GEOLOGIC STATUS REPORT, APRIL 1965, MAHAD ADH DHAHAB AREA, SAUDI ARABIA

By

Paul K. Theobald, Jr.

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Introduction

About 1/2 square kilometer at the west end of Jabal Mahad adh Dhahab has been mapped geologically and sampled at a scale of 1:1000. The data have been compiled on the base map prepared by Gene Harbert. The samples taken at the surface have been prepared and analysed spectrographically by C. E. Thompson, U. S. Geological Survey. Drill core has been logged and sampled to an in-hole depth of 215 feet. All the core has been prepared and analysed spectrographically. The following constitutes a preliminary summary of the data available at this stage of the operation.

Geology

Rock units

A sequence of sedimentary and volcanic rocks underlie the greatest part of the area mapped. These are subdivided for mapping into a lower conglomerate; a middle sequence of sandstone, shale, and tuff; an agglomerate and tuff sequence; and an upper sequence of tuffaceous sandstone.

The lower conglomerate is present in only two small outcrops in the area of detailed mapping. Both are confined between faults and are presumed to have come from the upper part of the unit as they are pebble conglomerates. One of the outcrops, 110 meters N.80 W. of the collar of the drill hole is within the main NNW-trending fault zone that is the target for the drill hole. The other outcrop, at the extreme south limit of the mapping, lies between a NNW-trending fault and a

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NW-trending fault in the acute angle of intersection of these structures, suggesting that it also is physically separated from other rocks of the unit. The conglomerate generally consists of well rounded pebbles and cobbles in a poorly sorted matrix of finer rubble. Most of the debris was apparently derived from the complex of andesitic rocks that lies unconformably beneath the conglomerate 300 meters to the south of the area mapped in detail. There is a general decrease in grain size of the conglomerate from the base upward; boulders are common at the base and pebbles predominate at the top. Bedding units are thick and crude, and are best recognized where sandstone laminae interrupt the coarser sequence. Sandstone, shale, and tuff laminae are more abundant in the upper part of the conglomerate sequence, and the upper contact is gradational by interlamination.

The middle sequence is predominantly sandstone in semi-syclic alterations from coarser to finer grained. The general system throughout the unit is toward finer sediments at the top. Whereas granule sands are common at the base, interlaminated with medium to fine-grained sandstone, shales interlaminated with siltstones and fine-grained sandstones are common at the top. Most of the finer-grained laminae appear to have been tuffaceous and locally layers exhibit flow banding and streaking characteristic of ash flows. Locally a new cycle of sedimentation is marked by a sedimentary breccia in which angular fragments of the immediately underlying laminae are reworked into a matrix of medium to coarse sand. These are particularly striking in the drill core. The most conspicuous characteristic of the unit in outcrop is its prominent lamination. The lower contact is gradational with the conglomerate sequence by interlamination. The upper contact where exposed in the west bank of the drainage channel 100 meters N.35E. of the collar of the drill hole is sharp and apparently conformable. The thickness of the sequence cannot be precisely determined in the area studied in detail; however, judging by exposures to the west and southwest of the collar of the drill hole, it is at least 100 meters.

The agglomerate and tuff sequence is generally massive, without visible signs of bedding. It is poorly sorted, consisting of sub-round to angular, pebble to cobble sized fragments of volcanic rocks, or the underlying sediments, enclosed in a dissoriented mass of clayey material presumed to have been in large part tuff.

Lapilli are fairly common and occasional large ellipsoidal masses are presumed to have been bombs. Felsitic debris predominates but andesitic fragments are common. In the prominent hill in the west-central part of the area studied in detail, the agglomerate gives way upward to a massive tuff. The contact of the two units is gradational over a fairly short distance, less than a meter, by dissappearance of the coarse fraction of the agglomerate; the tuff being essentially the same as the matrix to the agglomerate. At the east base of the hill, where the drill hole should terminate, the tuff-agglomerate contact is sharp and marked by well bedded, variegated, tuffaceous sediments. Pumice fragments as large as 10 cm diameter are locally abundant near the middle of the tuff, and in this part of the section a crude bedding can be distinguished. An agglomerate layer is interbedded with the tuffs in the upper part of the section. Thickness of this agglomerate is erratic, and its continuity to the west edge of the exposure is questionable. Above this agglomerate the tuffs are better stratified.

The lower contact between the agglomerate-tuff sequence is occupied by a flow of probable rhyolitic composition. The flow is light gray in color and has a pitted weathered surface from the selective erosion of altered clots of mafic minerals. The groundmass is aphanitic. The flow is massive with a suggestion of columnar jointing near the top. It is apparently conformable with both the underlying sediments and the overlying agglomerate, and occupies the contact intermittently for a distance of at least 100 meters.

The location and nature of the upper contact of the agglomerate and tuff sequence is dependent upon the nature of correlation among the three isolated exposures that are assigned to this sequence. At the northwest corner of the hill on the west side of the area mapped in detail, the pumice-rich, crudely bedded tuffs give way abruptly to thin-bedded, commonly ripple marked, fine-grained, tuffaceous sandstones. Though abrupt, this contact in apparently conformable. A thin bed of agglomerate lies above these sandstones at the edge of the outcrop. The agglomerate at the north edge of the detailed map is overlain in turn by up to one meter of thin-bedded, tuff, a bed of mildly contorted red chert, and thin-bedded, fine-grained sandstones. The agglomerate at the east edge of the detailed map is overlain, apparently conformably, by thin-bedded, tuffaceous sandstones about 50 meters north of the mapping.

The upper sequence of tuffaceous sandstone is represented by the small outcrops, described above, along the upper contact of the agglomerate. Further description of the sequence is hampered by the absence of detailed information to the west and the absence of outcrops beneath the broad pediment and valley to the north.

Four tectonically controlled rock units have been distinguished in the area of detailed mapping: 1) quartz-sealed breccia zones with accompanying silicification of the sedimentary rocks, 2) through-going quartz veins, 3) andesite dikes, and 4) open fault zones.

The quartz sealed breccias and through-going quartz veins were not separated in mapping as their distribution is quite similar. In general the breccias consist of angular fragments of the local sedimentary rock set in a matrix of clear to somewhat milky quartz. The size of individual breccia fragments varies from about 5 cm. on a side upward. The smaller fragments are generally misoriented whereas larger blocks commonly retain a structural orientation parallel to that in the surrounding sediments. The predominate trend of quartz veinlets in the breccia is northerly though the zones of breccia may have ENE or NW trends. The interlacing nature of the quartz veinlets filling the voids among the breccia fragments prohibits more than a generalized statement of trends. The boundaries of the breccia zones are likewise generalized. As the size of the breccia fragments increases, the width of the quartz veinlets separating the fragments decreases. This combination of changes leads to a fairly sharp break between material mapped as breccia, where the fragments are a few meters across or less and quartz constitutes about 10 percent or more of the rock, and material mapped as the original sediment, where quartz veinlets are sparse and thin.

The through-going quartz veins are milky or white, translucent to opaque quartz with fairly well defined borders. They commonly exhibit comb structure. The veins trend within 20 degrees of north and may persist for more than a kilometer. They vary in width from a centimeter or less to more than 10 meters. Variation in width along the strike of a vein is gradual.

Wherever distinguishable and seen together, the through-going quartz veins are younger than the quartz of the breccia zones. Spatially, however, there is almost complete overlap of the two units. The breccia occurs where the veins are most numerous and fills in between veins. Secondary copper minerals, mostly malachite, occur locally along the borders of the quartz veins or in or on the borders of the quartz breccia zones. Most of the copper concentrations are in shallow, old prospect pits. These are most common on a NW-trending allignment 140 meters NE of the collar of the drill hole. Copper minerals are also common along a NNW-trending quartz vein 80 meters SW of the collar of the drill hole.

One andesite dike, 200 meters N 25 E of the collar of the drill hole, was found in the area of detailed mapping. It is a green, aphanitic rock, younger than the through-going quartz veins. Its trend is northward, as is the trend of a similar dike in the drainage just to the southeast of the detailed mapping. Another dike of this type, exposed in the north-facing slope of Jabal Mahd adh Dahab just to the west of the mine, trends ENE.

Open fault zones are most common in the western part of the area studied in detail. These are composed of gouge and mylonitized chips of the sedimentary rocks or vein quartz. Some of these are the same age or older than the quartz-breccia zones as they pass along strike from open faults to quartz-sealed breccia. Others are younger than the quartz breccia as they truncate breccia zones and include chips of the quartz. They trend generally north or northwest in the western part of the area. In the northeast corner of the detailed map an open fault zone trends ENE within and parallel to the trend of a quartz breccia zone.

A variety of surficial deposits covers about two thirds of the area. These have been lumped for mapping into a single Quaternary cover unit. Currently active alluvium is pretty well confined to the main stream channels and attain mappable width only along the west edge of the mapped area. The alluvium is flanked by a fairly thin pediment gravel in the west half of the area studied in detail and by more steeply sloping cones of talus in the east half of the area. The talus cones generally merge with the pediment gravels and both have been dissected by the existent drainage. The coarse debris, ranging from well rounded pebbles and coarse sand along the western margin to huge angular blocks in the eastern part of the area, is locally derived. Evidence from geochemical orientation studies indicates that finer debris, particularly in the 100 to 200 mesh range, is of foreign origin, presumably transported into the area by aeolian processes.

Bedding in the sedimentary rocks dips northward, generally from 40 to 60 degrees. The dip is somewhat steeper in the east than in the west. The strike varies from WNW in the east to ENE in the west, defining a broad north-plunging anticline. The axis of this anticline is roughly the trace of the wide fault zone passing 50 meters to the west of the collar of the drill hole. Flexure of the rocks involved in the folding is not uniform and locally, notably to the west and southwest of the collar of the drill hole, the fold is tighter than in other areas.

Faults, usually seen as quartz veins, predominately trend northward. Their plane is approximately parallel to the axial plane of the folding, suggesting a genetic relationship. The nature of the movement on the faults is unknown but displacement indicates, with few exceptions, downward or southward movement of the western block with respect to the eastern block.

Stress was also released along more widely spaced ENE - and NW - trending faults. These are both older and younger than the north-trending faults and commonly exhibit reversed apparent displacement relative to the north-trending faults. On a regional scale, geochemical evidence from stream sediment sampling suggests that the ENE-trending faults provided the principal conduits for mineralizing solutions. The principal zones of visible metal mineralization, malachite at the surface, lie along the NW-trending faults in the area of detailed mapping.

The pattern of folding and faulting can be related to a single stress field, a model producing the simplest explanation. This model invisages simple E-W compression in a plane now canted about 50 degrees to the south. The major introduction of quartz is along the N-S tensional openings, while the metal mineralization is along the shear direction.

Surface geochemical exploration

A series of eight lines were laid out to cross the areas of outcrop in the vicinity of the drill hole and in the eastern part of the area where a second drill hole has been contemplated. Chip samples of bedrock were taken along these lines at 10-meter intervals and at intermediate sites of unusual lithology. A total of 93 samples were collected. These were crushed to one-eighth inch, split, and pulverized for semi-quantitative spectrographic and chemical analysis.

The samples were scanned for 27 elements in the spectrographic analyses. A series of histograms giving the number of samples falling in each of the concentration ranges for each of the elements is adequate to group the elements sought into 5 categories as follows:

1) Elements not detected. Minimum detectable concentration given in ppm (parts per million).

   Be 2, Bi 20, Cd 50, La 20, Nb 50, Sb 200, Sn 10, W 50, Ge 20.

2) Elements exhibiting no measurable variation. Median concentration given in ppm.

   B 20, Ga 10, V 50

3) Elements exhibiting a small, possibly significant, variation. Range given in ppm; the symbol < means "less than".

   Ag < 1 to 3, Cr < 10 to 100, Sc < 10 to 20, Sr 50 to 300

4) Element exhibiting small but significant variation. Range given in ppm.

   Co < 5 to 30, Mn 70 to 1000, Ni < 5 to 20, Ti 300 to 7000, Y < 10 to 50, Zr 20 to 150.

5) Elements exhibiting a large variation. Range given in ppm. The symbol > means "greater than"; 10,000 ppm is 1 percent.

   Ba 70 to 10,000, Cu 10 to > 10,000, Mo < 2 to 150, Pb 10 to 5000, Zn < 100 to 7000.

This subdivision is based on two characteristics of the histograms; the range and the kurtosis. For the elements listed in category 2 the range is small, the majority of the analyses fall at the median (75 percent for V, 90 percent B and Ga), and the remaining analyses are symetrically distributed about the median. From the distribution of the analyses for these three elements it may be seen that the precision of these analyses is somewhat better than is normally attributed to semiquantitative spectrographic techniques.

The range of values for V is the same as or greater than the range of values for Ag, Co, Cr, Ni, and Sc; excluding one erratic sample rich in Co, Cr, Ni, and Sc. These elements were distributed among categories 3 and 4 because the values obtained are more evenly spread through the range. In category 3, 60 to 65 percent of the values fall at the median for Ag, Cr, and Sc. In category 4; about 40 percent of the values for Co and Ni fall at the median. Though its range is somewhat greater than that for the elements just discussed, Sr is placed in group 3 because more than 70 percent of the values fall in the median.

Not only is the range of values generally greater and the spread of values through the range more even for the elements placed in group 4, but there is a marked tendency for the distributions of values for these elements to be bimodal. This suggests that two populations, each with a distinct metal concentration, have been sampled. No attempt has been made yet to distinguish these populations or interpret them.

The elements in group 5 exhibit a large variation and are the elements commonly associated with hydrothermal deposits. The range is two orders of magnitude or greater, far more than can be attributed to the natural variation of the sedimentary rock types that were sampled. The possible exception is barium, and even its variation is unusually great. Background for these elements, the amount expected in the sedimentary and volcanic rocks sampled, should be as follows (the maximum expected is given in ppm):

Ba 2000, Cu 70, Mo 2, Pb 20, Zn 100.

Median values for these samples are (in ppm):

Ba 1000, Cu 150, Mo 7, Pb 50, Zn 200

With the exception of Ba, the median values are about twice the maximum expectable background.

Profiles of the individual sample lines have been prepared for these five elements. Unfortunately, strikingly anomalous values are absent from only one of the lines, line 7 traversing the agglomerate - tuff sequence on the west side of the area. The seven samples along this line exhibit the following range of values:

Ba 500 to 1500, Cu 10 to 50, Mo $<$2 to 5, Pb 10 to 30, Zn$<$100. The maximum values for Mo and Pb are somewhat above expected background, and these highs coincide and lie at the east end of the line, near the postulated northward extension of the major fault following the anticlinal axis. This line of samples provides the best estimate of the local background. That this background is not confined to the tuff-agglomerate sequence is confirmed by a few adjacent samples on line 8 that have similar metal content though taken from the sandstone sequence. Virtually all other samples are anomalous for one of the metals.

To develop the pattern of distribution of most anomalous samples a second threshold value was taken about an order of magnitude above background, as follows:

Cu 700, Mo 70, Pb 500, Zn 2000.

Barium is excluded since its variation lies within the order of magnitude above and below background. Plotting the location of metal values exceeding this upper threshold on the geologic base, two metal rich zones are evident. The larger and richer is a series of highs along lines 4, 5, and 6 in the northeast part of the area, centered on the group of malachite displays noted before. These anomalies, numbering at least 6, two on each line, are predominately copper. Three are bolstered by lead anomalies, and one of these is further bolstered by a molybdenum anomaly. The second anomaly on line 6 is bolstered by a zinc anomaly. The richest anomaly of the area is on line 4 where the maximum for copper, lead, and molybdenum overlap; copper exceeds 1 percent and lead is about 0.5 percent. All of these anomalies lie in or adjacent to the quartz-sealed breccia zones with the richest of the anomalies straddling one of the zones; the molybdenum maximum on one side and the copper-lead maximum on the other side of the zone of quartz-sealed breccia.

The second group of anomalies are on lines 1, 2, and 8. They are lead anomalies coinciding with the major north-trending fault zone in the middle of the area and subsidiary quartz veins and quartz-sealed breccia on both sides of this fault. One of these anomalies, at the west end of line 8, is on an ENE-trending fault.

Barium distribution is less easily interpreted. In general, the copper-rich anomalies are associated with abnormally low barium while the lead anomalies are asociated with abnormally high barium. A series of barium lows and a high occur on line 3, where prominent concentrations of the other metals are absent.

Diamond Drill Hole I

A diamond drill hole was spotted on a basis of geologic and geochemical information from 1:10,000 and 1:50,000 scale geologic mapping and a geochemical wadi sediment study. It was spotted to intersect one of the most prominent and persistant north-trending fault and vein systems near its intersection with a postulated east-northeast-trending structure thought to be one of the principle zones of mineralization. The detailed mapping and sampling just described establishes the presence of both structures, and that both are, where sampled on lines 1 and 8, rich in lead. It is possible from the detailed geologic mapping to guess at the location of the postulated intersection. Presuming a straight drill hole, the drill should pass through the acute, southern angle of the intersection, traversing both structures. The drill should enter the north-trending structure at about 300 feet and pass out of the east-northeast-trending structure at about 400 feet. The end of the hole should be in the agglomerate and tuff sequence near its contact with the underlying sedimentary sequence.

The drill core to date has been from the middle sequence of sandstone, shale and tuff. To depth of 190 feet the rocks are oxidized, in the supergene zone, and yellow or brown colors predominate. Below 190 feet blue-gray patches of unoxidized rock appear and become more frequent with depth. Pyrite appears to have been ubiquitous and serves as an indicator of the oxidation state. In the upper part of the hole soft hematite psuedomorphs or casts of pyrite are common. With depth these give way to hard hematite psuedomorphs which, in the less porous and less fractured rocks, may preserve relict pyrite in the cores of grains. By the depth of the color transition pyrite crystals are fairly common and below this depth hematite psuedomorphs are confined to porous, coarse-grained sedimentary rocks or shattered rocks.

Few sulfides other than pyrite have been seen in the core. Grains of a light colored, nearly white, pyrite-type mineral are locally preserved in tight quartz veins near 90 and 155 ft. This mineral is tentatively identified as arsenopyrite. In a similar habitat a black mineral of fairly high luster, with a prominent platy cleavage may be sphalerite. This latter mineral is commonly associated with a pale green secondary mineral resembling smithsonite. Sphalerite (?) is most common in the interval 100 to 120 feet, but has been recognized occasionally throughout the core. Chalcopyrite, with malachite, occurs locally as fine grains in the interval from 150 to 210 feet. A single, soft, flaky aggregate at 215 feet is tentatively identified as molybdenite.

Quartz veins and quartz breccia zones are common throughout the core, particularly in the interval from 100 to 170 feet. These are commonly vuggy in the supergene zone, and the cavities commonly have a rhombic shape. Separate, open veins are locally common, again with suggestions of removal of rhombic minerals. At somewhat greater depth, approaching the transition from supergene to hypergene, carbonate relicts appear in these vugs and at still greater depth the vugs are filled and carbonate veins are preserved. The carbonate is a dirty, dark-brown, coarse-grained aggregate suggestive of siderite or another of the ankerite clan of minerals.

Geochemistry of the core

The core has been sampled continuously, about a one-half split being retained for reference and the remainder prepared for analysis. The sample interval is controlled by the sampling interval of the drillers, which provides the only

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The U. S. Geological Survey is releasing in open files the following reports. Copies are available for consultation in the Geological Survey library, 1033 GSA Bldg., Washington, D. C.:

1. Geologic status report, April 1965, Mahad Adh Dhahab area, Saudi Arabia, by Paul K. Theobald, Jr. 13 p.

2. Log of diamond drill core, Hole Number 1, Lahuf mine, Saudi Arabia, by P. K. Theobald, Jr., C. E. Thompson, and Louis Geonzalez. 22 p., 3 figs., 1 table.

3. Geology and mineral resources of Libya, a reconnaissance, by Gus H. Goudarzi. 377 p., 78 figs., 10 tables.

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The following reports are available for consultation in the Geological Survey libraries, 1033 GSA Bldg., Washington, D. C., 20242; Bldg. 25, Federal Center, Denver, Colo. 80225; 345 Middlefield Rd., Menlo Park, Calif. 94025; and 601 E. Cedar Ave., Flagstaff, Ariz. 86001:

4. Investigation of in situ physical properties of surface and subsurface site materials by engineering geophysical techniques--Quarterly Report, Oct. 1, 1965-Dec. 31, 1965, edited by Joel S. Watkins. 97 p., 2 pl., 25 figs., 13 tables.

5. Investigation of in situ physical properties of surface and subsurface site materials by engineering geophysical techniques--Annual Report, fiscal year 1965, edited by Joel S. Watkins. 151 p., 48 figs., 8 tables.

6. Development of computer programs for analysis of lunar geophysical survey data, by Robert D. Regan and Janet L. Herskovits. 24 p.

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precise measure of the position within the hole. Subsidiary breaks within their interval, only rarely across it, are made at prominent lithologic breaks. A total of 67 samples have been analyzed from the first 215 feet of drilling. The largest interval represented by a single sample is 10 feet, 180 to 190 feet, at the change from AX to EX core, where recovery was very poor. The average interval is less than 5 feet.

As in the surface samples, almost all samples of core have anomalous amounts of at least one of the elements. The exceptions to this generalization are the samples where quartz vein material constitutes the greatest part of the sample. This is particularly true of the veins of milky, translucent to opaque quartz similar to the through-going veins on the surface. Although six of these have been sampled separately, only two, with 300 and 200 ppm Cu, are anomalous. The quartz-sealed breccias, 12 of which have been sampled separately, usually have anomalous amounts of one of the metals. In two samples the breccias are barren, and in one sample they are strikingly anomalous, with 2000 ppm of copper. Three adjacent sample intervals at 200 feet, aggregate thickness 5 feet, are barren and the first sample interval 5 feet, is barren, constituting the only barren zones in the intervals predominated by sedimentary rocks. Thus, of the 67 intervals sampled, only 10 do not have anomalous metal and 6 of these are intervals of vein quartz or quartz breccia.

Marked separation of the metals is apparent. The Cu and Zn anomalies have so far been the richest, contrary to surface indications. Zinc is most abundant in the first 150 feet of core where the average metal content is about 1000 ppm. Copper is most abundant between 160 and 200 feet where the average is about 1000 ppm. Molybdenum is present in anomalous amounts in about half of the samples. The magnitude of the anomalies is however, unimpressive; the maximum is 30 ppm in the vicinity of 30-40 feet and 200 feet. Lead values are anomalous in only two sample intervals near 40 feet; the maximum is 500 ppm.