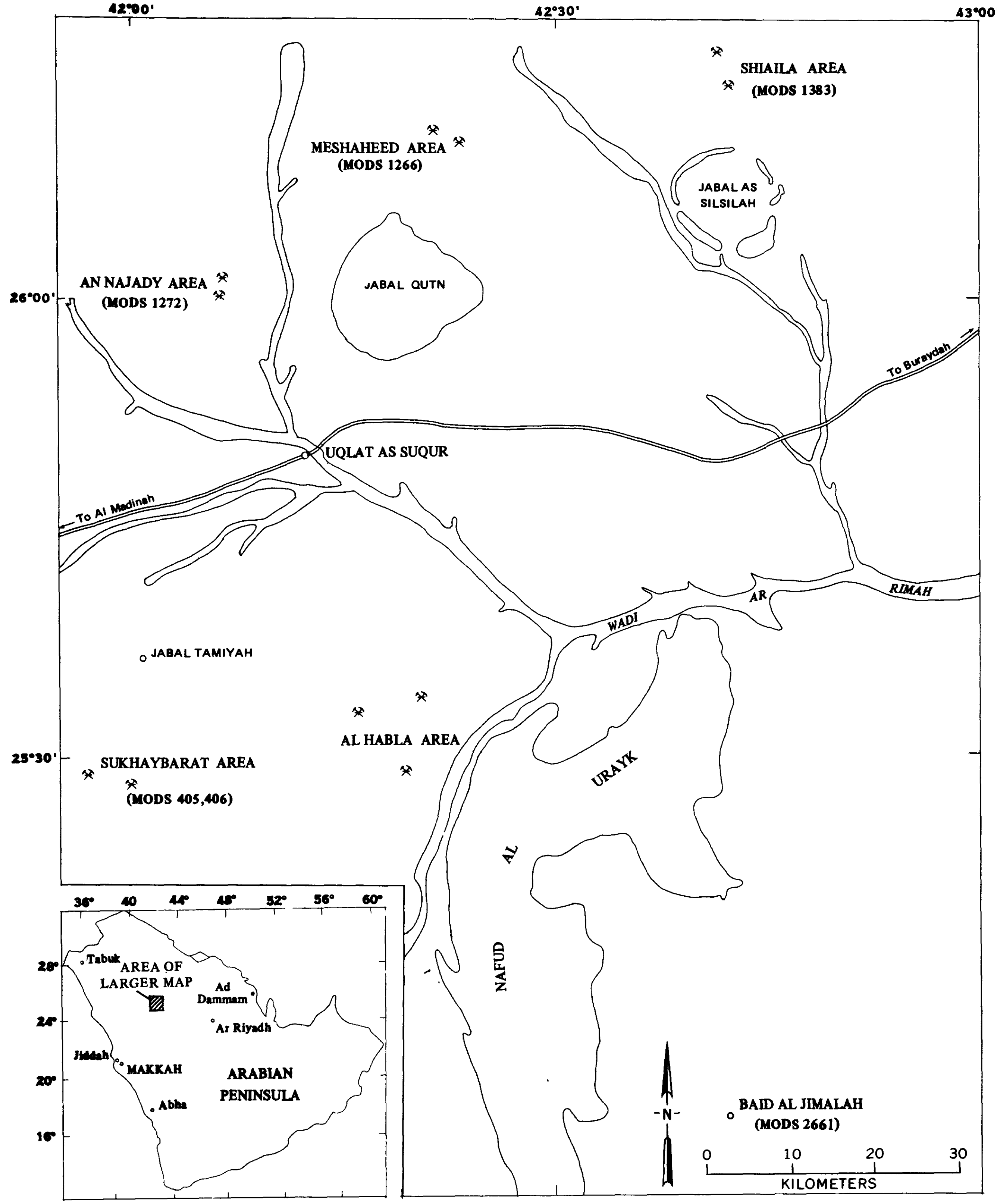


FIGURE 1.—Locations of Al Habla and surrounding mineral localities, Kingdom of Saudi Arabia. Numbers in parentheses are identifiers used for these mineral localities in the Mineral Occurrence Documentation System of the Deputy Ministry for Mineral Resources.

Previous work

A number of workers have visited the area in recent times; the earliest record available is a report written by Ahmad Omer Fakhry of the Saudi Arabian Mining Syndicate (Fakhry, 1941) in which ancient workings at Al Habla are briefly described. In 1946, G. A. Dirom of the same organization, mapped and sampled the main workings at Al Habla and wrote a report (Dirom, 1946), and later, in 1955, D. F. Schaffner of the Directorate General for Mineral Resources trenched and sampled the workings and, on the basis of assay results, made recommendations for core drilling (Schaffner, 1955). Nine drill hole positions were surveyed at the time, but the drilling was never accomplished. In 1963, low-level aerial photography ordered by the Directorate General for Mineral Resources covered part of the Al Habla area, including the main workings, at 1:12,500 scale.

J. W. Mytton of the U.S. Geological Survey made a brief examination of the area in 1965 and summarized work which had been done to that date (Mytton, 1970). I. C. Colliver and A. C. Woollett of Riofinex made a reconnaissance assessment of the Halaban-Al Batrah-Nuqrah-Afif region in 1979, and after a brief examination of the Al Habla ancient mines, recommended further work there (Colliver and Woollett, 1981). E. J. B. Begg, a consulting geologist for Riofinex, made a reconnaissance study of gold deposits in the Jurdhawiyah-Afif area in 1980, at which time he examined and sampled the workings at Al Habla and Al Habla East. Based on sampling results, he recommended no further work at Al Habla and moderate work at Al Habla East (Begg, 1980). E. H. MacDonald, a consultant for Riofinex, briefly reconnoitered the Wadi ar Rimah drainage system in 1981 during assessment studies of placer gold potential in the region that includes Al Habla. He concluded that the region has little placer potential (MacDonald, 1982). D. M. Boyle and V. G. Atkinson of Riofinex (1982) continued this work in 1981 and concluded that (p. 28) "no potential is envisaged for the development of gold-placer deposits in the lower reaches of the wadi, east of 41°30', or in the wadi as a whole."

Regional geology of the Al Habla area has been investigated during 1:100,000-scale reconnaissance geologic mapping of the Uqlat as Suqur quadrangle (24/42 A; Cole, 1984a) and the Wadi al Jarir quadrangle (25/42 C; Young, 1982). Although the geology and location of workings are shown on plate 1 at a scale of 1:20,000, little mapping was done at this scale during our studies; most of the data concerning the general geology were supplied by Cole and are described in the section on Geologic setting and igneous controls of mineralization.

Kleinkopf and Cole (1982), in a study of aeromagnetic data of the Wadi al Jarir quadrangle, established a correlation between these data and major lithologic units, and this correlation has been extended into the Al Habla area and verified by Cole (1984a). Kleinkopf and Cole (1982, p. 24-26) also speculated on a genetic connection between mineralization similar to that found at Al Habla and Al Madraba and certain intrusive bodies with distinct magnetic signatures. This theory is supported by the present work, and by that of Boyle and Howes (1983) in similar environments south and west of Al Habla.

Present Work

The work on which this program was based was performed generally in accordance with a work agreement between the U.S. Geological Survey and the Saudi Arabian Ministry of Petroleum and Mineral Resources, and specifically in accordance with the work program of the Deputy Ministry for Mineral Resources for the years 1402-03 A.H.; sub-project 3.12.28 "Prospecting for gold--Al Habla area."

The main objectives of our work were to (1) Perform rough geologic reconnaissance and search for unworked quartz veins and additional ancient mines in the area, (2) Re-sample the ancient workings at Al Habla and compare results with those of Dirom and Schaffner, and (3) Obtain details of depositional environments of gold-quartz veins and gain some idea of their thickness and continuity.

The present study by the authors began in the field season 1401-02 A.H. and consisted of a field party including geologists M. A. Hussain and M. A. Basheer, prospector Ghanim Jeri Alharbi, and field assistants Wais Issa Assumali and Ali M. Dualeh. Work during that time consisted mainly of dump sampling, but general reconnaissance in search of additional ancient workings was also undertaken, and several ancient mining areas, most notably Al Madraba and Southeast Al Habla, were found as a result. Virgil Trent, U.S. Geological Survey, spent two weeks at Al Habla during detailed sampling activities, and he acted as general supervisor; in addition, C. W. Smith made visits and observed sampling procedures during this time.

Further field work was accomplished in the field season 1402-03 A.H. by C. W. Smith and R. M. Samater, at which time most of the ancient workings were mapped in detail by plane-table method. Additional sampling was also done during this time. After detailed mapping and sampling were completed, numerous trenches across ancient workings were cut by backhoe. Samater was in charge of this work. Following review of the first draft of this report, J. C. Cole wrote the included section to describe the regional geologic context of the mineral occurrences in the Al Habla area.

For the sake of clarity, the most extensively mined region in the western part of the Al Habla area shall be termed the Al Habla workings, and groups of ancient mines located elsewhere in the area are named Al Habla East, Southeast Al Habla, South-Central Al Habla, and Al Madraba (plate 1). Individual groups of workings are designated on plate 1 and figures 3-11 by a prefix with the initials of the grouping followed by a number; e.g.; workings number 3 in the South-Central Al Habla group are designated SC-3.

Sampling procedures

Since ancient workings in the area are linear and extend for great distances, sampling procedure consisted of collecting quartz from dumps along 50-m transects without regard to obvious mineralization. Each transect constituted one sample, but dumps that measured less than 50 m also constituted one sample. Transects were marked by rock cairns and spray painted, and the last three digits of the sample number were painted on the surface near the rock cairn. All of the ancient workings and rock cairns were then surveyed by plane-table method. Only the workings themselves were mapped; no attempt was made to outline dump material. Samples were assayed in the Directorate General for Mineral Resources laboratories in Jiddah under the direction of J. Curry, U.S. Geological Survey (USGS). Atomic absorption analytical methods were used for the analyses of gold, silver, copper, lead, zinc, cobalt, and nickel; and colorimetric methods were used for analyses of arsenic, antimony, molybdenum, and tungsten. In addition, semiquantitative emission spectrographic analyses were made for these and 20 other elements. Gary Selner (USGS) computed correlation coefficients for 11 elements assayed in the sampling program. All assistance is gratefully acknowledged.

GEOLOGIC SETTING AND IGNEOUS CONTROLS OF MINERALIZATION

by

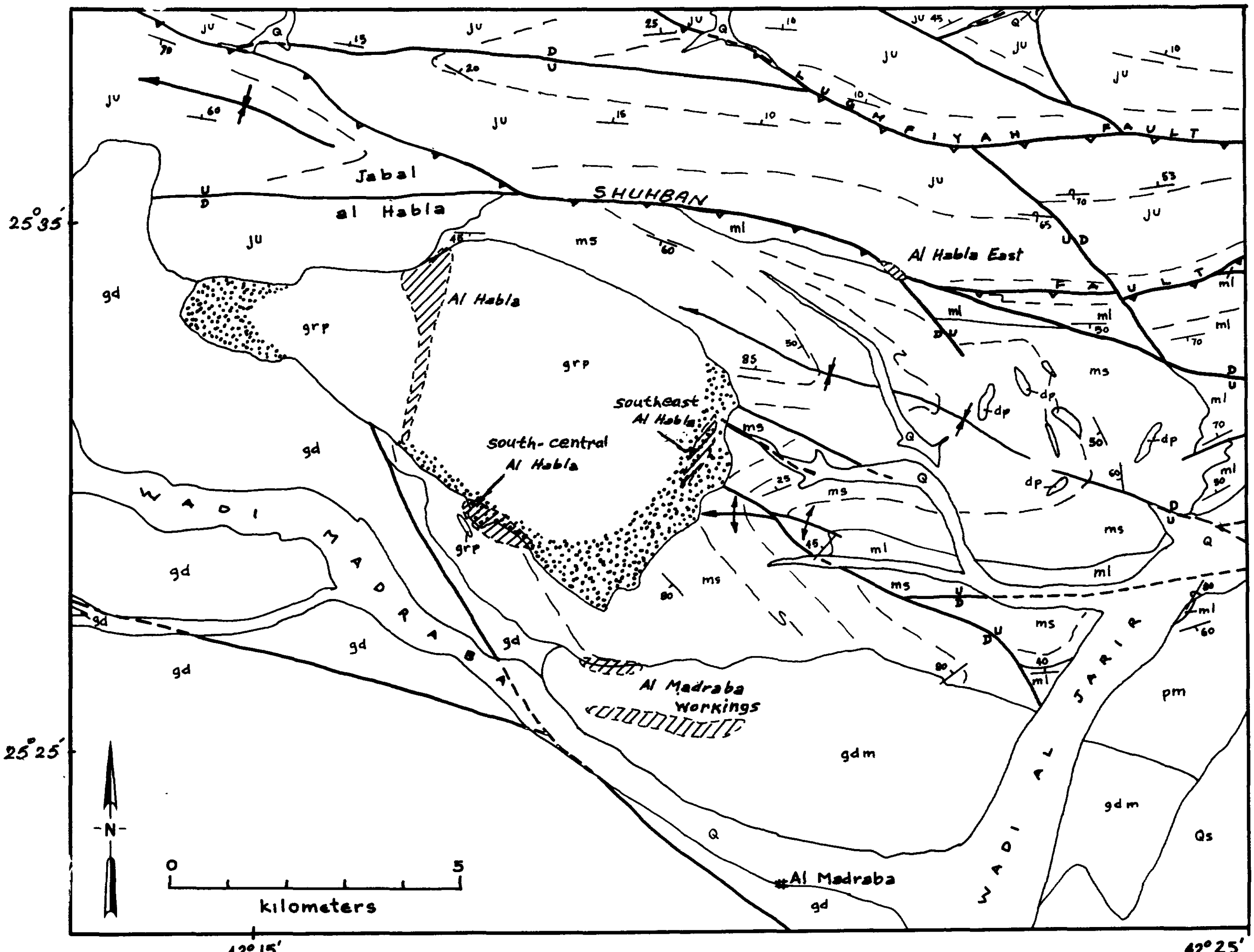
James C. Cole

The mineral occurrences investigated in this study were formed in two geologic environments and probably at two distinct times. The Al Habla East workings follow fractured layered rocks in the Shuhban fault near its intersections with other faults. Parallel faults in the region with similar geometry and movement history are truncated by the later plutonic rocks that host the dikes and mineralized veins at Al Habla (main, South-Central, and Southeast workings) and at Al Madraba. The simplest interpretation of these observations is that the mineralization at Al Habla East predates emplacement of granodiorite and granite, although at this early stage of investigation, other interpretations are also plausible. Smith and others (see Discussion, elsewhere in this report) consider it possible that the fault zone at Al Habla East was mineralized at the same time that the Al Habla and Al Madraba deposits formed in plutonic rock, and that the distinct geochemical signature at Al Habla East reflects gradients in a single hydrothermal system. These two interpretations remain open to further investigation.

The oldest layered rocks in the Al Habla area consist chiefly of well bedded, coarse- to fine-grained, calcareous, pyrite-bearing marine sandstone correlated with the Murdama group (Cole, 1981, 1984a; Young, 1982). Down-section to the east, at the bottom of a regional syncline (fig. 2), this sandstone rests conformably on well bedded siliceous and locally stromatolitic limestone which, in turn, rests locally on thin, discontinuous wedges of polymict conglomerate; the limestone and (or) conglomerate together constitute the basal units of the Murdama group (Greene, 1983; Boyle and Howes, 1983; Cole, 1984a). The "basement" of the Murdama group is sparsely exposed due to younger intrusive rocks, but consists of weakly cataclastic meta-andesite east of (beneath) the Murdama syncline and may include intrusive rocks that are preserved in a complicated plutonic terrane south of Wadi Madraba (Young, 1982; Kleinkopf and Cole, 1982; Cole, 1984a). Granophyre clasts, common in Murdama sandstone (Cole, 1981, 1984a), are very similar to the coarse granophyric matrix of intensely altered, locally cataclastic granitic rocks in that plutonic terrane.

The Murdama is unconformably overlain by subaerial and shallow-water deposits of the Jurdhawiyah group; this unconformity crops out just north of the Al Habla granite and dips northward at about 30 degrees. Rocks of the group consist chiefly of fresh pyroxene and hornblende andesite, andesitic and dacitic lapilli tuff, and coarse, poorly bedded conglomerate and minor sandstone derived from the contemporary volcanic piles (Cole, 1981, 1984a). The Jurdhawiyah depositional basin north of Al Habla was actively deforming as it was being filled and, in the terminal stages, was folded toward the north by displacements on the Lughfiyah and Shuhban faults (fig. 2; Cole, 1984a). The mineralization of intensely cataclastic rock along faults at Al Habla East, in my opinion, probably coincided with this deformational event. There is no evidence at this site for a genetic relation to intrusive rocks, and the distinct silver-dominated character of the deposit (table 1; see description elsewhere in this report) suggests that it formed during a discrete event.

The margins of the Murdama and Jurdhawiyah depositional basins largely coincide in the vicinity of Al Habla, and Cole (1984a) concludes from regional data that these basins were controlled by pre-Murdama structures (probably faults). The younger granitic rocks that host the Al Madraba and Al Habla deposits may have risen along this same crustal discontinuity and basin hinge line. The form of these plutons, their composition and texture, and their aeromagnetic signature suggest that they



EXPLANATION

LAYERED ROCKS

Alluvium (Q) and eolian sand (Qs)	Q, Qs
Al Jurdhawiyah group--Undivided andesite and volcaniclastic rocks	ju
Murdama group--Marine sandstone (ms) and limestone (ml)	ms, ml
Pre-Murdama altered metavolcanic and metaplutonic rocks	pm

INTRUSIVE ROCKS

grp	Al Habla granite porphyry--Pattern denotes red phase
gdm	Al Madraba granodiorite
gd	Granodiorite
dp	Dacite porphyry--Remnants of dikes in Murdama group rocks

Area of ancient trenches

Strike and dip of beds:
- 25 Inclined
- 65 Overturned

Trace of bedding

High-angle reverse fault--Teeth on upper plate

U/D Normal fault--Sense of offset shown where known; fault dashed where concealed

Folds (showing direction of plunge):
- Anticline
- Syncline

FIGURE 2.—Generalized geology of the area surrounding the Al Habla ancient mine workings, Kingdom of Saudi Arabia. Adopted from Cole (1984a).

were emplaced during a widespread intrusive event in this part of the shield; thus, they are correlated with the Idah suite (Cole, 1984a). Regional studies (Kleinkopf and Cole, 1982; Boyle and Howes, 1983) have shown the common association of gold deposits with plutons of the Idah suite (Cole, 1984a). These deposits are most common near small stocks emplaced in Murdama group rocks and are characterized by dilational quartz veins that contain gold with minor associated copper. The Idah suite has been dated at about 620 to 615 Ma (Cole and and C. E. Hedge, unpub. data, 1984), and it postdates the regional high-angle faults that were mineralized at Al Habla East.

The pluton at Al Madraba consists of gray, medium-grained, biotite-hornblende granodiorite that is massive and fresh; it characteristically contains small cognate inclusions rich in biotite and amphibole. South of Al Habla and west of the northwest-trending fault (fig. 2), similar rock crops out, but it contains less biotite and coarse hornblende, it is intruded by far fewer cogenetic dikes, and those dikes are oriented differently from dikes in the Al Madraba pluton. This leucogranodiorite body is inferred to be slightly older than the granodiorite at Al Madraba, because it is clearly intruded by the Al Habla granite (Cole, 1984a).

Three sets of dikes at Al Madraba are considered to be comagmatic with the host granodiorite. The oldest set trends north to northeast and consists of fine-grained felsite. The intermediate set, which is associated with the primary structural control of mineralization, trends east-west and appears to offset older dikes in a left-lateral sense. These intermediate-age dikes consist of red microgranite or felsite and are similar to dikes that parallel mineralized zones in the Al Habla granite. Fine-grained hornblende diabase dikes follow the north to northeast trend of the earliest set and cut across the east-west felsic dikes in the mineralized area; a short distance east, these diabase dikes are the dominant set, and a few extend north of the granodiorite contact into Murdama group rocks, but none of them intrude the Al Habla pluton.

The Al Habla granite forms a simple elliptical body with a weak zonal structure; a distinctly red, altered, and somewhat finer grained border phase typifies the western lobe and the southern and southeastern margins of the pluton (fig. 2). The Al Habla body consists of biotite syenogranite that is pale pink to orange-red, leucocratic, massive, and notably porphyritic. Phenocrysts make up about 60 to 70 percent of the rock and consist of about equal amounts of embayed quartz, perthitic microcline (locally orthoclase), and weakly zoned oligoclase. The matrix contains the same minerals, intergrown in an allotriomorphic-granular texture. Accessory minerals, which generally compose less than 7 percent of the rock, consist of irregular red-brown biotite and minor white mica. On the basis of optical properties and habit, two white micas are present in the granite. Coarse-grained plates of weakly pleochroic (colorless to pale brown) mica appear to have crystallized from the melt and are probably a primary lithium zinnwaldite. Small ragged flakes of colorless sericite(?) are contained in the cores of oligoclase grains and also replace biotite along cleavage planes. A high-relief, pleochroic mineral embedded in sericitic mica has the optical properties of cassiterite, although it is too fine-grained for certain identification. Accessory phases include magnetite, zircon, and apatite; fluorite is commonly found in this kind of granite porphyry, but none was identified during examination.

The altered red granite phase along the margins of the Al Habla pluton differs slightly from the core-phase granite in that it is finer grained and locally grades into aplitic and pegmatitic phases. Vugs in pegmatites are lined with well terminated quartz crystals. Coarse pyrite may have also crystallized in the pegmatites, inasmuch as cubes, pyritohedrons, and irregular masses of earthy iron oxides and hydroxides (1-2 cm in diameter) are common in grus near pegmatite in the southern part of the pluton. Alternatively, the original pyrite may have formed during the alteration event (G. L. Raines, oral commun., 1983), during which disseminated hematite was formed and some feldspars were replaced by sericite, clay(?) minerals, and calcite.

The Murdama group rocks and, to a lesser extent, the Jurdhawiyah group rocks to the north have recrystallized to dimensionless hornfelses in the contact zones of the Al Habla and Al Madraba plutons. Relict detrital grains are preserved in the Murdama, but the matrix has largely recrystallized to fine-grained brown biotite, acicular amphibole, granular magnetite, and porphyroblasts of cordierite. The extent of textural and mineralogical modification is greatest in the ridge of Murdama rock that separates the Al Habla granite from the granodiorite pluton at Al Madraba, and rare porphyroblasts of staurolite locally accompany cordierite in this area.

The granodiorite at Al Madraba is very similar to most rocks of the Idah suite (Cole, 1984a), but the Al Habla granite is unusual, and its correlation with the Idah is not as certain. Porphyritic leucogranites with primary biotite and zinnwaldite or muscovite, similar to the Al Habla granite, are rare in the Idah suites but rather are more typical of granites formed during a separate intrusive event at about 585 to 575 Ma (Elliott, 1983; J. Stuckless and others, 1984; J. C. Cole and C. E. Hedge, unpub. data, 1984). Examples of these younger, two-mica granites include (fig. 1) Baid al Jimalah (Cole and others, 1981), Jabal Qutn (Stuckless and others, 1982, 1984; Williams, 1983; Cole, 1984a), Fawwarah granite at Jabal as Silsilah (du Bray, 1983), and Jabal Minya (Moore, 1984). All of these examples are fluorine-rich, tin-bearing granites, and all except Jabal Qutn are known to have produced mineralizing hydrothermal systems dominated by tin and (or) tungsten. The Al Habla granite differs from the younger granites in this respect, and because it lacks fluorite and contains far less (or none) of the trace elements characteristic of the younger two-mica granites: tin, tungsten, lithium, beryllium, and fluorine (Cole, 1984b). Samples of the Al Habla granite and of the felsic dikes do, however, contain minor amounts of tungsten (as much as 70 ppm) but also contain molybdenum (as much as 20 ppm), which is not commonly associated with the younger tin-enriched granites (Cole and others, 1981; Lofts, 1982; E. A. du Bray, oral commun., 1983; Cole, 1984b).

On balance, the Al Habla granite probably correlates with the Idah suite (620 to 615 Ma) and was emplaced prior to the event at 585 to 575 Ma that generated tin-enriched magmas. The trace element chemistry of the Al Habla granite is distinct, and--perhaps more important--the type of mineral deposit formed with it is characteristic of the Idah suite. The regional association shows that, whether the Idah suite intrusion is granodiorite, diorite, or granite, the typical mineral deposit contains free gold and minor base metals in late-stage dilational quartz veins within the pluton or in the contact-metamorphosed aureole of Murdama metasediments (Kleinkopf and Cole, 1982; Boyle and Howes, 1983; Cole, 1984a). The source for the gold and base metals, therefore, would seem to be the Murdama because it is the common factor. The local heat provided by Idah suite intrusion may have generated hydrothermal convection systems that scavenged fugitive metals from the Murdama and deposited them in fractures generated by pluton emplacement and crystallization.

ECONOMIC GEOLOGY

The granite porphyry and granodiorite unit (gdp, pl. 1) is covered by a veneer of floodplain sand and gravels in many areas and also by mining debris near the mines. As a result, most observations concerning veins were made by examining material on dumps, or by studying newly cut trenches. Close examination of low-level aerial photographs is beneficial for some areas, where linear trends may indicate subsurface veins or faults. This is particularly true for the north end of the Al Habla vein system, but farther south, floodplain sands and gravels obscure most details of geology.

The relatively competent granitic rocks, which fractured to a greater degree than the layered rocks, became the major host of gold-quartz veins. In most places, veins extend only short distances into metasediments or metavolcanics. Major fractures, first occupied by felsic dikes, afforded openings for gold-quartz deposition in the Al Habla region. All of the quartz veins in the granite are associated with felsic dikes except those at Southeast Al Habla, and even there, dikes may be present but not found during our examination. At Al Habla and Southeast Al Habla, well defined quartz veins show sharp boundaries, and vein selvages in granite or felsic dikes are unaffected by hydrothermal alteration. The quartz veins in granite locally contain potassium feldspar and locally bear minor fine crystals of pyrite, galena, and sphalerite. The quartz ranges from tan, to white, to light gray, is medium to coarse grained, and displays ribbon structure only locally. In contrast, quartz veins in layered rocks are generally copper stained and contain moderate amounts of coarser crystalline galena and sphalerite. No other sulfide minerals were recognized in this region. This very simple mineralogy was confirmed by x-ray studies conducted by Hussain, who found only these sulfide minerals in the vein quartz samples, in addition to a number of secondary minerals of silver, lead, zinc, and copper. Probably a major part of the gold in quartz veins is in a free state, but no silver minerals were recognized. Free gold in quartz was observed in many places, and generally the gold-bearing quartz appears to be tan to light gray, and medium crystalline. Gold is visible along micro-fractures in quartz or rimming pyrite, and it appears to have a direct correlation with the pyrite content of the quartz. The white to milky variety of quartz has fewer sulfides and generally contains less gold. Assay results show that silver is present in minor quantities in most samples, its content being one-half to one-quarter that of gold. The metal is probably locked into the lattice work of galena, but more detailed laboratory studies are needed to confirm this.

Table 1 contains analytical data for copper, lead, zinc, cobalt, nickel, gold, silver, arsenic, antimony, molybdenum, and tungsten for all of the dump samples. From these data, lead is shown to be the most important base metal. Nevertheless, even this metal appears in minor amounts, with a range of 5-2350 ppm. Arsenic values are low in most quartz veins, the exception being Al Habla East, where the arsenic range is 80-1200 ppm. Low tungsten values were found in the central Al Habla workings.

Correlation coefficients for sampling in the entire district were computed for the 11 elements analyzed (table 3). The highest correlation of gold with any other element is with silver. Otherwise, correlations are low with base metals and antimony and are negative with arsenic, molybdenum, tungsten, nickel, and cobalt.

The Al Habla mine area (MODS 1286)

This area includes ancient workings AH-1 through 6 (pl. 1; figs. 3-6) and is in the western part of the study area. Workings AH-1 through 5 are arranged en echelon and are situated along a northerly trend for a distance of 3.7 km, or approximately the width of the granite porphyry pluton in this region. The AH-6 workings are isolated and about 2 km west of the main group. In addition to the workings, outcropping quartz veins and surface traces of veins are plotted on plate 1. The quartz vein

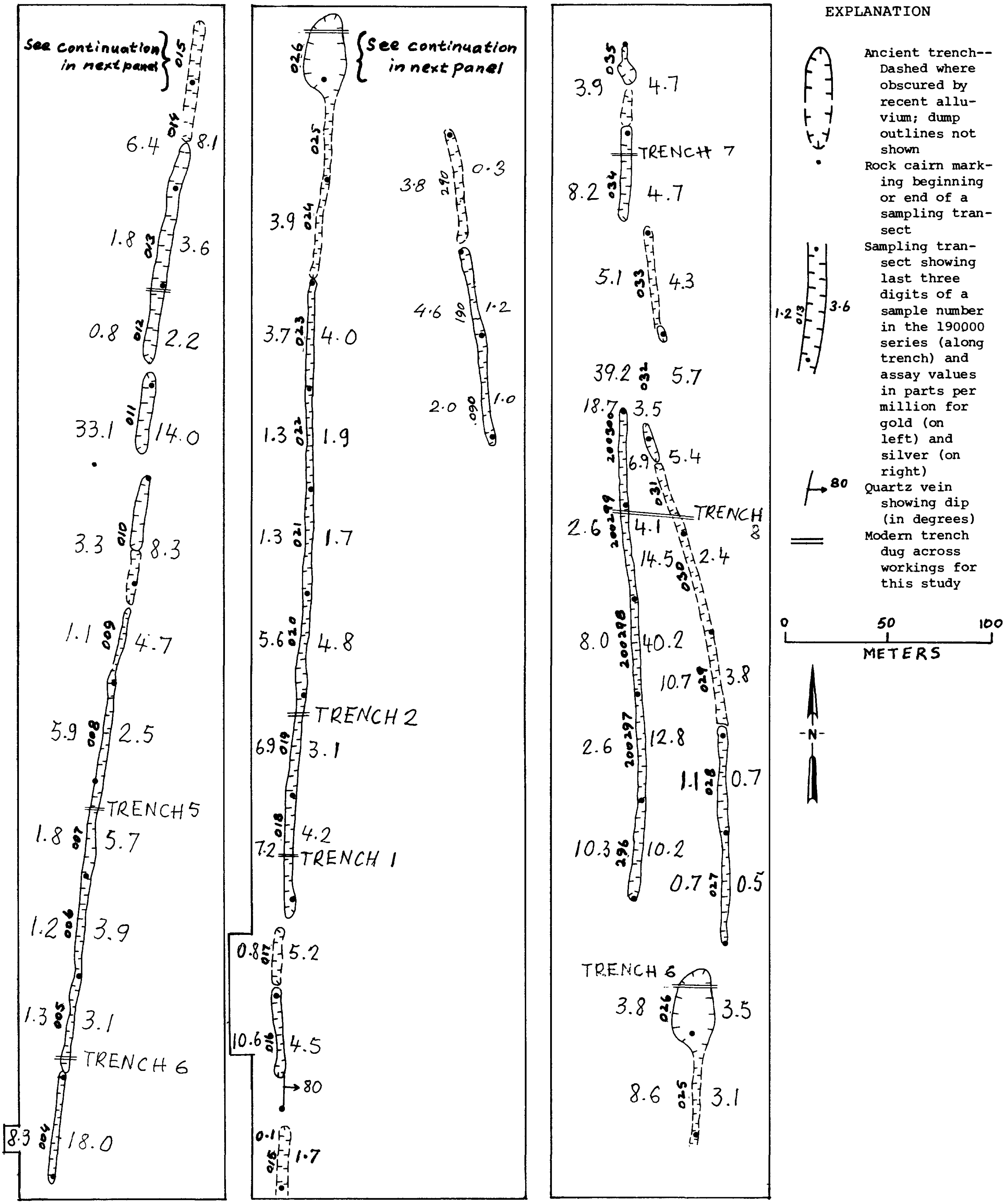
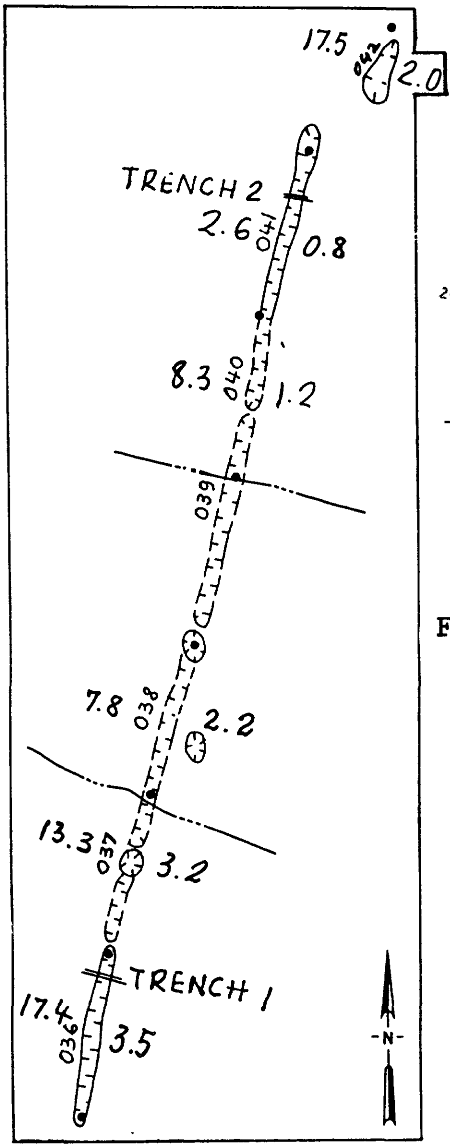


FIGURE 3.—Plan of the Al Habla ancient workings AH-1, showing sampling transects. These workings are 2350 m south-southeast of the AH-2 workings (fig. 4) and 1500 m northwest of the SC-1 workings. (See pl. 1.)



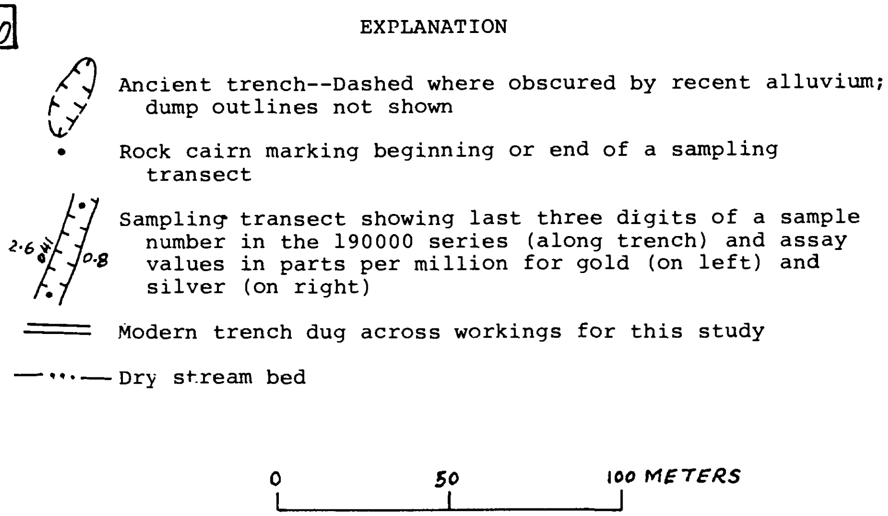


FIGURE 4.—Plan of the Al Habla ancient workings AH-2, showing sampling transects. These workings are 2350 m north-northwest of the AH-1 workings (fig. 3) and 650 m south-southeast of the AH-3 workings (fig. 5). (See pl. 1.)

west of the AH-1 workings is as much as 10 m thick, tan to light gray, and finely to coarsely crystalline and contains disseminated pyrite. The vein traces, observed in low-level aerial photographs and confirmed by ground studies, are lines of desert bushes. Examination of these linear zones discloses weathered quartz-vein rubble in many places, indicating quartz veins are near the surface. Quartz in these areas ranges from tan to light gray to milky, and it contains pyrite, galena, and sphalerite in some places, just pyrite in some places, and no sulfides at all elsewhere.

By taking ancient workings, outcropping quartz veins, and vein traces into account, a quartz vein system at least 900 m wide is indicated in the northern part (pl. 1). Vein traces plotted on plate 1 east of workings AH-1 were not examined in the field and, therefore, cannot be counted as part of the system at this time. Ancient workings and vein traces are along the same trend in several places, indicating that veins are of much greater length than shown by ancient workings. The AH-2 workings

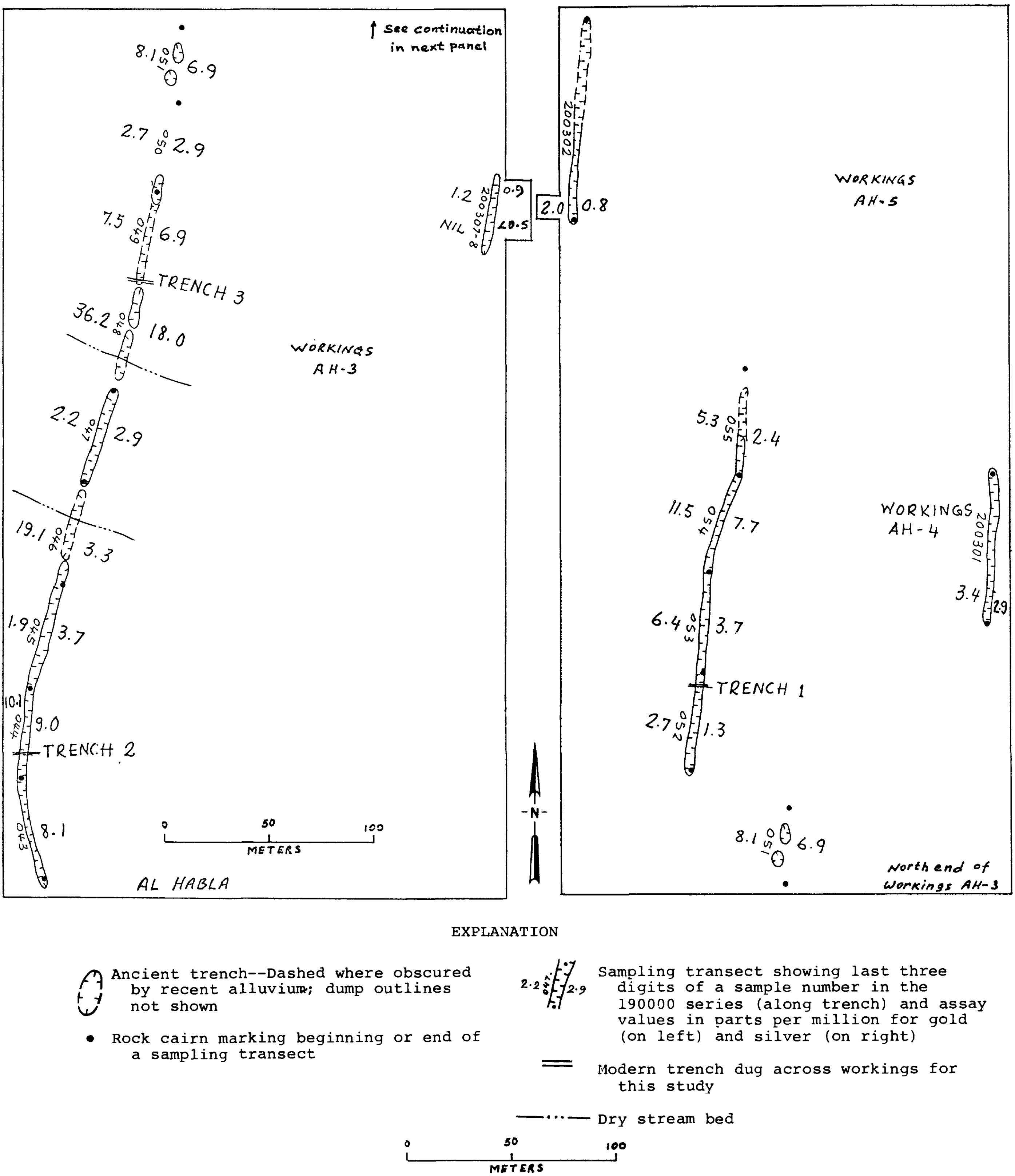


FIGURE 5.--Plan of the Al Habla ancient workings AH-3, -4, and -5, showing sampling transects. Workings AH-3 are 650 m north-northwest of the AH-2 workings (fig. 4).

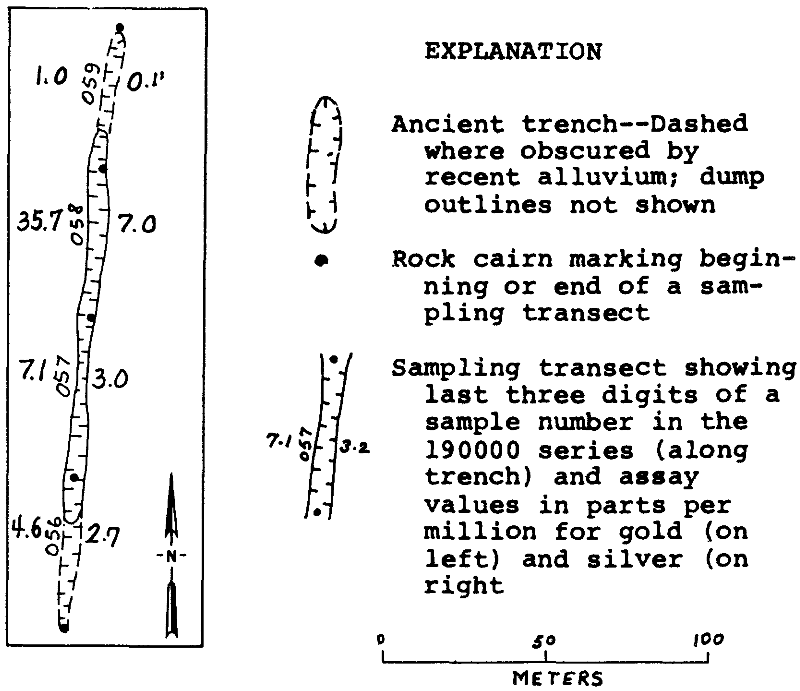


FIGURE 6.—Plan of the Al Habla ancient workings AH-6, showing sampling transects. These workings are about 2.2 km west of the other Al Habla workings AH-1 through -5. (See pl. 1 for location.)

project south about 700 m to a quartz-vein outcrop, and the AH-6 workings project about the same distance to a felsic dike. The arrangement of mined quartz veins in workings AH-1 indicates that the veins branch in places; also, the projection of the workings suggests that the AH-1 vein joins the AH-2 vein farther north. In short, it appears that the vein system is moderately complex. To add to the complexity, veins may be displaced by faulting in an east-northeast direction. Faint lineations visible on low-level aerial photographs indicate this possibility, although this aspect was not examined thoroughly in the field.

Vein outcrops are scarce, and trenches encountered veins only where the ancients had mined them to shallow depths in the Al Habla vein system. Trenches cut veins whose widths range from 10 to 80 cm along the AH-1 workings (fig. 12). Consequently, it is probable that vein thicknesses are less than 1 meter along some of this vein system, but some of the veins cut in the trenches are subsidiary in nature, as they seem to have been bypassed by ancient miners. More than one vein or veinlet was encountered in one trench, so it is possible that the vein system in some zones may consist of several narrow veins. Probably the mined veins vary in thickness in the same manner as the quartz vein that crops out about 40 m west of workings AH-1, which varies in thickness from 2 to 10 meters. Surface and trench observations of vein attitudes indicate dips from 45° to 80° east.

Mine dumps are normally small, but much dump material has been dispersed over wide areas, probably by flash floods. The dumps contain mostly granite or felsic dike material, and quartz is unevenly distributed but present throughout the mined area.

Summary of analytical data

Gold and silver values for individual dump samples are plotted on figures 3-6 and assay data are listed in table 1. Dumps are ordinarily aligned on both sides of ancient workings in all of the Al Habla region, but dump outlines are not shown in any of the detailed mapping.

Sixty-four dump samples, representing 3185 m of transect, were collected from the Al Habla workings, but one sample from the AH-2 workings was lost. The remaining 63 samples yielded the following assay values for gold and silver:

Workings	No. of samples	Total transect distance (m)	Gold Range (in ppm)	Gold Mean (in ppm)	Silver Range (in ppm)	Silver Mean (in ppm)	Au/Ag ratio
AH-1	40	1990	0.11-39.24	6.34	0.3-40.2	5.59	1.13
AH-2	6	295	2.62-17.53	11.16	0.8- 3.5	2.15	5.19
AH-3&4	13	650	1.92-36.14	9.31	1.3-18.0	5.4	1.72
AH-6	4	200	1.04-35.19	11.99	0.4- 3.0	6.8	1.7

Sampling of the AH-5 workings and two small trenches east of workings AH-3 and 4 was not done systematically along 50-m transects. Hence these results are not included here but are shown on figure 5.

Mean gold and silver grades for workings AH-1, 2, 3, 4, and 6 were calculated by weighting the number of samples in each workings times the mean grade, and the following are the results for roughly 3200 m of dumps:

Gold.......................... 7.82 ppm
Silver........................ 5.25 ppm

Dirom (1946) sampled the same group of workings and included workings AH-5 in his survey. His sampling methods were roughly the same as ours, except that he did not sample zones where workings were not definitely evident. Using this method, he calculated about 2000 m of quartz on dumps with a mean grade of 7.54 ppm gold. Schaffner (1955) collected 26 samples to coincide with zones of higher gold assays in Dirom's sampling. He calculated a mean gold grade of 6.03 ppm with a range of 1.03-10.62 ppm over a dump sampling length of 1063 m.

Other sampling in the Al Habla mine area consisted of collecting quartz from small ancient mine workings, or vein-fault trends, and chip-sampling outcropping quartz veins. Sample localities are shown on plate 1, and analytical results are given in table 2. Twelve quartz samples on vein traces gave the following analytical results:

Range (ppm)	
Gold	Nil-3.77
Silver	0.5-3.9

Mean	
Gold	0.84
Silver	1.37

Three samples from dumps of small ancient prospects at the north end of the vein system ranged in gold values from 1.2 to 5.11 ppm. Three chip samples of the large quartz vein west of workings AH-1 (pl. 1) ran nil gold and low silver values, and one chip sample of a quartz vein that crops out west of workings AH-3 ran 1.69 ppm gold and 3.0 ppm silver.

South-Central Al Habla (MODS 1267)

Several ancient workings are located along the contact of granite porphyry with metasediments in this region (pl. 1). The SC-1 workings were sampled along 50-m transects (table 1, samples 190000 through 190003), but the remaining workings SC-2 through 4 were not sampled by this method because their locations were not known during the first field season, when a sufficient crew was available for transect sampling. Instead, they were sampled by collecting quartz on dumps over their entire length, or at varied intervals. The average trend of the ancient trenches is about N 65° W. Two are in metasedimentary rocks and two are in granite. Workings SC-1 and 2 parallel a quartz vein and a hydrothermally altered aplite dike, respectively, and two trenches in workings SC-4 are on a quartz vein controlled by a northwest-trending fault that is clearly visible on low-level photographs (pl. 1). The granite on dumps along workings SC-4 was noted as being silicified and epidotized in places, but sampling indicated only traces of precious metals in this material. Quartz on dumps contains streaks of potassium feldspar.

Summary of analytical data

Workings SC-1, 2, 3, and 4.--Eleven quartz samples were collected from 850 m of dumps in this area (plate 1, table 2). The following are the analytical data:

Range (ppm)	
Gold	0.15-44.58
Silver	0.4-7.8

Mean (ppm)	
Gold	12.51
Silver	2.89

Gold-silver ratio
4.32

Southeast Al Habla (MODS 3512)

A northeast striking quartz vein on the east edge of the granite porphyry pluton has a shallow dip to the west and was mined intermittently along a distance of 1.2 km (pl. 1; fig. 7). This vein is probably lenticular, because trenching in some places intersected no vein or very narrow veins, and yet large quartz boulders are present on dumps of some of the larger ancient excavations. Vein outcrop in one limited zone displays faint copper and iron staining, but generally the quartz on dumps is similar to that in the main Al Habla area: it contains very finely crystalline pyrite, galena, and sphalerite. Free gold was observed at several places along the vein system. Granite in the vein walls is not hydrothermally altered, and veins exposed in trenches have sharp boundaries. Felsic dike material is absent from mine dumps, and dikes were not found during trenching.

Summary of analytical data

Workings SE-1.--Seventeen dump samples collected along 50-m transects (fig. 7; table 1), for a total of 850 m, yielded the following analytical data:

	Range (ppm)
Gold	0.22-36.27
Silver	.05-41.0

	Mean (ppm)
Gold	5.76
Silver	6.96

Gold-silver ratio
0.82

Two chip samples of outcropping quartz vein ran 53.92 and 27.91 ppm gold and 140.0 and 52.0 ppm silver. A large parallel quartz vein crops out 900 m northwest of the Southeast Al Habla workings (pl. 1), and two chip samples from this vein ran 0.84 and 0.08 ppm gold and 33.7 and 4.8 ppm silver.

Al Habla East (MODS 1287)

A line of ancient trenches trends southeast in gray metasedimentary rocks at workings E-1 (pl. 1; fig. 8). Dumps contain sparse to moderate amounts of iron-stained white quartz and hydrothermally altered, calcareous metasediments. Iron oxides give tan, brown, and various hues of red coloration to the metasediments, which are mainly fine-grained clastic rocks. These workings are on quartz veins in a major fault. Trenching found no veins in place, but rocks in vein walls have undergone intense cataclasis. The E-1 workings are in a slight topographic depression near a dry stream bed, and no vein outcrops are visible.

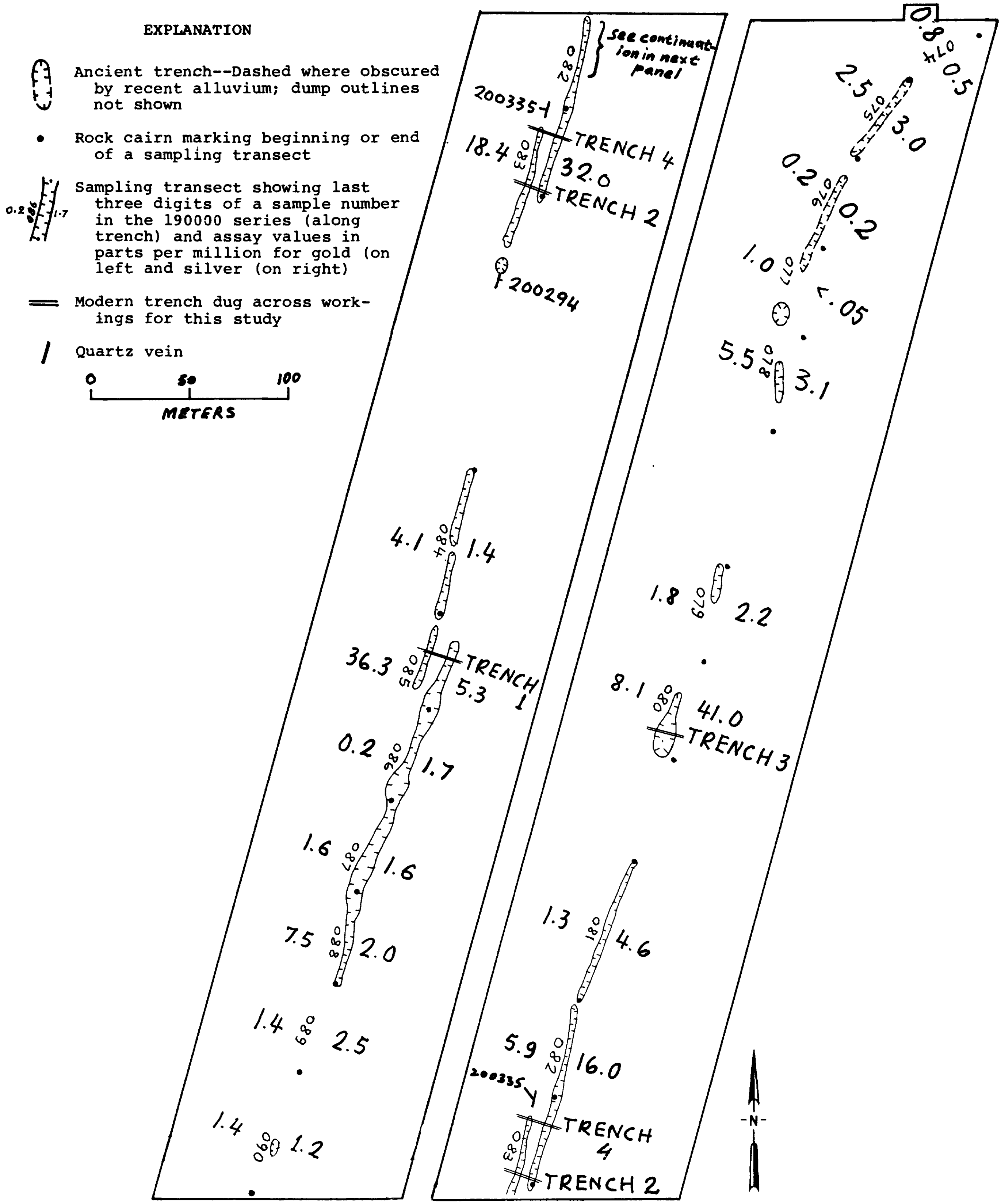
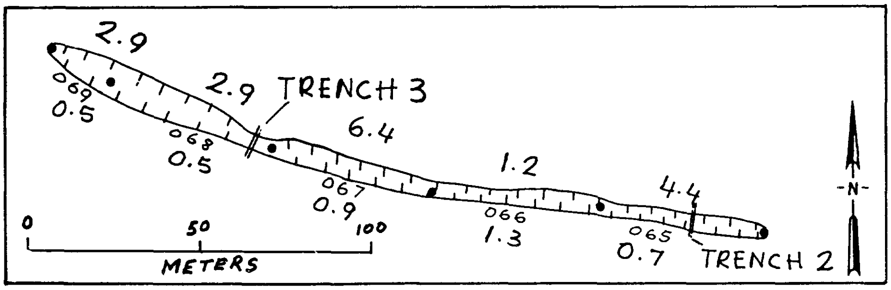


FIGURE 7.—Plan of the Southeast Al Habla ancient workings SE-1, showing sampling transects. See plate 1 for location.



EXPLANATION

Ancient trench--Dump outlines not shown

• Rock cairn marking beginning or end of a sampling transect

Sampling transect showing last three digits of a sample number in the 190000 series (along trench) and assay values in parts per million for gold (above trench) and silver (below (trench)

Modern trench dug across workings for this study

FIGURE 8.—Plan of the Al Habla East ancient workings E-1, showing sampling transects. See plate 1 for location.

The E-2 workings are 105 m long (pl. 1) in limestone and calcareous argillites. The mined zone strikes N 75° E, and quartz on dumps displays abundant copper-stained, limonitic boxwork. Galena was found locally, as was a yellow secondary mineral that was not identified. These workings are also in a topographic depression, and quartz vein outcrops were not observed.

Summary of analytical data

Workings E-1.--Nine dump samples totalling 369 m were collected for assay (fig. 8; table 1). The following are the resulting analytical data for gold and silver:

	Range (ppm)
Gold	0.09-6.39
Silver	0.2-1.3

	Mean (ppm)
Gold	3.16
Silver	0.66

Gold-silver ratio
4.79

These gold values are definitely lower than those of veins in granite. Quartz is sparse on dumps in this area and may not be representative of the material mined by the ancients. Trenches across workings did not find the bottoms of the mined zones, indicating that gold must have been found in sufficient amounts to encourage mining to greater depths.

A small set of workings several hundred meters east along the same fault was also dump-sampled with the following results:

Sample number	Length (m)	Gold (ppm)	Silver (ppm)
190070	20	0.1	0.7
190071	50	4.7	.7
190072	50	2.3	.2
190073	29	.6	.2

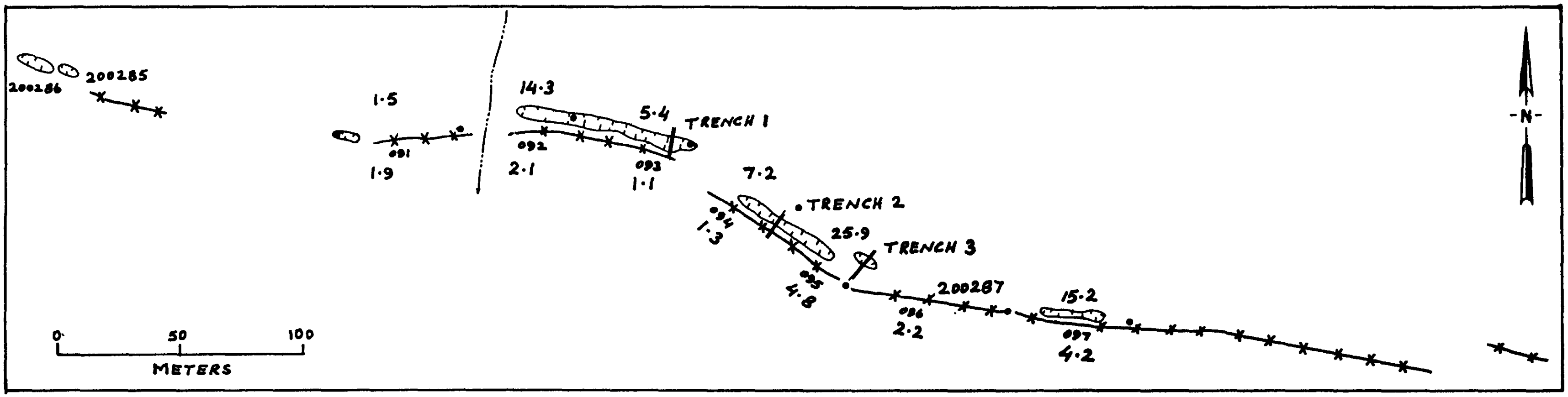
Workings E-2.--Quartz collected along the entire length (105 m) of the dumps, made up one sample (200275), assaying nil gold and 10.2 ppm silver (pl. 1; table 2).

Al Madraba (MODS 3513)

Ancient workings in this region are on quartz veins that are in or adjacent to west-northwest-trending felsic dikes in granodiorite (pl. 1; figs. 9-11). They are scattered along a distance of 3 km, and it is probable that more workings are to be found in the Al Madraba area. Quartz veins in outcrop are very scarce, as the ancients mined nearly all of the outcrops. Dumps have been washed away by flood waters to such an extent that it is difficult to recognize ancient works in places. Such are the conditions mapped at workings M-5 (fig. 10) where there are moderate amounts of quartz fragments lying adjacent to a felsic dike, but no positive indications of ancient workings.

Much of the granodiorite in this area is light gray, medium to coarse grained, and massive, although red patches are found locally, especially in workings M-6, where they may represent small dikes or may be the result of introduced potassium feldspar. Dike swarms that have a predominant northeast trend in the eastern part of the Al Madraba area (pl. 1) are the oldest dikes, and they are slightly offset by east-west fractures along which younger dikes intruded. Repeated fracturing then allowed gold-quartz deposition, mainly in or adjacent to the younger dikes.

Quartz veins in the Al Madraba region, in most respects, resemble those at Al Habla and Southeast Al Habla, except that pyrite (or oxidized relicts of that mineral) is more predominant locally. Gold assays are generally higher and free gold is more apparent in these sulfide-rich zones. Vein exposures were not disclosed by mapping or trenching, and vein widths were not determined. Quartz veins are on the hanging walls of felsic dikes that dip north about 45°, and in places parts of the dikes themselves were mined by the ancients. These dikes evidently had been fractured and thus had become the site of gold-quartz deposition in the form of veins, stockwork veinlets, or pockets. The dikes are hydrothermally altered only in areas where they contain disseminated pyrite. In some areas granodiorite wall rocks are propylitically altered and contain quartz veinlets. In areas where dumps contain granite fragments that have a high content of potassium feldspar, quartz veins are also impregnated with that mineral.



EXPLANATION

Ancient trench--Dump outlines not shown

Rock cairn marking beginning or end of a sampling transect

Fine-grained felsic dike

Modern trench dug across workings for this study

Sampling transect, showing last three digits of a sample number in the 190000 series (along transect) and assay values for gold (above transect) and silver (below transect)

Dry stream bed

FIGURE 9.—Plan of the Al Madraba ancient workings M-3, showing sampling transects. Workings M-4 (fig. 10) continue this same trend to the east, on the other side of an interval of about 600 m that is covered by wadi sediments. (See pl. 1.)

Summary of analytical data

Transect samples.--Thirty dump samples were collected from the Al Madraba workings M-3 through M-6, along 1500 m of transect (figs. 9-11; table 1), and gave the following gold and silver assay values:

Workings	No. of samples	Total transect distance (m)	Gold (ppm) Range	Gold (ppm) Mean	Silver (ppm) Range	Silver (ppm) Mean	Au/Ag ratio
M-3	7	350	1.47-25.91	9.53	1.1- 4.8	2.51	3.8
M-4&5	13	650	3.06-37.50	11.43	1.1-13.0	7.53	1.55
M-6	10	500	1.24- 8.70	3.62	.5- 2.3	1.04	3.48

The M-6 workings are unique for the area, as they are the only ones found that follow quartz veins adjacent to northwest-trending dikes (fig. 11).

By weighting individual workings according to the number of samples times mean gold and silver grade, the following mean gold and silver grades are determined for all 1500 m of dump sampling in the Al Madraba area:

Gold............................ 8.38 ppm
Silver.......................... 4.11 ppm

Grab samples.--Workings M-1 and M-2 are each a single short trench, and the M-7 workings comprise two short trenches (pl. 1). A single grab sample was collected from each of these trenches (table 2), and these yielded the following values:

Workings	Length of trench (m)	Assay values for single grab sample (ppm) Gold	Silver
M-1	20	3.02	31.0
M-2	60	23.15	36.0
M-7	100	.72	.8
M-7	20	.76	1.1

The M-1 workings are in metasediments (pl. 1) and have galena-rich quartz in their dumps.

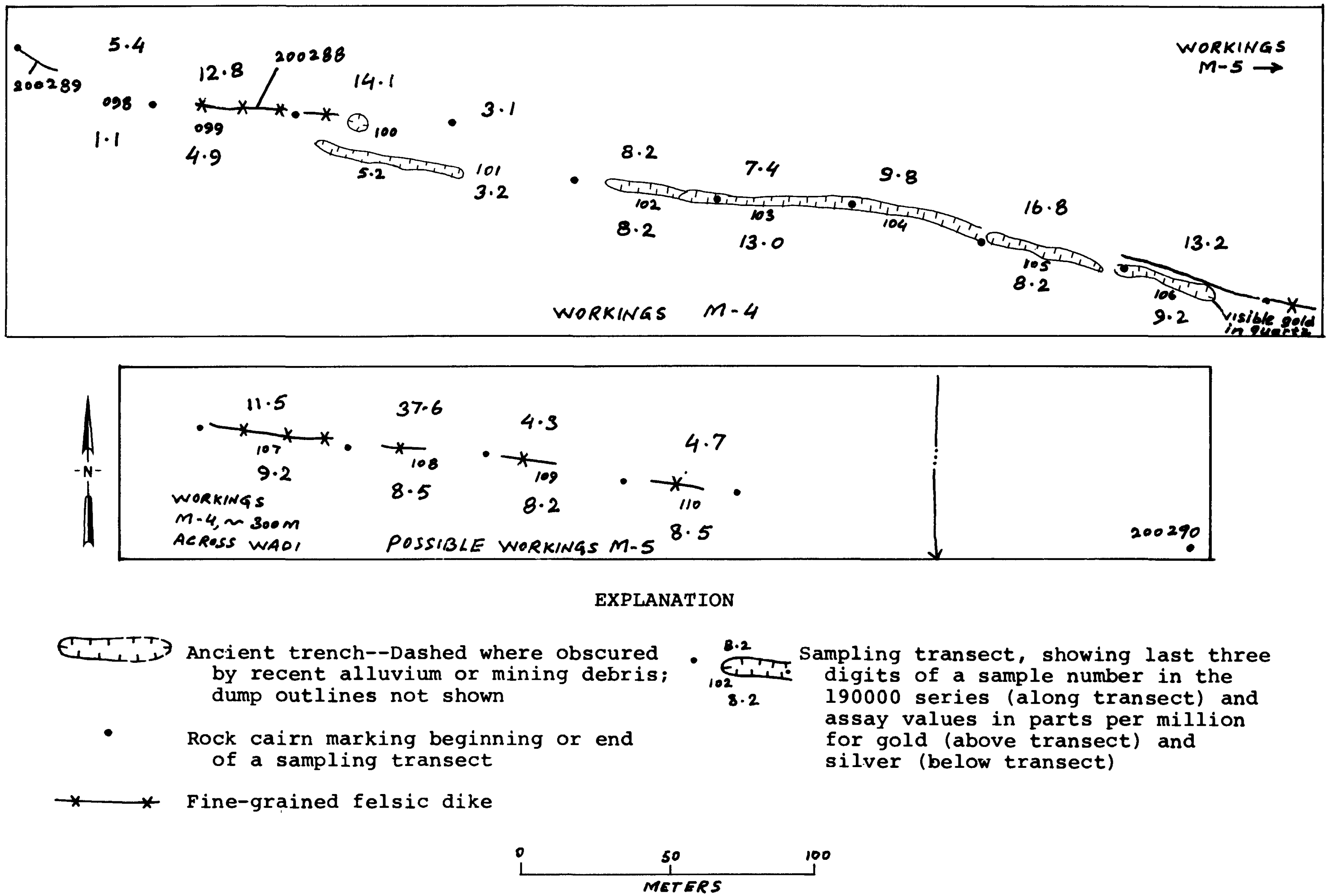
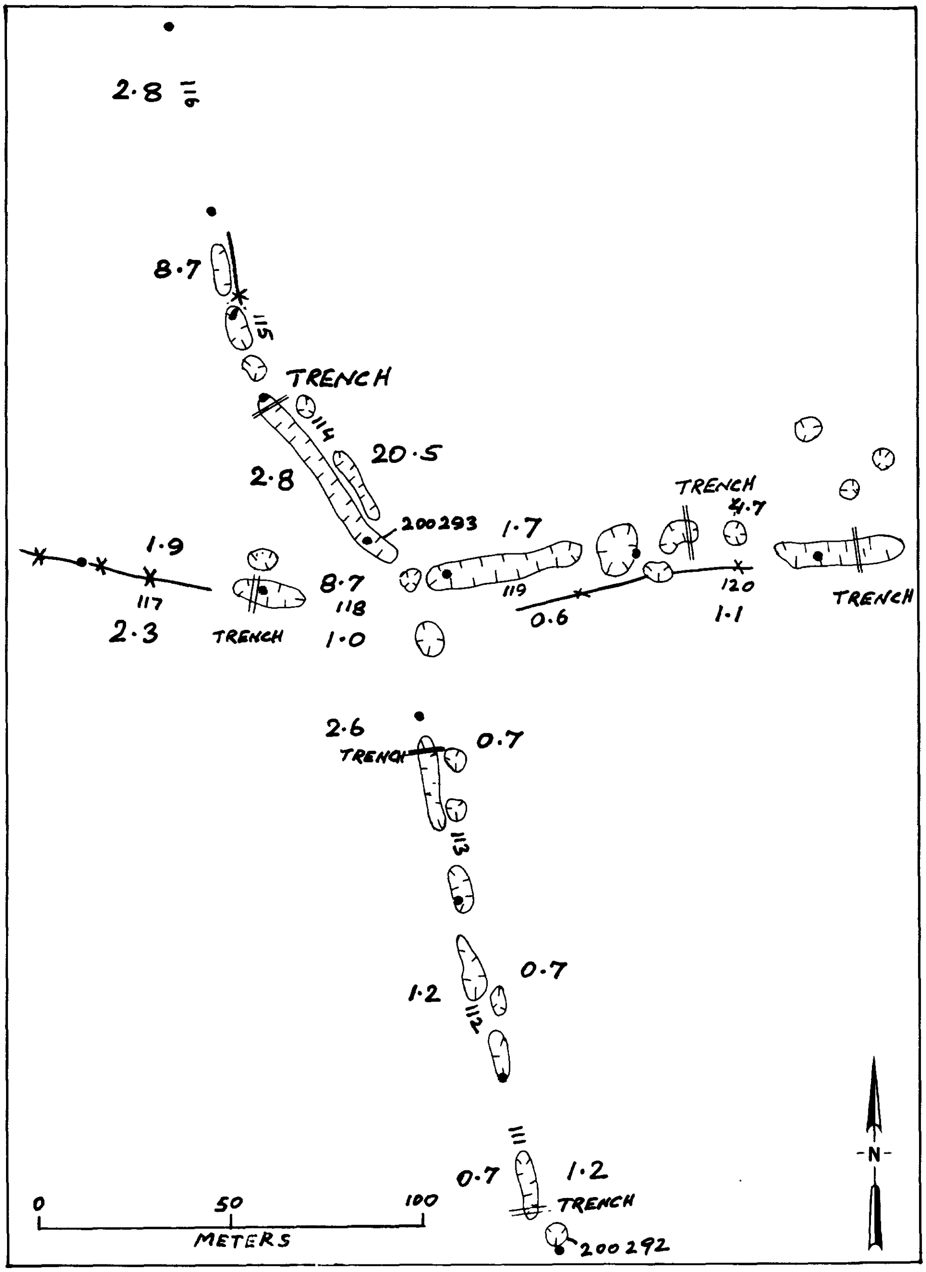


FIGURE 10.—Plan of the Al Madraba ancient workings M-4 and -5, showing sampling transects. These workings continue the trend of workings M-3 (fig. 9) and are about 600 m farther east. At M-5, scattered quartz fragments adjacent to a felsic dike are inferred to be remnants of a dump that has been washed away; ancient workings were not clearly discernible.



EXPLANATION

Ancient trench--Dashed where obscured by recent alluvium or mining debris; dump outlines not shown

Rock cairn marking beginning or end of a sampling transect

Sampling transects, showing last three digits of sample numbers in the 190000 series (along transects) and assay values in parts per million for gold (above east-west transects and left of north-south transects) and silver (below east-west transects and right of north-south transects)

Modern trench dug across workings for this study

Fine-grained felsic dike

FIGURE 11.--Plan of the Al Madraba ancient workings M-6, showing sampling transects. These workings are about 600 m east of workings M-5 (fig. 10) and are the only ones found in this area that have some trenches parallel to northwest-trending dikes.

Comment on analytical results

The analytical results of dump sampling are encouraging for gold exploration if the type of material and the extent of sampling are considered. As the quartz on dumps was apparently considered to be waste by the ancient miners, then the material from which they recovered gold was presumably of higher grade. Dirom (1946) considered two cases and calculated grades of ore on the supposition that the quartz on dumps is either 50% (case 1) or 25% (case 2) of the value of ore milled. Worl (1979), from experience at the Mahd adh Dhahab and Hajr mines, estimated the grade of quartz on dumps to be 25-35% of the grade of the quartz in which gold was recovered. At present we are unable to make an estimate of the tonnages of ore mined and treated. A large ancient village at the Al Habla workings (pl. 1) has numerous housing foundations and a large quantity of quartz tailings strewn about over a large area, indicating a great amount of milling activity, but flood waters have dispersed the material to the extent that estimates of tonnages are not feasible. The same is true for a smaller ancient village at Al Madraba.

TRENCHING IN THE AL HABLA AREA

Trenching was done by a backhoe that had a maximum trenching depth capability of 3.3 m. Twenty-eight trenches across ancient workings in the Al Habla area were completed, and of these, eighteen cut quartz veins or quartz veinlet stockworks in felsic dikes. Only rubble-filled open cuts and barren wall rocks were exposed in the remaining trenches.

Figures 12-16 show detailed geologic cross sections and sample localities for 21 trenches. The remaining seven are not shown in detail because they did not cut quartz veins, nor reach the bottoms of ancient workings, nor yield notable values of gold and silver in any of the sampling. Locations of the trenches are shown on figures 3-11.

Al Habla ancient mines

Six trenches cut veins in workings AH-1 (fig. 12). Quartz veins as much as 80 cm thick were exposed, and two of the trenches cut veins that had not been worked by the ancients. The remaining trenches cut veins that had been worked only to a limited extent. All of the veins exposed dip east from 45° to 80°, all are light gray to tan and medium crystalline, and some contain minor pyrite. Wall rocks of both granite and felsic dikes are relatively unaltered, and only the felsic dikes contain minor pyrite. The quartz vein exposed in trench 1 is apparently between granite wall rock and the hanging wall of a felsic dike. Other trenches did not cut dike rock, but such rocks were found in most of the dumps along this vein. Figure 12 shows analytical data from vein and wall rock sampling in the trenches, indicating low gold and silver content for quartz veins and barren wall rocks. Five trenches in workings AH-2, 3, and 4 did not reach the bottoms of the ancient workings.

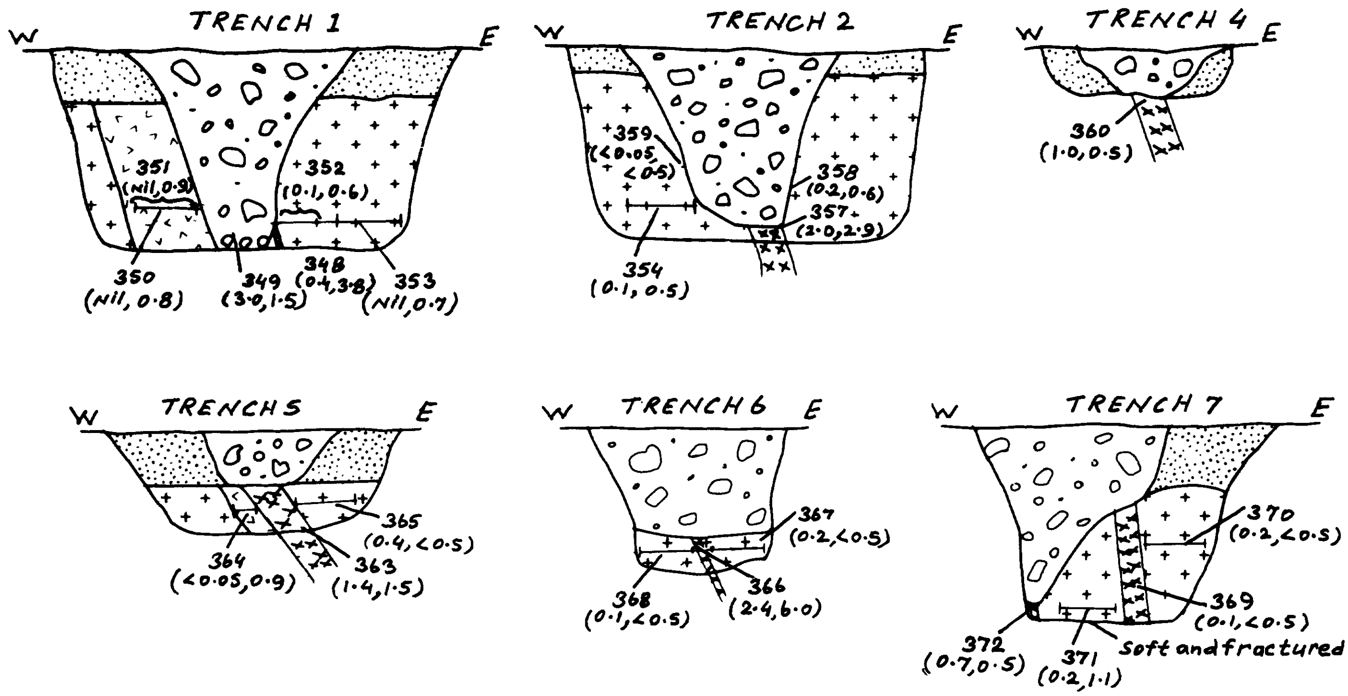


FIGURE 12.—Geologic cross sections of trenches across the Al Habla ancient workings AH-1, showing sample localities and assay data. See figure 3 for locations of trenches.

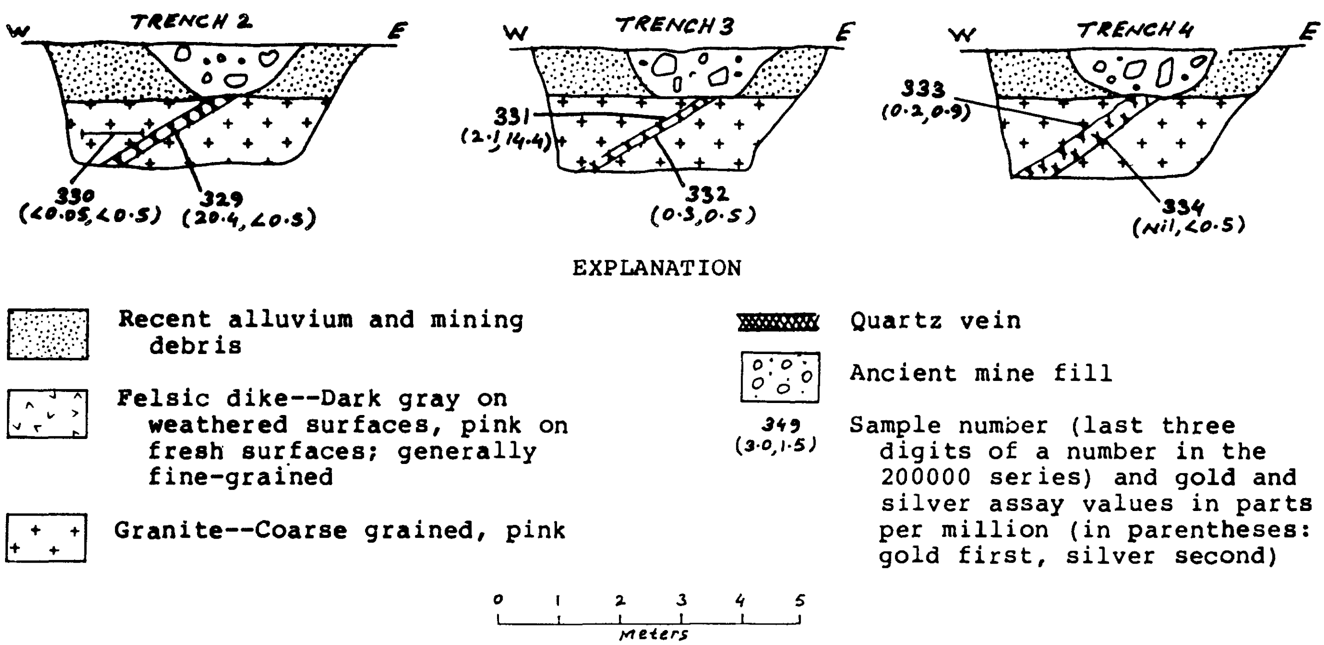


FIGURE 13.—Geologic cross sections of trenches across the Southeast Al Habla ancient workings SE-1, showing sample localities and assay data. See figure 7 for locations of trenches.

Southeast Al Habla

Trenches 2, 3, and 4 cut quartz veins in place, and trench 1 was only dug to slightly more than 1-m depth because of poor digging conditions. The quartz veins exposed all dip westerly at 30 to 40 degrees, and all are narrow, ranging from 12 to 30 cm thick (fig. 13). They range in texture and color from medium grained and white to coarsely crystalline and translucent, and all varieties contain disseminated pyrite. The range in gold values from vein samples (fig. 13) is Nil-20.43 ppm; and silver ranges from less than 0.5 to 14.4 ppm. Samples of granite selvages were low in both gold and silver values.

Al Habla East

None of the three trenches in the line of workings at locality E-1 reached the bottom of ancient workings, but detailed cross sections in figure 14 are shown to display sample localities in vein selvages. Exposed rocks show intense cataclasis and low-temperature quartz and calcite in the form of veinlet networks and pockets. Individual rock fragments are partially rounded, and deep weathering has dispersed iron oxide through much of the fragmented material. These trenches have obviously exposed a major fault, and although no veins in place were exposed, the outline of the ancient workings indicates that quartz veins with a near-vertical dip were emplaced in the fault zone. Sampling of the fault zone in the vein walls yielded only very low values for gold and silver (fig. 14).

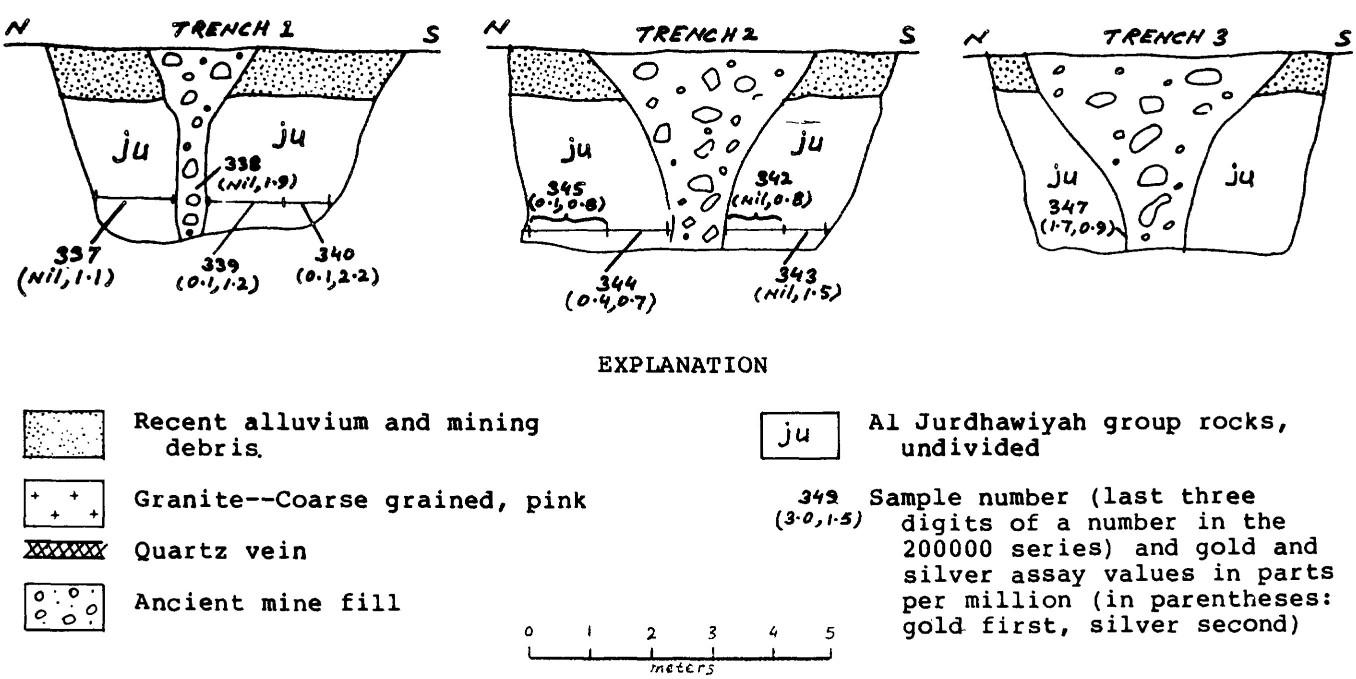


FIGURE 14.—Geologic cross sections of trenches across the Al Habla East ancient workings E-1, showing sample localities and assay data. See figure 8 for locations of trenches.

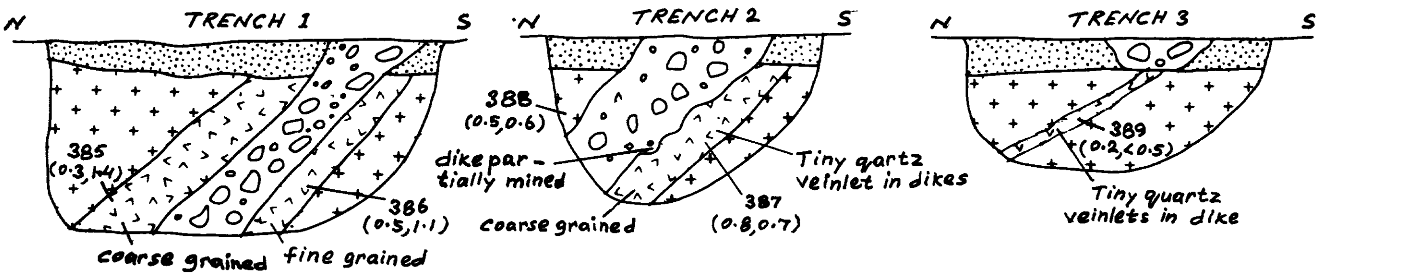


FIGURE 15.—Geologic cross sections of trenches across the Al Madraba ancient workings M-3, showing sample localities and assay data. See figure 9 for locations of trenches.

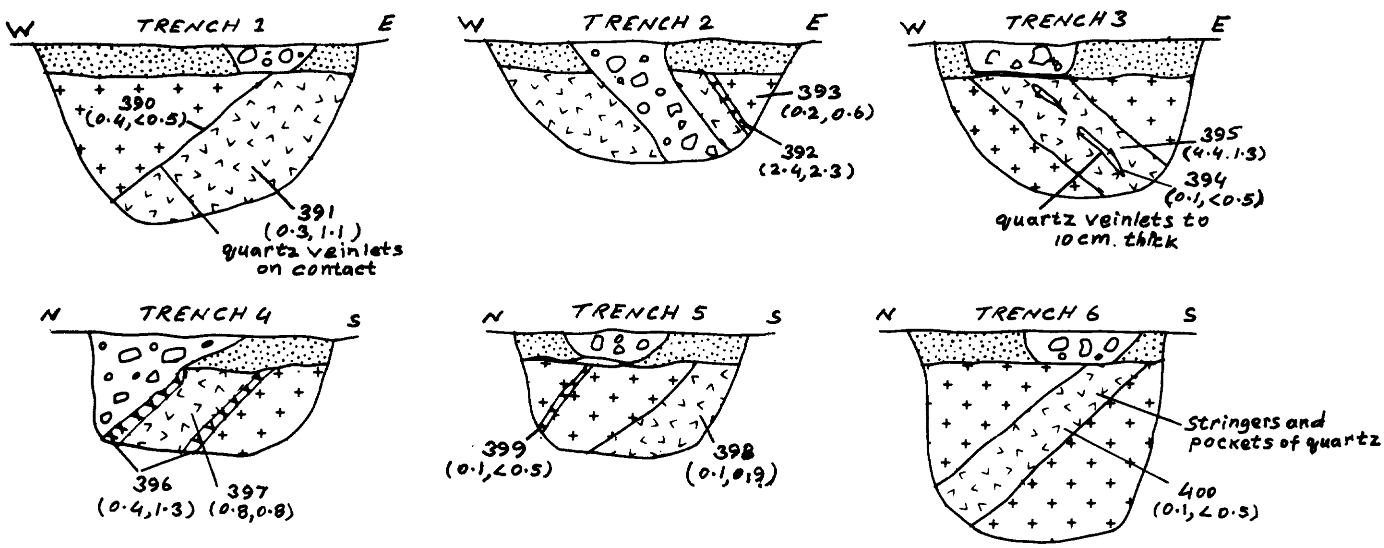
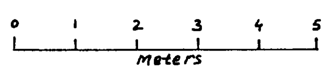
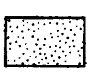


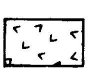
FIGURE 16.—Geologic cross sections of trenches across the Al Madraba ancient workings M-6, showing sample localities and assay data. See figure 11 for locations of trenches.



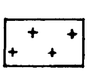
EXPLANATION



Recent alluvium and mining debris

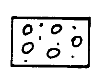


Felsic dike--Dark gray on weathered surfaces, pink on fresh surfaces; generally fine-grained



Granite--Coarse grained, pink

Quartz vein



Ancient mine fill

349
(3.0, 1.5)

Sample number (last three digits of a number in the 200000 series) and gold and silver assay values in parts per million (in parentheses: gold first, silver second)

Al Madraba

Workings M-3.--Two trenches did not reach the bottom of mine workings, and trench 3 exposed only a thin dike (fig. 15). Trench 1 exposed mine workings between two dikes dipping 40° north: a fine-grained felsic dike on the footwall and a coarse-grained dike on the hanging wall. The coarse-grained dike contains minor pyrite and clear quartz veinlets, and the fine-grained dike contains 1- to 3-mm-thick quartz veinlets along joint planes. Samples of both dikes were very low in gold and silver. Trench 2 exposed mine workings on the north-dipping hanging wall of a coarse-grained felsic dike which contains a network of quartz veinlets. Sections of the dike have been partially mined. One sample of the dike material and one of granodiorite in the hanging wall contained little gold or silver (fig. 15). Trench 3 exposed a thin, north-dipping felsic dike containing thin veinlets of quartz. One sample of the dike also yielded low values in gold and silver.

Workings M-6.--Trench 1 cut a westerly dipping felsic dike not apparently worked by ancient miners (fig. 16). One sample of thin quartz veinlets on the contact of the felsic dike with the granodiorite had low gold and silver values. Trench 2 did not reach the bottom of the ancient workings, which are in an east-dipping felsic dike. One sample of a thin quartz vein on the contact between granodiorite and felsic dike ran 2.42 ppm gold and 2.3 ppm silver (fig. 16). The vein had not been worked by ancient miners. A sample of the wall-rock granodiorite yielded low values for gold and silver. Trench 3 intersected an east-dipping felsic dike in granodiorite; the latter is fractured and pyritized, but not otherwise hydrothermally altered, and contains quartz veins and veinlets. One sample of the quartz contained little precious metal, but a sample of slightly pyritized dike rock contained 4.42 ppm gold and 1.3 ppm silver. Three trenches on east-trending ancient workings were not successful in finding veins worked by the ancients. Trenches 4 and 5 found only shallow workings and north-dipping felsic dikes in granodiorite. Trench 4 also cut two veins which had been bypassed by ancient miners and which assayed low in gold and silver. One thin quartz veinlet, a felsic dike containing quartz stockwork veinlets, and granodiorite wall rock in trench 5 all assayed low for gold and silver.

Summary of trenching results

Trenching succeeded in exposing only a few veins that had been worked extensively by ancient miners and that obviously had a high gold content. It was successful, however, in exposing details of structure, depositional environments of quartz, and the extent of hydrothermal alteration. Trenching also revealed the erratic distribution of deeper mine workings along vein systems, which is not apparent by surface studies alone. The continuous distribution of ancient workings along some vein systems indicates that entire vein systems were prospected but were seriously mined only where the quartz had a high gold content. This, in turn, indicates the heterogeneous nature of gold deposition along quartz vein systems. The ancient miners were not infallible--some high grade gold samples were obtained from unworked or lightly worked quartz veins--but the general indications are that they were efficient gold prospectors in these types of quartz vein systems.

DISCUSSION

The pertinent geologic features in various areas of the Al Habla region are as follows:

Gold-quartz veins in granite at the Al Habla and Southeast Al Habla workings:

1. Evidence of hydrothermal alteration is scarce.
2. Ranges of analytical values are 5-575 ppm for base metals, 2-18 ppm for arsenic, and 0-72 ppm for antimony.
3. Gold-quartz veins are adjacent to fine-grained felsic dikes.
4. A few tungsten values are in the 200-400 ppm range, mostly concentrated along the central part of the Al Habla vein system.
5. Gold/silver ratios of the veins are approximately 2.

Gold-quartz veins in metasediments at Al Habla East:

1. Veins at workings E-1 were emplaced in a major fault.
2. Arsenic is an important constituent of the veins at workings E-1, with a range of 80-1200 ppm.
3. Silver is relatively unimportant. (Au/Ag of quartz in workings E-1 is 4.79.)
4. One quartz sample gathered along dumps at workings E-2, in calcareous metasediments, contained no gold and gave relatively high silver, copper, lead, and zinc values.

Gold-quartz veins at South-Central Al Habla workings SC-1 and SC-4 and at Al Madraba:

1. Gold-quartz veins are generally adjacent to fine-grained felsic dikes, and in places dikes are shattered and pyritized and contain gold-bearing quartz stringers.
2. Quartz in workings M-4, 5, and 6 has lead values in the range 4-2350 ppm and arsenic in the range 36-167 ppm. Higher gold and silver values generally correlate with higher lead and arsenic values.
3. Veins and granite wall rock in much of the area show pink potassium-feldspathic alteration and moderate propylitic alteration, including epidotization of mafic minerals in granite. The granite is also silicified locally.

4. Some ancient dumps have hydrothermally altered granite boulders containing quartz stockworks.
5. Gold/silver ratios for these veins are higher than those of Al Habla and Southeast Al Habla, generally being in the range of 3 to 4.

The implications of these data may be that a zone represented by Al Madraba and the South-Central workings approximates the center of a hydrothermal system that deposited gold, pyrite, minor base metals, and arsenic. Hydrothermal wall-rock alteration and the local occurrence of quartz stockworks in dikes and granite within this central zone contrast with the rocks at Al Habla and Southeast Al Habla, where these conditions are absent and where arsenic is found in minor quantities. In addition, gold/silver ratios are 3 to 4 at Al Madraba and the South-Central workings, whereas they are approximately 2 in the Southeast Al Habla zone. These factors clearly show that depositional conditions were different in the two zones, but their significance for overall zoning of the hydrothermal system is not known.

Sampling results of quartz veins in metasediments are more difficult to interpret. For example, the high arsenic values and the gold/silver ratio found at workings E-1 imply the same conditions as Al Madraba and South-Central Al Habla. However, one quartz sample from workings E-2, which has no gold and relatively high silver, copper, lead, and zinc values, may indicate a pattern of reduced temperature and/or pressure in the direction of Al Madraba and South-Central Al Habla, to the northeast (pl. 1).

Boyle and Howes (1983) described ancient gold workings at Sukhaybarat, some 30 km west-southwest of Al Habla (fig. 1). These deposits are in a similar geologic setting to those of Al Habla, being in felsic intrusions within Murdama group metasediments and within metasediments themselves. They found that alteration--especially of the felsic rocks in the form of carbonatization, ferruginization, and sericitization in some areas, and potassium feldspathization in other areas--indicated zones of higher gold values both in quartz and wall rock. Detailed dump sampling in the Al Habla, Southeast Al Habla, and Al Madraba ancient workings indicates only slight differences in gold content of the quartz from area to area. Consequently, no correlation between hydrothermal alteration and gold content is apparent in the Al Habla deposits. However, the lack of correlation could be attributed to ineffectiveness of the sampling procedure. Also, hydrothermal alteration, fracturing, and quartz stockworks appear to be much less prominent in the Al Habla area than at Sukhaybarat, based on Boyle and Howes' description.

A study of correlation coefficients for 11 elements assayed in all of the dump sampling shows that gold has the highest correlation with silver, a moderate correlation with base metals, and negative correlations with arsenic, molybdenum, tungsten, nickel, and cobalt. The gold-arsenic relationship is undoubtedly influenced by the high gold and low arsenic values obtained at Al Habla and Southeast Al Habla, and by the low gold and high arsenic values obtained at Al Habla East. The negative correlation of gold with tungsten also implies that tungsten values in the 200-400 ppm range neither enhance nor diminish the likelihood of gold deposition in the area.

RECOMMENDATIONS

Further detailed studies are recommended as a first-order task to delineate, if possible, additional quartz veins, vein systems, or ancient workings. The low-level aerial photography presently completed covers a region including most of the Al Habla and all of the South-Central Al Habla workings. These black-and-white photographs with high resolution are very useful in identifying rock structures even beneath sand and gravel cover. Surface traces of quartz veins are readily identified on these photographs. Hence, it is recommended that the entire Al Habla area, including all of the known ancient mines, be covered by low-level photography. A large area including the Al Habla and Southeast Al Habla is covered by a thin veneer of sand and gravel, and detailed mapping of any structures which show through this material may be successful in locating additional veins. Concentrations of quartz in numerous places in the alluvium cover in this region seem to indicate the presence of nearby quartz veins. Mapping and sampling of such concentrations may then serve as a basis for further detailed work. In addition, the geology of the area should be mapped in careful detail to provide a good base for future mineral exploration, and by doing so, it is highly probable that other veins and workings will be found and more details of the environments of gold deposition revealed.

Extensive trenching in the north Al Habla vein system and elsewhere in covered areas should be done to expose veins suggested by surface mapping. Extensions of veins not worked by ancient miners should be examined by this method. Finally, core drilling should be considered after the completion of detailed mapping, sampling, and trenching.

DATA STORAGE

Mineral localities described in this report are entered into the Mineral Occurrence Documentation System (MODS) data bank and are each identified by a unique 5-digit number. Inquiries regarding this data bank may be made through the Office of the Technical Advisor, Saudi Arabian Deputy Ministry for Mineral Resources, Jiddah.

MODS entries for South-Central Al Habla (MODS 1267), Southeast Al Habla (MODS 3512), and Al Madraba (MODS 3513) were made as a result of this study.

Field and laboratory data used in this report are filed as USGS-DF-04-44.

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Table 1.--Atomic absorption and chemical analyses for detailed transect sampling of ancient mine dumps in the Al Habla area, Kingdom of Saudi Arabia

[Sample localities are shown on figures 3-11. Results are in parts per million. Letters in parentheses indicate type of analysis: AAP, atomic absorption assay following partial digestion of sample; AAT, atomic absorption assay following total digestion of sample; CM, colorimetry assay. N, not detected]

Sample number	Cu (AAP)	Pb (AAP)	Zn (AAP)	Co (AAP)	Ni (AAP)	Au (AAT)	Ag (AAT)	As (CM)	Sb (CM)	Mo (CM)	W (CM)
190000	10.0	630.0	55.0	10.0	20.0	1.5	7.8	16.0	0.0	10.0	16.0
190001	25.0	290.0	90.0	10.0	30.0	1.0	1.8	38.0	.0	10.0	25.0
190002	35.0	80.0	80.0	15.0	50.0	1.7	1.3	135.0	1.6	5.0	3.0
190003	50.0	300.0	155.0	15.0	60.0	.8	5.3	42.0	.0	5.0	25.0
190004	30.0	345.0	200.0	10.0	20.0	8.3	18.0	10.0	.0	75.0	320.0
190005	30.0	200.0	65.0	10.0	25.0	7.3	3.1	6.0	.0	40.0	12.0
190006	35.0	160.0	35.0	10.0	25.0	1.2	3.9	16.0	.0	250.0	32.0
190007	20.0	260.0	60.0	10.0	15.0	1.8	5.7	6.0	.0	50.0	35.0
190008	20.0	210.0	75.0	10.0	20.0	5.9	2.5	6.0	.0	75.0	44.0
190009	15.0	280.0	75.0	10.0	25.0	1.1	4.7	4.0	.0	20.0	40.0
190010	15.0	480.0	60.0	10.0	15.0	3.3	8.3	6.0	.0	40.0	5.0
190011	50.0	575.0	70.0	10.0	20.0	33.1	14.0	8.0	3.2	20.0	22.0
190012	10.0	160.0	30.0	10.0	20.0	.8	2.2	6.0	.0	20.0	62.0
190013	25.0	345.0	35.0	10.0	15.0	1.2	3.6	8.0	3.2	40.0	11.0
190014	50.0	385.0	55.0	10.0	30.0	6.4	8.1	8.0	5.6	75.0	19.0
190015	5.0	90.0	10.0	10.0	10.0	.1	1.7	2.0	.0	50.0	112.0
190016	15.0	245.0	40.0	10.0	20.0	10.6	4.5	2.0	2.8	10.0	7.0
190017	10.0	165.0	45.0	10.0	20.0	.8	5.2	2.0	.0	10.0	14.0
190018	25.0	245.0	45.0	10.0	15.0	7.2	4.2	6.0	6.4	15.0	109.0
190019	15.0	225.0	45.0	10.0	15.0	6.9	3.1	4.0	.0	20.0	62.0
190020	10.0	225.0	60.0	10.0	15.0	5.6	4.8	6.0	.0	20.0	25.0
190021	10.0	130.0	20.0	10.0	20.0	1.3	1.7	6.0	2.8	15.0	14.0
190022	30.0	115.0	55.0	15.0	20.0	1.3	1.9	8.0	3.2	40.0	27.0
190023	15.0	170.0	50.0	10.0	25.0	3.7	4.0	10.0	1.2	40.0	37.0
190024	30.0	265.0	120.0	10.0	15.0	3.9	6.3	10.0	19.2	20.0	48.0
190025	25.0	160.0	55.0	10.0	20.0	8.6	3.1	4.0	3.6	20.0	34.0
190026	30.0	155.0	40.0	10.0	20.0	3.8	3.5	6.0	6.8	25.0	11.0
190027	50.0	30.0	25.0	15.0	45.0	.7	.5	12.0	.0	15.0	29.0
190028	25.0	20.0	15.0	15.0	20.0	1.1	.7	8.0	.0	10.0	3.0
190029	30.0	15.0	15.0	15.0	20.0	10.7	3.8	8.0	10.0	10.0	11.0
190030	15.0	70.0	20.0	10.0	15.0	1.5	2.4	6.0	5.6	10.0	11.0
190031	25.0	65.0	70.0	10.0	10.0	6.9	5.4	10.0	4.0	5.0	38.0
190032	50.0	70.0	40.0	10.0	10.0	39.2	5.7	14.0	48.0	5.0	52.0
190033	90.0	65.0	45.0	10.0	30.0	5.1	4.3	28.0	72.0	10.0	300.0
190034	80.0	110.0	40.0	10.0	15.0	8.2	4.7	20.0	40.8	10.0	290.0
190035	45.0	135.0	60.0	10.0	20.0	3.9	4.7	20.0	10.8	10.0	260.0
190036	50.0	100.0	10.0	10.0	15.0	17.4	3.5	24.0	59.2	15.0	218.0
190037	45.0	115.0	25.0	10.0	25.0	13.3	3.2	.0	14.8	.0	.0
190038	60.0	45.0	10.0	10.0	15.0	7.8	2.2	18.0	27.2	5.0	27.5
190040	15.0	35.0	5.0	10.0	10.0	8.3	1.2	6.0	7.2	5.0	375.0
190041	20.0	25.0	10.0	10.0	10.0	2.6	.8	14.0	4.8	10.0	237.0
190042	40.0	60.0	10.0	10.0	15.0	17.5	2.0	18.0	17.6	10.0	172.0
190043	30.0	170.0	30.0	10.0	15.0	7.4	8.1	12.0	60.0	5.0	11.0
190044	55.0	230.0	105.0	10.0	10.0	10.1	9.0	10.0	12.0	N	N
190045	35.0	160.0	45.0	10.0	15.0	1.9	3.7	12.0	.0	5.0	186.0

Table 1.--Atomic absorption and chemical analyses for detailed transect sampling--Continued

Sample number	Cu (AAP)	Pb (AAP)	Zn (AAP)	Co (AAP)	Ni (AAP)	Au (AAT)	Ag (AAT)	As (CM)	Sb (CM)	Mo (CM)	W (CM)
190046	35.0	130.0	45.0	10.0	40.0	19.1	3.3	12.0	1.6	5.0	337.0
190047	15.0	95.0	90.0	10.0	10.0	2.2	2.9	10.0	0.0	5.0	5.0
190048	25.0	305.0	145.0	10.0	20.0	36.2	18.0	12.0	.0	20.0	5.0
190049	30.0	205.0	120.0	5.0	10.0	7.5	6.9	18.0	60.8	10.0	1.5
190050	30.0	90.0	45.0	10.0	15.0	2.7	2.9	12.0	.0	5.0	N
190051	40.0	195.0	90.0	5.0	10.0	8.1	6.9	9.0	.0	N	4.0
190052	25.0	20.0	10.0	5.0	15.0	2.7	1.3	4.0	.0	20.0	3.0
190053	30.0	25.0	15.0	5.0	20.0	6.4	3.7	8.0	15.2	15.0	5.0
190054	65.0	50.0	35.0	5.0	10.0	11.5	7.7	10.0	5.2	15.0	12.5
190055	30.0	25.0	10.0	10.0	15.0	5.3	2.4	6.0	5.2	10.0	2.0
190056	35.0	45.0	25.0	5.0	15.0	4.6	2.7	4.0	6.0	10.0	2.0
190057	30.0	40.0	20.0	5.0	15.0	7.1	3.0	6.0	12.4	10.0	1.0
190058	40.0	90.0	25.0	5.0	25.0	35.7	7.0	6.0	7.6	20.0	41.0
190059	15.0	5.0	5.0	5.0	10.0	1.0	.4	4.0	.0	25.0	N
190060	10.0	10.0	N	5.0	10.0	2.0	1.0	2.0	.0	5.0	5.0
190061	30.0	15.0	10.0	5.0	20.0	4.6	1.2	6.0	4.8	5.0	8.0
190062	50.0	15.0	10.0	5.0	5.0	3.8	.3	4.0	24.0	10.0	215.0
190063	5.0	5.0	5.0	5.0	10.0	.1	.2	4.0	.0	10.0	3.0
190064	5.0	10.0	5.0	10.0	45.0	.1	1.0	2.0	.0	20.0	2.0
190065	30.0	20.0	65.0	15.0	20.0	4.4	.7	1200.0	8.0	10.0	1.0
190066	25.0	20.0	20.0	10.0	25.0	1.2	1.3	130.0	10.0	10.0	2.0
190067	50.0	25.0	70.0	15.0	20.0	6.4	.9	90.0	22.0	10.0	5.0
190068	55.0	20.0	25.0	10.0	5.0	2.9	.5	180.0	38.8	15.0	1.0
190069	45.0	10.0	15.0	5.0	20.0	2.9	.5	90.0	4.0	10.0	1.0
190070	70.0	10.0	15.0	10.0	25.0	.1	.7	80.0	10.0	10.0	2.0
190071	25.0	25.0	20.0	10.0	30.0	4.7	.7	400.0	16.0	5.0	7.0
190072	15.0	10.0	10.0	5.0	10.0	2.3	.2	200.0	14.4	5.0	3.0
190073	10.0	5.0	10.0	5.0	80.0	.6	.2	250.0	9.2	5.0	2.0
190074	5.0	10.0	N	5.0	10.0	.8	.5	4.0	.0	5.0	2.0
190075	5.0	65.0	10.0	10.0	10.0	2.5	3.0	30.0	.0	10.0	3.0
190076	5.0	25.0	5.0	5.0	10.0	.2	.2	2.0	.0	5.0	1.0
190077	5.0	5.0	N	5.0	5.0	1.0	<.5	6.0	.0	5.0	2.0
190078	15.0	80.0	75.0	5.0	5.0	5.5	3.1	16.0	12.0	10.0	1.5
190079	5.0	70.0	20.0	10.0	10.0	1.8	2.2	6.0	12.0	10.0	1.5
190080	20.0	445.0	200.0	10.0	5.0	8.1	41.0	34.0	7.2	40.0	3.0
190081	10.0	185.0	40.0	10.0	5.0	1.3	4.6	8.0	.0	25.0	7.0
190082	15.0	385.0	75.0	10.0	5.0	5.9	16.0	16.0	2.0	15.0	3.0
190083	15.0	370.0	90.0	10.0	5.0	18.4	32.0	14.0	43.2	15.0	N
190084	5.0	20.0	5.0	15.0	5.0	4.1	1.4	4.0	.0	10.0	5.0
190085	5.0	30.0	5.0	5.0	N	36.3	5.3	24.0	.0	5.0	22.0
190086	5.0	20.0	N	15.0	N	.2	1.7	6.0	.0	5.0	N
190087	5.0	15.0	10.0	5.0	5.0	1.6	1.6	6.0	.0	5.0	1.0
190088	5.0	45.0	10.0	10.0	5.0	7.5	2.0	10.0	1.2	10.0	4.0
190089	5.0	210.0	5.0	15.0	5.0	1.4	2.5	38.0	1.2	20.0	.0
190090	5.0	80.0	5.0	15.0	15.0	1.4	1.2	14.0	.0	10.0	1.0
190091	10.0	25.0	10.0	15.0	15.0	1.5	1.9	40.0	.0	15.0	2.0
190092	10.0	30.0	5.0	5.0	10.0	14.3	2.1	44.0	.0	10.0	4.0
190093	10.0	10.0	5.0	10.0	10.0	5.4	1.1	26.0	.0	5.0	5.0
190094	10.0	25.0	20.0	15.0	5.0	7.2	1.3	30.0	.0	5.0	4.5
190095	10.0	35.0	5.0	5.0	20.0	25.9	4.8	58.0	.0	5.0	10.0

Table 1.--Atomic absorption and chemical analyses for detailed transect sampling--Continued

Sample number	Cu (AAP)	Pb (AAP)	Zn (AAP)	Co (AAP)	Ni (AAP)	Au (AAT)	Ag (AAT)	As (CM)	Sb (CM)	Mo (CM)	W (CM)
190096	10.0	105.0	20.0	15.0	10.0	7.8	2.2	36.0	0.0	10.0	7.0
190097	5.0	40.0	20.0	10.0	10.0	15.2	4.2	20.0	.0	10.0	1.0
190098	10.0	45.0	45.0	10.0	5.0	5.4	.5	32.0	.0	5.0	35.0
190099	15.0	130.0	300.0	5.0	10.0	12.8	4.9	46.0	.0	15.0	5.0
190100	10.0	415.0	95.0	10.0	10.0	14.1	5.2	93.0	21.2	15.0	7.5
190101	5.0	90.0	25.0	10.0	15.0	3.1	3.2	36.0	11.6	10.0	11.0
190102	5.0	450.0	140.0	10.0	15.0	8.2	8.2	100.0	108.0	10.0	13.5
190103	15.0	740.0	150.0	15.0	20.0	7.4	13.0	167.0	18.8	15.0	12.5
190104	20.0	300.0	120.0	15.0	25.0	9.8	8.2	38.0	12.0	15.0	10.0
190105	10.0	405.0	105.0	15.0	25.0	16.8	8.2	167.0	74.8	10.0	7.5
190106	10.0	305.0	105.0	15.0	15.0	13.2	9.2	76.0	36.8	5.0	10.0
190107	15.0	480.0	150.0	10.0	15.0	11.5	9.2	117.0	26.8	20.0	13.0
190108	15.0	665.0	130.0	15.0	20.0	37.6	8.5	120.0	27.6	75.0	7.5
190109	5.0	90.0	15.0	10.0	25.0	4.3	8.2	28.0	46.8	5.0	17.5
190110	30.0	280.0	35.0	10.0	20.0	4.7	8.5	52.0	76.0	30.0	1.0
190111	15.0	110.0	5.0	15.0	15.0	.7	1.2	36.0	1.2	5.0	17.0
190112	10.0	50.0	5.0	15.0	20.0	1.2	.7	34.0	7.2	5.0	12.5
190113	10.0	140.0	65.0	20.0	35.0	2.6	.7	167.0	6.4	10.0	16.5
190114	30.0	355.0	85.0	20.0	30.0	2.8	<.5	117.0	16.0	5.0	15.0
190115	75.0	2350.0	250.0	15.0	25.0	8.7	1.6	150.0	16.0	40.0	18.5
190116	5.0	95.0	5.0	10.0	20.0	2.8	1.7	58.0	4.4	5.0	17.5
190117	N	15.0	N	10.0	20.0	1.9	2.3	66.0	4.4	5.0	13.0
190118	5.0	75.0	20.0	15.0	25.0	8.7	1.0	110.0	4.8	N	7.5
190119	10.0	35.0	20.0	10.0	20.0	1.7	.6	26.0	4.4	5.0	1800.0
190120	15.0	50.0	15.0	10.0	20.0	4.7	1.1	56.0	4.8	5.0	10.0
200296						10.3	10.2				
200297						2.6	12.8				
200298						8.0	40.2				
200299						2.6	4.1				
200300						18.7	3.5				
200301						3.4	2.9				
200302						2.0	.8				

Table 2.--Analytical data for miscellaneous sampling in the Al Habla area. Sample locations are posted on plate 1

Sample Number	Description	Atomic absorption analyses Au ppm	Ag ppm	Noteworthy semi-quantitative emission spectographic analyses (ppm)
200267	Grab, quartz, vuggy, with no sulfides--along 100 m of dump	0.7	0.8	AS-200
200268	Grab, granite with quartz stringers--along 20 m of dump	.8	1.1	AS-300, W-10
200269	Felsic dike, heterogeneous pyrite	<.05	1.3	Ba-700
200270	Grab, sorting pile, quartz, coarsely crystalline, sparse limonite	--	.4	
200271	Grab, quartz with galena, along 20 m of dump	3.0	31.0	Pb-500
200272	Chip sample quartz vein with moderate FeO	.8	33.7	Bi-70, Pb-700
200273	Same as above.	.1	4.8	Bi-30
200275	Grab, quartz with CuO, PbS and abundant limonite--along 105 m of dump	--	10.2	Pb-2000, Cu-700, Zn-2000
200276	Grab, quartz, milky with sparse iron staining, along 25 m of dump	44.6	4.8	
200277	Altered aplite dike adjacent to workings	--	.4	
200278	Grab, quartz, milky, slightly iron stained, along 40 m dump	2.7	1.7	
200279	Grab, as above, along 40 m dump	.1	.6	
200280	Grab, quartz, milky, some with orthoclase, along 150 m dump	27.9	3.1	
200281	Grab, quartz, no FeO, along 140 m of dump	15.0	1.7	
200282	Grab, as above, along 130 m of dump	2.1	.4	
200283	Silicified granite wall rock, dump	.3	.3	
200284	Grab, quartz with limonite, along 36 m of dump	42.2	3.3	
200285	Grab, quartz	22.4	3.7	
200286	Grab, quartz	14.7	5.0	
200287	Grab, sorting pile(?), quartz, white	--	.5	

Table 2.--Analytical data for miscellaneous sampling in the Al Habla area. Sample locations are posted on plate 1--[Continued]

Sample Number	Description	Atomic absorption analyses Au ppm	Ag ppm	Noteworthy semi-quantitative emission spectographic analyses (ppm)
200288	Quartz vein, up to 40 cm thick in felsic dike	1.4	0.5	
200289	Quartz vein, gray	--	<.5	
200290	Grab, scattered quartz with sparse CuO, FeO- eroded vein rubble	--	.9	Cu-300
200291	Grab, quartz with locally abundant galena- along 60 m of dump	23.1	36.0	Pb-200
200292	Granite outcrop in pit	--	1.1	
200293	Granite, altered, from dump	.5	1.0	
200294	Quartz with CuO	53.9	140.0	Cu-500
200295	Quartz with galena	6.4	55.0	Pb-300, Zn-700, Bi-100
200303	Quartz, weathered vein rubble	--	.2	Mo-150
200304	Grab, quartz from small working	3.4	1.3	
200305	Do.	2.9	4.6	
200306	do.	5.1	4.5	
200307	Do.	1.2	.9	
200308	Quartz veinlets in granite	--	<.5	
200309	Quartz, eroded vein rubble, some with K-spar	3.8	.8	Au-30 (?)
200310	Quartz, eroded vein rubble	--	<.5	
200315	Quartz, eroded vein rubble, with pyrite	--	<.5	
200316	Do.	.3	.5	
200317	do.	0.1	.5	
200318	do., with galena and pyrite	.5	3.9	Bi-10, Pb-70
200319	do.	--	.3	
200320	do	--	.4	
200321	do., with cubic pyrite	2.9	3.2	
200322	Do.	.03	.9	
200323	Quartz vein, flatly dipping to east (?)	1.7	3.0	
200324	Quartz, eroded vein rubble	--	3.0	
200325	Quartz vein, up to 10 m wide, with moderate pyrite	--	<.5	
200326	Do.	--	4.3	
200327	Do.	--	2.7	
200335	Quartz vein with pyrite and galena	27.9	52.0	

Table 3.--Array of correlation coefficients for elements determined in dump samples from the Al Habla area

[Letters in parentheses are as defined in table 1]

	Cu (AAP)	Pb (AAP)	Zn (AAP)	Co (AAP)	Ni (AAP)	Au (AAT)	Ag (AAT)	As (CM)	Sb (CM)	Mo (CM)
Cu (AAP)	1.0000	0.1907	0.1805	-0.0102	0.2234	0.1538	-0.0019	0.0348	0.2756	0.0860
Pb (AAP)	0.1907	1.0000	.6505	.2615	.0868	.1799	.3079	.0475	.1572	.2221
Zn (AAP)	.1805	.6505	1.0000	.1794	.1012	.2265	.4842	.1070	.1836	.1788
Co (AAP)	-.0102	.2615	.1794	1.0000	.2343	-.0799	.0022	.2170	.0515	.0412
Ni (AAP)	.2234	.0868	.1012	.2343	1.0000	-.0927	-.1202	.1945	-.0012	.0733
Au (AAT)	.1538	.1799	.2265	-.0799	-.0927	1.0000	.3398	-.0236	.2200	-.0008
Ag (AAT)	-.0019	.3079	.4842	.0022	-.1202	.3398	1.0000	-.0816	.2011	.1437
As (CM)	.0348	.0475	.1070	.2170	.1945	-.0236	-.0816	1.0000	.1080	-.0627
Sb (CM)	.2756	.1572	.1836	.0515	-.0012	.2200	.2011	.1080	1.0000	-.0810
Mo (CM)	.0860	.2221	.1788	.0412	.0733	-.0008	.1437	-.0627	-.0810	1.0000
W (CM)	.0909	-.0614	-.0416	-.0151	.0372	-.0167	-.0590	-.0650	.0323	-.0194