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SUMMARY OF RESULTS FROM A TRIP FEBRUARY 6-MARCH 5, 1966, TO BI'R IDIMAH, JABAL ASHIRAH, AND AS SARAT MOUNTAINS, SAUDI ARABIA

by

William Courtney Overstreet 1919-

1968

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2. Preliminary geologic map of the Great Falls-Browns Lake area, northwestern Montana, by Melville R. Mudge. 1 map, explanation (2 pieces), and 3 data sheets. Scale, 1:250,000. 1012 Federal Bldg., Denver, Colo. 80202; 8102 Federal Office Bldg., Salt Lake City, Utah 84111; 678 U.S.Court House Bldg., Spokane, Wash. 99201; 510 First Ave. North, Great Falls, Mont. 59401; and Montana Bureau of Mines and Geology, Montana School of Mineral Science and Technology, Butte, Mont. 59701. Material from which copy can be made at private expense is available in the Spokane office.

3. Mineral investigations between Khamis Mushayt and Bi'r Idimah, Saudi Arabia, by William C. Overstreet. 15 p., 3 p. tabular material.

4. Preliminary report of a mineral reconnaissance in the Al Maddah-Harfayn area, Asir quadrangle, Saudi Arabia, by Jesse W. Whitlow. 4 p., 2 figs.

5. Report on allanite occurrence near Hamdtha on Wadi Tathlith, Saudi Arabia, by Glen F. Brown. 2 p.

6. Mineral exploration between Bi'r Idimah and Wadi Haraman, Asir quadrangle, Saudi Arabia, by William C. Overstreet. 70 p., 11 tables.

7. Preliminary results of a trip October 30-December 21, 1965, to the area between Sha'ya and Jabal Bani Bisqan, Saudi Arabia, together with a synopsis of mineral reconnaissance in the Asir quadrangle, by William C. Overstreet. 48 p., 9 tables.

8. Summary of results from a trip February 6-March 5, 1966, to Bi'r Idimah, Jabal Ashirah, and As Sarat Mountains, Saudi Arabia, by William C. Overstreet. 47 p., 1 fig., 6 tables.

PREFACE

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 Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian government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

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SUMMARY OF RESULTS FROM A TRIP FEBRUARY 6-MARCH 5, 1966, TO BI'R IDIMAH, JABAL ASHIRAH, AND AS SARAT MOUNTAINS, SAUDI ARABIA.

by

William C. Overstreet

Contents

Illustrations

Tables

Abstract

The geologic setting of the pyrite replacement deposit at Wadi Wassat was mapped in February 1966. From this mapping it is inferred that the pyrite deposits occur along a sub-vertical, north-trending fault in andesite and other rocks at the crest line of an anticline in a roof pendant. The pendant is in a composite pluton formed by a per-alkalic magma series. Diorite and biotite granite are the most common and older members of the series. Pyroxene granite and quartz porphyry are less common younger rocks in the series. Extrusive equivalents of these plutonic rocks form dikes in the area. The pyrite is interpreted to have been deposited from hydrothermal solutions after diorite and biotite granite were consolidated and while pyroxene granite was being emplaced. Structures controlling the deposition of the pyrite are regional. Exploration at 1:2,500 scale by geologic, geochemical, and electro-magnetic methods are recommended. Diamond drilling should accompany the other exploration.

Chemical analyses of 22 specimens of Precambrian marble from the Asir quadrangle shows that seven deposits have a composition within the range of compositions of natural cement rocks used for Roman cement and quick-setting cement. None of the samples is rich enough in CaO for use as a raw material for Portland cement, and most samples of the marble have too much MgO for Portland cement.

Analyses of the major elements in 71 samples of lateritic material from the As Sarat mountains show that none of the laterite can be used as an ore for iron owing to too little iron and too much alumina, silica, and sulfur. One sample has the alumina-silica ratio of gibbsite or boehmite. One sample has alumina and sulfur in percentages suggesting the presence of alunite, and several other samples probably contain alunite. Because alunite is potash rich and might be used as a raw material for potash fertilizer, it is recommended that an airborne radiometric survey be made of the As Sarat mountains to locate potassium-rich parts of the laterite.

Introduction

The area between Bi'r Idimah and Jabal Ashirah, Saudi Arabia, comprising the

30-minute quadrangle bounded by parallels 18°N. and 18°30'N. and meridians 44°E. and 44°30'E., was mapped geologically to permit interpretation of the setting of the large pyrite deposit on Wadi Wassat. Further exploration for mineral deposits was also done in the area, extending an appraisal first undertaken in late 1964 (Overstreet, 1965). Samples of rocks were collected from the Jabal Ashirah zoned pluton and the Wadi Wassat area for use in age determinations. Sufficient samples were obtained to bracket the period of formation of the pyrite deposit under the Wadi Wassat gossan and to permit construction of a isochron plot of the Jabal Ashirah per-alkalic magmatic series if the sample material is fresh enough for analysis. A traverse was made across the new road from Najran to Zahran al Yemen to examine relations among andesite, chlorite-sericite schist, and slate which bear on the stratigraphic and structural features of the Asir quadrangle (Brown and Jackson, 1959). The great laterite in the As Sarat mountains was viewed again with special reference to the possible presence of potash-rich secondary minerals. Pyritiferous schist north of Abha was re-examined to compare it with the pyrite deposits at Wadi Wassat.

The trip lasted from February 6 to March 5, 1966, and covered a route of 3264 km. The writer was accompanied by Misri Madak and Khalif Ali, drivers employed by the Directorate General for Mineral Resources. The Directorate also supplied the two Ford 3/4-ton, 4X4 pickup trucks used for transport. Between February 28 and March 5, 1966, Richard Reesman, geochronologist with the U. S. Geological Survey, joined the field party to supervise the collection of rocks for age determination and to evaluate in the field the problem of rock weathering, which affects results of geochronological studies in Saudi Arabia.

The work was undertaken as part of the mineral exploration agreement negotiated in September 1963 between the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia, and the United States Geological Survey. The principal results of the trip are a geologic map of the Bi'r Idimah-Jabal Ashirah area, the discovery of three large gossan, and renewed interest in the As Sarat laterite as a possible source for alunite, a potash-rich aluminum sulfate which might be used as a fertilizer raw material. Seventy-one new analyses of the major elements in laterite from the As Sarat mountains, made by the staff of the Chemical Laboratory of the Directorate General for Mineral Resources, are presented. Twenty-eight new trace-elements analyses of gossan from Wadi Wassat and the Bi'r Idimah-Jabal Ashirah area, made by C. E. Thompson, U.S.G.S. and Mohamed Jambi, D.G.M.R., were specially prepared for this report, the results being obtained three days after the samples were transmitted. Twenty-two analyses of specimens of marble collected on previous trips were transmitted by Jamal Sumbul, chemist with the Directorate General for Mineral Resources, in time to be incorporated here.

Bi'r Idimah - Wadi Wassat gossan

Geology

The geologic setting of the Bi'r Idimah-Wadi Wassat gossan was mapped in the 30-minute quadrilateral bounded by parallels 18°N. and 18°30'N. and meridians 44°E. and 44°30'E. in the period February 12-27, 1966. A small part of this area is shown here as figure 1 [1]. The geologic relations are summarized below using figure 1 as

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[1] Fig. 1. Geologic setting of the gossan in the Bi'r Idimah-Wadi Wassat area, Saudi Arabia.

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the reference. It should be noted, however, that this area is framed by the structures forming the east wall of the great gneissic batholith depicted on the 1:500,000-scale map of the Asir quadrangle (Brown and Jackson, 1959), and that a final explanation for the occurrence of immense masses of pyrite in the Wadi Wassat area can only be made in the context of the regional geology of this part of the Precambrian shield of Arabia.

<u>Rock types.</u>

The sequence and general description of the types of rocks in the Bi'r Idimah-Wadi Wassat area are given in the explanation of figure 1. A group of Precambrian layered rocks, dominantly andesite and graywacke with sparse marble, are intruded by a magmatic differentiation sequence of plutonic rocks leading, from oldest to youngest, from biotite diorite through biotite granite and pyroxene granite to quartz porphyry. Swarms of dikes are related to some, possibly to each, of the members of the plutonic magmatic sequence. Overlying the Precambrian rocks is the ferruginous Wajid sandstone of Permian or greater age. It is not intruded by the dikes. Erosion of the Wajid sandstone has exposed the old rocks. Water-and wind-borne detritus from them forms the young sedimentary deposits of Quaternarary age in the wadis.

Precambrian layered rocks:-- A thick sequence of andesite, andesite porphyry, trachytic andesite porphyry, agglomerate, conglomerate, graywacke, argillite, and marble forms the oldest rocks in the area. Much of the sequence is massive to poorly bedded; thus, the mapping on figure 1 does not bring out the folds and faults that warp and dislocate the layered rocks.

The layered rocks form a roof pendant between plutons of biotite diorite (di) and biotite granite (b). The granitic bodies lie along the northeastern and southwestern flanks of the pendant, and the diorite intrudes the western and northwestern parts of the pendant. To the southeast, a few kilometers beyond the edge of the map, the pendant of Precambrian layered rocks probably terminates against intrusive masses of gabbro and granite porphyry, but the actual relations are obscured by the overlying Wajid sandstone.

The largest part of the Precambrian layered rocks, and the part interpreted to be the older, is called andesite (a) on figure 1 because massive andesite dominates. A variation in lithology takes place across the unit.

East of Wadi Wassat the unit consists of massive andesite and andesite porphyry with non-oriented feldspar phenocrysts up to 1/2 cm wide and 3 cm long. The andesite is slightly chloritized and epidotized, but it does not appear to have been affected by regional metamorphism, nor is any appreciable contact metamorphism caused by the intrusions of diorite, biotite granite, rhyolite, and syenite porphyry. In the extreme eastern part of the area around station 30050 the feldspars in the andesite porphyry are oriented in a primary flow banding that strikes N.55°W. and dips 70°SW., giving the andesite porphyry a strong trachytic texture. Agglomerate is present in the massive andesite around station 30051. Most of the andesite exposed along Wadi Wassat is massive and only slightly metamorphosed.

West of Wadi Wassat the andesite is less massive and is variably metamorphosed. The andesite is interlayered with thin beds of argillite and fine-grained graywacke. Locally, as east of station 30043, layers of conglomerate are present. The conglomerate consists of pebbles and cobbles of andesite set in a matrix of graywacke.

In the central part of the area, on either side of the gossan and extending intermittently westward to the western edge of the andesite unit, are many small masses of a fine-grained diorite or pseudo-diorite in andesite and graywacke. This rock is cut by diamond drill hole number 1. It has not been separated on figure 1, and its relations to the other rocks are but poorly known. On a regional scale this fine-grained diorite or pseudo-diorite is persistently present with andesite in the Asir quadrangle. It has been interpreted (Overstreet, 1966a, p. 10-11) to be older than the diorite (di) genetically related to the massive granites, and it was thought to be either hypabyssal igneous feeders to the overlying pile of andesite, or andesite altered through potash metasomatism.

In the western part of the area lenticles of marble are interlayered with the dominant andesite, and beds of graywacke tend to be slightly calcareous. The appearance of these lenticles of marble is the beginning of the gradational contact between the andesite unit and the sericite-chlorite schist unit.

The sericite-chlorite schist unit (sc) is interpreted to be younger than the andesite unit and to occupy a tight syncline. It is a greenschist facies metamorphic rock formed by contact and cataclastic metamorphism of graywacke, argillite, and andesite where graywacke and argillite are dominant and andesite is subordinant. Where andesite is dominant in the same local metamorphic environment, the unit formed is called hornblende schist (hs) on figure 1. Marble (m) is more common in the sericite-chlorite schist (calcarious graywacke suite), than it is in the hornblende schist and andesite.

Thus, the western part of the roof pendant of Precambrian layered rocks consists mainly of clastic sediments, and the central and eastern parts of the pendant consist of volcanic rocks becoming increasingly more massive toward the east.

Intrusive plutonic rocks:-- In the area of figure 1 the intrusive plutonic rocks consist of biotite diorite (di) grading into gabbro, and differentiation products genetically related to it consisting mainly of biotite granite (b) with a little pyroxene granite (pg) and quartz porphyry (qp). This assemblage is part of the per-alkalic granite (gp) of the Asir quadrangle (Brown and Jackson, 1959). None of the older granitic rocks of the Asir quadrangle are represented in the area of figure 1. The time relations and compositional differences of the plutonic ingeous rocks are very clear. They are here interpreted to be a magmatic differentiation sequence leading from gabbro and diorite through biotite granite and pyroxene granite to quartz porphyry. South of the area of figure 1, around Jabal Ashirah, the differentiation sequence extends to massive, plutonic syenite, but in the Wadi Wassat area the syenite is represented only by late dikes of syenite porphyry (p).

The plutonic igneous rocks have been forceably intruded into the Precambrian layered rocks, as is attested by the magmatic stoping features and swarms of inclusions present in the areas north of Stations 30049 and 30050 east of Wadi Wassat, and along the contacts north of stations 30066 and 22988 in the west. On a regional scale the invasion of the layered rocks by the magma series is clearer than it is on figure 1. The intrusive contacts have been locally modified by faulting. The contact between biotite granite and andesite at the north end of the gossan is a fault. The magnitude of the faults at the contacts is not known.

Few felsite or pegmatite dikes are associated with the plutonic rocks. Very small amounts of these rocks seem to be derived from the biotite granite and are shown on the map by the symbol g north of stations 30034 and 30035. Similar rocks thought to be related to the quartz porphyry are shown by the symbol fg between stations 22989 and 30026. Small quartz veins of diverse metamorphic and igneous origins are sparsely present in the andesite unit and other rocks, but they have not been shown on the map. One large quartz vein (q) makes a prominent outcrop between the road to Najran and station 7990. It is thought to be genetically related to quartz porphyry and pegmatite. This vein is barren of mineralization. The few veins and pegmatite dikes associated with the diorite and granites suggests that these rocks were remarkably free of volatiles when they crystallized.

Dikes:-- A distinctive feature of the Wadi Wassat area is the persistent swarms of dikes of several generations and having characteristic orientations. None of the dikes are related genetically to the andesite flows of units a, hs, or sc; all are younger, and they are interpreted to be related to the plutonic magmatic rocks.

The oldest dikes are diorite (di). They make a small satellitic swarm in the andesite unit north of a small intrusive plug of diorite at station 30033 near the northern edge of the map. They are thought to be part of the biotite diorite intrusive phase, but their relations are in doubt owing to their west-northwesterly trend, which is that of the youngest dikes known in the area.

The next oldest dikes, and economically an important set owing to their close spatial relations to the Wadi Wassat gossan, are called rhyolite (r) on figure 1. These distinctive rocks are light to dark gray, buff, pink, and red. Locally, particularly where they are strongly pyritized, they are more or less silicified and nearly black. The rhyolite has sparse phenocrysts of quartz and spessartite and contains a little biotite and magnetite. Pyrite is variably present in amounts up to 12 percent of the rock; the most pyrite is in rhyolite in the Wadi Wassat gossan. Joints in the rhyolite are commonly coated with epidote. The rhyolite occupies north-trending fractures where it forms dikes from a meter or two wide and a few hundred meters long to dikes 350 m thick and 1600 m long. Practically all these dikes are restricted to the andesite unit, but north of station 30048 at least one dike is in biotite granite, between Wadi Wassat and the Najrah road several rhyolite dikes are in diorite, and south of station 7996 a large dike crossed the contact between andesite and diorite. The rhyolite is also present in sericite-chlorite schist near 30027. This rhyolite does not contain pyroxene, and it has not been found to intrude pyroxene granite or quartz porphyry. From these relations it has been assigned a stratigraphic position younger than the layered rocks, diorite, and biotite granite, but older than the pyroxene granite, quartz porphyry, and other dikes. The rhyolite is cut by pegmatite and felsite (g) related to the biotite granite (b), but its relations to granite dikes (g) derived from the biotite granite is complex. Some of these dikes, gradational into felsite and pegmatite, cut the rhyolite, but it is possible that other granite dikes like those near station 30035 are older than the rhyolite. The rhyolite (r) is here interpreted to be the extrusive equivalent of the biotite granite (b).

A group of dark dikes younger than the rhyolite are represented on the map as dacite, dacite porphyry, and diabase. The dacite is generally older than the diabase, but it is probable that the dark dikes are penecontemporaneous. They are most abundant in the diorite, biotite granite, pyroxene granite, and quartz porphyry in the southwestern part of the mapped area, and in diorite, hornblende schist and sericite-chlorite schist in the western part of the area. A number of dacite and diabase dikes are present in the andesite, diorite, and biotite granite between stations 30047 and 30050 in the eastern part of the area. The classification of these dikes, like that of the other rocks in the area, is based on megascopic study only. Those dikes with recognizable ophitic texture and pyroxene are called diabase, and those dikes with biotite, potassium feldspar, and plagioclase were called dacite. No plutonic rocks in the area of figure 1 can be related to these dark dikes. They precede in time of emplacement two groups of felsic dikes which appear to be closely related to the end stages of the plutonic magma series; therefore, it is inferred that the dacite and diabase are also part of it.

Pyroxene rhyolite and syenite porphyry intersect and offset the dark dikes and the older rhyolite. Most of the pyroxene rhyolite dikes are in two parallel swarms trending about N.20°W. near the south edge of the area covered by figure 1. These dikes extend southward and become common near stocks of granite porphyry and pyroxene granite. From these relations the pyroxene rhyolite dikes are inferred to be extrusive equivalents of the pyroxene granite.

The syenite porphyry is the youngest dike rock in the area. It forms a distinctive swarm that strikes about N.70°W. across the area. This direction is a common fault direction in the Asir quadrangle, with left lateral horizontal movement on the fault. Some of the syenite porphyry dikes occupy such faults, and strong left lateral displacement can be seen across some of the dikes, for instance on the gossan north of station 30042. Most of the syenite porphyry dikes contain small plagioclase crystals. It is possible that some of these dikes have the composition of latite. Although plutonic syenite is not exposed around Wadi Wassat, it is present farther south near Jabal Ashirah. The syenite is there thought to be one of the differentiation products in the magma series including biotite diorite, biotite granite, and pyroxene granite. Syenite porphyry in the Wadi Wassat area is interpreted to be the hypabyssal equivalent of the syenite, and is the youngest differentiate in the sequence.

Post-Cambrian sedimentary rocks:-- The Precambrian rocks are unconformably overlain by Permian or older Wajid sandstone and Quaternary alluvial and eolian sand. The Wajid sandstone (Brown and Jackson, 1959) is a reddish-brown, yellow, tan, and white crossbedded sandstone with ferruginous cement and concretions in some layers. Thin conglomerate layers and lenticular beds of clay are present. Locally the Wajid sandstone overlies deeply weathered Precambrian rocks. Apparently the Permian or older erosion surface on which the Wajid was deposited was weathered, and the weathering products, though in part deposited in the sandstone as lenticles of clay, were not everywhere removed, and relict saprolite was preserved under the sandstone. These relations are of some importance in a consideration of the age of the gossan at Wadi Wassat.

Poorly sorted alluvium of Quaternary age mantles the floors of the wadis. It is locally cemented by limonite and hematite from the gossan. Samples of such cement can be seen at stations 7974 and 30059. Cemented alluvium, like the Wajid sandstone with ferruginous cement, has no commercial value. Moderately to well sorted eolian sand masks areas in the northeastern and southwestern parts of the area covered by figure 1.

Gossan:-- The outlines of the large gossan at Wadi Wassat are shown on figure 1, but the outlines of the gossan do not represent the actual widths and lengths of the bodies of pyrite and pyritized rocks from which the gossan was derived. The gossan consists of buff, brown, and maroon, scoriaceous to delicately banded, pulverent to hard and brittle mixtures of hematite, limonite, goethite, jaspar, chalcedony, kaolinite, and gypsum with variable, often large, quantities of relict leached argillite, andesite, diorite, granite, and rhyolite. It is developed on and from pyrite-bearing rocks and massive pyrite through the oxidation of the pyrite in the zone of weathering. The oxidation was caused by the circulation of ground water from the surface down to the pyrite. Soluble sulfates of iron and other elements were brought to the surface in the water and there precipitated as insoluble oxides and sulfates (Overstreet, 1965, p.7-9; 1966b, p.31-45). At many places the oxides are unmoved residue from which the soluble compounds have been dissolved. Data from three drill holes at the northern end of the gossan show that the gossan is 25 m to 40 m deep. There may be places where it is deeper.

Analyses of minor elements in the gossan have been made for samples numbered in the 7000 series in the southwestern half of the gossan and described by Overstreet (1965, p. 7-9), for samples between localities 30036 and 30040 (numbered 1-42) by Overstreet 1966b, table 6), and for outcrop and core samples (nos. 31000 to 31027) by Overstreet (1966b) table 8. New analyses of minor elements in surface samples of the gossan from locality 30040 near the north end of the gossan to 30063 near the road to Najran, and 30065 and 30067, west of the road, were made especially for this report by C. E. Thompson, U.S.G.S., and Mohamed Jambi, Directorate General for Mineral Resources (table 1). The results of the new analyses show that the minor elements in the gossan have a similar range in distribution throughout the full length of the gossan. Small variations in barium, chromium, copper, molybedum, nickel, tin, strontium, vanadium(?), and zinc suggest that detailed geochemical exploration over the gossan might produce a distributive pattern for the elements which could be related to the detailed surface geology of the gossan, to electro-magnetic profiles, and drill-hole data to produce a meaningful correlation with the distribution of pyrite at depth. The scale of the present map is obviously inadequate to bring out this detail. Sample 30059 shows that the trace amounts cobalt, chromium, copper, gallium, molybdenum, nickel, and tin in the gossan are carried with solutions from the gossan and precipitated with the iron oxides. This evidence for the movement of these elements, though pretty weak, gives a little encouragement that the distribution of the minor elements

Table 1. Minor elements in surface samples of gossan from Wadi Wassat, Saudi Arabia, in parts per million (analyzed by C. E. Thompson, U. S. G. S., and Mohamed Jambi, Directorate General for Mineral Resources).

Sample	B	Ba	Co	Cr	Cu	Ga	Mn	Mo	Ni	Pb
30040	50	100	20	20	<10	<10	30	5	7	-
30041	-	150	50	70	<10	15	20	10	5	-
30042	-	300	50	100	15	15	50	10	5	-
30043	-	100	50	200	50	15	200	15	20	-
30044	-	200	30	50	10	<10	150	10	10	-
30058	<10	700	50	50	10	10	50	15	15	<10
30059 a/	-	100	50	50	20	15	100	10	20	-
30060	-	50	30	30	10	10	70	20	10	-
30061 b/	-	700	50	150	20	15	1500	2	50	-
30062	-	150	30	30	10	<10	70	15	15	-
30063	-	50	70	30	30	10	50	20	15	-
30065	-	70	50	20	20	10	20	15	5	-
30067	-	300	50	50	30	10	100	10	15	-

a/ Recent wadi sediment cemented by iron oxides from gossan.

b/ Andesite with disseminated pyrite.

The following elements, and their limit of detection, were looked for but not found: Ag, <1; Be, <2; Bi, <20; Cd, <50' Ge, 20; La, <50; Nb, 50; Sb, 200; W, 50.

Table 1. Minor elements in surface samples of gossan from Wadi Wassat, Saudi Arabia, in parts per million (analyzed by C. E. Thompson, U.S.G.S., and Mohamed Jambi, Directorate General for Mineral Resources). (contd.)

Sample	Sc	Sn	Sr	Ti	V	Zn	Y	Zr
30040	<10	-	<50	1500	30	-	<10	30
30041	<10	15	70	1500	30	-	<10	20
30042	<10	15	200	2000	50	100	<10	30
30043	<10	15	50	1500	70	150	<10	20
30044	<10	10	150	2000	50	-	<10	50
30058	<10	10	50	1500	50	-	<10	30
30059 a/	<10	10	<50	1000	30	-	<10	20
30060	<10	10	<50	3000	50	-	<10	50
30061 b/	20	<10	300	2000	50	-	20	50
30062	<10	<10	50	5000	30	-	<10	70
30063	<10	20	<50	1500	50	-	<10	50
30065	<10	10	<50	1000	30	-	<10	30
30067	<10	10	<50	200	50	-	<10	20

a/ Recent wadi sediment cemented by iron oxides from gossan.

b/ Andesite with disseminated pyrite.

The following elements, and their limit of detection, were looked for but not found: Ag, <1; Be, <2; Bi, <20; Cd, <50; Ge, 20; La, <50; Nb, 50; Sb, 200; W, 50 in surface materials may help in determining the position, size, and relative tenor of the major bodies of sulfide. Sample 30061 gives some measure of the extent to which barium, barium, manganese, and nickel tend to be leached from parent materials of the gossan.

No new analytical results have been received for major elements in the gossan and its source rocks, but 18 samples of pyritic core from diamond drill hole number 1 were being analyzed for major elements to learn if the material is of an acceptable grade for commercial pyrite. Major elements in the gossan have been reported (Overstreet, 1966b, table 9).

The age of the gossan is, of course, younger than the age of the pyritic rocks from which it formed. On figure 1 the age is shown as Permian (?) to Quaternary. The highest parts of the present gossan appear to be nearly as high as the old erosion surface on which the Wajid sandstone was deposited. A reconstruction of that surface awaits adequate topographic maps and elevations to the base of the Wajid east of Wadi Wassat, but Brunton sightings from the tops of high points on the gossan to the Wajid suggest that the present highest parts of the gossan may be less than 30 m below the former base of the Wajid. Presence of saprolite under the Wajid sandstone is strong indirect evidence that a gossan was also present over the pyritic rocks at Wadi Wassat prior to the deposition of the Wajid. The flat erosional surface on which the sandstone was deposited is evidence of long exposure and erosion prior to the deposition of the Wajid. During that time it is probable that a gossan of considerable but unknown thickness developed there. After the gossan was covered by Wajid sandstone it is likely that the unconformable interface between the Precambrian rocks and the Wajid sandstone was a surface on which ground water continued to move. This ground water would have filtered into the pre-existing gossan and continued the leaching and oxidation of the pyrite, thereby extending the gossan to greater depth. Eocene(?) lateritic weathering, which reached as deep as 130 m in the As Sarat mountains only 110 km west-southwest of Wadi Wassat, seems not to have affected the rocks around the gossan; therefore, the Wajid sandstone probably covered the Precambrian rocks at that time in the Wadi Wassat area. However, if the Eocene(?) climate was notably wet, it is possible that deep oxidation proceeded then at the Wadi Wassat gossan. Unroofing of the gossan in post-Eocene(?) time brought to the surface once more a weathering product of great antiquity. Continued weathering and erosion into Recent time formed the exposures we now see. Cemented Quaternary alluvium adjacent to the gossan is proof that the process of oxidation and solution is continuing at the gossan. Inasmuch as weathering tends to bring diverse materials toward a uniform chemical composition, the postulated long continued weathering at Wadi Wassat would help explain the slight variation in the distribution of the minor elements in the gossan.

Structure:-- The andesite in the roof pendant of Precambrian layered rocks is variably cleaved. Most of the cleavage is a close-spaced fracture cleavage along which no recrystallization of minerals has occured. The fracture cleavage forms a tight fan across the andesite unit. It strikes toward the north. In the western part of the area underlain by the andesite unit the cleavage dips steeply toward the east, and in the eastern part of the area it dips steeply westward. Along the gossan west of Wadi Wassat the fracture cleavage tends to be vertical. This fan of fracture cleavage may define an anticline developed across the andesite unit. The crest line of this anticline may be at or near the gossan.

Increase in intensity of the cleavage near the gossan may reflect a vertical or sub-vertical, north-trending fault zone along the gossan with the west side of the fault zone moved relatively northward. Both the contact between the granite and the andesite north of the gossan and the contact between andesite and diorite south of the gossan have the appearance of being offset along such a zone, but the present mapping is not detailed enough to prove the offset, although there is evidence that the pyritized rocks under the gossan are in a fault zone. The faulting would have to have taken place after the diorite (di) and biotite granite (b) were crystallized and before the syenite porphyry (p) was intruded, because the granite and diorite are inferred to be offset and the syenite porphyry crosses the postulated fault zone without offset. The syenite porphyry occupies west-northwest-trending faults along which the postulated northerly fault zone is offset.

The rhyolite (r) which intrudes the andesite unit is interpreted here to have been emplaced in the north-trending fault zone at the crest of the anticline during the last stages of the faulting. Parallel faults on the east and west flanks of the anticline were also occupied by rhyolite (r) related to the biotite granite (b). Shears and fractures in the rhyolite dikes parallel to their walls are evidence that the dikes were emplaced while the faulting was under way.

The west side of the sericite-chlorite schist unit is strongly sheared by a north-northeast-trending fault zone which is offset by prominent northwest-trending faults along which the north side moved relatively northwestward. Movement on the north-northeast-trending fault appears to follow the same plan as on the north-trending, rhyolite-bearing faults in the andesite, but rhyolite is absent in the fault in sericite-chlorite schist except the dikes north of station 30014 in the northern part of the mapped unit, and it is not certain these dikes are in the fault. Dacite (da) follows this fault direction. No mineralization was seen on this north-northeast trending fault. However, a strong north-trending fault zone, which lies 6 km west of the area covered by figure 1, is mineralized (see below).

Minor overthrust faults that strike east and dip 15° to 20°S. with the upper block moved relatively north are the loci of some low-grade gossan in granite (b) and diortie (di) around stations 7974, 7980, and 30066 west of the Najran road. The relations of these faults are obscure. They are in a composite pluton near its contact with layered rocks. Possibly the faults were formed by outward movement of the wall of the pluton when later phases of the magma series (pyroxene granite and quartz porphyry) were intruded into the consolidated, or marginally consolidated, pluton.

The long N.25°W.-to northwest-trending faults on the west side of the area of figure 1, and mentioned above, are younger than the faults that strike north and north-northeast. They are also younger than the dacite (da), but they seem to be penecontemporaneous with the diabase (d) and pyroxene rhyolite (pr) dikes.

Faults that strike about N.70°W. display the same relative movement as the long northwest-trending faults: the northern block moved relatively westward. These faults, which in many places are filled by syenite porphyry, are younger than the faults that strike toward the northwest. They are the latest faults along which igneous activity proceeded, but they are unmineralized.

Faults younger than the Wajid sandstone are present in the region (Brown and Jackson, 1959), but none was certainly identified in the area of figure 1. Where they have been seen south of this area, they are unmineralized tension fractures.

The direction of strike of the faults along which dikes occur in the area of figure 1 tends to be rotated increasingly westward with decreasing age of the fault. Only the dacite-bearing fractures that strike N.20°E. in the western part of the area do not fit the pattern. Thus, the oldest rhyolite (r) - bearing faults strike north, the diabase (d)- and pyroxene-rhyolite (pr) - bearing faults strike N.25°- 45° W., and the youngest syenite porphyry (p) - bearing faults strike N.70°W. These directions are regional in the Asir quadrangle; therefore, they are related to regional instead of local deformation. Except for the minor overthrust faults, mineralization is restricted to the faults that strike north.

The minor overthrusts seem to be related to a local intrusive feature. They may be developed by movement on primary flat-lying fractures in the pluton.

The steep fracture cleavage fan in the roof pendant of andesite may be the result of a push from below, and the probable anticline it defines is a bend fold caused by the intrusion of granite under the andesite. These structures are interpreted to mean that the pluton of biotite granite (b) on the northeastern margin of the pendant merges at depth with the body of biotite granite (b) on the southwestern margin of the pendant. Both masses of granite are transgressive with respect to the diorite (di); therefore, probably more granite than diorite is under the pendant.

Origin:-- The origin of the gossan was discussed under the description of the gossan given above, where it was shown that the gossan is the product of long-continued weathering of pyrite-rich rocks. A more fundamental and difficult problem is the origin of the pyrite.

The pyrite under the Wadi Wassat gossan appears to the writer to have been deposited as a hydrothermal replacement mineral. Some of the evidence was presented by Overstreet (1966b, p. 31-45). Additional reasons for this interpretation are listed below.

The eastern half of the pyritized zone follows a regional fault zone at the crest of an anticline in a roof pendant of andesite in granite and diorite. The full pyritized zone occurs in diverse rocks: andesite, graywacke, argillite, diorite, biotite granite, and rhyolite. Pyritized zones have been found in low-angle overthrust faults in diorite and granite (stations 7974, 7980, and 30066). The large N.70°W. - striking fault south of drill hole number 1 is said (W. E. Davis and Rex Allen, oral communication, 1966) to be mineralized southeastward beyond any possible drag of pyrite into the fault plane from the principal pyritized zone. A small gossan in andesite north of station 30040 cuts across the andesite. Small gossans southwest of station 7980 and at station 30031 are in sericite-chlorite schist. Small gossans south of station 30066, southeast of station 22000, and east of station 22984 are in pyroxene granite. Gossan is present in pyritiferous rhyolite (r) at station 30034. Pyrite and gossan are present in granite at station 30037 and 30039.

The pyrite replaces the host rocks and preserves delicate features in them. Small cracks in the host rocks, as well as large fissures, are filled with pyrite.

The wall rocks, particularly the andesite, are hydrothermally altered adjacent to the pyritized areas. Andesite is bleached to a pistachio yellow-green color as far away as 20 to 40 m from the margin of the gossan. This alteration is quite variable. It is best seen in the vicinity of diamond drill hole number 1.

The period of possible emplacement of the pyrite is very narrowly restricted by the sequence of geologic events as presently interpreted for the Wadi Wassat area. Differentiation and emplacement of the per-alkalic magma series was well along before the pyrite was introduced, but the pyrite is thought to be genetically related to the per-alkalic magma series because of its close spatial and temporal relations to it and because accessory magnetite from pyroxene granite of the per-alkalic series (Overstreet, 1966b, p.5) tends to have high anomalies in molybdenum as does the pyrite from drill hole 1 at Wadi Wassat (Overstreet, 1966b, table 8).

The diorite (di) and biotite granite (b) in the per-alkalic magma series at Wadi Wassat are interpreted to have been emplaced as a composite pluton with the granite being younger than the diorite. Emplacement of these rocks arched the roof pendant of Precambrian layered rocks creating a fan of fracture cleavage the most intensely fractured parts of which were a zone along the crest of the anticline and zones near the east and west margins of the pendant. The central fractures were also a zone of faulting on which the west side moved relatively north after the granite was consolidated but while rhyolite (r) was being emplaced. Very minor dikes of granite, pegmatite, and felsite were introduced, followed by intrusion of the pyroxene granite.

During differentiation and emplacement of the pyroxene granite sulfide-rich hydrothermal solutions rising along the apical fracture zone in the roof pendant replaced rock materials with pyrite. Subsidiary fractures leading westward into the composite pluton of diorite and granite exposed southwest of the pendant were also widely pyritized. Small displays of pyrite, or gossan formed on pyrite, in pyroxene granite intrusive into the composite pluton can be seen west of the Najran highway. It is thought that the period of magmatic differentiation producing the pyroxene granite is the period of formation of the pyrite, because pyroxene granite is the youngest of the rocks having abundant pyrite. Pyrite-free diabase is present in the gossan just west of station 7985 and the syenite porphyry dikes are barren of pyrite. However, at many places outside the area of figure 1 the rhyolite (r) thought to be related genetically to the biotite granite (b) is pyrite bearing, as are some granite, pegmatite, and felsite dikes (g). It would appear that release of a sulfide-rich hydrothermal fluid from the differentiating per-alkalic magma began with the rhyolite (r) phase and peaked in the pyroxene granite (pg) phase.

The possibility exists that the interface berween the arch of andesite in the pendant and the top of the composite pluton of diorite and granite formed a trap under which only part of the sulfide minerals migrated to the present surface of exposure. The areal distribution of gossan, increasing as it does toward the exposed contact between the southwestern edge of the roof pendant and the diorite and granite, is encouraging to this possibility. Methods that might be used to search for possible hidden sulfide masses are given below under exploration.

The possible presence of sulfide minerals in the extension east of the gossan of the fault that strikes N.70°W. south of drill hole number 1 (W.E. Davis and Rex Allen, oral communication, 1966) poses a problem with the genetic interpretation given above. The fault is younger than the inferred period of pyritization, and movement along it offsets the north-trending pyritized zone. Perhaps it means a second mineralization is present. Possibly the gossan between stations 7985 and 7990 is developed over sulfide minerals of the same generation. Much more needs to be done with the problem.

Size and exploration

The presently known gossan at Wadi Wassat has an aggregate length of 17 km, but the total length of sulfide bodies underlying the gossan is unknown. Their total length is unknown because the gossan blankets the exposures to a depth of 25 to 40 m, and the distribution of the pyrite-bearing zones below the gossan cannot be determined by surface geologic mapping at a scale of 1:50,000. The minimum aggregate length of the sulfide-bearing bodies under the gossan may well be greater than the length of the gossan. Detailed ground geophysical methods empolying electro-magnetic techniques to measure the conductivity of the rocks appears capable of defining the pyritized zones under the gossan (W.E. Davis and Rex Allen, oral communication, 1966), but diamond drilling is the only way to get a direct measure of the thickness and tenor of the pyritized rocks. With a mineralized zone of such great size, some kind of surface exploration must be used to guide drilling. The following procedures are recommended:

1. A topographic map of the area of the gossan be prepared photogrammetrically at a scale of 1:2,500 with a contour interval of 5 meters and a supplemental contour in the flat areas of 2-1/2 m. This is a revision of my original request of May 8, 1965, when I recommended 1:10,000 scale and a 10 m contour interval. The larger scale of 1:2500 is mandatory to give map space to plot the details of surface geology, geochemistry, geophysics, and drill hole

data to provide adequate guides for exploration. Copies of the 1:2,500 scale topographic map could be reasonably enlarged or reduced for other work. Vertical and horizontal control for the area was completed in the field during February and March 1966 by Gene Harbert and Thomas Taylor, U.S.G.S., and Peter Curtis of the Directorate General for Mineral Resources. The control thus established is adequate for photogrammetric compilation at 1:2,500 scale with 5 m contours and 2-1/2 m supplemental contours. Photogrammetric compilation should be done by an engineer with geologic training who can add the dikes visible on the photographs to the map.

2. Detailed geologic mapping of the gossan area at 1:2,500 scale to show the surface variations of the gossan and the wall rocks.

3. Detailed geochemical study at 1:2,500 scale to accompany the geologic mapping. In addition to the elements for which analysis has previously been made, it is recommended specifically that determinations of tellurium and mercury be added. It is hoped that the distribution of tellurium, which belongs to the same subgroup as sulfur in the Periodic System, and other elements will give a subdued reflectance of the distribution of the pyrite even after the long continued weathering the deposit has undergone.

4. Ground electromagnetic survey and ground gravity survey.

5. Integration of the data from 2-4 with data from holes already drilled to spot the most favorable locations for further drilling.

As of March 1966 the eastern part of the gossan having an aggregate length of 7.7 km between stations 30036 and 30063 had been examined by ground electromagnetic methods (Rex Allen, oral communication, 1966). Further EM work is necessary in the areas between stations 7990 and 7984, between 7976 and 7974, and around stations 7988, 7986, 30066, and 22000. From surface exposures the most favorable of these areas are, in order of interest: (1) 7990 to 7984, (2) the two gossan around 7988 and 7986, and (3) the gossan at 22000. Possibly six weeks of work is needed.

As of the same date the only geologic mapping and geochemical sampling in the Wadi Wassat area is that shown here on figure 1, and discussed in this and previous reports. Geologic mapping and geochemical sampling at 1:2,500 scale should be done. By restricting the mapping to a strip along the gossan about 2 km wide, the work could be performed in four months.

Three diamond drill holes have been sunk at the northern end of the gossan. At least two, and possibly three, more holes will be needed to evaluate the pyrite at that end of the gossan.

Possible hidden sulfide deposits, not expressed at the surface of the ground by gossan, might be sought, by a combination of detailed geologic and geochemical mapping with emphasis on rock alteration, and variations in mercury, tellurium, barium, chromium, copper, molybdenum, nickel, tin, strontium, vanadium (?), and zinc, and geophysical methods using ground and airborne electromagnetics and ground gravity surveys.

Other gossan between Bi'r Idimah and Jabal Ashirah

Gossan is exposed at other localities between Bi'r Idimah and Jabal Ashirah, but none of the exposures is as large as the one near Wadi Wassat. Pyrite is the principal source of the iron oxides in all the gossan. Copper is very sparse.

Locality north of Bi'r Idimah

The south end of a discontinuously exposed gossan about 2000 m long crops out 1.8 km N.40°E. of Bi'r Idimah. The gossan is in porphyritic biotite granite and pyroxene granite within 200 m of the contact between the intrusive granites and a mass of diorite lying east of them. The diorite and both granites are part of the per-alkalic magma series found in the Wadi Wassat area, and in many respects the Bi'r Idimah gossan resembles that at Wadi Wassat. The Bi'r Idimah gossan is 11.5 km due north of the Wadi Wassat gossan, and may be said to be along the direct projection of the part of the Wadi Wassat gossan east of the Najran road. The area between the two gossan is biotite granite largely covered by wadi alluvium and eolian sand. A search by truck and aircraft failed to disclose exposures of gossan between that northeast of Bi'r Idimah and that at Wadi Wassat.

At the southern end of the Bi'r Idimah gossan, red porphyritic biotite granite is intruded by north-trending dikes of rhyolite grading into felsite. These rocks are fractured along faults striking N.30°W. and dipping 70°E. Hydrothermal solutions introduced pyrite along these fractures. The rhyolite and felsite dikes seem to have been more readily replaced by pyrite than the wall rocks, possibly because the dikes were more brittle and more fractured than the granite. Up to 12 or 15 percent disseminated pyrite is present in the rhyolite and felsite, but none was seen in the granite. Weathering of the pyritiferous rhyolite, possibly under way even when it was roofed by Wajid sandstone, has led to impregnation of limonite and goethite along small cracks in all the rocks. Acid water from the oxidizing pyrite has produced extensive leaching of the wall rocks. No copper stain is present.

Individual rhyolite and felsite dikes are 2 to 12m thick, and they are spaced over a zone about 200 m wide. Gossan is very irregular, both along and across strike. Pyrite grains are individually less than 0.1 mm across, but little veinlets and fracture fillings consist entirely of pyrite. Cubes of pyrite up to 3 mm across are present in felsite and quartz porphyry into which the rhyolite grades, but these rocks seldom contain as much as 1 percent of pyrite, and much of that pyrite is in vugs and masses of quartz in cracks in the felsite and porphyry.

At its northern end the gossan is about 400 m wide and is in sheared porphyritic pyroxene granite and diorite. The highest point on the ridge forming the northern end of the gossan, and thus the closest point to the formerly overlying Wajid sandstone, is capped by scoriaceous, tubular-textured very pure limonite 1 to 3 m thick. The tubular texture is interpreted to show that the limonite was deposited in moving water.

Four samples from the gossan were analyzed spectrographically by C. E. Thompson, U.S.G.S., and Mohamed Jambi, Directorate General for Mineral Resources with results (table 2) that resemble closely the distribution of trace elements in the wadi Wassat gossan, except for the anomalous Be, La, Y and Zr in sample 30000. This anomalous sample is from the east edge of the gossan at its southern end in porphyritic biotite granite. Anomalous beryllium, lanthanum, yttrium, and zirconium has been detected at other places in Saudi Arabia in the per-alkalic granites, but they have not previously been reported from the southern part of the Precambrian Shield in Saudi Arabia. No unusual enrichment in allanite or zircon was noted in the field; thus, the actual source of these elements is not known.

Further geochemical and geological study of this gossan should be made. Ground electromagnetic and radiometric surveys should also be made of it. One man-month should be sufficient to prepare a plane-table geologic map of the deposit, collect samples for analysis, and perform the geophysical surveys.

Table 2. Minor elements in surface samples of gossan exposed 1.8 km northeast of Bi'r Idimah, Saudi Arabia, in parts per million (analyzed by C. E. Thompson, U.S.G.S., and Mohamed Jambi, Directorate General for Mineral Resources).

Element	Sample numbers			
	22998	22999	30000	30002
Ba	100	200	20	300
Be	-	-	2	-
Co	50	50	70	70
Cr	30	70	10	20
Cu	15	20	30	30
Ga	10	10	10	10
La	-	-	70	-
Mn	100	100	300	50
Mo	15	10	30	20
Ni	5	10	10	10
Sc	<10	10	<10	<10
Sn	10	10	20	15
Sr	50	150	<50	<50
Ti	700	1000	1500	1000
V	20	50	50	30
Zn	-	-	-	-
Y	<10	<10	30	<10
Zr	20	20	1000	20

The following elements, and their limit of detection, were looked for but not found: Ag, <1; B, <10; Bi, <20; Cd, <50; Ge, 20; Nb, 50; Pb, <10; Sb, 200; W, 50; Zn, <100.

Exposures in Wadi Talham

Three exposures of gossan are provided by the steep eastern wall of Wadi Talham near a sharp bend in the wadi about 8.5 km due west of the southwestern end of the Wadi Wassat gossan. The most spectacular of the three exposures is the one (18°19' 30"N.x 44°04'15"E.) farthest to the west where the wadi curves southward. Strong bright yellow and red crusts occupy an area more than 50 m wide and 600 m long in sheared and pyritized graphitic slate, rhyolite, and sericite schist, in which a vertical cleavage strikes N.10°E. Copious melanterite is in the crusts on the leached rock, but limonite is estimated to make up less than 15 percent of the gossan. The balance is kaolinite, rock detritus, and leached rock residuals. A spectrographic analysis material from the gossan (sample 22991) was made by C. E. Thompson, U.S.G.S., and Mohamed Jambi, Directorate General for Mineral Resources, with the following results:

Element	Abundance (parts per million)
Ba	70
Co	50
Cr	70
Cu	15
Ga	10
Mn	100
Mo	10
Ni	15
Sc	<10
Sr	100
Ti	2000
V	30
Y	10
Zr	50

The sample lacks the small amount of tin that is found in Wadi Wassat gossan, but it is otherwise indistinguishable chemically from Wadi Wassat gossan.

Two hundred meters to the east of the above gossan, and nearly parallel to it, graphitic slate and sericite schist with sills of rhyolite up to a meter or two thick have a veneer of gossan about 4 m wide in an area of the rhyolite. The gossan is intermittently exposed along strike (N.25°E., dip 80°NW.) for 150-200 m. The gossan consists of copious red and yellow stains but there is no thick accumulation of limonite. From 5 to 8 percent of fine-grained pyrite is present in the rhyolite, and the slate has about 1 percent of fine-grained pyrite. Oxidation of this pyrite formed the gossan.

Southeastward about 300 m across Wadi Talham a similar gossan is present in sericite schist and pyritiferous rhyolite sills. It extends southward for several hundred meters. Elsewhere in this part of Wadi Talham pyrite-bearing rhyolite dikes or sills are brightly colored by the oxidation products from the pyrite. None of these occurrences except the larger one mentioned first justifies any further work. However, at the gossan from which sample 22991 was taken about one man-week of combined geologic mapping, geochemistry and electromagnetic surveying should be done to determine the characteristics of the Wadi Talham gossans.

Localities near Bi'r El Avahbat

Bi'r El Avahbat (18°09'N.x 44°06'E.) is in Wadi Avahbat 20 km northwest of Jabal Ashirah and about 32 km west of the Najran road. At least 20 separate exposures of gossan are along the walls of the wadi and in adjacent hills southeast of the well, and at least 15 separate exposures of gossan are upstream to the northwest along the wadi from the well. The source of the gossan at each of the exposures is pyrite-bearing rhyolite in massive, unmetamorphosed to slightly metamorphosed andesite and sparse argillite. In both localities the rhyolite appears to occur as dikes and sills, which seem to be folded with the andesite. No copper stains were seen, nor were other sulfide minerals than pyrite identified; however, several samples (22968-22971, 22973-22974) from the southeastern end of the gossan have greater trace amounts of copper (table 3) than have been found in gossan in the Bi'r Idimah-Wadi Wassat area. Spectrographic analyses by C. E. Thompson, U.S.G.S., and Mohamed Jambi, Directorate General for Mineral Resources, also show than gossan near Bi'r El Avahbat contains more barium, chromium, and strontium, and less molybdenum and tin than the gossan at Bi'r Idimah and Wadi Wassat. It is not known what factors control these differences, but they seem more likely to be caused by difference in geologic age or regional variation in the composition of the pyrite-bearing rhyolite from which the gossan formed than to any difference in the kinds of sulfide minerals in the unweathered rocks under the gossan.

Southeast of the Bi'r.

The numerous outcrops of gossan southeast of Bi'r El Avahbat are exposed over a length of 3 km, the northernmost exposure being about 1 km south of the well. On the eastern side of the southern end of these exposures a practically unmetamorphosed sequence of andesite and argillite with sills or beds of rhyolite strikes N.70°W. and dips 40°S. with a strong vertical fracture cleavage striking N.30°E. The beds are right-side up. Shear zones trending N.70°E. and dipping 60°S. are copiously stained with limonite, and pyrite-bearing gray rhyolite beds or sills are also conspicuously stained with limonite. The pyrite occurs as disseminated grains up to at least 2 mm across, but they are generally only about 0.5 mm across. This pyrite appears to be later than the rhyolite, to replace it, and to fill tiny cracks in it. About 5 to 10 percent of pyrite is present in the rhyolite, but the andesite associated with the rhyolite is essentially barren of pyrite and has no heavy limonitic stain.

The limonitic stain forming this gossan occurs principally in fractures downslope from the pyrite-bearing rhyolite. It seems to have been produced by the oxidation of iron sulfate carried downslope in solution by rain water moving downward in the fractures. The iron oxide thus produced precipitated where it formed. Pyrite upslope was the source of the iron sulfate. Limonitic stain in the rhyolite consists of crusts a few millimeters thick in fractures. Under the crust the rhyolite is fresh and the pyrite is unweathered. Where the rhyolite is less than a meter thick and is intensely fractured it is deeply weathered, but thick deposits of limonite, hematite, and jasper are lacking.

On the western side of the southern end of the gossan southeast of Bi'r El Avahbat, about 300 m east of the eastern groups of exposures, strongly developed gossan crops out in a small basin. This gossan can be seen at 18°05'30"N.x 44°06'36"E.

Table 3. Minor elements in surface samples of gossan from the Bi'r El Avahbat area, Saudi Arabia, in parts per million (analyzed by C. E. Thompson, U.S.G.S., and Mohamed Jambi, Directorate General for Mineral Resources).

Sample	Ba	Co	Cr	Cu	Ga	Mn	Mo	Ni	Sc	Sn	Sr	Ti	V	Y	Zr
22967	200	20	150	20	<10	500	2	30	10	10	200	1500	50	10	50
22968	500	30	200	70	15	30	7	20	30	<10	500	2000	50	15	50
22969	300	50	50	70	10	30	7	20	20	-	300	2000	50	10	50
22970	300	70	200	100	10	100	10	50	20	-	300	2000	50	15	50
22971	200	70	150	100	10	100	15	50	20	10	200	2000	50	15	50
22972	200	50	200	30	10	50	10	15	15	10	200	2000	50	10	50
22973	300	70	300	150	15	200	5	70	20	-	200	2000	70	20	50
22974	100	50	100	100	10	100	5	30	20	-	200	2000	50	15	50
22975	300	50	30	20	10	30	20	20	20	10	200	2000	30	10	50
22976	500	30	150	20	10	100	10	15	15	-	300	2000	50	10	50

The following elements, and their limit of detection, were looked for but not found: Ag, <1; B, <10; Be, <2; Bi, <20; Cd, <50; Ge, 20; La, <50; Nb, <50; Pb, <10; Sb, 200; W, 50; Zn, <100.

on the 1:50,000 scale mosaic sheet 8F. The eastern part of the basin floor exposes flat outcrops of yellow (22967, table 3) to red, weathered, andesite and rhyolite, with the darker colors over the rhyolite (22968, table 3). From these exposures, which extend about 100 m southward and vary in width between 8 and 50 m, an unstained area reaches westward 360 m to a second band of gossan which is about 3 m wide, irregularly exposed, and may extend southward for several 100 meters (22969, table 3). Two hundred-twenty meters farther west a third zone of gossan crops out. It forms the base and lower slopes of the east side of the westernmost hills bordering the basin. This gossan consists of limonite and hematite-stained fractures in weathered, pyrite-bearing, brecciated rhyolite. The gossan extends at least 250 m to the north and 400 m to the south of the basin, and it is up to 15 m wide. There are no heavy limonite ledges, but this zone is the largest in the southern end of the group. Sample 22970 of table 3 is from it. About 60 m farther west, and upslope, a fourth band of gossan (22971, table 3) is formed on fractures in rhyolite 4 to 10 m thick and possibly 400 m long. Seven meters farther upslope a fifth layer of altered rhyolite is exposed. It is 1 to 2 m thick and a few tens of meters long (22972, table 3). At a distance of 2-1/2 to 3 m farther upslope a lenticular mass of altered rhyolite is interbedded with argillite, graywacke, and andesite. This lenticle is possibly 3 m thick and 20 m long. It is so closely brecciated and thoroughly altered to argillaceous material impregnated with iron oxides that it was not possible to identify the parent rock, but it is interpreted to have been pyrite-impregnated rhyolite (22973, table 3). Interestingly, it is the most thoroughly altered rock in the Bi'r El Avahbat area, and it was the source of the highest value for copper in gossan from the whole Bi'r Idimah-Jabal Ashirah area. Along the crest of the ridge just west of this altered rock, the local metamorphic grade increases, and the rocks become sericite-chlorite phyllite with well developed foliation at N.30°E. 45°NW. Possibly this foliation and local rise in metamorphic grade takes place along a fault.

Copper stains are absent, and no other sulfide than pyrite was seen. The gossan in the floor of the basin has a few small pits from which Bedouin have collected salts, probably mainly copperas.

About a half kilomter northeast of these occurrences, and on the steep south wall of Wadi Avahbat, gossan represented by sample 22974 in table 3 is exposed. The gossan is formed on fractured gray rhyolite with 3 to 8 percent of disseminated very fine-grained pyrite which apparently replaces the rhyolite, because it fills thread-like fissures in the rhyolite. At least five sills or flay-lying dikes of rhyolite up to 2 m thick are interlayered with andesite in the wall of the wadi. Each body of rhyolite is stained with crusts of limonite and melanterite, but such stains are not on the andesite. From this locality intermittent exposures of pyrite bearing, limonite-stained, rhyolite in andesite extend along the southern wall of Wadi Avahbat for 1.6 km northwestward whence they swing northward for 1.2 km on the east side of the wadi. Most likely these intermittent exposures are on a continuous swarm of thin rhyolite sills which follow folds in the andesite. Sample 22975 in table 3 is from gossan developed on north-trending, pyrite-bearing rhyolite exposed 0.6 km south of the northern end of the gossan south of Bi'r El Avahbat.

Northwest of the Bi'r.

A group (18°10'N.x 44°04'30"E.) of at least eight exposures of gossan cluster in the low hills north and south of Wadi Avahbat about 3 km N.70°W. from Bi'r El Avahbat; two exposures are south of the wadi 1 to 1.3 km east of the cluster; and five exposures of gossan are from 1 to 2.5 km north and northwest of the cluster. The exposed widths of individual bodies of gossan are from 4 to 20 m vary up to several hundred meters. The gossan appear to be developed on rhyolite and andesite hydrothermally altered to a tough, porous argillaceous material with maroon iron oxide stains along fractures. No heavy limonitic gossan is present. Sample 22976, table 3, is from the main cluster of gossan south of Wadi Avahbat. It does not contain as much copper as the gossan southeast of the Bi'r.

Exploration.

The gossan southeast and northwest of Bi'r El Avahbat are the second largest known in the Bi'r Idimah-Jabal Ashirah area, and at their southeastern end have a very slight positive copper anomaly. It is recommended that geologic mapping at about 1:5,000 scale be done to work out the relations of the gossan. At the same time they should be sampled geochemically and assays for precious metals should be made. The results of this survey should be used to pinpoint localities for detailed ground electro-magnetic geophysical studies. One man-month would be required to do the geologic mapping and geochemical sampling, and about a man-month would be needed for the geophysical survey.

Minor pyrite

Minor occurrences of pyrite lacking gossan were observed at stations 22977 (18°12'N.x 44°03'E.), 22994 (18°28'N.x 44°07'E.), and 30010 (18°33'N.x 44°04'E.) in the Bi'r Idimah-Jabal Ashirah area. At 22977 deformed sericite-chlorite schist and graphite schist derived from pyroclastic rocks, possibly rhyolitic ash, and carbonaceous shale, contain about 0.5 percent of pyrite in small disseminated cubes. Despite the weathering of pyrite to limonite pseudomorphs, gossan has not formed. Fine-grained red biotite granite at station22994 contains less than 0.5 percent of tiny, disseminated cubes of pyrite. Massive pink pyroxene granite at station 30010 has inclusions of biotite granite and andesite. Sparse accessory pyrite is present in the biotite granite but not the pyroxene granite or andesite. None of these occurrences of pyrite requires any further study, because they are not associated with mineral deposits.

Other mineral occurrences in the Bi'r Idimah-Jabal Ashirah area

Some previously unreported mineral occurrences and industrial rocks in the Bi'r Idimah-Jabal Ashirah area are listed in table 4. Only the building stone has possible use.

Composition of marble from the Asir quadrangle

Many occurrences of marble were listed in previous reports (Overstreet, 1965; 1966a; 1966b) on mineral occurrences in the Asir quadrangle, and megascopic estimates of the probable purity of the marble were given. Analyses of 22 samples of Precambrian marble from the area of the Asir quadrangle have recently been completed by Jamal Sumbul in the Chemical Laboratory of the Directorate General for Mineral Resources, Jiddah. The results of these analyses are given in table 5. Most of the

Table 4. Previously unreported mineral occurrences in the Bi'r Idimah-Jabal Ashirah area, Saudi Arabia.

Locality	North latitude	East longitude	Comment
			Quartz-magnetite vein
22943	18°08'	44°17'	Rare, thin, quartz-magnetite veins in syenite.
			Quartz-ankerite veins and quartz-chlorite veins
22977	18°12'	44°03'	White quartz veins with chlorite and ankerite occur as metamorphic differentiation products in sericite-chlorite schist and graphite schist. No sulfides, but ankerite forms limonite stains.
30014	18°24'	44°11'	Quartz-ankerite veins in faults in chlorite schist with interlayered lenticles of marble. No sulfide minerals.
30053	18°22'	44°14'	Quartz-chlorite-calcite veins cement fault breccia in andesite. No sulfides.
			Garnet
22951	18°07'	44°12'	Up to 5 percent almandine in biotite-almandine skarn interlayered with biotite-hornblende schist. Almandine grains are up to 4 mm across, clear but fractured, of no value.
			Allanite
22979	18°15'	44°14'	Pyroxene-bearing, red, orthoclase-rich pegmatite contains scattered accessory allanite in crystals up to 7 mm across. Float. Source not found.

Table 4. Previously unreported mineral occurrences in the Bi'r Idimah-Jabal Ashirah area, Saudi Arabia. (contd.)

Locality	North latitude	East longitude	Comment
			Building stone
22983	18°17'	44°10	Porphyritic, medium-grained, biotite granite which would make a good building stone is easily accessible from the Tathlith-Najran road. However, porphyritic texture would make it undesirable for monumental stone, and rather close joints mean that monoliths could not be quarried, although high dome on south side of small wadi at this locality possess otherwide satisfactory quarrying character.
30021	18°28'	44°15'	Pink, quartz-rich, biotite granite of even, medium grain, most feldspars being 2 to 6 mm long and the quartz generally 3 to 5 mm across, is free from dikes and inclusions. Joints and dome-like exposure make this rock suitable for quarrying. It could be used for building stone, including ashlar, dimension stone, and monumental stone.
			Marble
22953	18°10'	44°08'	Silicified dolomitic marble in masses up to 12 m thick and of unknown length interlayered with andesite and agglomerate.
22987	18°22'	44°10	Rare,thin lenticles of brown silicified marble in sericite-chlorite schist.

Table 4. Previously unreported mineral occurrences in the Bi'r Idimah-Jabal Ashirah area, Saudi Arabia. (contd.)

Locality	North latitude	East longitude	Comment
			Marble (contd.)
22988	18°22'	44°09'	Gray to brown, thinly layered, ferruginous marble bed 8 m thick exposed intermittently along strike for at least 3 km in sericite-chlorite schist. Too ferruginous for industrial use.
30014	18°24'	44°11'	Marble beds up to 1/2 m thick and 200 m long in chlorite schist.
30027	18°24'	44°12'	Gray to brown, siliceous and ferruginous marble in layers 10 to 20 cm thick and of unknown length in chloritized andesite and andesite porphyry.

samples of marble proved to be more siliceous and argillaceous than was thought from field estimates. None of the samples is rich enough to CaO to be used for Portland cement and most have too much MgO for that use. At least seven of the bodies of marble have compositions within the range of composition of natural cement rocks used to make Roman cement and quick-setting cement. These are identified in table 5.

Jabal Ashirah zoned pluton

The geology of the Jabal Ashirah zoned circular pluton was previously commented upon (Overstreet, 1965). Further work was done at the pluton during this trip to select the most suitable places to collect rocks for age determination. From this work it was possible to distinguish the following members of per-alkalic magma sequence: gabbro, diorite, porphyritic biotite-quartz granite, granite porphyry, pegmatite, felsite porphyritic pyroxene-biotite granite, pyroxene granite, and cognate inclusions in the biotite granite. Samples of these rocks were taken with the help of Richard Reesman, U.S.G.S., with the hope that the mineral grains in the rock will be fresh enough for use in an isochron plot. If these samples can be satisfactorily dated, and the samples of dikes from the Wadi Wassat area can be dated, it should be possible to determine within reasonable limits the age of the pyrite at Wadi Wassat and to determine the period of time involved in the differentiation of the per-alkalic magma series

Traverse from Najran to Zahran al Yemen

The new road from Najran (17°30'N.x 44°13'E.) to Zahran al Yemen (17°40'N.x 43°28°E. gives access to a potentially mineralized area which is otherwise quite difficult to reach. The route crosses a belt of chlorite-serict schist, slate and andesite (Brown and Jackson, 1959) whose stratigraphic relations are important to an interpretation of the geology of the Asir quadrangle (Overstreet, 1966a, p.6-7). A traverse was made across the road on March 2, 1066. Considerable difficulty was experienced in plotting the route on the 1:500,000-scale geologic map of the Asir quadrangle owing to generalizations in the shaded relief. However, enough evidence of hydrothermal alteration in schist and slate was found to suggest that the area be given further attention for possible ore deposits. The most practical type of exploration would be by helicopter from camps set along the new road. Gasoline for the helicopter could be drawn from

Table 5. Major elements in Precambrian marble from the area of the Asir quadrangle, Saudi Arabia, in percent (analyses by Jamal Sumbul, Directorate General for Mineral Resources).

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	CO_2
7564	14.44	11.4	1.1	27.0	5.99	1.6	38.6
7587	15.76	13.6	3.2	25.8	5.53	1.1	37.01
7742*	23.48	11.6	1.0	26.4	3.3	0.98	35.05
7933	51.66	13.01	3.5	5.1	7.4	1.1	28.36
22377	2.04	1.8	0.4	48.0	3.1	0.5	41.6
22381	33.1	3.3	1.1	30.6	0.9	0.92	26.97
22487A	7.6	2.5	0.57	35.4	9.6	1.2	41.7
22512A	72.4	2.4	0.50	10.2	1.9	1.97	12.8
22526A	7.8	6.6	0.2	36.1	8.4	1.05	38.8
22693A	11.8	0.4	3.4	40.7	3.1	2.5	36.1
22724A	36.7	6.1	2.2	22.1	2.7	1.95	26.8
22728A*	14.6	2.7	0.5	43.5	1.3	2.5	48.2
22746*	11.2	4.4	1.1	36.4	8.1	1.03	40.4
22753*	14.6	4.9	1.07	34.4	7.4	0.5	36.2
22756	7.94	3.04	0.7	28.8	16.7	0.4	41.5
22763A*	16.4	4.09	1.5	40.0	3.03	0.2	36.4
22805*	12.9	3.3	0.5	27.4	15.9	0.93	32.2
22896	5.5	3.1	0.5	30.0	16.4	0.8	43.7
22914*	13.8	7.6	0.51	43.0	2.8	0.68	35.1
22919A	20.26	3.6	0.7	43.2	0.5	0.69	33.7
22934	6.6	14.0	0.6	24.5	16.7	0.6	43.5
22935	7.1	4.3	1.0	26.6	16.5	0.6	43.8

* Within range of composition of natural cement rocks

the airport at Najran, and the trips driven to bring in aviation fuel could be used to re-supply automotive gasoline, water and maintain liaison with the Ministry's Beaver or Otter aircraft. Investigation of the area opened by the new road would take about three months. It should be given a lower priority than investigations of the Escarpment.

Possible stratigraphic relations between slate and andesite

The geologic map of the Asir quadrangle (Brown and Jackson, 1959) shows a broad unit of slate, felsite, and quartzite (sl) overlain successively by chlorite-sericite schist (sc) which is carbonaceous and quartzose, and by andesite and meta-andesite (sb) northwest of Najran. These units are the southern end of the Hamdah ultra-basic belt which passes northward through the west side of the area shown on figure 1 in this report. At Zahran al Yemen the andesite and meta-andesite appears to close around the southward plunging nose of the gneissic batholith forming the central core of the Asir quadrangle (Brown and Jackson, 1959). West and northwest of Zahran al Yemen and Khamis Mushayt the andesite and meta-andesite (sb) give way to immense tracts of greenstone (g) interpreted by Brown and Jackson to be younger than the slate (sl), chlorite-sericite schist (sc), and meta-andesite (sb). Correlation of the units east of Zahran al Yemen with those west of Khamis Mushayt, and a resolution of the stratigraphic position of the slate (sl) and chlorite-sericite schist (sc) between Najran and Zahran al Yemen would assist in an interpretation of the geologic history and chronology of mineral deposits in the area.

The route of the new road northwest of Najran discloses that the dominant dip of bedding in andesite and meta-andesite (sb), slate (sl), and chlorite-sericite schist (sc) is westward, and that the dip steepens regionally toward the west. The meta-andesite (sb) exposed 5 km east of Bani Hamim (17°47'N.x 43°58'E.) projects southward under the Wajid sandstone of the 1:500,000-scale geologic map (Brown and Jackson, 1959), and crops out along the new road in part of the area marked diorite and andesite (d) on the map. Its dip is about 40° westward. Thus, this meta-andesite appears to be dipping under the slate (sl). The slate is strongly cleaved in three directions; thus, bedding is difficult to define with certainty, and the rocks are doubtless tightly,probably isoclinally, folded and are laced with faults. Calcareous layers in the slates display distinctive buff to brownish stains. From the distribution of these layers it is thought that the slates have a prevailing regional dip to the west, and that the dip steepens westward. Stratigraphic up may be toward the west in these rocks.

Difficulty was had in separating the rocks into relatively unmetamorphosed slates and metamorphosed chlorite-sericite schist. Most of what is shown as slate northwest of Najran has the mineral composition of low-rank quartzose sericite-chlorite schist in which pale green to silvery sericite dominates over chlorite. Although I would prefer to call these rocks sericite-chlorite schist, and in fact have done so on figure 1, the terminology doesn't affect the stratigraphic interpretations.

Very few basic dikes are present in the slate (sl) and chlorite-sericite schist (sc) units, or sericite-chlorite schist as I prefer tentatively to call them. The sparseness of basic dikes is a characteristic feature of the unit wherever it is exposed in the eastern part of the Asir quadrangle. It seems most improbable that all the andesite, meta-andesite, and greenstone in the Asir quadrangle can be younger than the slate (sl) and chlorite-sericite schist (sc), if those rocks don't have many feeder dikes to supply a cover of andesite. The andesite and meta-andesite (sb) throughout the eastern part of the quadrangle is intruded by numerous basic dikes, some of which certainly are feeders for a volcanic pile.

East of Zahran al Yemen about 7 km the slate (sl) is shown on the geologic map of the Asir quadrangle (Brown and Jackson, 1959) to be in fault contact with meta-andesite (sb). The bedding was not well enough observed on this part of the traverse to be certain if the meta-andesite is on the emerging west limb of a large syncline, and is therefore correlative with the meta-andesite on the east near Bani Hamim, or if the meta-andesite (sb) east of Zahran al Yemen is dropped down into the slate (sl) along one of the many graben which drop the Wajid sandstone at least as much as 100 m into the Precambrian rocks in this area. If the meta-andesite east of Zahran al Yemen occupies a graben, the interesting possibility exists that it is the greenstone (g) unit and not the older meta-andesite (sb) unit.

These observations do not resolve a difficult problem in regional stratigraphy. They do suggest a possible revision in interpretation. This tentative revision would put a thick unit of andesite and meta-andesite in which basic dikes swarms are common at the bottom of the stratigraphic sequence in the Asir quadrangle. The meta-andesite is overlain by a thick sequence of graywacke in which conglomerate, marble, and carbonaceous beds are present, but basic dikes (other than late Precambrian dikes related to the per-alkalic magma series) are sparse. This sequence includes the conglomerate (cg), slate (sl), marble and quartzite (mq), and chlorite-sericite schist (sc) units of the Asir quadrangle. These variably metamorphosed sedimentary rocks are overlain by greenstone (g) in which pillow lava and sedimentary rocks are present.

Exhumed pre-Permian peneplain

The pre-Premian peneplain on which the Wajid sandstone was deposited has been exhumed over broad areas by the erosion of the Wajid. The peneplain surface is flat and black. In aerial photographs it resembles the top of the Wajid sandstone. It is doubtful if the two surfaces can be separated accurately with an ordinary pocket stereoscope such as geologists use in the field. Accurate control of elevation from known geologic points will be needed to separate remnants of Wajid from the exhumed peneplain surface. If check points were established in the field and a Kelsh plotter was used in the office, a satisfactory photo-interpretation of this surface could be made. It should be done as part of mineral exploration along the new road, because the 1:500,000-scale geologic map shows more Wajid sandstone and less diorite and slate than are actually present between Jabal al Manfah and Jabal Antar.

Graben structures

Spectacular graben structures are present at least from the vicinity of Harshaf (17°50'N.x 43°52'E.) westward into Wadi al Maslulah and to Mayza, about 5 km east of Zahran al Yemen. In the slate and schist the grabens are difficult to spot on a quick traverse, but where the Wajid sandstone or the exhumed pre-Permian peneplain are present, the grabens are very readily seen. Vertical displacements as great as 100 m were observed. What the maximum displacement may be along these faults is not known. Where the actual fault planes were seen, they are vertical. Diverse strikes were noted, but the main orientation of the graben structures is unknown.

Dikes and veins are absent along the fault planes and in the Wajid sandstone.

Mineralization

Two pyritized shear zones and an outcrop of ferruginous silicified marble were observed along the new road.

A weak gossan 20 to 40 m wide and at least 250 m long is developed on pyritiferous sericite-chlorite schist on the north side of the new road 38 km west of the point the road enters the mountains north of Najran. About 5 to 8 percent pyrite is disseminated in a sheared zone in the schist striking N.10°E. and dipping 75°E. Very little quartz is present.

Intense red and maroon weathering is present in three zones in slate and sericite-chlorite schist about 1 km to the north of the road 7 km west of the gossan described above. Bedding in the slate strikes north and dips steeply west, and the slate is intruded by diorite. None of the weathered zones is wider than 10 m. They are each about 300 m long. Probably the red and maroon weathering products are derived from pyrite.

Silicified, ferruginous marble makes a conspicuous hogback striking N.30°E. and dipping 55°W. in sericite-chlorite phyllite 12 km west of the first gossan described above (or 50 km west of the point the new road enters the mountains north of Najran). The marble is at least 20 m thick and 1.5 km long. It produces a gossan-like outcrop. Much graphite schist is associated with the marble, and the schist persists strongly westward toward Harshaf beyond the west end of the layer of marble.

Laterite in the As Sarat mountains

Extensive laterite of Eocene(?) age is exposed in the flanks of the As Sarat mountains (18°05'N.x 43°10'E.) (Brown and Jackson, 1959). It has been appraised as an unfavorable source for bauxite, iron ore, and clay, but it was thought to be a possible source of raw materials for the manufacture of potash fertilizer (Overstreet, 1965; 1966b). Seventy-one analyses of major elements in laterite and associated weathering products from the As Sarat mountains have been made by the staff of the Chemical Laboratory of the Directorate General for Mineral Resources under the direction of Sayyad Matoug Bahijri. The results of these analyses are given in table 6.

Several samples are rather rich in Al_2O_3, but all except one have alumina-silica ratios which indicate the alumina is in kaolinite. Sample 7839, with 46.7 percent of alumina, 29.0 percent of silica, and low SO_4, probably contains either gibbsite or boehmite, but the identity of the aluminum mineral cannot be told from the analysis owing to the low amount of water reported.

The greatest percentages of Fe_2O_3 are 50.76, 45.76, 32.74, and 31.6. The analysis showing 45.76% Fe_2O_3 (sample 7866) has an unacceptably large summation, and the high percentages of iron in the three other samples are accompanied by considerable SiO_2, Al_2O_3, and SO_4. None of the material represented by these samples is an ore for iron.

The presence of alunite (hydrous potassium aluminum sulfate) in the As Sarat laterite seems to be substantiated by sample 7822 which has 36.5 percent of Al_2O_3 and 21.95 percent of SO_4. Other samples are also rather rich in alumina and sulfur: 7825, 7860, 7861, 7862, 7863, and 7870. Possibly 7825, 7860, and7870 are also alunite-bearing. The trhee other sulfur-rich samples may be gypsiferous inasmuch as they are water-laid sediments. Until determinations of K_2O are made on these sulfur-bearing samples it is not possible to state how widespread alunite may be in the As Sarat. However, a striking feature of the group of analyses is the general abundance of sulfur.

Alunite is a potential source for potash for use in fertilizer and alumina for use as a raw material for aluminum, and processes to use it have been developed (Wilmot, 1960, p.20), but it has not been so used. The possible presence of alunite near the large pyrite deposits at Wadi Wassat suggests that further exploration should be done for alunite in the As Sarat. Because alunite is a potash-rich mineral, an initial exploration plan should include airborne radiomatric surveys. When the

Table 6. Major elements in laterite and associated weathering products in the As Sarat mountains, Saudi Arabia, in percent (analyzed by the staff of the Chemical Laboratory, Directorate General for Mineral Resources, under supervision of Sayyad Matouq Bahijri).

Sample	Al_2O_3	TiO_2	Fe_2O_3	SiO_2	SO_4	H_2O	Description
7815	4.06	1.52	3.575	29.38	3.69	1.04	Gray siliceous laterite
7816A	4.74	0.30	5.58	41.02	1.01	0.63	White " "
7816B	5.13	0.61	5.7	27.08	0.70	0.59	Mottled red " "
7817	1.46	0.52	5.29	21.78	0.23	1.02	Gray " "
7818	4.78	0.88	13.01	12.14	0.62	0.8	Brown " "
7819	33.8	0.52	8.01	41.58	0.51	1.6	Purple " "
7820	2.53	0.66	17.59	68.48	0.96	1.69	Variegated gray to purple siliceous laterite
7821	32.67	0.88	7.15	17.44	1.69	0.60	Ferruginous laterite
7822	36.5	0.64	2.29	28.36	21.95	0.64	White pisolitic laterite
7823A	12.62	0.58	2.15	34.46	2.7	0.68	" clayey "
7823B	12.9	0.46	10.01	41.26	1.37	0.87	Red mottled pisolitic laterite
7824	11.18	0.45	4.43	32.66	0.91	1.14	" " laterite
7825	23.6	1.1	7.15	37.54	6.52	0.3	Syenite saprolite
7827	11.00	0.55	6.29	37.84	0.74	1.1	Reticulate mottled saprolite
7828	18.95	0.45	31.6	43.06	0.94	0.94	Saprolite grading into laterite
7829	20.08	0.3	41.18	23.2	0.63	0.46	Ferruginous concretionary laterite
7832	12.65	1.6	2.29	63.54	0.38	0.15	Gray clay
7834	11.2	1.0	10.0	18.18	0.59	0.56	Pisolitic ferruginous gray clay
7835A	5.59	0.65	1.86	47.5	0.86	0.67	Green siliceous laterite
7835B	15.05	0.25	1.86	48.82	0.73	0.41	White " "
7836	8.5	0.25	2.14	34.2	0.9	0.28	" " "
7837	2.88	0.7	7.36	26.62	0.49	0.54	Weathered schistose pyroclastic rock

Table 6. Major elements in laterite and associated weathering products in the As Sarat mountains, Saudi Arabia, in percent (analyzed by the staff of the Chemical Laboratory, Directorate General for Mineral Resources, under supervision of Sayyad Matouq Bahijri). contd.

Sample	Al_2O_3	TiO_2	Fe_2O_3	SiO_2	SO_4	H_2O	Description
7838	4.57	0.55	13.72	29.0	0.82	0.61	Lag gravel with ferruginous cement
7839	46.7	0.4	13.72	29.0	0.82	0.95	Ferruginous concretionary laterite
7841	6.4	4.8	7.15	29.06	0.68	1.48	Weathered rhyolite
7842	7.51	0.7	1.86	33.34	0.53	0.78	Gray to white kaolinitic conglomerate
7843A	10.95	0.15	1.86	54.48	0.61	0.57	Granite saprolite
7844	13.5	0.7	5.15	44.26	0.65	1.25	Granite saprolite with quartz replaced by kaolinite
7845	2.87	0.2	1.78	38.34	1.09	0.79	Laterite from granite
7846	13.33	2.0	9.15	42.4	1.19	0.4	Limonitic Laterite from granite
7847	19.52	0.3	32.74	31.6	1.06	0.63	Ferruginous concretinnary laterite
7848	11.43	0.45	6.86	22.7	0.98	0.42	Hornblende schist saprolite
7850A	13.22	0.1	2.0	77.74	0.51	0.62	Granite saprolite
7850B	15.7	0.1	1.58	77.0	4.0	0.51	Granite saprolite with clay concretions
7851	2.98	0.2	4.0	81.3	0.48	0.96	Hornblende schist saprolite
7853	6.06	0.2	1.36	81.3	7.68	1.37	Quartz-bearing procelaneous laterite
7858	6.31	0.85	5.86	38.8	1.98	2.74	Red laterite from basalt
7859	11.67	0.6	11.15	51.6	3.85	3.57	Yellow " " "
7860	22.82	3.2	13.73	30.82	11.53	9.46	Basalt saprolite
7861	12.32	6.8	7.72	43.44	9.3	1.85	Buff to white sedimentary clay from saprolite
7862	20.37	4.4	22.88	54.78	8.89	0.31	Gray to black sedimentary clay from saprolite

Table 6. Major elements in laterite and associated weathering products in the As Sarat mountains, Saudi Arabia, in percent (analyzed by the staff of the Chemical Laboratory, Directorate General for Mineral Resources, under supervision of Sayyad Matouq Bahijri). contd.

Sample	Al_2O_3	TiO_2	Fe_2O_3	SiO_2	SO_4	H_2O	Description
7863	26.41	1.3	14.16	20.38	11.52	2.13	Maroon sedimentary clay from saprolite
7864	26.33	4.8	5.29	48.4	1.78	2.23	Blue-gray sedimentary clay from saprolite
7865	9.0	0.3	2.43	76.12	2.26	0.72	Weathered granite gneiss
7866	5.6	0.85	45.76	68.59	1.63	0.86	Granite saprolite
7867	2.93	0.65	4.29	21.26	1.96	0.86	Ferruginous laterite
7870	21.93	0.5	4.29	35.56	14.22	0.50	Granite saprolite grading to laterite
7878	9.02	3.6	9.72	40.68	1.4	0.32	Syenite saprolite
7880	5.48	4.8	11.72	42.6	1.48	2.96	Basalt "
7881	12.8	4.8	11.36	35.34	1.7	9.24	Ferruginous residuum
7882	7.21	5.2	8.3	49.54	1.65	1.71	" "
7883	0.8	0.2	4.29	59.8	0.89	1.0	Syenite saprolite
7884	11.3	0.15	2.16	73.7	0.94	0.72	Laterite on syenite
7885	21.69	1.25	4.44	55.56	2.08	1.03	Yellow transported clay on syenite
7886	17.02	0.9	15.3	46.34	0.71	0.71	Ferruginous laterite formed from clay on syenite
7887	12.48	0.2	2.58	65.02	1.03	0.3	Granite saprolite
7889	2.26	0.1	2.0	65.36	0.49	0.42	Granite gneiss saprolite
7890A	11.72	0.3	5.0	63.42	1.54	1.21	" " "
7890B	14.11	0.45	4.29	65.06	0.72	0.86	" " "
7891	12.74	1.15	6.0	60.7	0.8	1.1	Mottled red and white laterite
7892A	8.18	0.45	4.43	70.52	0.49	1.25	" " " " "
7892B	5.46	0.3	4.72	69.36	1.61	0.14	" " " " "

Table 6. Major elements in laterite and associated weathering products in the As Sarat mountians, Saudi Arabia, in percent (analyzed by the staff of the Chemical Laboratory, Directorate General for Mineral Resources, under supervision of Sayyad Matouq Bahijri). contd.

Sample	Al_2O_3	TiO_2	Fe_2O_3	SiO_2	SO_4	H_2O	Description
7894	1.23	0.35	4.86	55.46	0.23	0.12	Granodiorite gneiss saprolite
7895	17.1	0.15	2.86	53.0	0.44	0.3	" " "
7896	16.23	0.35	4.58	59.76	0.51	0.45	Laterite
7897	17.54	0.8	7.58	40.5	0.33	0.81	Transported clay
7898	9.27	0.85	6.72	48.94	0.41	0.76	Rubified laterite
7899	8.18	0.6	25.74	44.06	0.04	0.43	Clay matrix pebble conglomerate
7910	10.73	1.0	2.57	61.5	0.43	0.93	Granodiorite gneiss saprolite
7911	13.5	0.9	10.44	52.46	1.26	1.65	Mottled laterite
7912	9.0	0.9	50.76	17.4	0.56	0.52	Concretionary ferruginous laterite

Ministry's Otter aircraft is instrumented for radiometric surveying, the rim of the As Sarat mountains should be flown to determine if there is unusually high radioactivity in the laterite. The outcrops of laterite can be easily seen from an aircraft. If radioactivity highs are found, they should be examined and sampled.

Pyritiferous schist north of Abha

Sericite-chlorite schist north of Abha (18°12'N.x 42°30'E.) was examined for 24 km along the road between Abha and Faya. In general this schist resembles the sericite-chlorite schist west of Najran and the schist in the western part of figure 1 of this report except that there is more marble and dolomite in the Abha area. In neither the Najran nor the Abha areas are andesite or meta-andesite dikes visible in the schist, but granite dikes are common in it near Abha. There should be at least as many andesite dikes in the sericite-chlorite schist as in the andesite if the schist is older than the andesite. Because there are no andesite dikes in the schist north of Abha, it must be inferred to be younger than the andesite.

Disseminated pyrite in the sericite-chlorite schist was previously commented upon (Overstreet, 1965). The pyrite is common east of the road to Faya from the outskirts of Abha northward, but nothing resembling the gossan at Wadi Wassat was seen.

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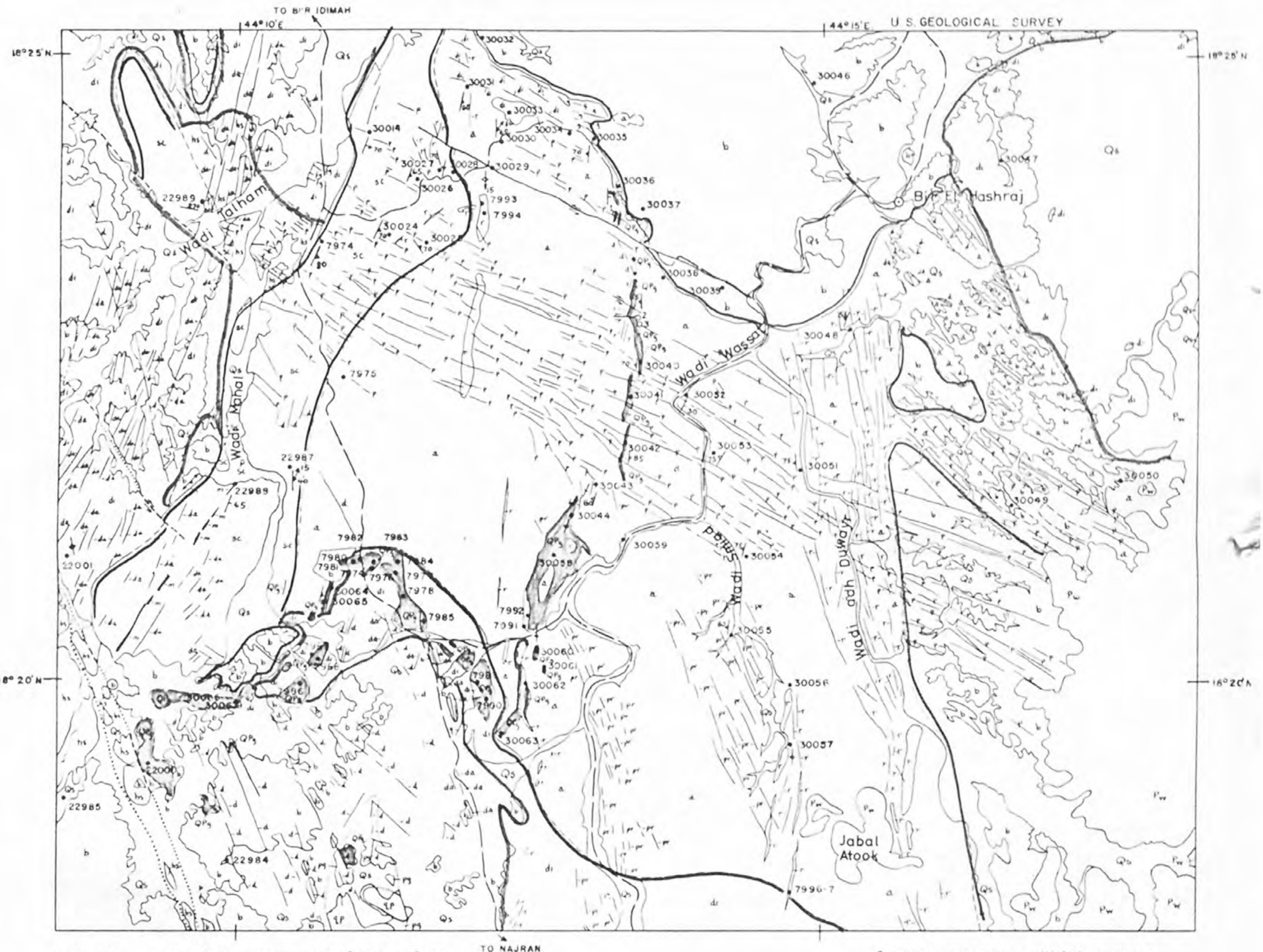

Base from controlled mosaic, Aero Service Corp.
Philadelphia, Pa., 1951

Geology mapped by W.C. Overstreet,
U.S. Geological Survey, Feb. 22–27, 1966

Fig. 1 – Geologic setting of the gossan in the Bir Idimah – Wadi Wassat area Saudi Arabia

1 0 1 2 3 4 5 6 Kms

Scale 1:50.000

1966

EXPLANATION

QUATERNARY

Qs

Alluvial and eolian sand
Poorly sorted alluvial sand along wadi floors; eolian sand in northeastern and southwestern part of area.

PERMIAN(?) TO QUATERNARY

QPg

Gossan
Buff, brown, maroon, and red gossan consisting of scoriaceous to delicately banded, pulverent to hard and brittle mixtures of hematite, limonite, goethite, jasper, chalcedony, kaolinite, and gypsum, and including relicts of leached argillite, andesite, diorite, granite, and rhyolite, developed on pyrite-bearing rocks.

PERMIAN OR OLDER

Pw

Wajid sandstone
Reddish-brown, yellow, tan, and white crossbedded sandstone, limonite- and hematite-cemented layers and concretions, thin conglomerate and clay lenses; locally overlies saprolite.

PRECAMBRIAN

p

Syenite porphyry
Light to dark gray syenite porphyry dikes with dark gray fine-grained matrix in which are set phenocryts of white to pink orthoclase; biotite generally present; swarm trends N. 70° W.

pr

Pyroxene rhyolite
Light to dark, gray to red pyroxene rhyolite dikes; commonly strike N. 20° W. in swarms; pyroxene may be absent in individual dikes, or replaced by biotite pseudomorphs.

d

Diabase
Dark gray to black fine-grained diabase dikes, chilled margins common, ophitic texture with pyroxene.

da

Dacite and dacite porphyry
Gray to dark gray, medium- to fine-grained dacite and dacite porphyry; biotite common dark mineral; phenocrysts orthoclase and oligoclase.

PRECAMBRIAN

fg q

Felsite and granite dikes, quartz vein
Gray to red felsite dikes grading into granite porphyry, quartz porphyry, graphic granite, and pegmatite, fg; differentiates from quartz porphyry, qp, and pyroxene granite, pg; massive white quartz vein, q

qp

Quartz porphyry
Massive medium-grained, pink to red quartz porphyry; occurs as masses and dikes; grades into granite porphyry; differentiate from biotite granite, b

pg

Pyroxene granite
Massive, pink to red, aegirine-bearing granite; occurs as masses and dikes; locally pyritic; differentiate from biotite granite

g

Granite, pegmatite, and felsite
Massive pink to white dikes of biotite granite, pegmatite, and felsite; epidote common on joints; differentiate from biotite granite, b; the granite dikes may be in part older than rhyolite, r

r

Rhyolite
Light to dark gray, buff, pink, and red rhyolite dikes, weathering white to buff, with sparse phenocrysts of quartz and spessartite, rare biotite and magnetite; pyrite variably present in amounts up to 12 percent of rock; epidote common on joints; forms north-trending masses and swarms

b

Biotite granite
Massive pink to red, medium-grained biotite granite; occurs as plutons and dikes

di

Diorite
Massive, dark gray to black biotite diorite; grades locally into gabbro; occurs mainly as plutons and small masses, locally accompanied by satellitic dike swarms

PRECAMBRIAN

sc /m

Sericite-chlorite schist
Gray-green sericite-chlorite schist, sc, formed by contact metamorphism and cataclastic metamorphism from graywacke, argillite, and andesite; graywacke dominant; lenticles of marble, m, common

hs

Horblende schist
Dark green hornblende schist, actinolite schist, chlorite schist, and schistose diorite, formed by contact metamorphism from andesite, andesite porphyry, graywacke, and diorite; andesite dominant

a

Andesite
Green to dark green, massive to poorly bedded, locally strongly cleaved andesite, andesite porphyry, agglomerate, conglomerate, graywacke, and argillite, occurs as a roof-pendant in diorite, di, and biotite granite, b; western part of unit contains calcareous sedimentary rocks including lenticles of marble; eastern part of unit is massive andesite; conglomerate near central part of unit; variably but generally little metamorphosed, bleached along contacts of gossan, QPg, especially west side of gossan

Contact
Dashed where indefinite; dotted where concealed

Fault showing relative horizontal movement

50
Strike and dip of beds

70
Strike and dip of fracture cleavage

15
Strike of vertical fracture cleavage showing bearing and plunge of lineation

70 45
Strike and dip of foliation showing bearing and plunge of lineation

Road

• 30064
Sample locality and number

o1
Diamond drill hole and number

Well