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MINERAL EXPLORATION BETWEEN BI'R IDIMAH AND WADI HARAMAN, ASIR QUADRANGLE, SAUDI ARABIA

by

William C. Overstreet 1919-
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1. Geological literature on the San Joaquin Valley of California, by J. C. Maher and W. W. Trollman. 421 p., 2 figs. 504 Custom House, San Francisco, Calif. 94111; 7638 Federal Bldg., Los Angeles, Calif. 90012; 602 Thomas Bldg., Dallas, Texas 75202.

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.

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U. S. Geological Survey

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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Abstract

An area of 10,000 sq. km. between Bi'r Idimah and Wadi Haraman in southern Saudi Arabia was investigated for mineral deposits during the period May 8, 1965, to June 27, 1965. At least 25 different minerals and industrial rocks occur in the area, but of these materials only asbestos seems to have a real possibility for industrial development. Twenty occurrences of asbestos were found around the Higera gold mine and between Hamdah and Bi'r El Marwah. A favorable area for asbestos exists north and east of Tathlith, but none was discovered there. It is recommended that the Hamdah-Bi'r El Marwah area be examined in detail, and the Higera and Tathlith areas receive reconnaissance studies for asbestos. Asbestos is a high-value commodity which can be processed by air separation, thereby freeing its benefitiation from dependence on water. Examination of the asbestos deposits would have as a by-product an appraisal of the resources of soapstone, anthophyllite, talc, vermiculite, chromite, calcite, gold, and copper in the three asbestos districts.

Thirty-six occurrences of marble were found in the area. Several have favorable characteristics for industrial or architectural use.

One ancient mine, the Ishaaib (19°15'N.x 43°40'E.), may contain copper.

Introduction

The area between Bi'r Idimah and Wadi Haraman comprises principally the quadrilateral bounded by parallels 18°30'N. and 20°N. and meridians 43°30'E. and 44°E. in the east-central part of the Asir quadrangle (Brown and Jackson, 1959), Kingdom of Saudi Arabia. Also included in this area are the Precambrian rocks exposed west of the Wajid sandstone north of latitude 18°30'N. and east of longitude 44°E. The area thus defined is about 10,000 sq. km.

Mineral exploration of the area was conducted between May 8, 1965, and June 27, 1965, on a trip that covered a total distance of 5300 km. The writer was accompanied by two employees of the Directorate General for Mineral Resources, the guide Maeith Rejad, and the driver Homud Saud. The Directorate also furnished the two Ford 3/4 ton pickup 4x4 trucks used and dispatched their aircraft for four scheduled rendevous. Four-hundred ninety samples of wadi sand and an equal number of samples of detrital magnetite were taken for geochemical and heavy-mineral studies, and 41 samples of other geologic materials, mainly veins and gossan, were collected. The exploration was a continuation of work begun in 1964 (Overstreet, 1965) as partial implementation of the mineral exploration agreement of 1963 between the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia, and the United States Geological Survey.

Geologic setting

The area between Bi'r Idimah and Wadi Haraman is in the southeastern part of the Arabian Shield. The Precambrian rocks, which were the principal geologic objective of the exploration, are unconformably overlain throughout the eastern edge of the area by the Wajid sandstone of Permian or older age (Brown and Jackson, 1956). West of the sandstone the Precambrian rocks consist of a nearly continuous, north-trending, sinuous belt of andesite with inter-layered graywacke intruded by a succession of mafic and silicic igneous rocks. The principal mineral deposits of the Bi'r Idimah-Wadi Haraman area are in the andesite and associated serpentinite. This belt, which has become known as the Hamdah ultrabasic belt after the centrally located village of Hamdah (19°02'N.x 43°38'E.) and the occurrences of serpentinite, is from 10 km to 40 km wide. It is definable as a lithologic feature from a point 35 km north of the Yemen border and 95 km southwest of Bi'r Idimah to the northernmost part of the area investigated, 200 km north and northwest of Bi'r Idimah. West of the Hamdah ultrabasic belt the area is underlain by non-layered hornblende-biotite granite gneiss and granodiorite gneiss, diorite, and massive, normal biotite granite. In the southeastern part of the area from Bi'r Idimah northwestward for 60 km, the basic and ultrabasic rocks of the Hamdah belt are widely intruded by pink per-alkalic granite, unit gp of Brown and Jackson (1956). A few small erosional remnants of the Wajid sandstone cap prominent peaks in the southern part of the area west of the main outcrops of the Wajid; elsewhere erosion has cut many hundreds of feet below the former base of the sandstone. The present cycle of erosion shows evidence of rejuvenation, possible in Recent time, after a period when chemical weathering of the rocks was a factor in degradation of the land surface.

Main rock units

Hamdah belt.

The Hamdah ultrabasic belt actually contains a far larger volume of intermediate igneous rocks such as gabbro, diorite, and andesite and sedimentary rocks like graywacke than ultrabasic rocks like peridotite, pyroxenite, and dunite. Owing to the metamorphism which has affected them, many of the ultrabasic rocks have been altered to serpentinite. The ultrabasic rocks are discontinuously distributed in the form of dikes, stocks, and irregular igneous masses and as metamorphic replacement and diapiric bodies in the andesite and graywacke. The continuity of the Hamdah belt derives from the tectonic preservation of layered volcanic and sedimentary rocks into which the ultrabasic rocks are intruded. It is not an ultrabasic belt in itself.

The layered volcanic and sedimentary rocks of the Hamdah belt are interpreted here to be the oldest Precambrian rocks in the Bi'r Idimah - Wadi Haraman area; they are also part of the oldest rocks in the Asir quadrangle. The Hamdah belt is a great septum in the intrusive, non-layered, hornblende-biotite granite gneiss and hornblende-biotite granodiorite gneiss that makes up the central batholith of the Asir quadrangle (Brown and Jackson, 1956). The Hamdah septum appears to close southwestward at and south of the Yemen border with a wider septum of similar rocks entering from the northwest (Brown and Jackson, 1956). These two septa diverge northward around the widest part of the batholith. In the vicinity of Hamdah they are nearly 150 km apart, but they converge again toward the north, and at the northern limit of the area the Hamdah septum is only 38 km east of the western septum.

Both septa are here inferred to be relicts of the same volcanic-sedimentary sequence, now incompletely preserved in the area of the Asir quadrangle owing to the intrusion of the batholith. The Hamdah septum comprises a smaller segment of the original sequence than the western septum. It is unlikely that the layered rocks in the Hamdah septum are the stratigraphic equivalent of the rock in the western septum. The Hamdah rocks are here interpreted to have been deposited early in a geosynclinal cycle along the axial part of the geosyncline. Coarse clastic sediments are rare, volcanic rocks dominate, and these rocks are invaded by early intrusions of peridotite and pyroxenite which were largely altered to serpentinite prior to the intrusion of the granitic rocks. The serpentinites of the Hamdah belt are inferred to be ophiolites formed early in the geosynclinal history_/. At its southern end the Hamdah belt includes a sequence of slate, felsite, and quartzite (Brown and Jackson, 1956) which is here thought to overlie the thick volcanic sequence and ultrabasic rocks exposed near Hamdah. The possible equivalent to these rocks was found along the western edge of the Hamdah belt west of the extreme northwestern part of the Bi'r Idimah-Wadi Haraman area.

The volcanic and sedimentary rocks in the western septum are characterized by thick, persistent, layers of conglomerate and marble (Brown and Jackson, 1956) which are here interpreted to have been deposited in the distal part of the same geosyncline. It is possible that the rocks in the western septum are somewhat younger than those exposed in the Hamdah belt, and represent sedimentation transgressive from east to west. In the region near the Yemen border the layered rocks of the two septa merge (Brown and Jackson, 1956). Here a more nearly complete stratigraphic sequence can be expected than in either septum, and the true relations might be worked out. Possibly the unit of slate, felsite, and quartzite lies between the sequence in the Hamdah belt and that in the western septum.

The layered volcanic-sedimentary sequence was in part folded and cleaved prior to the intrusion of the batholith. As evidence of this folding the walls of the batholith cut across both bedding and foliation, and small inclusions of the layered rocks in the gneiss have planar structures locally oriented athwart the gneissic foliation of the batholith. The main pulse of the batholithic intrusion accompanied the folding. The batholith is here inferred to have breached the west limb of a geanticline in the volcanic-sedimentary sequence. The rocks along the Hamdah belt are interpreted to be among the oldest rocks, and to be preserved along an infold into the roof of the batholith. The eastern limb of the geanticline is inferred

_/ On a regional scale the Hamdah belt would be a zone of negative gravity anomalies if this is the relation.

to lie east of the Hamdah belt, and is covered by the Wajid sandstone.

Metamorphism of the rocks in the Hamdah belt is quite variable, thereby giving rise to diverse lithologic types which are thought to be part of the same stratigraphic sequence. The lithologic units shown on the Asir quadrangle (Brown and Jackson, 1956) give a good representation of this diversity.

The ultrabasic rocks in the lowest part of the stratigraphic sequence were among the earliest parts of the Hamdah belt to be affected by regional metamorphism. They were widely altered to serpentinite during initial folding of the belt. Increase in volume of the ultrabasic rock accompanying alteration caused some of the serpentinite masses to intrude diapirically the wall-rock andesite. Probably the serpentinitization was most complete where the wall rocks contained the largest quantity of connate water, because some large source of water would have been needed to convert the mafic minerals of the peridotite and pyroxenite to serpentinite. The later granites cannot have been the source of this water, because they are notably dry and they released only very small quantities of volatiles.

The distribution of serpentinite and veins of magnesite permit an inference to be made about the composition of the original ultrabasic rocks in the Hamdah belt. Where serpentinite is formed from olivine-bearing rocks more magnesium is set free than where serpentinite is formed from olivine-free rocks. Magnesite is much more common in and around serpentinites exposed in the part of the belt south of Hamdah than it is north of Hamdah (table 9). From this distribution it is inferred that peridotite and dunite were originally more common than pyroxenite south of Hamdah and less common to the north.

The andesite of the Hamdah belt is widely chloritized and epidotized. Doubtless both minerals were formed from a variety of geologic processes extending from the beginning of folding to the close of igneous activity in the area. However, it is probable that most of the chloritization and epidotization occurred contemporaneously with the formation of serpentine in the ultra-basic rocks, and was a related process of initial regional metamorphism.

Along most of the contact zone between the batholith of hornblende-biotite granite gneiss and hornblende-biotite granodiorite gneiss the layered rocks of the Hamdah belt display variable contact metamorphic effects. Generally the andesite is raised to hornblende schist and the graywacke to biotite-muscovite schist. Away from the contact a few hundred to a few thousand meters the andesite is raised to chlorite schist and the graywacke to chlorite-sericite schist. Farther away the effects of contact metamorphism, if any, blend with the pervasive epidotization and the rocks tend to be massive greenstones, or are altogether unaltered. The post-kinematic calc-alkalic and per-alkalic granites have produced highly variable, generally sparse, contact metamorphic effects. Although hornfels and hornblende schists are locally attributable to these granite plutons, there are places where the reaction along the walls of the pluton actually was retrogressive, and pre-existing hornblende schist was converted to chlorite-biotite schist.

The rocks of the Hamdah ultrabasic belt contain the principal mineral deposits of the Bi'r Idimah-Wadi Haraman area. They also contain the most important mineral deposits in the Asir quadrangle. No pyrope-bearing basic or ultrabasic rocks are present; therefore, the possibility of diamond deposits in this area is considered to be negligible. Norites are very scarce; thus, nickel and platinum are scarce to absent.

<u>Gneissic granite and granodiorite.</u>

Non-layered hornblende-biotite granite and hornblende-biotite granodiorite forms a late kinematic batholith which intrudes the basic and ultrabasic rocks of the Hamdah belt. The eastern edge of the batholith underlies the western part of the area between Bi'r Idimah and Wadi Haraman, but the batholith is actually the largest geologic feature of the Asir quadrangle (Brown and Jackson, 1956). In its central part, at a point 50 km southwest of Hamdah, the batholith is 150 km wide. Its axis strikes N.15°W. and is exposed for 235 km in the Asir quadrangle. The axis appears to plunge southward in the southern part of the batholith and northward in the northern part of the body.

The batholith is interpreted to be an early kinematic feature because it is generally concordant and harmonious with the wall rock andesite, but it is locally strongly cross-cutting. It contains inclusions of andesite, gabbro, diorite, and pyroxenite, often more or less metamorphosed, but it is also intruded by andesite, gabbro, diorite, pyroxenite, granite, pegmatite, rhyolite, and basalt. The inclusions are thought to be fragments from the lower part of the volcanic-sedimentary sequence of rocks, and from the early basic and ultrabasic intrusives into the volcanic pile. Basic rocks intrusive into the gneiss, exclusive of the basalt, are thought to be late feeders to the volcanic pile introduced after the onset of folding. The granitic intrusive rocks are late tectonic and post-tectonic with respect to the folding in the layered sequence of volcanic and sedimentary rocks. They are probably Precambrian in age. The plugs of basalt in the granite gneiss are either Tertiary or Quaternary in age.

The rock is here called hornblende-biotite granite gneiss and hornblende-biotite granodiorite gneiss from megascopic study only. The same unit, gg of the Asir quadrangle, is said by Brown and Jackson (1956) to contain pyroxene. The rock is medium- to coarse-grained, gray, non-layered, and gneissic. Very few felsite or pegmatite dikes are genetically related to it. Relatively more quartz veins are related to the gneiss, but they are also sparse. The gneiss is practically devoid of mineral deposits of any sort.

Diorite, gabbro, and pyroxenite.

Diorite, gabbro, pyroxenite, dunite, and periodotite of at least two ages are present in the Bi'r Idimah-Wadi Haraman area. One group of these basic and ultrabasic rocks is older than the hornblende-biotite granite gneiss. The other group is younger than the gneiss. The older group, as already stated in the discussion of the Hamdah ultrabasic belt, is inferred to be intrusive into the base of the volcanic-sedimentary sequence prior to the introduction of the granite gneiss. These coarse-grained basic and ultrabasic rocks in part served as feeders for higher-level accretion to the volcanic pile. These older basic and ultrabasic rocks are pretectonic and early tectonic. They are commonly metamorphosed to metadiorite, amphibolite, metapyroxenite and soapstone, and serpentinite. They are the hosts for asbestos. Dikes of all the different granitic rocks intrude them. Even where the serpentinite has flowed as diapirs it does not intrude the competent hornblende-biotite granite gneiss, but is restricted to piercing incompetent schists.

Massive diorite, gabbro, and pyroxenite, but probably not peridotite and dunite, intrude the rocks of the Hamdah ultrabasic belt and the batholith of hornblende-biotite granite gneiss. They are intruded by the late tectonic calc-alkalic granites and by the post tectonic per-alkalic granites. They may in part be early intrusives of the differentiation seuqnces leading to the calc-alkalic and per-alkalic granites. Locally these rocks are chloritized, or are metamorphosed to amphibolite, hornblende schist, and soapstone. Then their identity can only be determined by their relation to the granite gneiss. Small bodies of anorthosite are formed in the gabbro, commonly as segregation layers. The anorthosite is unmetamorphosed. A little enrichment in titanium is associated with the anorthosite.

The pre-tectonic and early tectonic basic and ultrabasic rocks are mostly the units called d, bu, and c on the geologic map of the Asir quadrangle (Brown and Jackson, 1956), and the late tectonic and post-tectonic basic and ultrabasic rocks are shown as units gb, bu, and c on the map. Although a descending order of age is shown from the youngest diorite (d) and gabbro (gb) to the oldest amphibolite (c), all these basic and ultrabasic rocks are shown as being older than the whole sequence of granitic rocks. The time relations between the granitic rocks and basic rocks is more complex.

Some of the rock called diorite and metadiorite (epidiorite) is a hybrid rock probably not strictly of magmatic origin. The epidiorites in part seem to have been formed from pre-existing layered rocks, probably mainly andesite and andesite porphyry, by pervasive late potash metasomatism. In the andesites one of the chief minerals formed was biotite. The same (?) period of late potash metasomatism may have produced much of the late tectonic or post tectonic granite.

Calc-alkalic granite.

The calc-alkalic granites, or normal series of quartz-bearing granitic rocks, are represented on the geologic map of the Asir quadrangle (Brown and Jackson, 1956) by the letter symbol gr. As described the rock is gray to pink and tends to be porphyritic with large microcline or orthoclase crystals especially common in the border facies. Quartz of the normal granite tends to be bluish, and pegmatite, quartz veins, and aplite are said to be rare. As shown by Brown and Jackson the normal granite occupies only a small part of the Bi'r Idimah - Wadi Haraman area. It appears in a series of northerly elongate masses in granite gneiss and diorite in the western part of the area. The actual areal distribution of the calc-alkalic granite is much greater in the Bi'r Idimah-Wadi Haraman area than is shown on the Asir quadrangle. Much of the rock underlying the Sahl al 'Amk (18°38'N.x 43°45'E.) is non-gneissic, normal biotite granite, as is Jabal as Safa (19°03'N.x 43°35'E.), Jibal al Kilab (19°25'N.x 43°45'E.) and the rocks in the upper reaches of Wadi Haraman (19°40'N.x 43°50'E.). Aplite is essentially absent. Simple pegmatite and white quartz veins are rare. The porphyritic facies provides one of the most important petrologic problems in the quadrangle.

The phenocrysts of the porphyritic facies commonly appear to be metacrysts formed in the solid state after, possibly long after, the host rock crystallized. A typical example of the relations can be seen at locality 22055 (18°44'N.x 43°59'E.) where fine-grained diorite, gabbro, and hornblende schist are intruded by pink, biotite-quartz monzonite followed by pink granite porphyry. Dikes and masses of the quartz monzonite anastamose through the basic rocks, and dikes of granite porphyry cut through all the rocks. Inclusions of all shapes and sizes, but commonly of ellipsoidal or ovoidal shape, of the basic rocks float in random orientation in the quartz monzonite. Flow bands in the quartz monzonite follow the outlines of the inclusions. No reaction can be observed between the inclusions and the quartz monzonite or later granite prophyry. However, the inclusions, especially the dioritic inclusions, the quartz monzonite, and the granite porphyry all have identical large crystals of pink potassium feldspar. In order to have the same feldspar in three generations of rock, the feldspar must be no older than the youngest rock, the granite porphyry. Perhaps the pink potassium feldspars are metacrysts formed in the solid state during potash metasomatism later than the consolidation of the granite porphyry.

Metacrysts of pink potash feldspar are quite common in dark inclusions in late tectonic and post-tectonic granite. At many places the feldspar metacrysts cross over the contact between the host granite and the inclusion; half of the metacryst is in inclusion and half is in "porphyritic" granite. No differential movement could have taken place between the inclusion and the host while the feldspar crystal was growing. Probably the growth took place in the solid state.

Locally, large potash feldspar crystals in pink to light gray biotite granite have included trains of biotite flakes oriented parallel to the main faces of the feldspar crystal. At least three such biotitic zones are present in the crystals, and a selvage of biotite surrounds the faces of the feldspar crystal. These biotitic zones are interpreted to be caused by successive stages of growth of the feldspar. They are found in crystals in "porphyritic" granite and in crystals growing across the boundary between granite and inclusions. Because they persist undisturbed across the boundary, it is inferred that the zoned crystals are metacrysts formed in the solid state.

The pervasiveness of potash metasomatism in the Bi'r Idimah-Wadi Haraman area of the Asir quadrangle, and of the quadrangle itself, has been impossible to evaluate satisfactorily. The possibility exists that large parts of the porphyritic facies of the massive biotite granite in the area was at least made "porphyritic" by the widespread addition of potassium. A more fundamental question is to what extent the biotite granites are themselves formed by metasomatic processes operating in the hornblende-biotite granite gneiss and hornblende-biotite granodiorite gneiss or in septa of slate, felsite, rhyolite, and quartzite in the gneiss. One of the most distinctive features of the distribution of the bodies of calc-alkalic granite (unit gr) shown on the Asir quadrangle (Brown and Jackson, 1956), is the linear northerly arrangement of the bodies from the unit (sl) of slate, felsite, and quartzite on the southwest end of the Hamdah belt to the area on the northwestern side of the Hamdah belt north of Tathlith, where rhyolite was found to be a component of the Hamdah sequence. These granite plutons, interestingly, are associated with extensive areas of diorite and epidiorite (unit d), and the trend of the granite and diorite through the gneissic batholith may mimic the trend of a pre-existing rhyolitic and andesitic sequence originally present to the west of the Hamdah belt.

The contacts are nebulous between massive biotite granite and the hornblende-biotite granite gneiss and hornblende-biotite granodiorite gneiss at many places in the Bi'r Idimah-Wadi Haraman area. The early gneiss appears to grade into massive granite through decrease in grain size and quantity of biotite, disappearance of hornblende, and increase in potash feldspar. At these places epidote and epidote-quartz stringers are common. Here the calc-alkalic granite may be derived from the hornblende-biotite granite and granodiorite gneiss through potash metasomatism with release of surplus Ca, Fe, Al, and Si into veins and joint coating.

Per-alkalic granite.

The commonest intrusive rock in the southeastern part of the Bi'r Idimah-Wadi Haraman area is called per-alkalic granite on the map of the Asir quadrangle (Brown and Jackson, 1956). The rock is a soda-rich, massive, red granite. Ordinarily it is somewhat low in quartz, but it has sparse simple pegmatite dikes grading into white quartz veins.

The extensive embayment of the basic rocks in the Hamdah belt by intrusive bodies of the per-alkalic granites had once been thought to make a favorable environment for scheelite. My trip of September-November 1964 (Overstreet, 1965, p.2) discounted the possibility. The results of that work were born out by the present investigation; scheelite is seldom associated with these rocks.

Extreme differentiation products of the per-alkalic granite are essentially absent. At locality 22508 (19°38'N.X 43°33'E.) an extremely altered mass of punky brownish-green rock is present in serpentinite. Veins of calcite and limonite occupy joints in the altered rock. No magnesite, chromite, or asbestos is present. The remote possibility exists that this brownish-green mass is a weathered carbonatite plug, or hydrothermally altered plug. A doubtful association of carbonate minerals and feldspar was observed which would help define the rock as carbonatite: patches of sericite seem to outline former crystals of feldspar in the punky residuum. However, other characteristic carbonatite minerals were not observed. Results of analyses for Ba, Sr, Nb, and RE will aid in identifying carbonatite if it is present, but the analyses are not finished. Nothing like this rock was seen elsewhere in the Bi'r Idimah-Wadi Haraman area. The only other extreme differentiation product of the per-alkalic granite noted in the area was two minor concentrations of boron minerals of no economic importance.

Wajid sandstone.

The Wajid sandstone of Permian or older age unconformably overlies the Pre-cambrian crystalline rocks along the eastern side of the Bi'r Idimah-Wadi Haraman area (Brown and Jackson, 1956). It is reddish-brown to white, crossbedded, well cemented sandstone with pebble beds and layers of black sand near the base. Also near the base is a ferruginous cement which, although not an industrial source for iron, may have been used by local people for hematite and limonite.

Basalt.

Vesicular, columnar-jointed, olivine-bearing basalt of probable Tertiary or Quaternary age occurs as a group of small plugs in the south-central part of the Sahl al 'Amk (18°34'N.x 43°38'E.). It was not found elsewhere in the Bi'r Idimah-Wadi Haraman area.

Silt.

Laminated silt, sand, and clay forms conspicuous deposits upstream from constrictrictions in the walls of wadis in the Bi'r Idimah-Wadi Haraman area. These deposits are shown on the geologic map of the Asir quadrangle (Brown and Jackson, 1956) as of Quaternary age, and they are interpreted to be flood-laid sediments. Good examples of this young geologic unit are present south of Hamdah along Wadi Tathlith at Al Ji'ayfirah (18°57'N.x 43°38'E.), at Jabal al Amlah (18°47'N.x 43°42'E.), and on Wadi Mlaha (18°32'N.x43°37'E.) where it joins Wadi Tathlith.

These sedimentary materials have local economic importance in that they are used to make the walls of houses, and, where there is enough water, the sandy silts and silty sands are cultivated. They have had a similar economic importance since ancient times. In the Wadi Tathlith area there is archaeological evidence that the silts had greater economic importance in antiquity than they do now, and that the decline in their value relates mainly to a decrease in the present supply of water.

In ancient times water for cultivation was available upstream along Wadi Tath-lith at least as far as the mouth of Wadi Mlaha (18°32'N.x 43°37'E.). At this point the rectilinear outlines of former cultivated fields on the silt can be seen on aerial photographs. Vestigial rectilinear erosion suggestive of former cultivation is visible in the narrower part of the great silt deposits on Wadi Tathlith and tributaries at Jabal al Amlah (18°47'N.x 43°42'E.). Extensive ruins of an agrarian community skilled in the construction of dams and the diversion and conservation of water are established on the silt in Wadi Tathlith at Al Ji-ayfirah (18°57'N.x 43° 38'E.) about 5-1/2 km. northwest of the Higera mine and 9 km. southeast of Hamdah.

At the present time Hamdah is the first point downstream in Wadi Tathlith where enough water can be obtained to support date palms and kitchen gardens. The amount of land cultivated at Hamdah is much smaller than the areas formerly cultivated upstream along Wadi Tathlith. From these relations it is inferred that the agricultural development of Wadi Tathlith has declined, and that the decline is consequent upon a lesser flow of water in the wadi which is caused by a decrease in rainfall in the basin.

The antiquity of the ruins at Al Ji'ayfirah seems to be greater than the Khaliphate ruins at the Higera gold mine, and the ruins at Higera show no evidence of settled cultivation. Stone work at Al Ji'ayfirah resembles structures some 2000 years old found in South Arabia (Bowen, 1958a, p-43-44, fig. 60-61). At Al Ji'ayfirah man-made structures are both <u>on</u> the present surface of the silt and partly buried <u>in</u> the silt. The buried parts demonstrate the deposition in historic time of at least that part of the silt overlying the construction. At the ruined village downslope from the Higera mine, all construction, tailings piles, and artifacts are <u>on</u> the silt. Nothing seems to be partly buried in silt. Thus, the sedimentary process giving the silt came to a halt before the last structures were built at Al Ji'ayfirah and before any structures were erected at Higera. At least the last layers of silt deposited at Al Ji'ayfirah were laid down in ponds formed behind man-made dams subparallel to the east wall of the wadi. If the upper part of the silt at Al Ji'ayfirah was deposited through the activity of man, then the question arises of how much silt in Wadi Tathlith was deposited under the control of man? In South Arabia silt up to 18 m. thick (Bowen, 1958a, p.43) was trapped on a wide scale behind man-made dams possibly contemporaneous with the former community of Al Ji'ayfirah. Al Ji'ayfirah is on an ancient caravan route leading northward from Najran, and ancient routes from South Arabia converged on Najran (Bowen, 1958b, pl.33).

The question of the role of man in the formation of the silts in Wadi Tathlith, and the age of the silts, cannot be answered with the data presently available. However, the data show that a long and intricate geologic evolution was needed to give the materials of which the silt is formed, and that these processes were related to climate change and change in stability of the land surface. Geological evolution gave the materials at the proper time for them to be fitted by man to his needs. Geological processes are still modifying the silts.

Throughout the basin of Wadi Tathlith, as elsewhere in the Bi'r Idimah-Wadi Haraman area, remnants of saprolite_/ are exposed in projections of crystalline rocks in the wadi floor and along the lower slopes of the wadi walls. In some large pediment areas like the Sahl al Amk (18°34'N.x 43°38'E.) an irregular mantle of saprolite is preserved on the crystalline rocks. A period of relative stability or slow uplift with enough rainfall to permit chemical weathering to take place is necessary for the formation of saprolite. Most discussions of weathered rock suggest that heavy rainfall is necessary, and Dr. Dorothy Carroll, who has recently reviewed over 300 reports on rock weathering, told me (oral communication, 1963) that these reports indicate at least 30 inches of rain per year are needed to give the degree of chemical weathering necessary to make saprolite. I think this average must be too agreat, and it was reached because most of the studies reviewed were reports on the classical regions of deep weathering under humid conditions. In this part of Arabia the present rainfall is about 2 inches per year. Farther west around Khamis Mushayt and Abha, where saprolite is very common, the present rainfall is about 4 to 8 inches per year. Eight inches of rain a year may be adequeate to have formed the Late Pleistocene (?) and Recent (?) saprolite in Wadi Tathlith. A drying from the postulated requisite 8 inches to the present 2 inches per year took place. During the time of drying agriculture was established in the wadi, sizeable communities based on agriculture were established, and they have shrunk with the drying to the little remnant at Hamdah and the larger communities downstream to the north.

_/ Saprolite is weathered rock soft enough to dig with pick and shovel, and unmoved. Because it is unmoved the structures and textures of the original rock are preserved.

Granite and granite gneiss are more resistant to chemical weathering and erosion in the Bi'r Idimah-Wadi Haraman area than the basic and ultrabasic rocks. Granite peaks stand 300 meters higher than the serpentinite hills in the Wadi Tathlith basin. White to buff silt and clay is spatially associated with the mafic rocks. It is found upslope on them, and appears to be a weathering product. It is also present on granite slopes, but not as common as on the weathered mafic rocks. Differential erosion of the mafic rocks and granite would lead to a greater volume of basic detritus entering a wadi from a given area of exposure than of granitic detritus. Where the two types of rocks are equally common, or where as much as one-fourth of the drainage basin is underlain by basic rocks, an important part of the wadi sediment is derived from the more deeply weathered basic rocks. It is in these areas that the silts are deposited. No large units of silt are present along the major wadis in wholly granitic terrane in the Asir quadrangle (Brown and Jackson, 1956).

The silt sequences are built up near major constrictions in the wadis. This geographic relation is a mechanical necessity whether the silt is deposited behind natural or man-made barricades.

The silt sequence between Hamdah and Al Ji'ayfirah consists of silt and clay laminae up to 3 cm thick which alternate with micaceous, sandy lenticular cross-bedded layers up to 12 cm thick. All the sediment is poorly sorted. The laminae of silt and clay commonly contain plant fossils, mostly reeds, but the layers of sand tend to be free of plant megafossils. Tubular, iron-stained zones normal to the bedding and up to 1.5 cm in diameter are generally filled with coarse sand but locally contain carbonized roots. The sand-filled ones may be animal or insect borings, which would show that the upper surfaces of some beds were exposed to wind action. The total thickness is about 14 m. About 7 m below the top of the section crusts of Na Cl are on exposed faces of the sandy lentils, reflecting freer movement of water in the sand lentils than in the clay. The base of the silt overlaps from normal wadi sand and gravel to crystalline rocks of the wadi wall.

The mica in the silt sequence is brassy yellow, weathered, hydrobiotite.

The clay beds are very thin and make up but a small percentage of the total thickness of the silts. Platelets of clay from these beds curl strongly at the edges. Intense curling of mud chips suggests non-kaolinitic clay, probably montmorillonite type clay. It would appear that of the small amount of clay present in the silt, the dominant variety is montmorillonite. Montmorillonite shrinks badly on firing, therefore it has little value for ceramic products. Montmorillonite is a typical weathering product of basic rocks.

Present erosion is cutting away the silt. Gully erosion is extending into the silt from the present channel of the wadi, and intricate badlands topography is being developed on the silt. On the upslope edges of the silt broad fans of pebbles and cobbles are locally being deposited. These fans are more common upstream in the Wadi Mlaha area than downstream in the Hamdah area. Where pebble and cobble gravel overlie the silt, they protect it from erosion. It is inferred that these fans reflect a more vigorous erosion than obtained when the silt was deposited. Probably this vigorous erosion is caused by Recent renewed uplift in the basin. Further evidence for possible renewed uplift is present in the form of knickpoints along most of the small tributary wadis a few kilometers upstream from their junction with Wadi Tathlith.

Structure

The main elements of the structure of the Bi'r Idimah-Wadi Haraman area were discussed in the sections on the Hamdah ultrabasic belt, the hornblende-biotite granite gneiss, and the calc-alkalic granite. Just west of the area a great zone of north-trending faults extends from the vicinity of latitude 18°30'N. in the southwestern part of the Sahl al 'Amk to the top of the area at latitude 20°N. This fault zone is thought to extend at least 130 km north of latitude 20°N. (J. W.Whitlow, oral communication, 1966), and is the site of a few small gold mines, one of which is in the Asir quadrangle but is west of the Bi'r Idimah - Wadi Haraman area. The most conspicuous bodies of calc-alkalic granite and diorite in the area lie along and are offset by this fault. Wadi Tathlith itself may mark the approximate trace of another major north-trending fault zone between the southern edge of the Sahl al 'Amk and Hamdah. North of Hamdah the evidence is less compelling, but it is possible that the zone continues northward nearly to latitude 20°N. Short, northwest trending faults, possibly tear faults related to the zone in Wadi Tathlith, are common around Hamdah and appear to have controlled deposition of the gold formerly mined in the small ancient workings between Hamdah and Bi'r el Marwah (19°02'N.x 43°46'E.).

Occurrences of minerals and industrial rocks

At least twenty-five different minerals and industrial rocks occur in the Bi'r Idimah-Wadi Haraman area. Of these materials only asbestos appears to have any potential for development. Some large deposits of marble probably suitable for industrial use are present in the northern part of the area, and seven ancient, small, gold mines are known. Nineteen of the different kinds of deposits are syngenetic in origin and six are of epigenetic origin. Syngenetic deposits of direct magmatic crystallization include: ilmenite, allanite, garnet (in part), scheelite and powellite (in part), granite used for grindstones, and chromite (in part). Syngenetic deposits of pegmatitic origin are: muscovite and feldspar, vermiculite (in part), pyrite (in part), garnet (in part), scheelite and powellite (in part), amythest, boron minerals (in part), and magnetite (in part). Metamorphic syngenetic deposits consist of asbestos, soapstone, anthophyllite, talc, magnesite, nickel, chromite (in part), magnetite, graphite, and marble. Syngenetic deposits of residual and sedimentary origin include clay, iron in sandstone, and gold placers. Among the epigenetic mineral occurrences are gold-bearing quartz veins, copper, quartz-hematite veins, gossan, quartz crystals, and clear calcite.

Magma deposits

Ilmenite.

Ilmenite occurs as an accessory mi .al in selvages of massive anorthosite which formed as magmatic differentiates from massive gabbro in the Bi'r Idimah - Wadi Haraman area. The richest observed concentration is only 1-1/2 percent ilmenite in a body of anorthosite about 6 sq. km. in area exposed (19°36'N.x 43°47'E.) in the upper part of Wadi Haraman. Rutile is not present. Tiny anorthosite dikes up to

5 cm. thick and 10 m. long intrude gabbro dikes in amphibolite at a point (19°14'N. x 43°42'E.) 23 km. north-northeast of Hamdah. These little dikes contain 0.1 to 0.25 percent of accessory ilmenite, but they lack rutile. Neither occurrence is more than a mineralogical curiosity.

Anorthositic selvages lacking visible ilmenite or rutile were seen at two localities in the Bi'r Idimah-Wadi Haraman area. One locality is at 18°36'N.X 43°44'E. in the Sahl al 'Amk where a feldspathic phase of gabbro grades into small masses of anorthosite. At the other place (19°13'N.x 43°40'E.) a composite, layered mass of gabbro intrudes granite gneiss and meta-andesite. The mass ranges in composition from diorite to gabbro with rare thin layers of anorthosite.

Even if the titanium mineral in these rocks had been rutile instead of ilmenite, at least 4 percent would be needed to make the rock an ore in a favorably situated mining district.

Allanite.

Scattered small grains of allanite were discovered at three localities (table 1), but none is as large as the occurrence reported by Brown (1965).

Garnet.

Spessartite and andradite of no commercial value were seen in, or at the contact of, granitic rocks in the Bi'r Idimah-Wadi Haraman area (table 2).

Scheelite and powellite.

Detrital scheelite was found in 17 samples of wadi sand out of 490 samples examined, but powellite was found in only 4 of the same suite of 490 samples. Only one powellite-bearing sample contained scheelite, and even in that sample the identity of the scheelite is in doubt (table 3). Powellite is much less common compared to scheelite in the Bi'r Idimah-Wadi Haraman area than it is in the prominent scheelite belt leading northward from Khamis Mushayt across the western part of the Asir quadrangle (Overstreet, 1965). In that area about 25 percent of the scheelite-bearing samples contain powellite, and the total number of powellite-bearing samples

Table 1. Allanite in the Bi'r Idimah - Wadi Haraman area

Sample number	Location		Description
	North latitude	East longitude	
22171	18°47'	43°49'	Scattered grains of accessory allanite accompanied by quartz are the centers of brown stains and radial fractures occupying about 1 sq. cm. each on the outcrop surface of massive, pink, biotite granite with phenocrysts of biotite and inclusions of hornblende-biotite diorite. Abundance of allanite for rock as whole is less than 0.01 percent of volume of rock, but this concentration increases 50 to 100 times in contact zones around diorite inclusions.
22209	19°05'	43°36'	Sparse, small grains of accessory allanite occur in pink granite porphyry intrusive into granite gneiss.
22230	19°10'	43°39'	A few crystals of allanite up to 1 cm across with dark reddish brown halo up to 3 cm across are accessory mineral in massive pink granite dikes intrusive into granite gneiss.

Table 2. Garnet in the area between Bi'r Idimah and Wadi Haraman.

Sample number	Location		Description
	North latitude	East longitude	
22139	18°56'	43°32'	Rare pale pink spessartite is accesory in hornfels at contact of pink granite.
22237	19°11'	43°46'	Accessory in felsite dikes 1.5 km. east of sample locality.
22266	19°04'	43°42'	Pale brown garnet is accessory in felsite dikes.
22309	19°21'	43°40'	Brown euhedral, andradite metacrysts in sheared and recrystallized pink biotite granite and pegmatite.

Table 3. Source of detrital scheelite and powellite in wadi sand from the area between Bi'r Idimah and Wadi Haraman.

Sample number	Location		Grains in standard sample	Description
	North latitude	East longitude		
			Scheelite	
22165	18°47'	43°56'	14	Coarse-grained, massive pink biotite granite intruded into chloritized diorite, long shear zone in meta-diorite with white quartz veins.
22197	18°57'	43°45'	3(?)	Gabbro, andesite porphyry, hornblende schist, and serpentinite with rare thin stringers of magnesite.
22207	19°01'	43°32'	3(?)	Gray granite gneiss intruded by dikes of gabbro and red granite.
22223	19°13'	43°46'	1(?)	Biotite granite gneiss intruded by dikes of andesite and pink biotite granite.
22245	19°07'	43°47'	2	Interlayered hornblende schist and biotite schist intruded in sequence by massive gabbro, andesite porphyry, and massive pink granite.
22262	19°06'	43°42'	1(?)	Contact between serpentinite and intrusive massive biotite granite.
22272	19°03'	43°51'	1	Biotite schist intruded by massive gray biotite granite and pink felsite.
22373	19°03'	43°49'	27	Hornblende schist with 1/2 to 1 percent disseminated pyrite; cut by small milky quartz veins containing pyrite and siderite.

Table 3. Source of detrital scheelite and powellite in wadi sand from the area between Bi'r Idimah and Wadi Haraman. (contd.)

Sample number	Location		Grains in standard sample	Description
	North latitude	East longitude		
			Scheelite	
22376	19°21'	43°48'	1	Gabbro threaded with stringers of pink granite and pink pegmatite.
22389	19°25'	43°45'	3	Gabbro intruded by andesite and massive red biotite granite; sparse small white quartz veins with a little pyrite.
22396	19°25'	43°48'	1	Interlayered hornblende gneiss and biotite gneiss intruded by massive gabbro and pink biotite granite.
22406	19°23'	43°50'	1	Massive gabbro intruded by dikes of fine-grained, massive, pink, biotite granite.
22435	19°34'	43°48'	1	Gneissic biotite granodiorite intruded by massive, pink, biotite granite.
22437	19°32'	43°84'	6	Fine-grained gabbro intruded by dikes of pink to red granite; both rocks broken by northerly faults containing white quartz veins with 1 to 3 percent pink microcline and less than 1 percent pyrite.
22466	19°41'	43°42'	1	Ancient prospect on white quartz lode in breccia zone in gabbro intruded by gray biotite granite.
22523	19°35'	43°33'	1	Meta-andesite and meta-andesite porphyry.
22528	19°46'	43°41'	4	Contact zone between marble and intrusive monzonite.

Table 3. Source of detrital scheelite and powellite in wadi sand from the area between Bi'r Idimah and Wadi Haraman. (contd.)

Sample number	Location		Grains in standard sample	Description
	North latitude	East longitude		
			Powellite	
22148	18°49'	43°37'	2	Gabbro intruded by coarse-grained, pink, biotite-hornblende granite and pink felsite.
22197	18°57'	43°45'	1	Gabbro, andesite prophyry, hornblende schist, and serpentinite with rare thin stringers of magnesite.
22210	19°04'	43°34'	2	Biotite granite gneiss intruded by hornblende-biotite felsite.
22492	19°37'	43°40'	3(?)	Biotite-quartz schist intruded by dikes of fine-grained gray to pink biotite granite; cut by thin, limonite-coated, shear zone.

is about 60 percent of the total number of scheelite-bearing samples. Most of the detrital scheelite occurs in basins underlain by hornblende schist, andesite, and gabbro intruded by dikes of pink biotite granite. In three basins the basic rocks were not intruded by granite. One scheelite-bearing source is the contact between marble and intrusive monzonite. The richest scheelite-bearing sample came from a bleached northwest-trending shear zone in metadiorite. Most of the powellite is also associated with massive, pink, biotite granite. None of the scheelite occurrences is worth further attention in a search for exploitable tungsten deposits; however, the fault zone giving the richest scheelite sample of the lot should be examined for base and precious metals.

Pyrite.

Disseminated pyrite was seen at 21 localities in the Bi'r Idimah-Wadi Haraman area (table 4), but no massive pyrite bodies were observed. Fifteen of the occurrences originated from magmatic activity of which four are of direct magmatic origin and 11 are from magmatic differentiation products including quartz veins. The magmatic pyrite occurs in late-stage rocks like fine-grained gray, pink, or red granite, red or white felsite, and rhyolite. Pyrite derived by magmatic differentiation is present in pegmatite, in pegmatite grading into quartz-hematite veins, and in possibly genetically related barren white quartz veins and auriferous quartz veins. Hydrothermal pyrite in white quartz is the commonest mode of occurrence in the area. Metamorphosed sedimentary rocks at four places contain pyrite which may be relict from original sedimentary deposition. Two small faults were found to have pyrite. At four places (22165, 22373, 22389, and 22437) a few grains of scheelite occur with the pyrite. Except for the association with gold at the Higera mine, none of the pyrite occurrences is accompanied by evidence of base or precious metals.

Granite used for grindstones.

A small quarry (19°32'N.x 43°46'E.) was opened in massive, porphyritic, pink, biotite granite at the northern end of Jibal al Kilab to supply grindstones for the ancient Avala gold mine 16 km. to the northwest. Exfoliation slabs 15 to 20 cm thick were broken into blocks which were slid off the north face of the mountain and dressed

Table 4. Pyrite between Bi'r Idimah and Wadi Haraman.

Sample number	Location		Description
	North latitude	East longitude	
22017	18°31'	44°07'	Inclusion of serpentinite in massive pink granite has strong limonite stain after pyrite in shear planes; no copper or nickel stain; on north-trending fault.
22021	18°36'	44°06'	Trace of disseminated pyrite in graphitic phyllite, on north-trending fault.
22068	18°35'	43°50'	Disseminated in footwall of simple quartz-orthoclase pegmatite grading into quartz-hematite vein.
22122	18°55'	43°40'	Quartz veins at Higera gold mine.
22143	18°53'	43°32'	Disseminated in northwest-trending fault zone in massive biotite granite.
22159	18°46'	43°58'	Disseminated (0.1% of rock) in fine-grained granite and red felsite.
22164	18°52'	43°58'	Scattered pyrite crystals in rhyolite.
22165	18°47'	43°56'	Sparse crystals of pyrite in white quartz vein striking N.30°W. in mylonite zone in diorite and granite.
22167	18°46'	43°46'	A few cubes of pyrite in quartz-poor pegmatite.
22181	18°51'	43°53'	Pyrite altered to hard limonite gossan on small quartz veins in northwest-trending fault.
22185	18°53'	43°48'	Sparse disseminated pyrite in graphite schist intruded by gray to pink felsite and granite.
22225	19°13'	43°40'	Faintly pyritiferous quartzite.

Table 4. Pyrite between Bi'r Idimah and Wadi Haraman. (contd.)

Sample number	Location		Description
	North latitude	East longitude	
22324	19°27'	43°37'	White quartz stringers with as much as 5% pyrite in cubes up to 4 cm across.
22343	19°18'	43°34'	Scattered grains of pyrite in white quartz vein 2 to 4 m thick 700 m long, striking north.
22373	19°03'	43°49'	Hornblende schist with 1/2 to 1% disseminated pyrite in cubes up to 0.5 mm across, and white quartz veins with about 1% of pyrite in cubes up to 6 mm across.
22378	19°19'	43°46'	Black, dustlike pyrite (less than 1/2%) in marble.
22389	19°25'	43°45'	Trace of pyrite in white quartz stringers in red granite.
22428	19°35'	43°43'	Gray to pink granite with less than 0.1% of disseminated pyrite.
22437	19°32'	43°48'	Gabbro and red granite cut by en echelon white quartz veins with 1-3% pink microcline and less than 1% of pyrite.
22539	19°47'	43°37'	Interlayered biotite quartzite and meta-andesite intruded by gabbro, red granite, and pink felsite. Sparse white quartz veins up to 30 cm thick and 50 m long contain less than 1/2% pyrite and are most common in and near felsite and granite.
22540	19°49'	43°38'	White felsite dike with 0.1% pyrite intrudes gabbro.

to final shape at the foot of the mountain. Stones in various stages of completion are scattered about. The rock is too porphyritic to make an acceptable building stone, but the face of Jibal al Kilab all around its perimeter would be easy to quarry, and at many places, particularly along the southwestern periphery, equigranular facies are present.

Chromite.

Chromite occurs as a minor accessory mineral in serpentinite replacing dunite in the Hamdah asbestos district and as scattered detrital grains in a wadi draining serpentinite east of Tathlith (table 5). The chromite is probably a relict mineral formed originally as an accessory in dunite. None of the displays of chromite is more than would ordinarily be expected in an average dunite. Detailed work on asbestos in this area would also disclose the extent and quantity of the chromite. The most favorable presently known occurrence of chromite in the Hamdah ultrabasic belt is locality 22273 in table 5, but minable quantities of chromite are not known there.

Pegmatitic deposits

Muscovite and feldspar.

Muscovite and feldspar occur in pegmatite dikes genetically related to massive biotite granite in the Bi'r Idimah-Wadi Haraman area. Most of the pegmatite dikes have no muscovite. Dikes rich in feldspar are small and the feldspar is generally intimately intergrown with quartz; therefore, the feldspar and quartz could not be readily separated by hand cobbing. Where good quality feldspar is present there are too few dikes to permit mining. Three occurrences of muscovite are listed in table 6, but they are of no commercial value.

Vermiculite.

Two small occurrences of vermiculite were found in the Bi'r Idimah-Wadi Haraman segment of the Hamdah ultrabasic belt. At one locality, station 22075 (18°38'N.x43° 53'E.) amphibolite is intruded by massive gabbro and both rocks are intersected by dikes of massive, pink, graphic-granite pegmatite. A trace of vermiculite is in the pegmatite. At the second locality, station 22103 (18°36'N.x 43°35'E.), massive gabbro

Table 5. Chromite in the Bi'r Idimah - Wadi Haraman area.

Sample number	Location		Description
	North latitude	East longitude	
22237	19°11'	43°46'	Rare specks of chromite in serpentinite in the Hamdah district.
22273	19°03'	43°49'	Masses of chromite up to about 8x20x70 cm make up 6 percent of a body of serpentinite replacing dunite in the Hamdah district; serpentinite as exposed is 7 m wide x 3 m high x 4 m long.
22300	19°06'	43°40'	Chromite is minor accessory in serpentinite replacing dunite in the Hamdah district.
22520	19°32'	43°31'	Detrital chromite in wadi draining serpentinite in the Tathlith district; a few small pieces only.

Table 6. Location of muscovite in the area between Bi'r Idimah and Wadi Haraman.

Sample number	Location		Description
	North latitude	East longitude	
22072	18°39'	43°51'	Muscovite books up to 1 cm across in graphic-granite pegmatite dikes up to 4 m thick and 25 m long; pegmatite consists mainly of quartz and microcline; mica is a minor accessory.
22217	19°14'	43°40'	Rare books of colorless, strongly reeved muscovite up to 3x4 cm in the inner zone of a well-zoned granite pegmatite.
22299	19°04'	43°42'	Strongly reeved book muscovite up to 1x2 cm makes up 6 percent of perthitic pegmatite grading into felsite; maximum width of pegmatitic part of dike is 3 m, length probably less than 20 m.

is intruded by pink granite. The original pyroxene of the gabbro is generally altered to hornblende and biotite, and some of the biotite and pyroxene are converted to vermiculite. Conversion to vermiculite is most complete where the gabbro is pervasively feldspathised and partly replaced by metacrysts of microcline. Neither locality is a commercial source for vermiculite.

If a commercial source for vermiculite could be found in the Hamdah ultrabasic belt, an outlet for vermiculite could be developed in the agricultural comminities west and northwest of the Hamdah belt, particularly those comminities near the escarpment. Presently great quantities of tomatoes, grapes, prickly pear apples, and other thin-skinned varieties of fruit and vegetables are wasted in the producing areas because the fresh food cannot be trucked to the major centers of consumption, like Ta'if, Mecca, and Jiddah, without unacceptable loss. Vermiculite would be especially effective in helping bring the grape harvest to market. It might reduce trucking damage to the other thin skinned commodities.

Examination of the Hamdah asbestos area might therefore include an appraisal of vermiculite.

Amythest.

Stringers of simple pegmatite up to 4 cm thick and 10 m long in pink, biotite granite gneiss contain amythestine quartz at locality 22195 (18°58'N.x 43°44'E.) about 8 km northeast of the Higera gold mine. The amythest forms subhedral crystals up to 1 cm long, but the crystals are mottled and fractured and are not of gem quality.

Boron minerals.

The boron minerals axinite and tourmaline were seen at a single place each in the Bi'r Idimah-Wadi Haraman area, and at both places the boron mineral is associated with per-alkalic granite or its differentiation products. Axinite occurs in brown sheafs 4 to 5 cm long in recrystallized pink pegmatite intrusive into diorite and gabbro at station 22309 (19°21'N.x 43°40'E.). Radial aggregates of black tourmaline up to 3 cm across form rare fillings in joints in hornfels at the contact of intrusive, pink, per-alkalic granite, station 22139 (18°56'N.x 43° 32'E.). The crystals of axinite and tourmaline are of scientific interest only;

neither mineral is a commercial source for boron, and the crystals at both localities lack gem quality.

Metamorphic deposits

Asbestos.

Asbestos deposits in the segment of the Hamdah ultrabasic belt between Bi'r Idimah and Wadi Haraman are one of the two most important mineral resources in the Asir quadrangle. Twenty occurrences of asbestos are known near the Higera gold mine and the village of Hamdah (table 7), and rocks favorable for asbestos crop out east of Tathlith (19°48'N.x 43°34'E.). Associated with the asbestos are small amounts of chromite, and locally a little soapstone, anthophyllite, talc, and clear calcite but none of these materials is known in commercial quality or quantity. Also present in the same general area is a little vermiculite and most of the ancient gold and copper mines between Bi'r Idimah and Wadi Haraman. Thus, if a detailed study _/ of this asbestos is made, by-product information would be developed on at least seven other mineral commodities. Because asbestos can be beneficiated by air separation it is ideal for mining under local conditions. Short-fiber asbestos would be wanted by a domestic asbestos-cement water-pipe industry based on Saudi Arabian raw materials. Long-fiber asbestos commands a high price in the international minerals market. The Hamdah district may prove to be a source for both.

Cross-fiber asbestos fills veins in serpentinite in the Hamdah ultrabasic belt. In the Higera and Hamdah districts the serpentinite seems to have been derived from olivine-bearing ultrabasic rocks like periodotite and dunite, because magnesite is a common by-product of the serpentinization. In the serpentinite east of Tathlith magnesite is less common, and calcite and dolomite veins are present. Possibly the serpentinite in that area is derived mainly from olivine-free pyroxenite and gabbro. At some places andesite and hornblende schist are altered to serpentinite. Brown calcareous crusts are forming in some places over the serpentinite in the present erosion cycle. These give a distinctive color to the serpentinite.

_/ Anyone entering the Hamdah and Higera areas would benefit initially by using as a local guide Hassan Ghanim al Messfer of Hamdah.

Table 7. Asbestos in the area between Bi'r Idimah and Wadi Haraman

Sample number	Location		Description
	North latitude	East longitude	
			Higera district
22122	18°55'	43°40'	Minor cross-fiber asbestos in serpentinite associated with hornblende schist and marble.
22123	18°55'	43°40'	Cross-fiber asbestos up to 7 cm long, generally 0.5 to 2 cm long, in veins dipping 20°S. in serpentinite and silicified marble.
-	18°58'	43°41'	Radial aggregates of asbestos 2 cm to 15 cm across in small lenticular masses of serpentinite 0.5 to 4 m long in amphibolite at ruins called Em Fagger; very little asbestos.
22297	18°56'	43°41'	Cross-fiber asbestos 0.5-8 mm thick in shear zones up to 15 cm thick in serpentinite; asbestos makes up 8 to 15 percent of the shear zone, no movement after formation of asbestos, which has very straight fibers; at many places in this area cross-fiber asbestos not exceeding 1 cm in length occurs in veins up to 40 m long which dip 30°S. and locally make up 20 percent of the exposed serpentinite.
			Hamdah district
22237	19°11'	43°46'	Cross-fiber asbestos 1 to 2 mm long in veins 20 cm wide and 200 m long dipping 80E. in serpentinite in hornblende schist.

Table 7. Asbestos in the area between Bi'r Idimah and Wadi Haraman (contd.)

Sample number	Location		Description
	North latitude	East longitude	
			Hamdah district (contd.)
22240	19°08'	43°44'	Tiny seams of short cross-fiber asbestos, not exceeding 0.5 mm and commonly 0.25 mm across, make up less than 0.1 percent of serpentinite mass 4,000 sq. m. in area.
22243	19°09'	43°46'	Cross-fiber asbestos in veins up to 1 mm wide in serpentinite, distribution masked by talus.
22248	19°08'	43°45'	Cross-fiber asbestos in veins up to 2 mm thick constitute up to 8 percent of the volume of the serpentinite in which they occur; average at least 0.5 percent of the volume of serpentinite in 40,000 sq. m.; cut by dikes of diorite and pink aplite; may be a good locality.
22249	19°07'	43°45'	Cross-fiber asbestos 0.5 to 1 mm thick in scarce veinlets in serpentinite; very sparse, dip 70° N.
22252	19°06'	43°46'	Trace of asbestos in serpentinite.
22255	19°04'	43°46'	Cross-fiber asbestos up to 6 mm across replacing serpentinite in gabbro, and diorite; asbestos makes up 0.5 to 1.5 percent of serpentinite underlying surface of 3,000 sq. m.
22269	19°04'	43°49'	Cross-fiber asbestos up to 20 cm long in veins dipping 65°N. in serpentinite in hornblende schist; asbestos fibers are broken by fractures sub-parallel to vein wall into lengths of 2 to 3 cm; poorly exposed but may be a good locality.

Table 7. Asbestos in the area between Bi'r Idimah and Wadi Haraman (contd.)

Sample number	Location		Description
	North latitude	East longitude	
Hamdah district (contd.)			
22275	19°03'	43°49'	Slip-fiber asbestos in fault dipping 60°N., 10 to 30 cm wide, vertical height exposure 2 m.
22286	19°02'	43°42'	Lenticular masses of cross-fiber asbestos up to 20 cm wide and 3 m. long dipping 40° N. in serpentinite; fractures sub-parallel to walls cut asbestos into fibers 2 to 3 cm long; slip-fiber asbestos developed parallel to slickensides in serpentinite where it covers surfaces 5 cm thick and up to 1 m long; intruded by dikes of gray granite and perthitic pegmatite; asbestos sparse at this locality.
22290	19°04'	43°38'	Cross-fiber asbestos with fibers up to 30 cm long in veins up to 5 m in length in serpentinite in hornblende schist; veins strike E. and dip 60°S., and thicken and thin along strike from 5 cm to 30 cm; asbestos veins replace 15 to 30 percent of serpentinite in an exposure at least 150 m long, 60 m wide, and 30 m thick; asbestos-bearing vein system may persist several kilometers along strike although individual veins are short; this exposure has excellent possibility as commercial source of asbestos.

Table 7. Asbestos in the area between Bi'r Idimah and Wadi Haraman (contd.)

Sample number	Location		Description
	North latitude	East longitude	
			Hamdah district (contd.)
22291	19°05'	43°39'	Cross-fiber asbestos up to 10 cm across in vertical veins up to 20 m long in serpentinite in hornblende schist; serpentinite forms lenticular masses from 3/4 m wide and 1-1/2 m long to 20 m wide and 300 m long in the foliation of the schist; 0.1 to 0.5 percent of volume of serpentinite is asbestos; outcrops of serpentinite occupy at least 10,000 sq. m.
22294	19°02'	43°42'	Cross-fiber asbestos in fibers up to 10 cm long in veins with random orientation in serpentinite masses conformable to layering of hornblende schist and quartzite that strikes N.65°W. and dips 75°N.; asbestos veins are individually short and tapering, up to 6 m long; in aggregate the veins make up less than 1 percent of the serpentinite.
22295	19°01'	43°43'	Cross-fiber asbestos veins up to 8 cm wide are in serpentinite in hornblende schist striking N.70°E. and dipping 65°N.; the serpentinite makes up about 20 percent of the exposed rock and forms lenticular masses a few meters to a few tens of meters thick by a few meters to a few hundred meters long; from 0.5 to 2 percent of the serpentinite is replaced by asbestos; all asbestos veins are sheared so that the

Table 7. Asbestos in the area between Bi'r Idimah and Wadi Haraman (contd.)

Sample number	Location		Description
	North latitude	East longitude	
			Hamdah district (contd.)
			longest fibers are only 2 to 3 cm long although the veins are 5 to 8 cm thick; slip-fiber asbestos is almost as common as cross-fiber asbestos; area is worth further study.
22300	19°06'	43°40'	Cross-fiber and slip-fiber asbestos formed in vertical fractures in dunite and serpentinite; in hornblende schist maximum length of cross-fiber asbestos is 4 cm, but exposure is crossed by myriad of thin veinlets of cross-fiber asbestos up to 5 mm wide which make up as much as 8 percent of the serpentinite in areas up to 2,000 sq. m.; the slip-fiber asbestos occurs in lenticular pods up to 25 cm thick and 1.5 m long; area is worth further study.
22304	19°06'	43°40'	Cross-fiber asbestos exposed for only a meter or two in veins that attain a thickness of 12 cm but are fractured sub-parallel to their walls so that the actual lengths of the fibers are less than the width between the walls; among the wide veins there are many thin veins of asbestos up to 2 mm across; in total the veins make up about 1 percent of the volume of serpentinite bodies that are hundreds of meters thick and at least several thousand meters long; area is worth further study.
			Tathlith district

None. See sections on magnesite and chromite.

The cross-fiber asbestos occupies fractures or replacement zones in the serpentinite. These zones are clearly older than the calc-alkalic and per-alkalic granitic rocks and related felsite and pegmatite, because many dikes of granite were found intruding the asbestos. Also, the amount of asbestos in the serpentinite bears no relation to the presence or absence of intrusive masses of granite.

Samples of the asbestos have been sent to the U. S. Geological Survey in Washington for appropriate examination by specialists. It is thought by the writer that much of the Hamdah asbestos is of the desirable chrysotile type, but special studies are required because surface outcrops of the asbestos are deeply weathered. Other forms of asbestos are present as the section below on anthophyllite shows. Results of the present reconnaissance suggest that probable chrysotile cross-fiber asbestos is many times more abundant than anthophyllite (massive aggregates of orthorhombic amphibole) or slip-fiber asbestos (monoclinic amphibole asbestos).

The physical characteristics of the known deposits of asbestos are summarized in table 7 which shows that most of the veins in the Higera district dip only 20° or 30° whereas the veins in the Hamdah district are nearly vertical. Four deposits, of which one (22297) is worth further study, are present in the Higera district. Of the 16 occurrences listed for the Hamdah district, six (22248, 22269, 22290, 22295, 222300, and 22304) are worth close examination, with localities 22290 and 22304 especially favorable.

Soapstone, anthophyllite, and talc.

Soapstone and talc were found at three localities each in the Bi'r Idimah-Wadi Haraman area (table 8), and anthophyllite was seen at one place. None of the occurrences are of any economic importance, but they show that these three industrial materials are present in the Hamdah ultrabasic belt. The possibility exists that one or more of them would be found in exploitable deposits during detailed investigations of the Hamdah asbestos.

The soapstone and talc seem to be younger than the asbestos and are found at contacts where serpentinite and asbestos are intruded by granite, or, in the instance of soapstone, where pyroxenite is altered by intrusive granite. The anthophyllite

Table 8. Soapstone, anthophyllite, and talc in the Bi'r Idimah - Wadi Haraman area.

Sample number	Location		Description
	North latitude	East longitude	
			Soapstone
22192	18°56'	43°45'	Lenticular masses of soapstone present in serpentinite of Higera district; long axes of masses strike N.20°E. and plunge 25°S.; reach 2 m in thickness and 8 m in length; weathered; no commercial use. Larger lenticular masses of soapstone occur just west of this locality. The lenticles are 50 to 60 m thick and up to 200 m long. They are badly weathered at the surface, but the texture of the weathered rock is interpreted to indicate possible commercial grade soapstone occurs below the zone of weathering, which probably extends at least 20 m. Many septa of serpentinite and hornblende schist, and dikes of granite in the soapstone would require that highly selective, probably uneconomically selective, quarrying would have to be used to remove the soapstone.
22204	19°00'	43°36	Lenticular masses of soapstone less than 1 m thick and 7 m long present in serpentinite of Higera district; soapstone of poor quality and of no commercial use.
22261	19°07'	43°42'	Poor quality soapstone formed from pyroxenite along contacts of intrusive granite; of no commercial use.
			Anthophyllite
22190	18°55'	43°46'	Small veins and radial masses of anthophyllite up to 15 cm thick and 15 m long present in hydrothermally altered serpentinite; not common.

Table 8. Soapstone, anthophyllite , and talc in the Bi'r Idimah-Wadi Haraman area. (contd.)

Sample number	Location North latitude	Location East longitude	Description
			Talc
22192	18°56'	43°45'	Small veins of poor quality talc, and layers of talc schist, are associated with soapstone in serpentinite in the Higera district. The veins cut across lenticular masses of soapstone and are very irregular. They do not exceed 70 cm in thickness. Length of talc veins may not exceed 30 m, but poor exposures prevent evaluation. The talc schist forms partial envelopes up to 30 cm thick along walls of bodies of serpentinite and fills small shear zones in serpentinite. Talc is near contacts of gray granite intrusive into serpentinite.
22273	19°03'	43°49'	Fault zone dipping 60°N., 10 to 30 cm wide, and exposed for 2 m in serpentinite in the Hamdah district is filled with talc and asbestos; thoroughly weathered; of no commercial use.
22298	19°02'	43°42'	Talc schist formed by hydrothermal alteration along shear zone in serpentinite; no value for talc, is associated with gold-bearing quartz veins.

asbestos may have formed at the same time as the chrysotile(?) asbestos. It is in radial masses and fibrous aggregates in contrast to the cross-fiber chrysotile(?) asbestos and slip-fiber monoclinic amphibole asbestos in the Hamdah area.

The most important asbestos area is the serpentinite exposed intermittently eastward from Hamdah 16 km to Bi'r El Marwah (19°02'N.x 43°46'E.). At least 150 sq km are potentially asbestos-bearing. The second most important asbestos area occupies about 50 sq km in the vicinity of the Higera gold mine. About 150 sq km north and east of Tathlith are potentially favorable for asbestos, but chrysotile asbestos may be sparse.

Magnesite.

Thin joint fillings, small veins, and irregular masses of magnesite have been seen at 22 localities in the Bi'r Idimah-Wadi Haraman area (table 9). They are in the Hamdah ultrabasic belt, where they are concentrated in the Higera and Hamdah districts. Only three occurrences of magnesite are known in the Tathlith district. All the magnesite is in serpentinite, except at locality 22283, where magnesite veins originating in serpentinite follow joints out of the serpentinite into biotite-muscovite schist. The magnesite is thought to have resulted from the alteration of peridotite and dunite to serpentinite with surplus magnesium released as magnesite. None of the deposits is an economic source for magnesite.

Nickel.

The only evidence of possible nickel in the Bi'r Idimah-Wadi Haraman segment of the Hamdah ultrabasic belt is green stains in a small mass of weathered serpentinite formed from dunite at locality 22300 (19°06'N.x 43°40'E.), which was recommended for further sutdy of asbestos. Analysis of the stains has not been made. Inasmuch as norite is very scarce in the ultrabasic belt it is thought that nickel in exploitable deposits is absent. The stains at this locality, even if they prove to be from nickel, are a mineralogical curiosity only.

Table 9. Magnesite in the area between Bi'r Idimah and Wadi Haraman.

Sample number	Location		Description
	North latitude	East longitude	
			Higera district
22130	18°58'	43°36'	Joints up to 1 cm thick in serpentinite locally filled with magnesite; less than 0.01 percent of rock is magnesite.
22132	18°58'	43°34'	Lenticular masses of magnesite up to 2 m thick and 8 m long in serpentinite; more common as joint fillings a few cm thick and 10 to 20 m long; makes up less than 1 percent of rock. Four small masses of magnesite observed on east wall of wadi 2 km east of 22132; the largest is 60 cm thick and 12 m long.
22133	18°57'	43°34'	Several pieces of magnesite weighing 300 grams or less are in wadi gravel at this point, showing that small amounts of magnesite crop out upstream.
22134	18°56'	43°35'	0.9 km west of this locality a body of serpentinite with magnesite is exposed; magnesite fills fractures in serpentinite and occupies 7 percent of volume of rock; largest masses of magnesite are 3 m thick and 15 m long, most are less than 20 cm thick and are highly variable in length; exposure estimated to contain 5 tons of magnesite per meter of depth, but it is intimately mixed with serpentinite.
22135	18°57'	43°34'	Prominent peak 2 km to north-west capped by what appear to be magnesite veins in serpentinite.

Table 9. Magnesite in the area between Bi'r Idimah and Wadi Haraman. (contd.)

Sample number	Location North latitude	Location East longitude	Description
			Higera district
22188	18°55'	43°46'	Brecciated serpentinite with fractures locally filled with magnesite up to 2 cm thick.
22190	18°55	43°46'	Sparse magnesite occurs as fillings along intersecting joints in serpentinite, up to 3 cm thick and 5 m long.
22196	18°58'	43°44'	Sparse magnesite coating a few joints in serpentinite for maximum thickness of 3 cm and length of at least 20 m; makes up less than 0.1 percent of serpentinite.
22197	18°57'	43°45'	Sparse magnesite coating a few joints in serpentinite.
22202	18°54'	43°44'	Sheets of magnesite 0.5 to 1.5 cm thick and up to 3 m long fill joints in serpentinite.
			Hamdah district
22204	19°00'	43°36'	Sparse detrital magnesite in wadi gravel at this locality and thin fillings of magnesite in joints in serpentinite 2.5 km southwest.
22262	19°06'	43°42'	Rare thin films of magnesite along joints in serpentinite.
22264	19°04'	43°42'	Rare thin films of magnesite in joints in serpentinite.
22281	19°03'	43°38'	Joint in serpentinite occupied by filling of magnesite 1 cm thick and 60 cm long.
22282	19°02'	43°37'	Sparse thin films of magnesite in joints in serpentinite.
22283	19°02'	43°38'	Magnesite veins occupy joints in serpentinite and extend out of serpentinite into biotite-muscovite schist; veins anastamose and attain a maximum thickness of 0.5m, contain many inclusions of host rock,

Table 9. Magnesite in the area between Bi'r Idimah and Wadi Haraman. (contd.)

Sample number	Location North latitude	Location East longitude	Description
			Higera district (contd.)
			and occupy about 15 percent of the rock mass underlying an area of 500 sq. m.
22284	19°03'	43°39'	Sparse veinlets of magnesite up to 2 cm thick in serpentinite.
22291	19°05'	43°39'	Scattered veins of magnesite up to 2 cm thick and 4 m long in serpentinite; asbestos also present.
			Tathlith district
22520	19°32'	43°31'	Sparse, thin seams of mixed magnesite and calcite fill scattered joints in serpentinite.
22521	19°34'	43°31'	Major joints in serpentinite filled with magnesite up to 2 cm thick.
22522	19°35'	43°32'	Trace of magnesite filling small fractures in serpentinite; calcite veins more common.

Magnetite.

Magnetite is a more than ordinarily abundant accessory mineral at 13 localities in the Bi'r Idimah-Wadi Haraman area, but it was not found in large amounts anywhere. The richest concentrations are in serpentinite, where the magnetite locally makes up as much as 15 percent of the rock (table 10), and magnetite quartzite, which contains up to 40 percent of magnetite. No surface evidence was found to indicate that large bodies of magnetite are to be found in either type of deposit. However, the little exposure of magnetite quartzite at station 22317 might be part of a larger metasedimentary deposit. The magnetite associated with felsite, pegmatite, and granite is only an accessory mineral of no economic importance.

Graphite.

Graphitic phyllite and graphite schist are known at five localities in the Bi'r Idimah-Wadi Haraman area, but graphite is not concentrated into minable masses or veins at any of the localities. Strongly cleaved graphitic phyllite is interbedded with andesite at station 22021 (18°36'N.x 44°06'E.). Graphite schist is intruded by gray to pink felsite and granite at station 22185 (18°53'N.x 43°48'E.), but crystalline graphite has not formed at the contacts of the dikes. Graphite schist is interlayered with biotite schist and intruded by serpentinite and late quartz porphyry at station 22243 (19°09'N.x 43°46'E.). Graphitic chloritoid schist is interlayered with quartzite and metamorphosed lithic tuff and this sequence is intruded by gabbro (station 22486 at 19°44'N.x 43°37'E.). Silicified marble and graphite phyllite are interlayered at station 22512 (19°37'N.x 43°34'E.).

Marble.

Thirty-six occurrences of marble and limestone in the Bi'r Idimah-Wadi Haraman area are listed in table 11. Most of the marble is industrially unacceptable owing to silica (8 localities), iron (2 localities), or small size (19 exposures). Some small beds of carbonate rock could be used as local sources for lime. The large and seemingly pure marble represented by stations 22377-22381, 22481, 22526, and 22542 could readily supply large volumes of lime and building stone. Marble at 22526

Table 10. Magnetite between Bi'r Idimah and Wadi Haraman.

Sample number	Location		Description
	North latitude	East longitude	
22123	18°55'	43°40'	Serpentinite at the Higera gold mine locally contains as much as 15 percent magnetite.
22128	18°59'	43°40'	Magnetite-biotite quartzite occurs as thin interlayers with hornblende schist.
22132	18°58'	43°34'	Magnetite is an abundant and commonly coarse-grained accessory mineral in serpentinite.
22133	18°57'	43°34'	Detrital magnetite crystals up to 2.8 cm across and 0.7 cm thick in wadi sand, probably derived from serpentinite.
22225	19°13'	43°40'	Magnetite-bearing quartzite, magnetite sparse.
22237	19°11'	43°46'	Garnetiferous, magnetite-bearing felsite dikes.
22245	19°07'	43°47'	Common accessory mineral in serpentinite.
22317	19°25'	43°40'	Magnetite quartzite and magnetite-biotite-quartz schist are interlayered with biotite-hornblende gneiss and intruded by gabbro and gabbro pegmatite. The magnetite-rich rocks contain 20 to 40 percent magnetite in grains less than 0.5 mm across intimately intergrown with quartz or quartz and biotite in layers rarely thicker than 3 cm which alternate with feldspathic layers 2 to 4 mm thick and free of magnetite. This sequence of magnetite-bearing quartzose layers and magnetite-free feldspathic layers is from 5 to 75 cm thick, and is interlayered with the hornblende

Table 10. Magnetite between Bi'r Idimah and Wadi Haraman. (contd.)

Sample number	Location		Description
	North latitude	East longitude	
			schist. Strike length of the magnetite-rich layers is at least 50 m, but width and other relations hidden by talus.
22327	19°25'	43°35'	Sparse float of magnetite in crystals up to 1 cm across at contact between hronblende gneiss and intrusive, red, biotite granite; may be from pegmatite.
22344	19°20'	43°38'	Sparse float of magnetite crystals up to 1x2x1 cm in area where granite gneiss is intruded by gabbro and massive, pink biotite granite.
22388	19°24'	43°46'	Small specks of accessory magnetite in massive, fine-grained red biotite granite.
22389	19°25'	43°45'	Do.
22391	19°27'	43°44'	Do.

and 22542 might also be suitable for ornamental stone. Simple field tests and megascopic examination suggests that marble at 22377-22381 and 22481 possess good chemical characteristics for industrial use, but analyses have not been made to determine its purity.

Residual and sedimentary deposits

Clay.

A small residual clay deposit formed by the weathering of pink granite porphyry was seen at locality 22030 (18°41'N.x 44°05'E.). The granite porphyry is weathered to white clayey saprolite, and joints in the unweathered prophyry are filled with clay brought down by ground water from the overlying saprolite. The veins are short and not over 1/2 cm thick. They die out downward. About 2 cu m of the white residual clay has been dug out by Bedouin for their use. The clay is probably kaolinite.

Many other small exposures of residual clay and saprolite are present in the Bi'r Idimah-Wadi Haraman area, but the only location recorded was the little pit described above. Other pits were not seen. At many of these small exposures a few cubic meters of kaolinite or other clay could be obtained by digging, washing, and decanting, but none is large enough to supply more than intermittent local use, for house decoration and medicine. No residual clay deposit adequate in size to support a village pottery was seen.

The thin sedimentary clays of probable montmorillonitic clays of probable montmorillonitic type have been mentioned in the section on Silt under Geologic Setting. They have no ceramic use.

Iron in Wajid sandstone.

Black sand:-- Concentrations of black sand in the Wajid sandstone were examined at several localities along the lower reaches of Wadi Idimah 15 to 25 km east-northeast of Bi'r Idimah, at Jebel Sarakh (18°47'N.x 44°08'E.), in the hills 8 km west of Jabal Shumraq (18°50'N.x 44°08'E.), and 5 to 10 km east of Jibal Lahu (18°53'N.x 43°49'E.). The black sand consists mainly of ilmenite and epidote with

Table 11. Marble in the area between Bi'r Idimah and Wadi Haraman.

Sample number	Location		Description
	North latitude	East longitude	
22014	18°31'	44°10'	Interlayered with hornblende schist; no commercial use.
22121	18°55'	43°41'	Silicified marble interlayered with hornblende schist at Higera gold mine; no commercial use.
22122	18°55'	43°40'	Brown silicified marble interlayered with hornblende schist at Higera gold mine, marble up to 1.4 m thick; no commercial use.
22123	18°55'	43°40'	Silicified marble in layers up to 1 m thick in serpentinite at Higera mine; no commercial use.
22125	18°55'	43°39'	Silicified marble, layers up to 2 m thick, in hornblende schist; no commercial use.
22127	18°57'	43°40'	Gray-green marble interlayered with hornblende schist; no commercial use.
22130	18°58'	43°36'	Brown marble in serpentinite; small; no commercial use.
22137	18°55'	43°35'	Gray limestone of apparently good chemical quality interbedded with graywacke; probably only a few meters thick and a few tens of meters long.
22192	18°56'	43°45'	Silicified, ferruginous marble associated with serpentinite and soapstone; no economic use
22212	19°07'	43°31'	Nearly flat-lying septum of impure white to green marble, intruded by dacite, in granite gneiss; no economic use.

Table 11. Marble in the area between Bi'r Idimah and Wadi Haraman.

Sample number	Location		Description
	North latitude	East longitude	
22218	19°15'	43°42'	Rare, thin lenticles of impure marble in amphibolite; no economic use.
22262	19°06'	43°42'	Isolated lenticular mass of brown marble in serpentinite; mass is about 20 m x 25 m x 35 m; no commercial use.
22263	19°05'	43°40'	Ferruginous marble in serpentinite altered to gossan of limonite and jasper 4-6 m thick, 700 m in diameter, caps hill; no commercial use.
22266	19°04'	43°42'	Thin layers of marble in quartz-biotite schist and hornblende schist; no commercial use.
22279	19°05'	43°40'	Thin layers of marble in hornblende schist; no commercial use.
22314	19°24'	43°37'	Interlayers with hornblende schist; no commercial use.
22337	19°23'	43°30'	Lenticular masses of brown, silicified marble in serpentinite; no commercial use.
22350	19°19'	43°35'	Brown silicified marble and metapyroxenite in layered biotite gneiss; no commercial use.
22364	19°19'	43°44'	Brown marble inclusions up to 8 m thick and 40 m long in gabbro; no commercial use.
22377	19°20'	43°46'	White to gray marble exposed along northwest wall of Wadi Bayaadth, strikes N.45°E., dip vertical, about 20 m thick and 5500 m long; appears to have excellent chemical quality.

Table 11. Marble in the area between Bi'r Idimah and Wadi Haraman. (contd.)

Sample number	Location North latitude	Location East longitude	Description
22378	19°19'	43°46'	Two parallel layers of very coarsely crystalline white to gray marble in northwest wall of Wadi Bayaadth; has 0.5 percent dustlike pyrite, and is cut by veins of white quartz; eastern layer 20 m thick, western layer 8 m thick; extends from 22377.
22380	19°17'	43°47'	Five layers of white to gray coarse-grained marble in biotite gneiss; layers are 1/2 to 4 m thick, very pure, extension of layers at 22378.
22381	19°18'	43°47'	White to gray marble, layers up to 1 m thick in biotite gneiss; white quartz veins in marble; end of layers starting at 22377.
22411	19°20'	43°50'	Black, fine-grained, impure marble interlayered with biotite-muscovite schist and meta-andesite; no commercial use.
22453	19°40'	43°41'	Impure marble interlayered with meta-andesite and meta-graywacke at Avala gold mine; no commercial use.
22481	19°40'	43°40'	Fine-grained, dark gray, very pure marble crops out over area 0.1 to 0.5 km wide and 2.5 km long; interlayered with meta-andesite, intruded by gabbro; total area of outcrop is 0.75 sq. km.
22482	19°41'	43°40'	Gray marble extensively intruded by gabbro and granite, strikes N.10°W., dips vertically; not as suitable as 22481 for commercial use.
22483	19°43'	43°40'	Gray marble interlayered with meta-andesite and intruded by gabbro and gray granite; not as suitable as 22481 for commercial use.

Table 11. Marble in the area between Bi'r Idimah and Wadi Haraman. (contd.)

Sample number	Location		Description
	North latitude	East longitude	
22484	19°44'	43°40'	Lenticular layers of white to gray marble in meta-andesite; intruded by gabbro and granite; no commercial use.
22487	19°43'	43°38'	Gray, fine-grained marble with sparse quartz stringers; outcrop forms ridge 20 to 60 m thick and 600 m long; suitable for local lime.
22500	19°41'	43°36'	Impure quartzose marble and hornblendic calcareous granulite interlayered with meta-andesite and intruded by gabbro; no commercial use.
22512	19°37'	43°34'	Beds of ferruginous, silicified red marble in graphitic phyllite; 1 to 2 m thick, up to 40 m long; no commercial use.
22522	19°35'	43°32'	Lenticular masses of brown marble in serpentinite; up to 2 m thick and 20 m long; no commercial use.
22526	19°46'	43°41'	White, gray, and blue marble form distinctive jebel; intruded by monzonite; large volume of marble of unknown purity, possibly commercially acceptable.
22529	19°45'	43°42'	Little lenticles of brown, silicified marble in meta-andesite; no commercial use.
22542	19°51'	43°40'	Dark gray marble interlayered with meta-andesite and lithic tuff; marble is about 20 m thick and 1 km long; probably commercially acceptable.

variable amounts of magnetite, amphibole, pyroxene, and a trace of zircon and garnet. The layers of black sand are up to 70 cm thick and are flatly lenticular, reaching several hundred meter in length. Locally they contain white quartz pebbles. They interfinger with well-sorted quartz sand and have a heavy ferruginous cement. No commercial use can be seen for them.

Hematite and limonite:-- Hematite and limonite are variably present as cement near the base of the Wajid sandstone, particularly in the lower 30 m of the exposed lower part of the section in the western part of its outcrop area. The cement is not an iron ore, but it locally makes up as much as 10 or 12 percent of the rock, although the average is only about .2 percent. At one place 17 km east-northeast of Bi'r Idimah a vertical opening 4 m deep and 90 cm in diameter explores a ferruginous part of the Wajid sandstone. The opening is called the ZamZam mine after words carved on the north face of a small sandstone butte standing as the first western outcrop of Wajid sandstone in Wadi Idimah. Every aspect of the opening is that of an unfinished and abandaned well, but local people carefully identified it as an iron mine. In the walls of the opening the ferruginous sandstone has joints up to 5 cm thick filled with nearly pure limonite and hematite. About 5 km west-southwest of ZamZam mine another vertical opening in ferruginous Wajid sandstone was pointed out as an iron mine, but it is filled with wind-deposited sand. Fragments of limonite and hematite a few centimeters thick and up to 15 cm long were scattered in rubble around the head of the shaft and may have come from it. In this area the Wajid sandstone has ferruginous layers up to 2 m thick, but they are too siliceous to constitute ore. Locally the sandstone has been replaced along bedding planes by nearly pure hematite, but these replacement masses are only 3 or 4 cm thick. Otherwise iron-free parts of the Wajid sandstone contain many spheroidal limonite concretions. Where circulating ground water has re-deposited iron in joints, massive limonite and hematite a few centimeters thick was formed. This massive oxide is what was sought in the two little pits described above.

Placers.

No placer deposits other than the black sand described above were investigated in the Bi'r Idimah-Wadi Haraman area, although it is possible there is a little placer gold in Wadi al Habajiyah 8 km east of Hamdah along the east wall of which five ancient little gold mines are situated, and in the little wadi at the Ishaaib mine described below. The probable amount of placer gold is too small to merit investigation.

On my return trip to Jiddah a little study was given Wadi Bida in quadrangle I-210A. The gold lodes and quartz veins eroded in the formation of the wadi may have contributed enough gold to justify a test of the alluvium in the wadi floor. Churn drilling or test pitting in the alluvium might disclose placer ground amenable to mining by bulldozer, doodle-bug, and movable dry concentrating plant.

Epigenetic deposits

Gold.

Four ancient centers of gold mining are in the Bi'r Idimah-Wadi Haraman area, and all are in the Hamdah ultrabasic belt. The southernmost center is the Higera mine (18°55'N.x 43°40'E.) known to the Directorate General for Mineral Resources and examined by D. F. Shaffner. The next center to the north is a group of small mines on Wadi al Habajiyah (19°03'N.x 43°41'E.) about 8 km east of Hamdah. These are thought to be previously unknown to the Directorate. To the north of the Wadi al Habajiyah center about 22 km is a center at the Ishaaib gold-copper mine (19° 15'N.x 43°40'E.). Ishaaib mine is also thought not to be known previously to the Directorate. The northernmost center is at the Avala mine (19°40'N.x 43°41'E), which has long been known to and was explored by the Directorate. The Higera and Avala mines are the largest in the Bi'r Idimah-Wadi Haraman area.

The four centers line up almost exactly along meridian 43°41'E., but there is no single geologic structure continuously following this meridian. However, at the Higera mine, the Wadi al Habajiyah center, and the Avala mine the principal structural control is north-trending high-angle faults and secondary control is northwest-to west-and northeast-to east-striking tension fractures related to the north-trending faults. The ore is principally white to gray quartz lodes with a little pyrite in the north trending faults. Some altered wall rock also apparently served as ore. The veins and lodes are in hydrothermally altered hornblende schist, gabbro, serpentinite, and marble generally intruded by gray biotite granite, white felsite, and pegmatite. The faults are younger than the granitic rocks; therefore, the auriferous quartz veins are younger than the granite. They may, however, be a late stage emanation from the granite following consolidation and fracturing. At Ishaaib mine an extensive gossan along a west-trending contact between hornblende schist and intrusive granite gneiss covers the outcrops, but the contact seems to have controlled the location of the deposit. The gossan itself served as ore, but some copper-bearing sulfides disseminated in the schist were also apparently mined.

Several mines were reported by Bedouin in the Bi'r Idimah-Wadi Haraman area, but they were not found.

Analytical data from samples collected during the trip are not available at this writing, nor are the reports of earlier visits by Directorate personnel to the Higera and Avala mines.

Higera mine:-- The ancient and abandoned Higera gold mine consists of a number of surface openings and underground workings occupying an area at least 1.3 km long and up to 0.4 km wide (18°55'N.x 43°40'E.) about 5-1/2 km southeast of the ruin of Al Ji'ayfirah. At the south end of the workings the principal tailings piles and the remains of a village extend onto silt in the broad valley of Wadi Tathlith. The mine openings are 2 km southwest of the main road from Bishah to Najran by way of Bi'r Idimah. They explore a sequence of metamorphosed and hydrothermally altered andesite, andesite porphyry, ultrabasic rock, and limestone which now appear as hornblende schist, serpentinite, and silicified marble which strikes N.50°E. and dips 15°NW. After regional metamorphism converted the volcanic-sedimentary sequence to schist, serpentinite, and marble, gently-dipping fractures in the serpentinite were altered to asbestos. Following the formation of the asbestos the rocks were intruded by gray quartz monzonite and then by red felsite dikes. Subsequently, the rocks were faulted at N.10°E. 70°W. with striations plunging 10°N. in the plane of the fault, and tension fractures opened in a fan striking from N.50°W. to N.80°W. and dipping steeply south. Along the N.10°E. fault lodes of white quartz with pyrite, hematite, and gold were deposited and the tension fractures were filled with white quartz containing pyrite and gold. Most, possibly all, the alteration of the wall rocks preceded the faulting and deposition of the quartz veins. The hornblendic rocks are but little altered; however, the marble is extensively silicified and stained with limonite. This alteration is thought to have occurred about the time the serpentinite was formed, but it may be as late as the formation of the asbestos.

Very little slag is present around the mine; therefore, it is assumed that free-milling gold was recovered. Although as much as 15 percent of magnetite is present locally in the serpentinite, and asbestos is common, there is no evidence that either mineral was mined.

The Higera mine was examined for the Directorate General of Mineral Resources by D. F. Shaffner about 1959. Higera is one of the largest gold mines in the Bi'r Idimah-Wadi Haraman area, but it is small compared to known major mines in Saudi Arabia.

Wadi al Habajiyah center:-- Five small, ancient gold mines are located along the east wall of Wadi al Habajiyah (also called Wadi Ghaarba) and the north wall of an eastern tributary about 15 km upstream from the confluence of Wadi al Habajiyah with Wadi Tathlith and 8 km east of Hamdah. The mines can be reached by driving up Wadi al Habajiyah, leaving the main road from Bishah to Najran near Bi'r Umm az Ziba. They can also be reached by driving cross-country from Hamdah.

The names used in the following account of the mines are the ones by which the openings are known locally. They were given by Hassan Ghanim al Messfer, a resident of Hamdah. They are described from south to north.

El Hlamiya, south, mine:-- The El Hlamiya, south, mine (19°03'N.x 43°41'E.) (locality 22293) is larger than the El Hlamiya, north, mine described farther along. El Hlamiya south consists of nine open pits at least two of which lead into shallow stopes, and two trenches, one of which opens into stopes at least 14 m deep. All workings are oriented north along the north side of a low, north-trending ridge. On the wadi flat north of the mine there are the ruins of 22 stone houses up to

4 by 5 m in plan. Slag is absent; therefore, the mine is assumed to have recovered free gold.

The principal working is an eastern trench, which leads into a stope; an immediately adjacent trench to the west, which is 65 m long, 2 to 3 m wide, and 1/2 to 1-1/2 m deep and possibly led into stopes now filled; and a pit about 4 m deep and 40 m off the west end of the long trench. These workings occupy a shear zone in hornblende schist intruded in sequence by serpentinite, granite, felsite, and andesite. Following the last intrusion the rocks were strongly sheared by a fault striking north and dipping 60°W. The fault is the contact between schist and serpentinite. Later they were cut by a cross fault striking N.70°W. and dipping vertical. Schist and serpentinite along the northerly fault are silicified, and a granular white to greenish quartz vein was emplaced in the fault. The vein is 0.3 to 1.8 m thick and of unknown length. It is followed by the stope in the eastern trench and seems to have been followed by the long trench, but the relations of the other openings to the vein are unclear. The pit 40 m off the west end of the long trench enters a small stope in a brown altered zone in hornblende schist. Elongation of the stope is N.40°E., and it is inclined 80°N. From the debris around the pit it is not possible to tell what was actually mined, but a mixture of silicified and rusty hornblende schist and serpentinite may have been taken out. No vein quartz was seen.

Jabal Ibn Hassun mine:-- The ancient and abandoned Jabal Ibn Hassun mine (19°04' N.x 43°41'E.) (locality 22289) is in a shear zone in serpentinite hills leading southward to Wadi al Habajiyah. The ruins of three small, square, stone houses are on the flat between the wadi and the mine, and at the mine two other ruined stone houses were found. These houses are about 2 m x 2 m to 3 m x 4 m in plan. The mine consists of three main open pits, all of which led into stopes, and one trench, with subsidiary test pits on the same hill and on adjacent hills. Dumps consist of leached and limonite-stained, sericitized serpentinite, bluish white quartz, and white felsite. There is no slag. A few fragments of grindstones were seen. From this it is inferred that free gold was recovered. Crushed tailings were estimated to have a volume of 2,000 cu m.

The trench at Jabal Ibn Hassun mine is oriented N.10°E. and is inclined 80° W. along the west side of a white felsite dike. It is 20 m long, 1 to 3 m wide, and 1-1/2 to 4 m deep in sheared and limonite-stained serpentinite. From the present appearance of the trench it is not clear what was taken out; perhaps chloritized hornblende schist forming a septum in the serpentinite was the ore.

The three pits approximately line up at N.55°E., but the long direction of each is N.10°E. to N.20°W.; thus, they are sub-parallel to the trench. They are in strongly sheared rock consisting of brecciated, chloritized and sericitized hornblende schist, serpentinite, and felsite. The northern pit is about 5 m long, 3 to 4 m wide and 3 to 5 m deep inclined steeply westward. The central pit consists of two intersecting trenches. The larger is 12 m long, 3 m wide, and 4 m deep oriented N.50°E.; the smaller is 8 m long, 3 m deep, and 3 m wide oriented N.40°W. Both are in serpentinite, but the one striking northwestward follows the wall of a felsite dike. At the southern pit the strike of the opening is N.10°E., the length is 22 m, and the width and length are 8 m and 1 to 4 m. It leads into a shallow stope at its northern end. The rocks are sericitized and chloritized hornblende schist, serpentinite, and felsite. It is not certain what was taken as ore from these pits. Probably it was altered metamorphic rocks containing gray and white mottled quartz.

Jabal Ibn Hassun extension:-- The so-called Jabal Ibn Hassun extension (19°02'N. x 43°42°E.) (locality 22298) is about 1-1/2 km east-southeast of the Jabal Ibn Hassun mine, and has no apparent geologic connection with it. The ancient workings are in closely folded, sheared, and altered hornblende schist and serpentinite intruded by white felsite. Axes of tight folds in the metamorphic rocks strike north and plunge 55°S. Chlorite replaces hornblende and talc replaces serpentine in the schist and serpentinite. Little stringers of gray to white quartz impregnate the chloritic and talcose rocks. These stringers make up narrow lodes about 20 to 40 cm wide. Several such lodes are present in a 3 m-wide face in a little pit or caved shaft about 2 m deep at the northern end of the Jabal Ibn Hassun extension. The lodes appear to have been the ore.

About 40 m to the southeast three small trenches 2 to 3 m long, 1 to 1-1/2 m wide, and 1/2 m deep explore minor alteration zones in hornblende schist near the crest of a little hill.

El Hlamiya, north, mine:-- The El Hlamiya, north, mine (19°03'N.x 43°41'E.) is very small (locality 22292). No houses are associated with it, nor are slag piles present. It seems to be a cluster of prospect trenches arranged in four groups, more than a mine, to explore gray, granular quartz veins in hornblende schist and serpentinite. The most northerly working is a trench 12 m long, 2-1/2 m wide, and 1/2 to 1 m deep on a narrow quartz lode parallel to foliation in hornblende schist striking N.10°W. and dipping 80°W. Windblown sand fills the trench, but it was probably little deeper originally than it is at present, because the dump is small.

Forty meters south of the trench are three small open pits arranged in a semi-circle on the southern crest of a low serpentinite hill capped with heavily limonite-stained serpentinite intruded by an irregular mass of sugary gray quartz. Each of the little pits is about 2 m long, 1-1/2 m wide, and 1/2 m deep. They appear to have explored little masses of quartz oriented about N.10°E. with 80°W. dip in the serpentinite. Practically no waste is present around the pits; therefore, most of what was extracted would seem to have been removed. Probably mainly quartz was taken out.

On a ridge about 60 m south of the pits mentioned above, a group of three small pits, of which the largest is 4 m in diameter and 1-1/2 m deep, are located on a shear zone in hornblende schist. The shear strikes N.50°E. and dips vertically. The west wall of the largest pit is sharply defined by the east side of a sill of gray felsite, which does not appear in the other pits. Along the shear the hornblende schist is altered to chlorite schist, which is by far the most common rock in the little dumps. Whether the ore was quartz or chlorite schist could not be determined.

The largest opening at the mine is 50 m south of the three pits in chlorite schist. It is a trench 15 m long, 2-1/2 m wide, and 4-1/2 m deep oriented N.5°E. inclined 85°W. on sheared and chloritized serpentinite with traces of relict asbestos. No quartz was seen. It is inferred that the chloritic gouge along the fault was the ore.

Riah mine:-- The Riah ancient and abandoned mine (19°04'N.x 43°42'E.) (locality 22299) consists of a number of pits and underground workings which appear to have followed the footwall contact of a white, muscovite-biotite felsite dike with selvages of pegmatite in serpentinite and hornblende schist. Riah mine is situated on the north bank of an eastern tributary to Wadi al Habajiyah. Neither slag nor houses are present. Probably free gold was obtained.

The major working of the Riah mine is a stope about 30 m deep on a 20° incline opening from a pit 7 m in diameter and 2-1/2 m deep. To judge from the pillars left standing the ore was a lode of quartz stringers 0.6 to 1.2m thick in biotite-rich schist possibly biotitized hornblende schist along the footwall of the flat-lying felsite and pegmatite dike. Locally the lode gives way to white or gray vein quartz, vuggy and rusty, which reaches the full width of the mined face.

At least three other pits were sunk on fractured dikes of felsite and pegmatite in biotitized and chloritized hornblende schist. These dikes are also flat lying and are either part of or sub-parallel to the dike under which the stope was opened. Fracture zones striking N.20°E. vertical through the felsite and pegmatite were excavated, along with biotite-rich schist under the dikes. At the northernmost pit the biotitized hornblende schist of the footwall was removed to a depth of 1.2 m from the bottom of the pegmatite over a face about 5 m wide. The pegmatite is 2 to 3 m thick. It consists principally of perthite with about 6 percent of muscovite and also platy green biotite mimicing the form of hornblende crystals up to 1.5 cm long.

A quarry on the northwest side of the Riah workings explored an L-shaped face of pegmatite in serpentinite. Each limb of the L is about 8 m long and 2-1/2 m high. Apparently the pegmatite was milled for gold. The pegmatite is a differentiate from the felsite and contains inclusions of felsite. At least nine other small test pits and quarries explore the pegmatite, but only one is in felsite.

Twenty meters south of the openings in the pegmatite, a trench 20 m long, 2 to 4 m wide, and 2 m deep was opened in a rusty pyritized zone in hornblende schist. The pyritized zone strikes N.35°E. and dips vertically. Dumps associated with this trench are much smaller than those around the pegmatite.

Possibly 2,000 to 4,000 tons of rock were mined at Riah, but the amount that was milled cannot be estimated. Pretty close control of the mining seems to have been maintained by grinding ore underground - a grindstone was found inside the workings. Possibly a high percentage of the rock removed was ore.

Ishaaib mine:-- The Ishaaib mine (19°15'N.x 43°40'E.) (locality 22301), and two ancient workings not seen by the writer, constitute the Ishaaib gold mining center. Ishaaib mine consists of the ruins of 14 stone houses, scattered small piles of slag, and several openings near the contact between hornblende schist and granite gneiss. The mine is about 8 km east of the main road between Bishah and Najran via Tathlith and Hamdah.

The mine workings are near the northern edge of a body of hornblende schist that strikes N.70°W. and dips 35°S. To the north the hornblende schist is separated from granite gneiss by a wadi which may cover an east-northeast trending fault. At the workings the hornblende schist is intruded by dikes of gray porphyritic biotite granite about 30 to 40 cm thick which strike N.40°W. and dip 43°S. Diabase dikes trending east and dipping 50°S. intrude the schist but not the granite. The hornblende schist supports two low parallel ridges oriented N.80°W. which are separated by a flat about 30 m across. The western ridge is the larger. Both ridges and the flat are covered by thick scoriaceous gossan and thoroughly weathered hornblende schist with weathering products cemented by limonite.

The workings consist of three small shafts on the western ridge, each about 1-1/2 to 2 m in diameter and 2 to 4 m deep. They may be caved. A pit explores gossan on the flat at the west end of the eastern ridge. The pit is 11 m long, 6 m wide, and 1-1/2 m deep with its long axis striking N.80°W. On the southern edge of the pit two vertical shafts about 1 m in diameter and at least 10 m deep enter granite gneiss. The principal mine buildings and slag piles are across a narrow wadi some 30 or 40 m south of the eastern ridge. Two large slag piles are about 15 m by 25 m with an average thickness of 0.5 m each; thus, they contain about 800 tons of slag each.

Ishaaib mine may have been worked for both gold and copper, because secondary copper carbonate is common on the dump around the two eastern vertical shafts.

Avala center:-- The Avala gold mining center in the Bi'r Idimah-Wadi Haraman area consists of the Avala mine and an unnamed prospect. Avala mine (19°40'N.x 43° 41'E.) is about 23 km northeast of Tathlith and the road between Bishah and Najran.

Avala mine:-- Avala mine (locality 22453) is on the southeast side of Jibal Bani Adla where the ancient workings extend northward for 1.2 km as a series of pits, trenches, shafts, and quarries. The white quartz of the dumps can be clearly seen on the aerial photographs. At the south end of the workings, and reaching southward for 0.2 km, are the ruins of the village associated with the mine. These ruins comprise at least 70 stone buildings, most of which have grindstones and tailings strewn about them. Slag is absent; therefore, it is inferred that the operation recovered free-milling gold. Total tailings may be about 30,000 cu. m.

The workings appear to be located along two intersecting fault zones. The southern workings are along a fault parallel to the cleavage in a sequence of meta-andesite, graywacke, and marble intruded by gabbro. This fault strikes N.25°E. vertical. The northern workings are along a fault trending N.15°W. vertical in dominant gabbro. The southern group of workings is about 400 m long and the northern group is 700 m long.

In the fault zone the gabbro is chloritized and silicified with brown chert, but the meta-andesite is only slightly altered. Through these chloritized and silicified rocks and parallel to the fault zone passes a lode of thin, brecciated and re-cemented white quartz stringers. Apparently the brecciated quartz and chert were the ore; at least they are the principal pulverized rocks in the grinding rooms. Massive white quartz forming a late vein up to 1 m thick in the central part of the workings was left unmined.

The Avala mine is known to the Directorate General for Mineral Resources and was examined and sampled by the Directorate about 1957.

Unnamed opening:-- A small open trench strikes N. 35°E. in a brecciated zone in gabbro intruded by gray massive granite at locality 22466 (19°41'N.x 43°42'E.) 3 km northeast of the Avala mine. Both rocks are brecciated and the breccia is cemented with white quartz which is also brecciated. The brecciated quartz is healed by white quartz. The trench is about 20 m long, 3 m wide, and 1 m deep. Probably the trench was originally nearly 2 m deep, because the dump is somewhat large for the opening. No sulfide minerals are present, and the breccia may not extend beyond the ends of the trench.

Other reported occurrences:-- The locations of five ancient mines were cited by local Bedouin, but the workings were either not visited during the course of the work, or efforts to find them failed.

An ancient mine was said to be just east of the first ridge east of station 22058 (18°43'N.x 43°54'E.), but its size was not described. The station is in massive pink biotite granite with inclusions of granite gneiss, an otherwise unfavorable environment for ancient mines in the Bi'r Idimah-Wadi Haraman area. The first ridge to the east of the station is in the same type of rock, and there is no evidence on the aerial photographs of quartz dumps or veins. The locality is 11-1/2 km east-northeast of Jibal Limaylih.

Local Bedouin reported they have been told, but have not actually seen, a small to medium size mine lacking a village on the west flank of Jabal Ghirban (18°57'N. x 43°45'E.). They did not know how to locate it.

A ridge (19°10'N.x 43°40'E.) of granite gneiss intruded by northeast-trending dikes of diorite and gabbro was stated to have a big ancient mine. Close examination disclosed none, but there are several man-made piles of rock unrelated to ancient mining.

A large mine was said to be on the hill north of station 22236 (19°12'N.x 43° 45'E.), but the specific locality was not known to the Bedouin, and a search failed to reveal it. The hill is supported by basic rocks intruded by granite dikes and stands 10-1/2 km east-southeast of the Ishaaib mine. It is thought that a mine probably exists in this area.

A mine with houses and grindstones was reported to be about 4 km east of the Ishaaib mine (19°15'N.x 43°40'E.), but a search with two guides failed to disclose the mine although several stone tumuli were found at the approximate location. The tumuli are more antique than the ruins associated with mines in this region.

Copper.

Two occurrences of copper carbonate minerals were found in the Bi'r Idimah-Wadi Haraman area. The occurrence at the Ishaaib mine, described above, is the larger. A very small amount of malachite was seen at station 22124 (18°55'N.x 43° 40'E.) about 1 km west-northwest of the Higera mine. Here the malachite coats cockscomb quartz in small vugs in milky white quartz veins in hornblende schist intruded by gray, fine-grained quartz monzonite. The vugs are 1 cm or less across, and the copper stains are of no economic importance.

Gossan and shear zones.

Small outcrops of gossan and possibly mineralized shear zones were noted in the Bi'r Idimah-Wadi Haraman area to which attention was not called in the descriptions of mineralized features listed about. The largest gossan in this area was mentioned under Ishaaib mine. Gossan is also present at four other localities; possibly much of it is formed from quartz-hematite veins.

Gneissic, quartz-rich, coarse-grained granite forms the core of a synform in hornblende gneiss at station 22054 (18°45'N.x 43°48'E.) on the north wall of Wadi Matbiq near Jibal Limaylih. The coarse gneissic granite is extensively iron stained, but no pyrite was observed and no other mineralization was seen.

A small gossan strikes N.45°W. and dips 80°E. parallel to the foliation of biotite-hornblende schist intruded by gabbro and white quartz veins at station 22315 (19°24'N.x 43°38'E.). The gossan is about 1 m thick and 100 m long. Source of the limonite in the gossan is uncertain; the gossan follows a lode in the schist occupied by pyrite-free white quartz. There may be weathered quartz-hematite veins associated with the lode.

Hornblende schist at station 22371 (19°19'N.x 43°40'E.) strikes N.35°W. and dips 50°N. It is cut by a shear zone striking N.75°W. and dipping 25°N. in which the schist is replaced by jasper, limonite, and hematite. The shear zone and gossan is 3 m thick and at least 75 m long. No copper stain seen, nor is there any evidence of ancient mining.

At station 22492 (19°37'N.x 43°40'E.) very fine-grained biotite-quartz schist is intruded by dikes of fine-grained gray to pink granite. The schist strikes N.45° W. and dips 80°N. A small linonite gossan 10 to 20 cm thick and about 15m long cuts across the foliation of the schist, occupying a small shear, but details are obscured by talus.

A northwest-trending shear and bleached zone at least 6-1/2 km long and probably 10 km long extends southeastward from the vicinity of the southeast flank of Jibal Lahu (18°53'N.x 43°50'E.). The southeastern end of the fault is at 18°47'N.x 43°56' E. The richest scheelite-bearing sample (22165) in table 3 came from the southeastern end of the fault zone, and blocks of limonite-cemented brecciated white vein quartz were found in the wadi on the northwestern part of the shear (station 22181 at 18°51'N.x 43°52'E.).

Brecciated and slightly chloritized pink granite and quartz porphyry is intruded by non-brecciated dark gray rhyolite dikes at a locality (station 22431 at 19°37' N.x 43°44'E.) 7 km southeast of the Avala mine. No mineralization was seen, but there is a light brownish stain over the brecciated rocks, and small lenticles of jasper with heavy limonite stain are present in the breccia. These lenticles are 8 to 10 cm long and up to 3 cm thick.

Quartz-hematite veins.

Quartz-hematite veins grade into pegmatite and rhyolite related to the late, massive biotite granite of the Bi'r Idimah-Wadi Haraman area, but the gradation is seldom seen. Some of these veins are the source of small gossan mentioned above. Quartz-hematite veins were also noted at several other localities.

Milky quartz veins containing chlorite and hematite strike N.45°W. and dip 70° N. in sheared and hydrothermally altered fine-grained diorite and andesite intruded by rhyolite dikes trending N.75°W. 70°S. at station 22049 (18°47'N.x 44°00'E.). Limonitic stain is associated with the veins, which are most common along the walls of the dikes.

At station 22068 (18°35'N.x 43°50'E.) a quartz-hematite vein containing pyrite but no other sulfide mineral is a segregation product derived from a simple pegmatite dike.

An albite-quartz-hematite vein in biotite-hornblende schist forms the crest of a low ridge elongated N.30°W. at station 22070 (18°37'N.x 43°52'E.). Coarse, gray, greasy-looking quartz is fractured into augen and sygmoidal-shaped particles 1/4 to 1 cm across. The fractures are healed by hematite, and hematite defines selvages and ribbons in the vein. Greatly coarsened biotite occurs in the schist along the walls of the vein. A prominent gossan is produced by the hematite, but copper stains are absent.

The quartz-hematite veins are most common in the part of the Bi'r Idimah-Wadi Haraman area where the per-alkalic rocks intrude the Hamdah ultrabasic belt.

Quartz crystals.

Quartz crystals were observed at two localities in the Bi'r Idimah-Wadi Haraman area, but neither exposure has any economic use. At station 22273 (19°03'N.x 43° 49'E.) in the Hamdah asbestos district, serpentinite is cut by veins up to 25 cm thick consisting of a core of white, coarse-grained crystalline calcite flanked by wall zones of cockscomb, white to colorless, singly terminated quartz crystals. The largest crystals of quartz are only 4 mm thick and 1.5 cm long. At the second locality, station 22330 (19°27'N.x 43°33'E.), scattered, small, vuggy quartz veins in layered hornblende-biotite gneiss contain sparse, singly terminated quartz crystals up to 1 cm thick and 4 cm long. The crystals are colorless, white, or brownish red, and they are twinned and fractured.

Clear calcite.

Clear calcite forms veins and small lenticular masses up to a few centimeters in thickness and a meter in length in serpentinite and pyroxenite exposed at station 22282 (19°02'N.x 43°37'E.) in the Hamdah asbestos district. The veins and masses of calcite are too small to be used as a commercial source for optical grade calcite, and a faint grayish-brown tint mars the nearly water-clear transparency of the calcite, but the remote possibility exists that larger and more perfect veins of clear calcite may be found in the ulttabasic area. Perhaps the Tathlith district offers the best chance for discovery, because more calcite veins occur there than in the Hamdah and Higera districts.

Recommendations

It is recommended that a high priority be given to detailed investigations of asbestos between Hamdah and Bi'r El Marwah where at least 150 sq km should be mapped at a scale of 1:25,000 on mosaics compiled from orthophotographs. After about six months of work in the Hamdah district to evaluate the surface outcrops of the asbestos, a drilling program should be introduced to explore the veins below the weathering. An estimated 3000 feet of diamond core drilling should be adequate to test the extent in depth and quality of the best exposures. At least 50 sq km around the Higera gold mine should be mapped at 1:50,000 scale on regular mosaics and examined for asbestos. About 150 sq km north and east of Tathlith should be mapped by 1:50,000 scale reconnaissance and examined for asbestos. By-product information from the asbestos investigation would include improved knowledge on the distribution and grade of soapstone, anthophyllite, talc, vermiculite, chromite, calcite, gold, and copper in these three districts. Airborne magnetometer surveys might possibly define the bodies of serpentinite, because the serpentinite contains somewhat more magnetite than the other rocks in the Hamdah ultrabasic belt. It is even possible that the most magnetite-rich parts of the serpentinite are those areas most altered to asbestos, but this relation is not established.

The small bodies of magnetite quartzite may be part of a larger mass of bedded magnetite in meta-sedimentary rocks. It is recommended that when airborne magnetometer is installed in the Ministry De Haviland Otter, the magnetite quartzite areas be flown.

The comparatively large gossan at Ishaaib mine should be explored by ground geophysical methods followed by diamond core drilling to search for copper and gold.

The northwest-trending sheared and bleached zone up to 10 km long with scheelite at the south end (station 22165) should be examined geochemically. Possibly ground electromagnetic surveys would help define sulfide bodies if any are present, but the shear is in extremely rugged terrain. Helicopter support would be needed.

Gold placers are remotely possible along Wadi al Habajiyah near the ancient gold mines east of Hamdah, and in the small wadi north of Ishaaib mine. A churn drilling program or deep test pitting would be needed to evaluate the placer possibilities. A very low order of consideration is justified, but no work of this sort should be done in this area until much higher priority investigations are completed.

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