UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF AREAS MARKED BY GEOPHYSICAL ANOMALIES (B-35 AND B-34), WADI BIDAH DISTRICT, KINGDOM OF SAUDI ARABIA

by

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U.S. Geological Survey
Open-File Report 82-668

U.S. Geological Survey
Jiddah, Saudi Arabia
1982

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ABSTRACT

Geophysical surveys in the Wadi Bidah district, in the southwestern part of the Kingdom of Saudi Arabia, have revealed anomalies of the type that may be caused by deposits of massive sulfides. Accordingly, a study was undertaken to investigate the geologic environment associated with the geophysical anomalies and to determine whether mineral exploration of the anomalous areas might be warranted. An extensive geochemical sampling program did not disclose any evidence of ore mineral concentrations in the rocks. Detailed geologic mapping shows the anomalous areas to be underlain by Precambrian carbonaceous graywacke, the outcrop patterns of which closely fit the anomaly patterns. Field evidence and petrologic studies indicate that carbonaceous material in the rocks is the cause of the geophysical anomalies.

Nothing was found in the anomalous areas that suggests the presence of mineral deposits of commercial grade, and further mineral investigations or exploration in the areas is not recommended.

INTRODUCTION

Purpose

The purpose of this geologic study is to investigate causes of geophysical anomalies detected in the southeastern part of the Wadi Bidah district, at sites referred to as the B-35 and the B-34 areas. This project is part of an ongoing mineral deposit investigation program by the U.S. Geological Survey, in accordance with its work agreement with the Saudi Arabian Ministry of Petroleum and Mineral Resources.

Location and accessibility

The Wadi Bidah district is in the southwestern part of the Kingdom of Saudi Arabia, between lat 20°00' and 20°46' N. and long 41°18' and 41°30' E. The B-35 and the B-34 areas are in the southeastern part of the Wadi Bidah district; the southern end of the B-35 base line is near the intersection of lat 20°11' N. and long 41°25' E. The B-35 area, which is the larger and more extensively studied of the two areas, covers about 9 km^2; the smaller B-34 area is about 2 km north of the B-35 area (fig. 1).

The B-35 area is 405 km southeast of Jiddah by road. It is accessible by surfaced highway from Jiddah to At Taif and from there south on the surfaced highway leading to Abha. About 195 km south of At Taif, 15 km north of the town of Al Bahah, on the divide at the head of Wadi Bidah, an unimproved road from the surfaced highway goes north 12 km to the B-35 area. This road continues north through the B-34 area, eventually reaching Al Aqiq.

The middle of the B-35 area extends more or less along the crest of the ridge that forms the eastern side of Wadi Bidah. Topography of the area is marked by pronounced relief. The average altitude along the base line in the B-35 area is about 2,040 m (as measured by aneroid barometer), whereas the altitude of the western boundary of the area, near the bottom of Wadi Bidah, is about 1,690 m. Several small, steep-gradient wadis drain east from the Wadi Bidah ridge into Wadi Haqeeth, a steep-walled wadi that drains northeast toward Al Aqiq.

Previous investigations

An airborne electromagnetic survey of parts of the Precambrian shield of western Saudi Arabia by Geoterrex Ltd. (written commun., 1977) revealed a number of electromagnetic anomalies in the Wadi Bidah district, two of which were identified as the B-35 and B-34 anomalies. The B-35 anomaly is the larger and more intensive of the two. As the airborne B-35 anomaly is comparable to anomalies reported over deposits of massive sulfides, it was decided to follow the airborne work by ground geophysical studies. Accordingly, a contract was let to the Arabian Geophysical and Surveying Company, Ltd. (ARGAS) to lay out north-south base lines and east-west traverse lines in the B-35 area and to make slingram electromagnetic (EM) and self-potential (SP) measurements. The ground studies revealed geophysical anomalies that agree generally with the airborne electromagnetic anomaly. Because of these findings a geochemical sampling program was carried out to see if the geophysically anomalous rocks contain concentrations of commercial metals. Five hundred chip samples of rocks were taken along the geophysical traverse lines. Prior to the geophysical surveys, the geology of the region, including the B-35 and B-34 areas, had been mapped at a scale of 1:100,000 by Greenwood (1975).

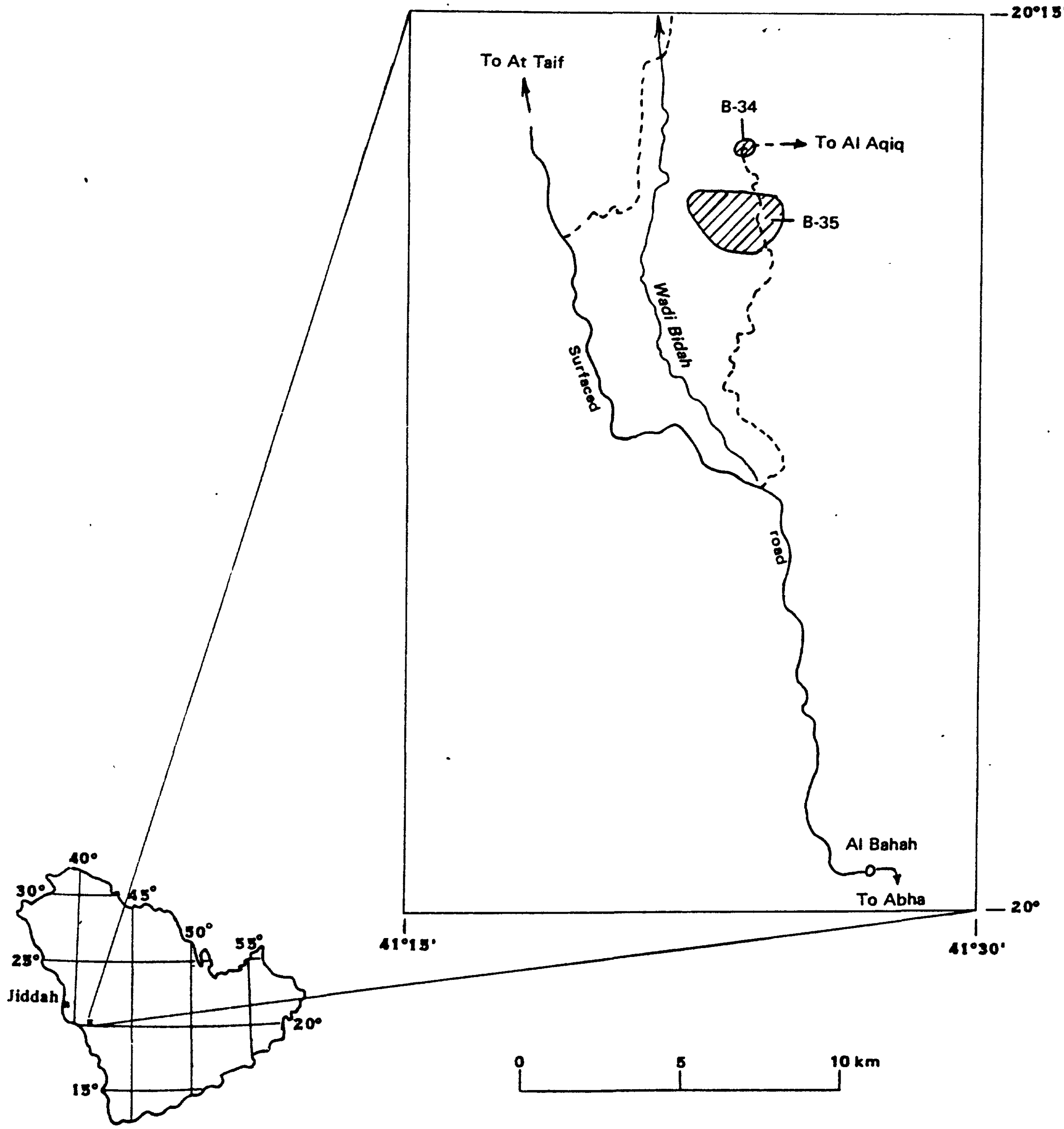


Figure 1.–Index map showing location of the B-35 and B-34 areas, Wadi Bidah district.

Present investigation

The present geologic study was undertaken to determine if the geophysical anomalies in the B-35 and B-34 areas might be associated with deposits of sulfide minerals.

Fieldwork in the areas was done from January 29 to March 4, 1980, and consisted largely of detailed geologic mapping and the collection of additional geochemical samples from the anomalous areas and from other localities that appeared suitable for mineral deposition. Most of the mapping was confined to the larger and more anomalous B-35 area. The B-34 area was mapped separately; however, as similar rock units crop out in both areas, the rocks and other geologic features of the two areas are described together. Excellent enlarged aerial photography at a scale of approximately 1:10,000 was available for the study, but geologic mapping of the B-35 area was done on a planimetric base, using surveyed points on base and traverse lines for location purposes. Measurements from the known points were made by use of a Lietz SD3D rangefinder, but other locations were established by Brunton compass resection.

The author was ably assisted in the field by Asa Wais and Ali Mohamoud Ali. Mr. Resaik Muradi served as camp boss and kept the field camp in excellent operating condition. Geochemical samples collected by the author, as well as the 500 samples collected previously, were analyzed at the Directorate General of Mineral Resources (DGMR)-U.S. Geological Survey (USGS) geochemical laboratory in Jiddah, under the direction of K. J. Curry, USGS. Appreciation is extended to D. J. Faulkender and F. J. Fuller for the additional traverse lines they surveyed in the B-35 area.

GEOLOGY

Geologic setting

The Wadi Bidah district lies along a north-trending belt of folded volcaniclastic and sedimentary rocks of Precambrian age. These rocks have been metamorphosed to the greenschist facies and intruded by igneous rocks of Precambrian age that range from gabbro to quartz monzonite in composition. Plutons of diorite and quartz diorite crop out south of the B-35 area, but in the area itself the only intrusive rocks are dikes, ranging from diorite to rhyolite in composition. Brown and others (1962) classified the layered metamorphic rocks as sericite and chlorite schist. On his 1:100,000-scale map of the Jabal Ibrahim quadrangle, which includes the B-35 and B-34 areas, Greenwood (1975) divided the schistose rocks into the Baish and the Bahah groups. He identified the older Baish group as predominantly basaltic pyroclastic rocks and volcanic and sedimentary breccias. In contrast, he noted that the Bahah group is characterized by graywacke, arkosic graywacke, chert, and marble. His map shows a triangular-shaped block of Bahah group rocks extending through the southwestern part of the B-35 area. This block is bounded on the western side by a north-trending regional fault, a member of a regional set of shears Greenwood referred to as the Wadi Bidah fault zone. Greenwood and others (1975, p. 519) noted that rocks of the Baish and Bahah groups were folded into tight north-trending folds, accompanied by development of axial-plane schistosity, during the Aqiq orogeny, an orogenic event associated with the Hijaz tectonic cycle of Precambrian age.

Baish group

All layered and sedimentary rocks in the B-35 and B-34 areas are considered as members of the Baish group (figs. 2, 3). Mappable units include metabasalt, cherty metatuff, metasedimentary rocks (chiefly graywacke), carbonaceous graywacke, chloritic tuff, and undifferentiated metabasalt and volcaniclastic rocks. All of the rocks have been regionally metamorphosed to the greenschist facies. Other volcaniclastic rock types are readily recognized in the B-35 area but were not differentiated in the present study because of time constraints and the lack of a suitable base map. The metasedimentary rocks mapped previously as units of the Bahah group (Greenwood, 1975) are interlayered with basaltic rocks and interbedded with water-sorted tuffaceous rocks and therefore are considered by the author as members of the Baish rather than the Bahah group.

Metabasalt

Most of the high ridge east of Wadi Haqeeth, as well as the ridge south of the B-35 area and the ridge east of the B-34 area, is underlain by massive greenstone, chiefly metamorphosed basalt. The rock is blocky and dark green, has fine crystalline texture, and exhibits a strong schistosity pattern that strikes northeast and dips steeply northwest. Interlayered in the metabasalt are thin units of bedded, water-sorted mafic tuff, some of which contain clots of dark-green chlorite that range from 0.5 to 1 cm in length and from 0.25 to 0.5 cm in width and are elongated parallel to schistosity. A few strands of carbonaceous graywacke too thin to show on the map are interbedded between layers of metabasalt.

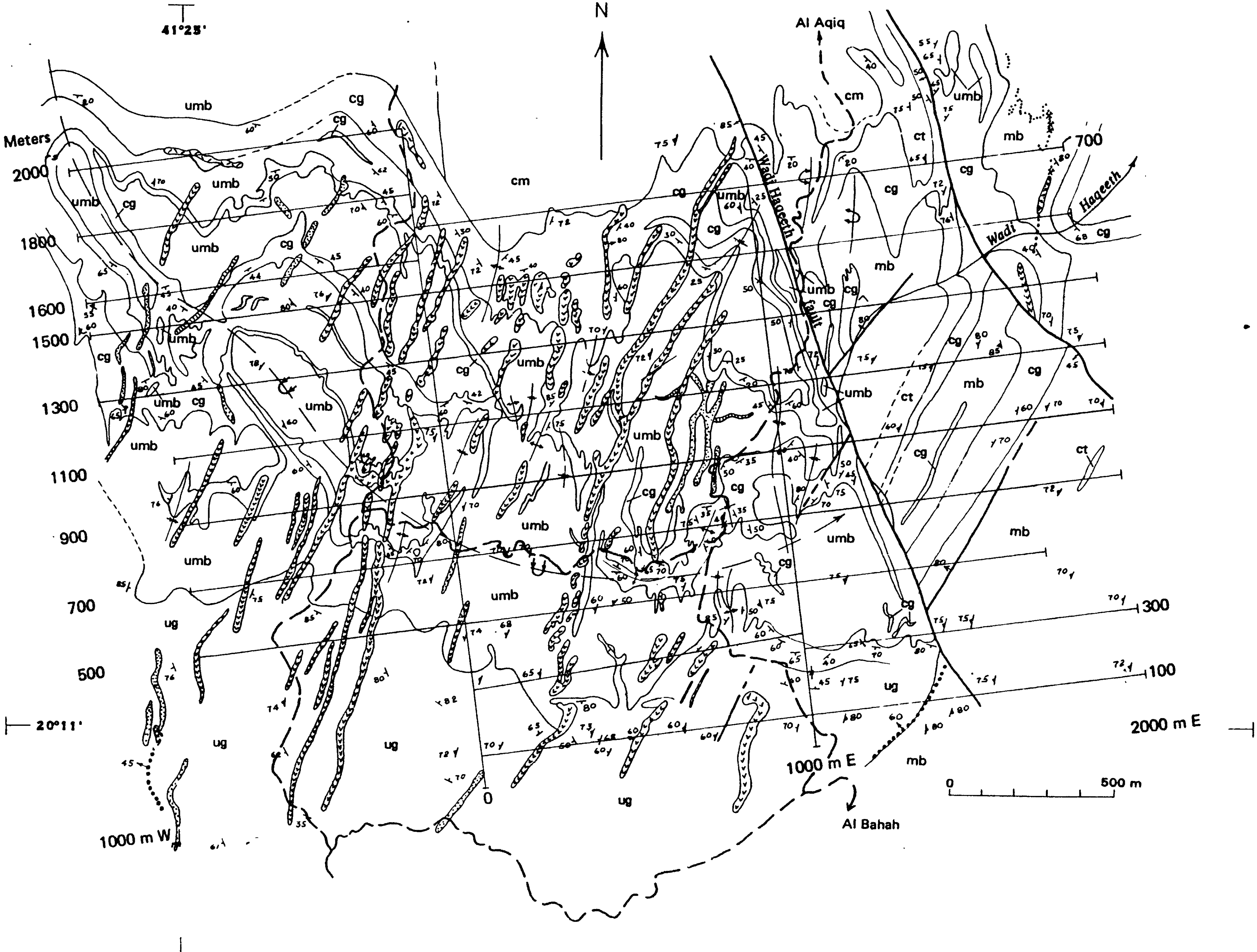


Figure 2.--Geologic map of the B-35 area.

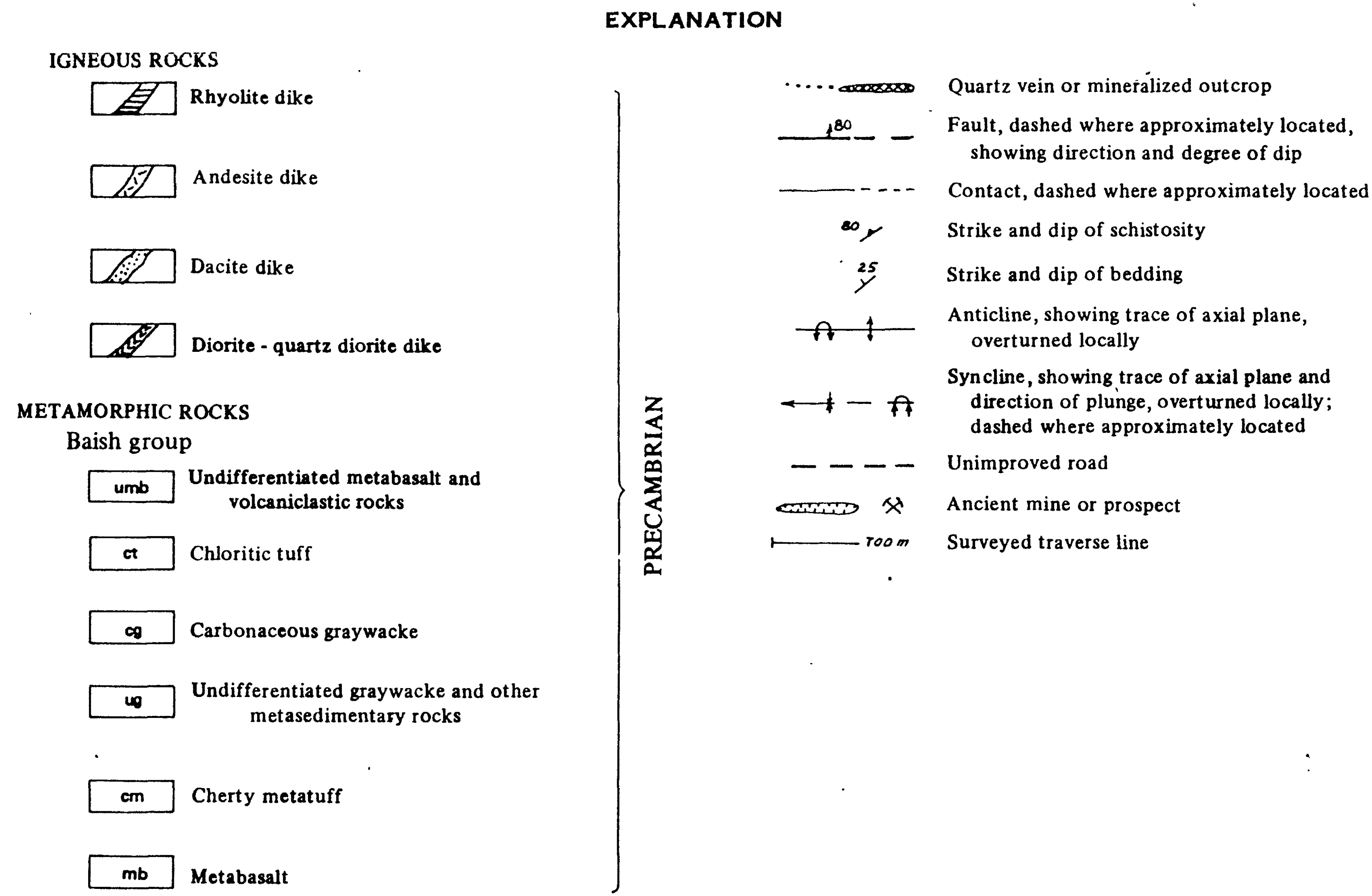


Figure 2.—Continued.

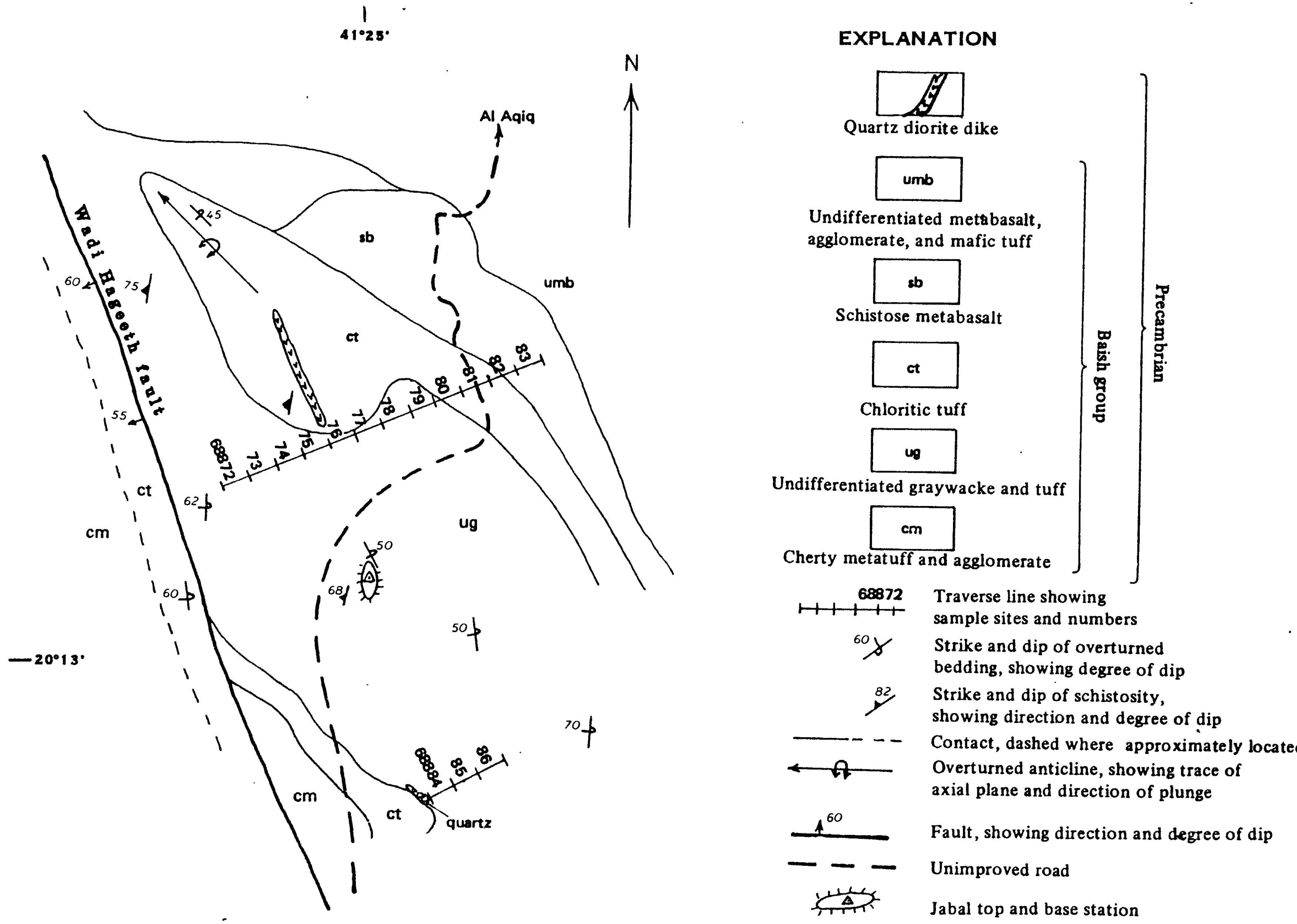


Figure 3.–Geologic map of the B-34 area.

In thin section the rock is seen to consist chiefly of chlorite that parallels and defines the schistosity. Hornblende is present in minor amounts and then only as remnants rimmed by chlorite. Plagioclase is present chiefly as phantom crystals altered largely to sericite. Plagioclase fresh enough to be identified is albite. Epidote, clinopyroxene, calcite, and very fine grained secondary quartz are present in minor amounts. Pyrite is a common accessory mineral; magnetite is an accessory mineral at some localities.

The metabasalt is mapped as the lowermost unit of the Baish group rocks because south of the B-35 area it is overlain by cherty metatuff, which in turn is overlain by graywacke, tuff, and undifferentiated volcaniclastic rocks in the northern part of the mapped area.

Cherty metatuff

Cherty metatuff crops out extensively in the northern part of the B-35 area and is conspicuous on the northern side of the east-draining wadi that is followed, more or less, by traverse line 1700 N from the zero base line to base line 1000 m E. Most of the ridge north of the B-35 area and west of the B-34 area is composed of cherty metatuff.

The rock is distinctive in texture, color, and outcrop pattern. Perhaps the most distinctive feature is flattened nodules of green chert that are elongated parallel to the schistosity. The nodules are enclosed by strands and wisps of chlorite and on steep hillsides weather out of the tuff and accumulate as rubbly debris. They range from 0.5 to 15 cm in length, although an average length is in the range of from 5 to 10 cm, and are as much as 10 cm thick. Some nodules are angular and give the rock the appearance of an agglomerate. Smaller clasts of chert, where concentrated in layers, give the rock a clotted appearance, similar to a lapilli tuff.

Along the east-draining wadi bottom, where the rock is waterworn, the green tuff has the appearance of a massive rock; only the outlines of the chert nodules are readily visible. On weathered slopes, however, the tuff and the contained chert nodules weather brownish red. On such slopes, the tuff exposures commonly have rough and somewhat hackly surfaces owing to the resistant nature of the chert. Outcrops of the cherty metatuff tend to be elongated northeast and to be interspersed along zones of lighter colored rubble; the elongated pattern is influenced, in part, by axial-plane cleavage. Zones of closely spaced cleavage planes weather more readily and, along with the elongated outcrop pattern, give the outcrop a striped and blotchy appearance that is very distinctive on aerial photographs.

The cherty metatuff dips south along the bottom of the east-flowing wadi and is overlain by a gray, spotted, dolomitic tuff that grades upward into carbonaceous graywacke and interlayered volcaniclastic rocks. South of the B-35 area, similar cherty tuff rests on older metabasalt.

Undifferentiated graywacke and metasedimentary rocks

No attempt was made to differentiate the various rock units that compose a block of metasedimentary rocks that crops out in the southern part of the B-35 area. Rocks in the block wrap around the southeastern part of the B-35 area and extend west into Wadi Bidah. South of the B-35 area the rocks rest on metabasalt; to the east they are cut off by the fault that extends along Wadi Haqeeth.

The principal rock type is graywacke, which ranges from quartz graywacke, essentially a quartzite, to carbonaceous graywacke in which carbonaceous material gives the rock a black color. Thin and locally highly contorted bedding in the rocks is distinctive of the graywacke, particularly where the strike is northwest. Along folds where the strike is northeast, bedding is obliterated in many places by pervasive northeast-striking axial-plane cleavage. Black carbonaceous graywacke is conspicuous along the northern side of the east-draining wadi, east of point 1000 m E on the 300 N traverse line, where the rock laps onto undifferentiated volcanic rocks. Other rock types in the block include interlayered water-sorted mafic tuffs and various bedded volcaniclastic rocks.

The undifferentiated metasedimentary rocks are interlayered with volcaniclastic rocks. About 1.5 km south of the southern end of the B-35 zero base line, a dip-slope exposure of the principal body of graywacke rests on metabasalt and is clear evidence that the graywacke is younger than the metabasalt.

Carbonaceous graywacke

Carbonaceous graywacke was the rock of principal interest to the investigator and was studied intensely because it was found to underlie the geophysical anomalies. It was mapped separately from the undifferentiated metasedimentary rocks in order to show its spatial relationship to the anomalies (fig. 2). Units of the intricately folded and contorted rock range from a few centimeters to more than 100 m in thickness. Thicker units may be followed from the eastern side to beyond the western side of the B-35 area. Some units appear to be thicker because of folding or topographic expression. Carbonaceous graywacke also underlies the B-34 anomaly (fig. 3), although at that locality it is included in the undifferentiated graywacke unit.

Graywacke exerts distinctive control on topography in the Wadi Bidah area. It erodes more readily than the massive volcanic rocks; thus downcutting wadis tend to follow graywacke units. Such wadis either are floored by graywacke or expose the rock in the wadi wall that is being eroded more rapidly. A typical example in the B-35 area is the northernmost graywacke unit, which, from a point about 100 m north of the northern end of the zero base line, forms the southern wall of a steep wadi that leads west into Wadi Bidah. East from the base line point, for about 1200 m, the same rock unit forms the southern wall of a large east-draining wadi that leads to Wadi Haqeeth. Even more conspicuous is the small wadi that follows a thin unit of graywacke northwest through point 350 m W on traverse line 900 N. The large wadi leading northwest from the northeastern corner of the B-35 area is floored by carbonaceous graywacke.

The rock is dark gray to black and consists of extremely fine, well-sorted mineral grains in beds rarely more than 0.5 mm thick. The bedding is wavy and often intricately contorted, particularly in the more carbonaceous units. Most contortions are the result of folding. The pliant graywacke, interlayered with thick flows of massive basalt, yielded more readily under folding stresses and consequently was distorted to a greater degree. Some of the crinkled and convoluted bedding, however, appears to be the product of subaqueous slumping of newly deposited sediments. Convoluted bedding and axial-plane cleavage cause the rock to weather into rodlike fragments as much as 20 cm long and 5 cm wide. Concentric layers of convoluted, bedded rock may be broken from the rodded fragments in many places.

At good exposures of the graywacke, where the entire thickness of a unit may be examined, faint graded bedding, fining upward, can be observed. Basal beds of the graywacke also are more quartzitic and lighter in color than rocks higher in the section, which are enriched in carbonaceous material. An example can be seen in the face of the bluff along traverse line 900 N, point 830 m E, where the quartzitic zone is commonly only a few centimeters thick; however, in thicker graywacke units, the quartzite may be several meters thick.

Locally, the carbonaceous graywacke is moderately dolomitic and weathers to a buff color. A noticeably dolomitic lense is in the eastern part of the B-35 area in the broad graywacke unit crossed by traverse line 900 N near point 1700 m E. For the most part, however, dolomite is only an accessory mineral.

On ridge tops or flat areas where the carbonaceous graywacke is deeply weathered, the rocks are coated by sericite and clay minerals and consequently are lighter in color. At such localities, weathered fragments commonly have a light-gray to buff sheen that, along with the schistose nature of the rock, makes it appear to be phyllite. Even the black carbonaceous material weathers to lighter colors and consequently is commonly difficult to recognize.

Discontinuous lenses and pods of white quartz are present locally in the graywacke. They generally crosscut the bedding and appear to be a product of metamorphism.

Carbonaceous material is widespread throughout the unit, and in both the hand specimen and thin section it appears to be graphite. Jackaman (1972, p. 24), in a study of the Wadi Bidah district, was the first to recognize that so-called graphite in Baish-like rocks is in fact carbonaceous material. Kiilsgaard and others (1978, p. 71-74) confirmed Jackaman's findings and noted that the carbonaceous material probably originated from algal deposition in marine waters. Subsequent regional metamorphism raised the host rock to the greenschist facies, a grade not high enough to convert the carbonaceous material to graphite. Concentrations of carbonaceous material commonly mark the bedding and, depending on the quantity present, determine the color of the rock. Some rocks are as as black as coal. In thin section the carbonaceous material is seen as laminae rarely more than 0.02 mm thick. Wisps of the material wrap around quartz grains but are replaced by pyrite.

Quartz is the principal mineral in the carbonaceous graywacke and in some thin sections composes 80 percent of the rock. The clastic quartz is well sorted, in thin beds, and very fine grained, commonly 0.01 mm or less in maximum dimension. In some specimens, the quartz grains range from 0.01 to 0.05 mm in maximum dimension, and rare grains may be as much as 0.10 mm in maximum dimension. Most of the quartz grains are subangular. Chlorite is abundant and tends to define the schistosity. Sericite also is abundant and may be oriented along the schistosity. Dolomite and trace amounts of zoisite also are in the rock.

Disseminated pyrite crystals as much as 1 mm wide are common in fresh exposures of the graywacke, and at a few localities, discontinuous layers of pyrite as much as 3 mm thick follow along the bedding. Pyrite casts can be seen on weathered exposures of the rock, as well as limonite that has oxidized from the pyrite. Limonite commonly is concentrated along fractures, where crusts of limonite as much as 6 mm thick were observed. It also stains the weathered rocks and, where concentrated, gives the outcrop a gossanlike appearance. Magnetite is present in minor amounts.

Veinlets of coarser textured, recrystallized quartz cut the graywacke at various angles to the bedding, but they contain no sulfide minerals.

The dark color, physical properties, and relationship with water-sorted tuff and subaqueous metabasalt make graywacke a logically descriptive term for this rock. In microscopic examination, however, it shows few of the characteristics normally associated with graywacke. The rock does not contain fragments of other types of rock, nor does it contain measurable quantities of feldspar. Grain size does not vary widely. Locally, the rock contains light- or dark-colored blebs as much as 1 cm long, which give it a somewhat spotted and porphyroblastic appearance and, in the hand sample, appear to be particles of other rocks. In thin section, however, the lighter spots are found to be aggregates of recrystallized quartz and most of the darker spots are chlorite. The size, abundance, and sorting of the quartz grains suggest that the rock could be classified as a siltstone or fine-grained quartzite. However, the angularity of the quartz grains would make it permissible to classify the rock in the wacke group. The scarcity of rock fragments and feldspars indicates that the rock might be termed a quartz graywacke, as defined by Williams and others (1954). However, as carbonaceous material is also a major component, the term carbonaceous graywacke would appear to be an acceptable classification and is so used.

The carbonaceous graywacke is the same age as the undifferentiated graywacke. It rests on and is younger than metabasalt south of the B-35 area but is interlayered with undifferentiated metabasalt and volcaniclastic rocks of the area.

Chloritic tuff

Green chloritic tuff is a conspicuous rock unit in the B-35 area, north of point 1250 m on traverse line 1700 E and as a band of rather uniform width that trends southwest, interbedded with metabasalt, in the eastern part of the area. The tuff terminates against the Wadi Haqeeth fault and was not recognized west of the fault.

The schistose tuff is strongly foliated and contorted. The basal section of the tuff contains discontinuous pods and lenses of sedimentary iron formation. Upward in the section, the rock grades into a distinctive spotted lapilli tuff, which contains concentrations of flattened lapilli ranging from 0.5 to 1.5 cm in length. Where strongly contorted, the tuff breaks into rodlike fragments that are as much as 8 cm thick and 40 cm long. The rods appear to have formed by compaction of the tuff along fold axes.

The correct position of the chloritic tuff in the stratigraphic succession of Baish group rocks is subject to question. In the eastern part of the area, the tuff rests on carbonaceous graywacke and is interlayered with metabasalt. However, in the northeastern part of the area the tuff grades upward into cherty metatuff, which farther west underlies carbonaceous graywacke. Therefore, the cherty metatuff in the northeastern section may be a different rock unit from the cherty metatuff unit west of the Wadi Haqeeth fault. The carbonaceous graywacke that underlies chloritic tuff in the eastern part of the area also probably differs in stratigraphic position from the carbonaceous graywacke that rests on cherty metatuff west of the Wadi Haqeeth fault. Because the chloritic tuff clearly overlies carbonaceous graywacke in the northeastern part of the area, it is shown as a younger rock in the stratigraphic section of the map (fig. 2).

Undifferentiated metabasalt and volcaniclastic rocks

A large part of the B-35 area is underlain by metabasalt and various volcaniclastic rocks, including both dark- and light-colored tuff, lapilli tuff, volcanic breccia, and agglomerate. Very thin beds of graywacke are interbedded with the volcaniclastic rocks. The various rock types are not shown separately on the map (fig. 2) because time constraints and the lack of a suitable base map did not permit proper presentation. The metabasaltic rocks are similar to those mapped as the metabasalt unit but are mapped as another unit because of their association with an abundance of volcaniclastic and metasedimentary rocks. Locally, as in the northeastern part of the B-34 area, the metabasalt is schistose.

Metabasalt and mafic metatuff are the principal rock types of the undifferentiated unit. The metabasalt is a massive, dark-green rock that forms bluffs and steep slopes in the western part of the B-35 area. On ridge tops and gentle slopes, the metabasalt weathers to prominent, somewhat rounded, smooth-surfaced rocks that locally are pitted by wind abrasion. Pillow structures were seen in the metabasalt at two separate localities and indicate that the flows were deposited in a subaqueous environment. The mineral assemblages of the metabasalt are similar to those of the previously described metabasalt unit. Of particular interest is magnetite, which locally makes the rock magnetic.

The metatuff is composed chiefly of chlorite. The fact that the layering of the rock is parallel to bedding of interfingered or contiguous graywacke indicates that the layering is a water-sorted feature. Thin layers of light-gray tuff indicate that more acidic volcanism also was active in the region at the time of deposition. The mountain south of traverse line 1700 N, point 950 m E, is capped by rubbly agglomerate.

The undifferentiated metabasalt is interlayered with and overlies carbonaceous graywacke; therefore, it is considered to be the youngest of the volcanic rocks mapped as units of the Baish group.

Igneous rocks

Dikes

A multitude of dikes crop out in the B-35 area; most of them trend northeast, following the northeast-trending axial-plane cleavage. The dikes range from those a few centimeters thick and too small to show on the map (fig. 2) to others 40 m thick. Some dikes have a continuous strike length of more than 1 km, whereas others are only a few meters long. When viewed from a distance, the large, northeast-trending dikes appear to be steeply dipping layers of basalt and thus give a false impression of the geology.

Most of the dikes are of diorite to quartz diorite composition. They are the largest and appear to be the oldest in the area, as they are cut by other types of dikes. A large pluton of quartz diorite crops out about 3 km south of the B-35 area, and the quartz diorite dikes possibly are apophyses from that mass. This possibility is supported by the rounded and irregular shapes of some of the dikes, exposures more typical of small stocks than dikes.

Other dikes are of dacite, andesite, and rhyolite composition. The rhyolite dikes and some of the andesite dikes are highly altered and iron stained. Fresh samples of these rocks contain small crystals of disseminated pyrite but no other sulfide minerals.

STRUCTURE

Folds

Two fold patterns are apparent in the B-35 area. The oldest pattern consists of northwest-trending folds, chief of which is a broad syncline overturned to the northeast, plunging southeast. Several smaller anticlines and synclines flank the broad syncline, making the pattern rather complex. The northwest strike of the graywacke is confirmed readily at many observation points (fig. 2), as is the southwest dip. The concept of an overturned, plunging syncline is predicated on closed fold noses to the northwest and subtle graded bedding in larger bands of carbonaceous graywacke. The axial trace of the syncline is shown only approximately on figure 2. The curvature of some bands of carbonaceous graywacke (fig. 2) is a topographic expression and not the result of folding.

The northwest-trending set of folds has been refolded into a northeast-trending pattern of small anticlines and synclines that trend more or less parallel to the conspicuous regional northeast-trending axial-plane cleavage in the area. These northeast-trending folds probably are part of the regional north-trending fold pattern described by Greenwood (1975). Traces of the axial planes of the more conspicuous of these folds are shown on figure 2, but many folds of this pattern are subtle and could be portrayed only through more detailed mapping on larger scale maps.

Faults

Two prominent sets of faults can be seen in the B-35 area: an older set of minor northeast-trending faults that are displaced along a younger set of larger northwest-trending faults. The principal fault, herein called the Wadi Haqeeth fault, accounts for the remarkably straight configuration of deeply incised Wadi Haqeeth, which trends northwest along the fault in the southeastern part of the area. The Wadi Haqeeth fault may be followed northwest through several sharply eroded defiles to, and beyond, the B-34 area (fig. 3). In the B-35 area, the Wadi Haqeeth fault displaces graywacke units to the extent that graywacke east of the fault cannot be correlated with graywacke west of the fault. Another strong northwest-trending fault is conspicuous on the ridge northwest and southeast of Wadi Haqeeth and extends southeast into Wadi Khadra. To the northwest, the fault trends along the western side of the wadi in which the B-34 area is located. The fault may merge with the Wadi Haqeeth fault near the B-34 area, or it may be in the wadi bottom of the B-34 area, in which case it was not recognized.

Schistosity (flow cleavage)

The most pronounced structural feature in the B-35 area is the northeast-striking schistosity. The schistosity, which is a form of flow cleavage, developed parallel to the direction of maximum shear stress exerted on the rock during metamorphism. All of the rocks in the area are schistose, some to the point where schistosity may be mistaken for bedding. At localities where bedding of the graywacke strikes northeast or close to northeast, the bedding may be so intensely masked by schistosity that it is difficult, if not impossible, to recognize. Dike emplacement appears to have been controlled to some extent by the flow cleavage pattern.

A minor pattern of northwest-striking fracture cleavage is present locally and is most noticeable in the massive metabasalt. The schistosity and fracture cleavage patterns intersect each other at an angle of about 45 degrees and locally form diamond-shaped fractures in the bedrock.

GEOCHEMICAL INVESTIGATIONS

Sampling and analytical procedures

Prior to 1980, members of the U.S. Geological Survey Saudi Arabian Mission collected 500 rock samples along traverse lines in the B-35 area. Each sample consisted of rock chips broken from the outcrop across a 25-m sampling interval. In 1980 an additional 99 rock samples were collected from the B-35 and B-34 areas. Sample localitites are shown on figures 2 and 3; samples collected in 1980 are in the sample-number series 68804 through 68931. Each sample consisted of about 0.5 kg of equal-sized rock chips, collected so as to be representative of the sampled interval. Because geologic mapping shows the geophysical anomalies in the B-35 and B-34 areas to be superimposed primarily on carbonaceous graywacke, most of the sampling in 1980 was confined to that rock type. The samples were not collected across a consistent interval but were oriented normal to the strike of the bedding. All of the samples were analyzed at the DGMR-USGS geochemical laboratory in Jiddah. Each sample was analyzed for 28 elements by the 6-step D.C.-arc method of semiquantitative spectrographic analysis. The samples also were analyzed for gold, silver, copper, lead, and zinc by the atomic absorption method (table 1). The semiquantitative spectrographic analyses were studied for abnormal concentrations of metal, but only the atomic absorption analyses are given in this report.

Table 1.--Metal content of Baish group rocks, dikes, and prospect samples, B-35 and B-34 areas
[Results in parts per million. --, indicates no data available]

Rock type	Number of samples	Copper		Zinc		Silver		Gold		Lead	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Metabasalt and associated volcaniclastic rocks	343	76	100	90	40	0.913 1/	0.534	0.062 2/	0.051	13 3/	6
Graywacke	210	67	54	89	48	.869 4/	.875	.170 5/	.078	26 6/	18
Dike rocks	35	52	56	94	55	1.94	5.60	.08	.04	11	6
Iron-stained rocks and old mine or prospect samples	11	85	57	38	24	.97	.57	.47	1.02	--	--

1/ Of 343 samples analyzed, 58 contain detectable silver below the determination limit (0.50 ppm). Each of these samples was assigned a value of 0.25 ppm silver for purposes of statistical analysis. One sample contained an abnormally high value of 14 ppm silver and was not included in the analysis.

2/ Of 343 samples analyzed, 77 contain detectable gold below the determination limit (0.05 ppm). Each of these samples was assigned a value of 0.025 ppm gold for purposes of statistical analysis. In addition, 33 samples contained nil gold and were assigned a value of zero. One abnormally high value of 3.89 ppm gold was not used.

3/ 53 samples.

4/ Of 210 samples analyzed, 55 contain detectable silver below the determination limit of (0.50 ppm). Each of these samples was assigned a value of 0.25 ppm silver for purposes of statistical analysis.

5/ Of 210 samples analyzed, 63 contain detectable gold below the determination limit (0.05 ppm). Each of these samples was assigned a value of 0.025 ppm gold for purposes of statistical analysis. In addition, 10 samples contained nil gold, and each of these was assigned a value of zero.

6/ 16 samples.

Evaluation of analytical results

No metal concentrations of possible economic significance were found in either the B-35 or B-34 areas. Metal content of the samples, as determined by the semiquantitative spectrographic and the atomic absorption methods, is considered normal for the rock types that were sampled. The analytical results do not show any patterns of metal concentration in the rocks, and the geologic mapping did not identify any outcrops that could be considered as gossans. No rock types or zones warrant additional or more intensive sampling.

Atomic absorption analytical determinations were analyzed statistically, according to rock type, and the results are presented in table 1. Arithmetic mean metal values for the different rock types are low, but the values for copper, zinc, and lead are comparable to the copper, zinc, and lead contents of similar rocks in the Earth's crust (Turekian and Wedepol, 1961; table 2). A comparison of tables 1 and 2

Table 2.--Distribution of the elements in the Earth's crust [Data from Turekian and Wedepohl, 1961. Values in parts per million. --, indicates no data available]

Rock type	Copper	Zinc	Silver	Gold	Lead
Basaltic rocks	87	105	0.11	0.004	6
Shales	45	95	.07	--	20
High-calcium granitic rocks	30	60	.05	.004	15

indicates that rocks of the Baish group contain more gold and silver than do similar rocks elsewhere in the Earth's crust. The differences in mean values of gold and silver in metabasalt would be even more pronounced, an increase to 1.06 ppm silver and 0.09 ppm gold, if only determinable analytical values had been used. However, samples that contained detectable but nondeterminable amounts of metal were assigned values midway between the determination limit and zero (table 1), as a means of presenting a more realistic evaluation of the metal content in the rocks.

Lead content in the sampled rocks is low, although comparable to similar rocks elsewhere. Actually, the mean values for lead (table 1) probably are not valid, as they are based on an insufficient sample population. Most of the samples contained detectable lead, though below the limit of determination (10 ppm). These samples were not considered in the statistical analysis.

Threshold values for the metals were determined as a means of searching for localities that might contain unusual amounts of metal. These values were determined by taking the arithmetic mean of the metal plus two standard deviations of the sample population (table 1), then rounding off the number to an even value. Threshold values are given in table 3, along with the samples that contain metal values equal to or greater than the threshold values. Most of the analytical values shown in table 3 are at or near the threshold values. From a statistical standpoint, these values could be considered anomalous, but none are considered significant because higher, erratic, and inconsistent metal values are common in volcanic rocks.

Figure 4 shows localities of samples in the B-35 area that contained threshold or greater metal values, and it illustrates a widespread and scattered distribution of metals. No distribution patterns are apparent, other than the indication that more anomalous samples are present in the metabasalt than in the carbonaceous graywacke. Sample 143357 contains the highest copper value (800 ppm) and was collected from an iron-stained lens of graywacke about 100 m from the eastern end of traverse line 700 N. Two samples, 68815 and 68816, subsequently were collected at that locality to check the copper content, but they contained only 45 and 95 ppm copper, respectively. Sample 143494, collected from metabasalt at point 525 m E on traverse line 500 N, contained 14 ppm silver, an abnormal amount for the sample population. The locality subsequently was examined with great care, but no evidence of mineralization or alteration was found. Sample 68901 contained 3.89 ppm gold and was collected near the 1000 m E base line, about 250 m from the southern end and near the road that leads to Al Aqiq. No evidence of mineral concentration was seen at that locality, and the sample is considered to be erratic. There is a slight concentration of higher silver values near the eastern ends of traverses 700 and 1100 N, chiefly in the metabasalt, but the values are at or near threshold limits and probably reflect only the difference in rock type between the metabasalt and the undifferentiated metabasalt to the west (fig. 2).

GEOPHYSICAL INVESTIGATIONS

Geophysical findings in the B-35 and B-34 areas are described in another report (Flanigan and others, 1981) but are discussed here in order to explain the relationship of geophysical and geologic features. All of the geophysical anomalies appear to be caused by geologic features examined in the field.

Table 3.--Metal threshold values for the B-35 and B-34 areas and samples that contain metal values equal to or greater than the threshold values
[Threshold values in parentheses. --, indicates less than threshold value]

Sample number	Copper (300)	Zinc (200)	Silver (2)	Gold (0.20)	Lead (60)	Sample number	Copper (300)	Zinc (200)	Silver (2)	Gold (0.20)	Lead (20)
143222	--	350	--	--	--	143324	350	--	--	--	--
143044	--	250	--	--	--	143325	450	--	--	--	--
143046	300	--	--	--	--	143337	300	--	--	--	--
143063	320	--	--	--	--	143339	--	--	--	--	--
143074	300	--	--	--	--	143341	--	--	2	--	--
143098	--	--	--	--	90	143342	--	--	2	--	--
143107	350	--	--	--	--	143343	300	--	--	--	--
143133	--	225	--	--	--	143345	--	--	2.1	--	--
143150	350	--	--	--	--	143351	--	--	2.5	--	--
143175	600	--	--	--	--	143352	--	--	2	--	--
143207	--	--	8	--	--	143355	--	--	2.7	--	--
143208	--	--	--	--	--	143356	--	--	2.1	--	--
143221	--	--	2.2	--	--	143357	800	--	2.5	--	--
143227	--	--	7	--	--	143391	450	--	--	--	--
143245	300	--	--	--	--	143409	--	200	--	--	--
143264	400	--	2	--	--	143421	350	--	--	--	--
143265	--	--	2	--	--	143432	750	--	--	--	--
143266	400	--	2	--	--	143468	--	--	4	--	--
143272	--	--	3	--	--	143494	--	--	14	--	--
143273	--	--	3	--	--	68884	--	200	--	--	--
143275	--	--	2.7	--	--	68876	--	--	--	0.27	--
143276	--	--	2.1	--	--	68879	--	200	--	--	--
143280	--	--	3	--	--	68880	--	200	--	--	--
143286	300	--	--	--	--	68883	--	200	--	--	--
143290	300	--	--	--	--	68901	--	--	--	3.89	--
143291	320	--	--	--	--	68916	--	200	--	--	--
143292	350	--	--	--	--	68918	--	200	--	--	--
143301	--	--	--	0.80	--	68921	--	200	--	--	--
143311	--	--	--	.60	--						

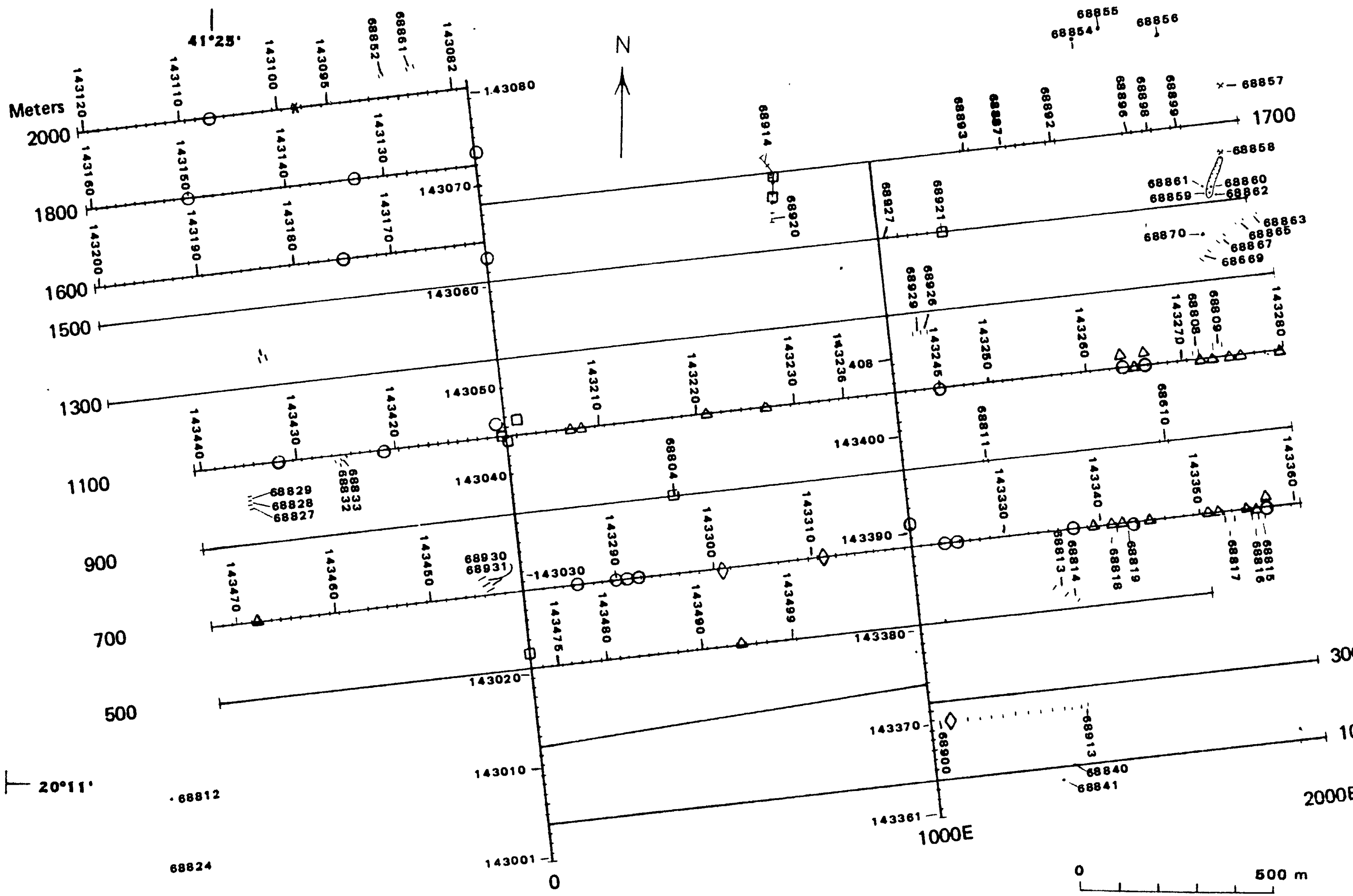
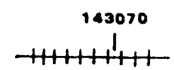
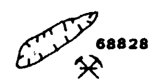


Figure 4.--Geochemical map of the B-35 area.

EXPLANATION



Traverse line, showing sample interval and number



Prospect or mine showing sample number

○ Copper, > 300 ppm

□ Zinc, > 200 ppm

△ Silver, > 2 ppm

◇ Gold, >0.2 ppm

× Lead, > 60 ppm

Figure 4.–Continued

The Geoterrex airborne electromagnetic survey (written commun., 1977) of the Wadi Bidah district revealed what since has been referred to as the B-35 and B-34 anomalies. The B-35 is the larger of the two, as shown on the electromagnetic map available from Geoterrex. An isomagnetic map, compiled from an airborne magnetometer survey by Geoterrex, shows a rather weak magnetic anomaly that essentially overprints the B-35 electromagnetic anomaly.

After the strong but rather generalized electromagnetic anomaly in the B-35 area was revealed by the airborne survey, subsequent ground electromagnetic (EM) and self-potential (SP) surveys of parts of the area were carried out. Because many sulfide deposits, particularly those of massive sulfides, are conductors of electrical energy, they may be detected by EM and SP surveys. Therefore, the EM and SP ground surveys were laid out to test the more intense parts of the airborne anomaly, and data were acquired along the base and traverse lines shown on figure 5. Data were not acquired along the additional traverse lines shown on figure 2 because those lines had not been surveyed when the geophysical surveys were made. Results of the EM and SP surveys are shown in figures 5, 6, and 7. Blank areas on figures 5, 6, and 7, in the northern and southern parts of the east side and in the middle part of the west side of the area, mark localities where no data were collected. If the geologic investigations reported herein had been more encouraging, the EM and SP surveys would have been expanded to cover the entire area.

Several in-phase EM anomalies are shown on figure 5; the principal anomaly is centered along traverse line 700 N, about 750 m east of the zero base line. The anomaly extends east and then bends north. If figure 5 is overlain on figure 2, it will be seen that the anomaly almost exactly overprints a unit of highly folded carbonaceous graywacke, as do other anomalies along the western parts of lines 700, 1600, and 2000 N. Another anomaly, centered at the intersection of the 100 m E base line and traverse line 300 N, partly overprints undifferentiated graywacke, which at this locality is highly carbonaceous; the northeast extension of the anomaly overprints a band of carbonaceous graywacke that extends northeast from the Wadi Haqeeth fault.

The out-of-phase electromagnetic map (fig. 6) shows a similar relationship of anomalous zones and carbonaceous graywacke. The principal anomaly, which lies partly along line 700 N, overprints the in-phase anomaly along that line (fig. 5). Other anomalies on line 900 N and the western parts of lines 700, 1600, and 2000 N (fig. 6) show patterns similar to anomalies on figure 5. All of the anomalies

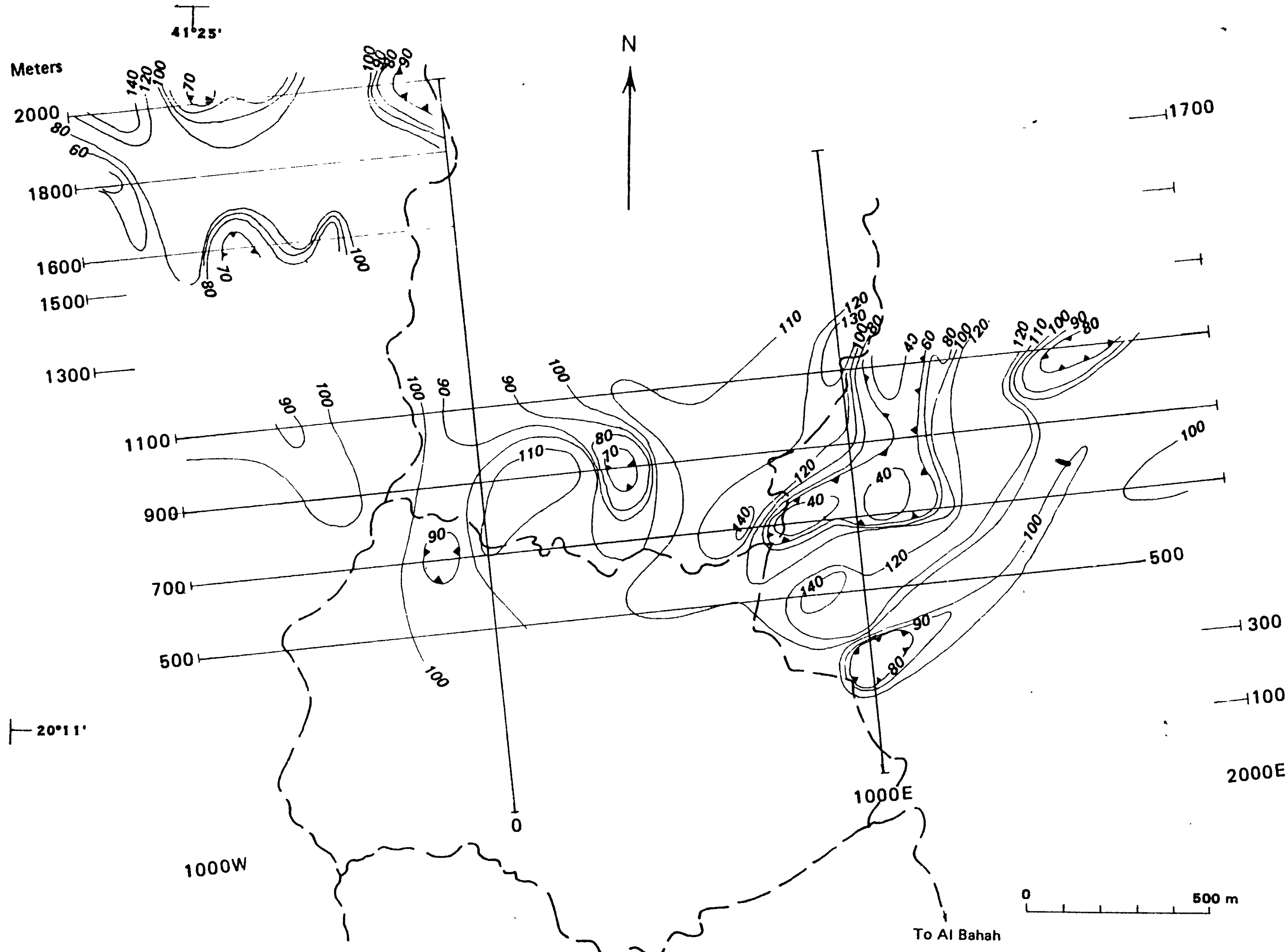


Figure 5.–In-phase electromagnetic map of the B-35 area. Contour interval is 20 percent of the primary field, measured at a power outage of 888 Hz.

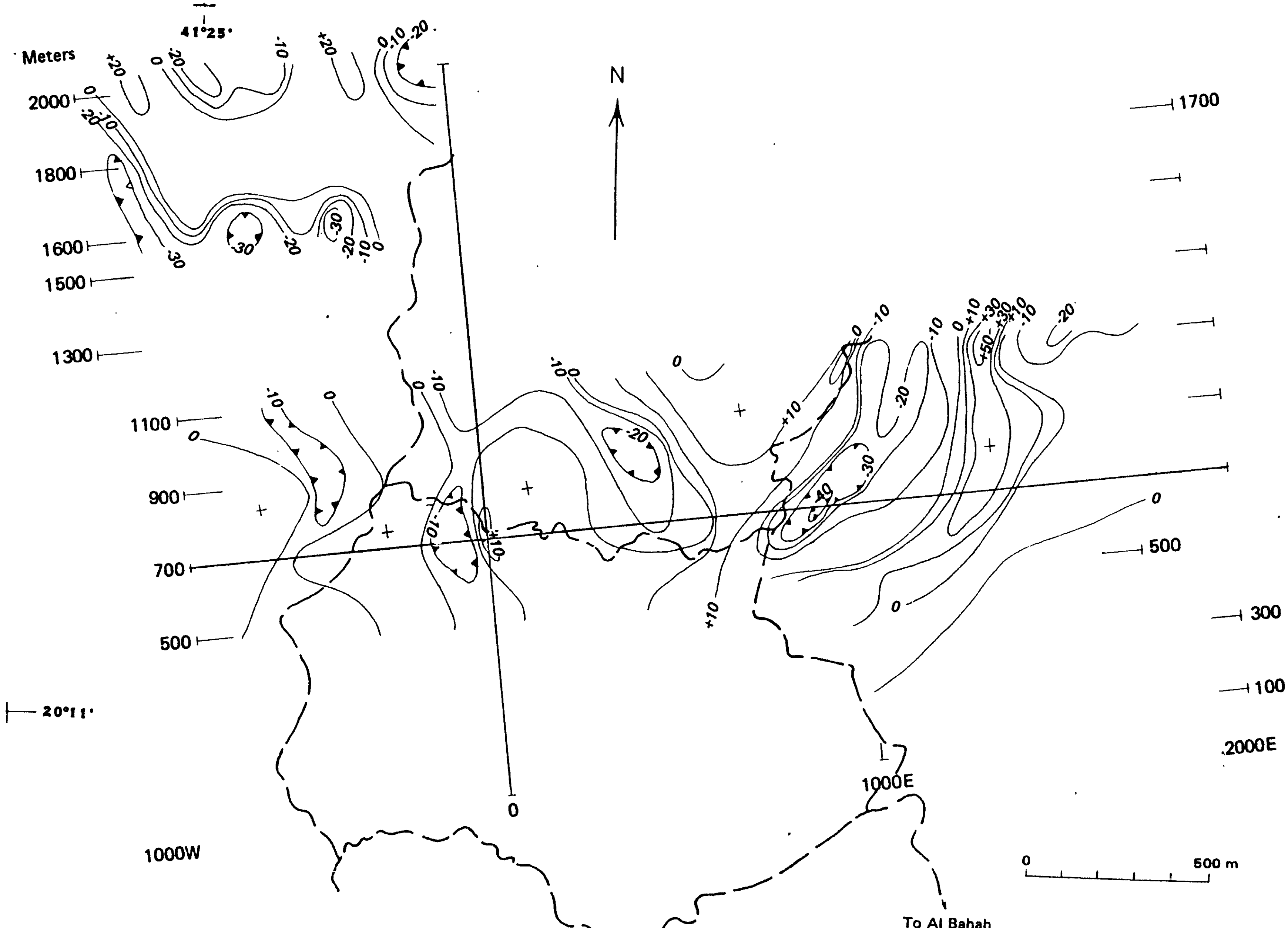


Figure 6.–Out-of-phase electromagnetic map of the B-35 area. Contour interval is 10 percent of the primary field, measured at a power outage of 888 Hz.

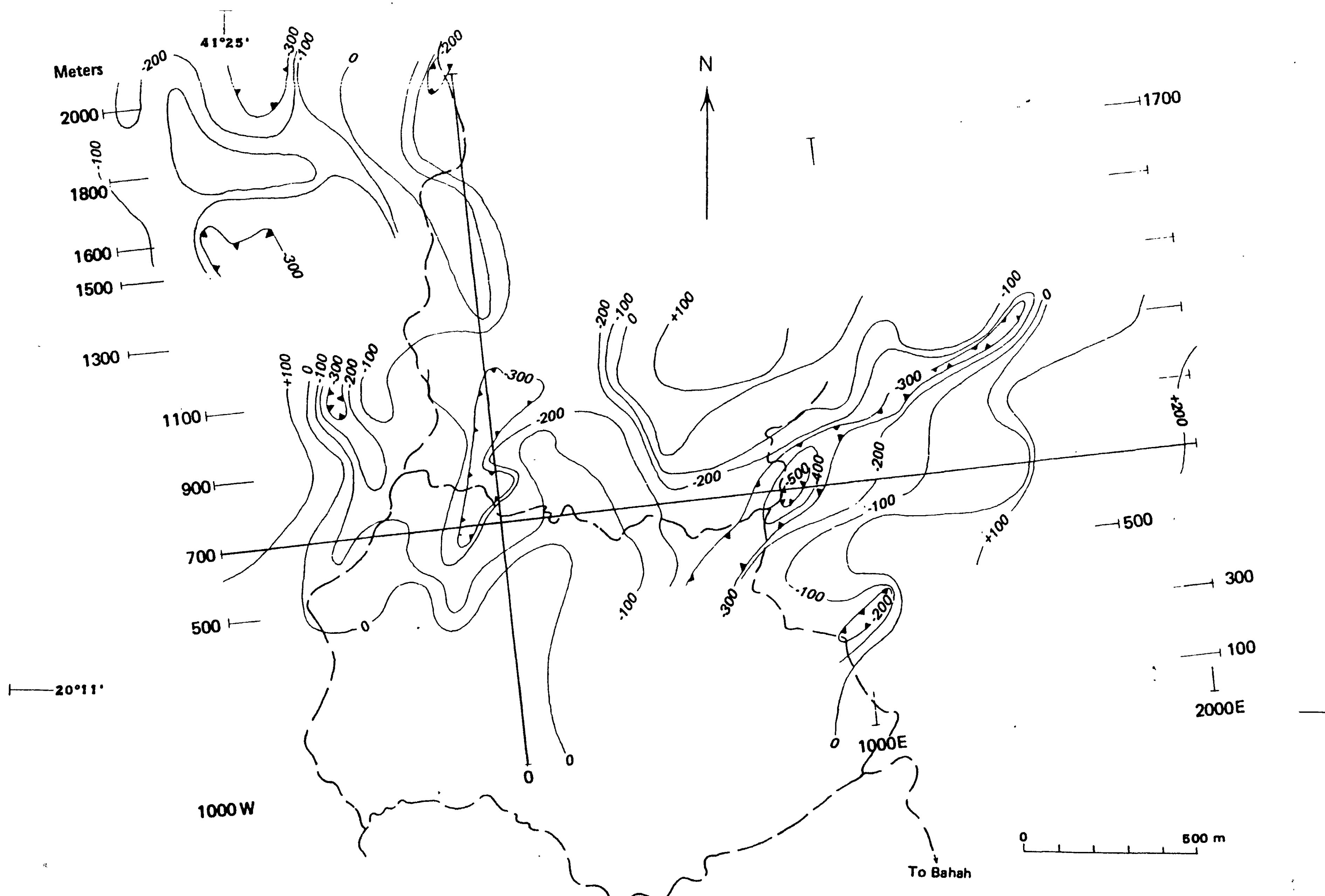


Figure 7.–Self-potential map of the B-35 area. Equipotential shown as contours measured from base station. Contour interval is 100 mV.

overprint and extend more or less along bedded units of carbonaceous graywacke.

The self-potential (SP) map (fig. 7) also indicates a close relationship between SP anomalies and carbonaceous graywacke. The trends of contour lines on figures 5, 6, and 7 suggest that if electromagnetic and self-potential data had been collected along lines 100, 300, 1300, 1500, and 1700 N, additional anomalies might have been discovered over the large exposures of carbonaceous graywacke in those areas.

Comparison of geophysical anomalies to geologic factors

There is overwhelming geologic evidence that the carbonaceous graywacke is the cause of the EM and SP anomalies. The anomalies overprint carbonaceous graywacke exposures even to the point of following folds and curving outcrops in wadi bottoms. The carbonaceous material is believed to be the conductor in the graywacke. Although pyrite is in all of the rock, it is too disseminated to be an effective conductor. No evidence was seen of massive sulfide deposits or of other conductive materials.

Graphite and other forms of carbon are well-known electrical conductors, and many electromagnetic anomalies discovered throughout the world have been shown to be caused by graphite and not by sulfide deposits. The carbonaceous material in the Baish graywacke is similar in most respects to graphite and indeed has been classed as graphite on other occasions (Kiilsgaard and others, 1978). Metamorphism carbonized the original organic material in the Baish group rocks, but, as noted previously, the rocks were not metamorphosed to a high enough rank to convert the carbonaceous material to graphite. The conductive properties of various ranks of carbonaceous rocks are not known to the author; however, it would appear reasonable that rocks containing little amorphous carbon would be less conductive than rocks containing greater concentrations of carbon.

Studies at other localities have shown that with increasing metamorphic grade, carbonaceous material undergoes continuous changes, such as increase in particle size, loss of hydrogen, nitrogen, and oxygen, increase in carbon content, and the eventual development of the well-ordered crystal structure of graphite (Grew, 1974). All of these changes would increase the conductivity of the material. Landis (1971) has shown that progressive graphitization is related to metamorphic grade as conventionally defined by mineral assemblages. Thus, carbonaceous material in zeolite-facies rocks is essentially amorphous, whereas material in greenschist-facies rocks shows a more advanced degree of crystallinity. As rocks of the Baish group are in the greenschist facies, it seems reasonable to assume that contained carbonaceous material has reached a state of crystallinity advanced enough to affect the conductivity of the material.

If it is assumed that carbonaceous material in the graywacke is the conductor reflected in the anomalies, a logical question is: Why is not the carbonaceous material in the carbonaceous graywacke anomalous everywhere rather than only at some localities? Many different factors undoubtedly help determine the conductivity of the material, but in the B-35 area two factors appear to dominate: the concentration of carbon and the degree of weathering.

Concentration of carbonaceous material in the graywacke varies widely, from sparse disseminations to concentration so enriched that the rocks are as black as coal. Some EM anomalies are closely related spatially to the more enriched rocks. Most of the anomalies overprint carbonaceous graywacke exposures in steep-gradient wadi bottoms, where weathered material is swept away continuously by erosion. Anomalies are less conspicuous on ridge tops and plateaulike surfaces, where weathering is deep and much carbonaceous material is difficult to recognize. The carbonaceous material breaks down under weathering and possibly becomes less conductive in the process. The weathered debris may even mask underlying unweathered material to the point that the locality is not as responsive to electrical activation. For example, the small B-34 airborne EM anomaly is centered on a low divide in a large wadi and carbonaceous graywacke underlies the wadi. At the divide fresh rocks are kept exposed by erosion, whereas downstream from the divide a pronounced soil profile is developed, as well as a cover of alluvium. These covered areas are not anomalous.

Magnetite is a common accessory mineral in metabasalt from the B-35 area and was identified in the field by a hand-held magnet and in thin sections of rock samples. A few hand specimens of metabasalt contained an estimated 1 to 3 percent magnetite, as did a sample from a basal section of carbonaceous graywacke. The most magnetic rocks examined were in the northwestern part of the B-35 area, essentially underlying the southern part of the magnetic anomaly shown on the Geoterrex isomagnetic contour map described above. The author believes that magnetite in the rocks of the Baish group is the main cause of the anomaly on the isomagnetic map available from Geoterrex.

ANCIENT MINES AND PROSPECTS

An ancient gold mine in Wadi Haqeeth and a small prospect pit immediately south of the area are the only evidence of former mining activity in the B-35 area. Two large but barren quartz veins crop out in the area.

Haffa Abith gold mine

The ancient Haffa Abith gold mine is in the northeastern part of the B-35 area, on the north wall of Wadi Haqeeth, at lat 20°11'50" N., long 41°26'25" E. It may be reached by following the unimproved road that extends north across the eastern side of the area to the large and northernmost east-draining wadi in the area. From there, access is by walking east, down the wadi, to Wadi Haqeeth and then north down that wadi to the mine, the lowest workings of which are about 20 m above the wadi floor, on the northern side.

The mine workings consist of a lower open pit about 1 m wide, 3 to 4 m deep, and 10 m long. Immediately north of the pit are two parallel open cuts from 1 to 1.5 m apart. Both cuts are about 1 m wide and range from 2 to at least 8 m in depth and from 20 to 30 m in length. The open pits trend N. 18° E. and extend to the top of the ridge, about 105 m above the wadi floor. Several shallow prospect pits, none more than 2 or 3 m deep, are on the ridge crest north of the open cuts. On the ridge top an old grinding site contains a few hundred kilograms of sand-size quartz and indicates that the mine was worked for gold.

The open-pit workings were excavated along a system of closely spaced quartz stringers and veins that range from 5 cm to 1 m in thickness. The total width of the vein system is about 3 m. The quartz veins strike parallel to the enclosing iron-stained graywacke host rock, which is flanked on either side by greenschist (metabasalt). The quartz veins do not extend north of the ridge crest, but the graywacke host rock does and, in that locality, pinches to about 1 m thickness and is folded intensely (fig. 2).

Nine samples were collected at the Haffa Abith mine. The richest sample, 68958, was collected across two quartz pillars at the north end of the open cuts and contained 3.51 ppm gold. Gold contents from other samples of the vein material ranged from 0.09 to 0.55 ppm. Sample 68870 was collected across the vein system about 100 m south of the mine workings, on the south side of Wadi Haqeeth. At that site, several quartz veins were sampled, the thickest of which was 20 cm. The total width of the sampled interval was 3 m, but the sample contained less than 0.05 ppm gold. All Haffa Abith samples contained only trace amounts of other metals.

Low gold contents in the narrow quartz veins suggest that the mine may have been worked at times when gold was in demand, but when profit was not a motive of mining. The low gold contents, narrow veins, discontinuity and overall short strike length of the veins, and absence of significant wall-rock alteration or other indications of mineralization indicate that the Haffa Abith gold mine is not a good prospective target and does not warrant exploration.

Ancient prospect pit

An ancient prospect pit is south of the B-35 area at lat 20°10'35" N., long 41°25'35" E. From the road junction in the southeastern corner of the B-35 area, the prospect may be reached by following the west road about 800 m west across the southern part of the area, to where the road crosses a north-trending wadi. From that point, the wadi is followed south for about 300 m and then west up the small ridge that flanks the wadi. The prospect is on the ridge crest.

The prospect pit is 3 m long, 1.5 m wide, and about 2 m deep. The bottom of the pit is covered by sand and debris. The pit explores an iron-stained, bedded interval of graywacke that strikes N. 22° E. and dips 88° NW. Yellow to red limonite and small aggregates of quartz crystals are present in the graywacke, but no copper stain or sulfide minerals were seen. The iron-stained unit of graywacke may be traced about 100 m northeast. Sample 68822, collected across 1.5 m of graywacke at the prospect pit, contained less than 0.05 ppm gold, 1.2 ppm silver, and 130 ppm copper. No grinding implements were seen at the prospect nor was there any evidence of slag. The ancient miners may have been looking for gold, or they may have used material from the pit as a source of paint pigment.

The prospect does not warrant exploration.

Southwestern quartz vein

In the southwestern part of the B-35 area, at lat 20°10'55" N., long 41°24'55' E., a large quartz vein strikes north and dips 45° W. The vein cuts across graywacke at an acute angle. The northern end of the vein is enlarged to a lens-shaped mass that is 30 m long and about 10 m wide. To the south, the vein ranges from 2 to 4 m in thickness. The quartz is brecciated and iron stained. Limonite-filled casts after pyrite can be seen, but no sulfide minerals were visible. No prospect pits have been dug in the vein.

Two samples were collected from the vein. Sample 68812 was collected across a width of 5 m at the north end of the quartz lens. The sample contained less than 0.05 ppm gold, less than 0.50 ppm silver, and 15 ppm copper. Sample 68824 was collected near the southern end of the vein, across a width of 3 m. It contained less than 0.05 ppm gold, 0.50 ppm silver, and 30 ppm copper.

The vein does not warrant exploration.

Southeastern quartz vein

In the southeastern part of the B-35 area, a large quartz vein may be traced for about 350 m northeast, from a point near the road to the bottom of Wadi Haqeeth. The midpoint of the vein is about lat 20°11'00" N., long 41°26'12" E. The vein trends along the contact of graywacke and metabasalt and dips 60° NW. No prospect pits were seen along the vein.

The quartz vein ranges from 1 to 3 m in thickness and is iron stained and vuggy. Near the southwestern end, the foot-wall of the vein is marked by 0.5 m of gouge and sheared metabasalt. Two samples were collected about 40 m apart, across a 2-m thickness of the vein. Sample 68840 contained less than 0.05 ppm gold, less than 0.5 ppm silver, and 160 ppm copper. Sample 68801 contained 0.35 ppm gold, 0.5 ppm silver, and 195 ppm copper.

The quartz vein does not warrant exploration.

CONCLUSIONS

As a result of the geochemical sampling program and detailed geologic mapping of the B-35 and B-34 areas, the following conclusions may be stated:

1. Geophysical anomalies in the B-35 and B-34 areas are underlain by carbonaceous graywacke, and the carbonized material in the rock appears to be the cause of the anomalies.

2. Intensive geochemical sampling in the B-35 and B-34 areas did not disclose any evidence of ore mineral concentrations.

3. No geologic features were seen that suggest the probability of significant deposits of ore minerals at depth.

4. Further investigation of the anomalous areas for mineral deposits or subsurface mineral exploration in the area is not recommended.

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