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MINERAL DEPOSITS OF THE NORTHWESTERN HIJAZ QUADRANGLE

KINGDOM OF SAUDI ARABIA

by

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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 Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian government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.

MINERAL DEPOSITS OF THE NORTHWESTERN HIJAZ QUADRANGLE, KINGDOM OF SAUDI ARABIA

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Abstract

A reconnaissance of portions of the Northwestern Hijaz quadrangle in the Kingdom of Saudi Arabia was made during 1964 and 1965 as part of a mineral survey of the Precambrian crystalline rocks of the country. The survey is being made under the terms of an agreement between the Saudi Arabia Ministry of Petroleum and Mineral Resources and the United States Geological Survey. Ancient gold and copper mines occur in the area, and deposits of iron minerals, chromite, copper minerals, asbestos, magnesite, gypsum, and glass sand have been discovered in recent years.

The land surface of the quadrangle consists of a narrow coastal plain, a mountainous belt, and a plateau. The mountainous belt is made up of Precambrian rocks that include three major stratigraphic units separated by unconformities. The two older units are slightly metamorphosed and are intruded by plutonic rocks of many kinds. Granitic rocks predominate but intrusions of syenite, diorite, gabbro, and peridotite are known. Dikes are abundant throughout the mountainous area. The Precambrian rocks have been folded on north- to northwest-trending axes. A major northwest-striking wrench fault zone crosses the central portion of the quadrangle. North-, northeast-, and east-trending faults are locally prominent.

The plateau lies in the northeastern part of the quadrangle. It is made up of unmetamorphosed gently dipping sandstone of Paleozoic age overlain in part by flood basalts of Tertiary to Quaternary age. Sedimentary rocks of Miocene(?) age crop out in the coastal area.

Gold was mined in the area during the eighth and ninth centuries A. D. The ancient gold mines were reexamined in the 1930s but were found to be too small and too low grade for mining. Exploration for minerals other than gold began in 1950.

The present work consisted of the examination of geological features that are potentially favorable for the presence of mineral deposits such as intrusive contacts, fault zones, quartz veins, and hydrothermally altered areas. Samples of wadi sediment were collected in areas that appeared most favorable. The samples were analyzed spectrographically for trace amounts of 27 elements to confirm the presence or absence of mineralization.

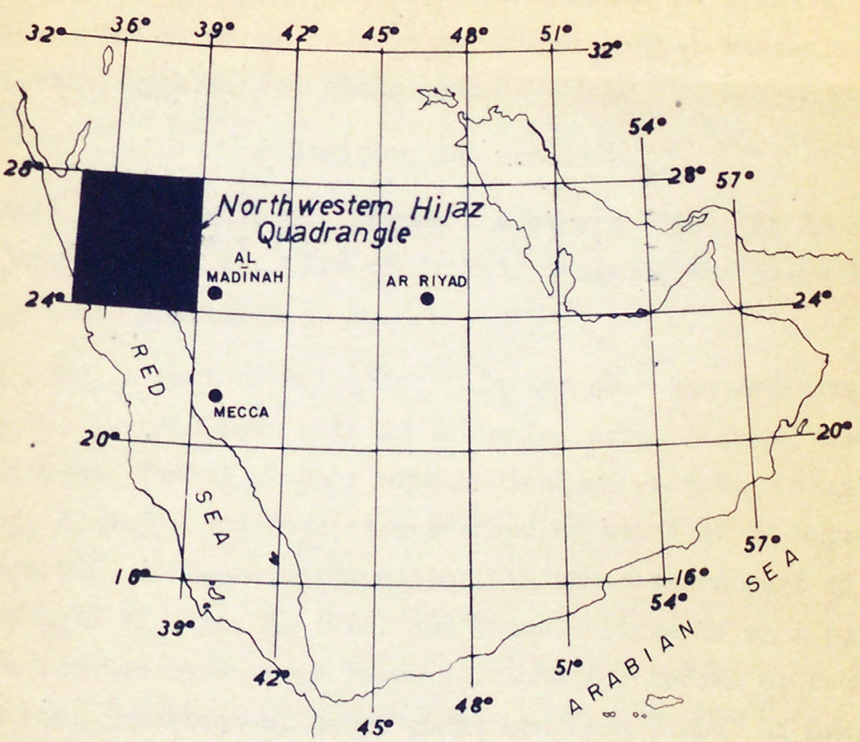
Massive magnetite bodies that range in size from a few hundred to a few thousand tons were discovered in the course of the work as well as widely scattered traces of secondary copper minerals. The wadi samples disclosed several areas that contain from 5 to 10 times the average trace amounts of base metals and molybdenum; these areas should be prospected in more detail.

Introduction

Purpose and scope

The Government of the Kingdom of Saudi Arabia has started an intensive search for mineral deposits in the central and western parts of the country. The search is part of an attempt to broaden the country's economic base which in the past has been limited to petroleum and pilgrims. An agreement reached in 1963 between the Ministry of Petroleum and Mineral Resources of the Kingdom of Saudi Arabia and the United States Geological Survey provided that geologists of the Survey were to undertake a mineral reconnaissance of that part of Arabia underlain by Precambrian rocks. Geophysical, geochemical and laboratory support was provided by personnel from the Survey using equipment purchased by the Saudi Arabian government. Counterpart scientists were assigned to the work by the Ministry, and the Ministry also supplied the vehicles, support personnel, and other facilities needed to conduct the investigation.

The work plan of the present investigation in the Northwestern Hijaz quadrangle (fig. 1) was to combine field observations with geochemical sampling in an effort to delineate mineralized areas for detailed study. Not enough time was available for complete coverage of the approximately 60,000 square kilometers of Precambrian rocks in the quadrangle so selected areas were studied as shown



INDEX MAP OF ARABIAN PENINSULA
SHOWING LOCATION OF QUADRANGLE

Figure 1

in figure 2. This report describes the results of the above work and gives a compilation of data on mineral deposits in the quadrangle, obtained from unpublished reports in the files of the Directorate General of Mineral Resources. The reports are on open file but are not readily available outside of Saudi Arabia. Gold deposits have been known in the area for many years and recent work has disclosed the presence of iron formation, copper minerals, chromite, magnesite, asbestos, gypsum, and glass sand.

Location and access

The Northern Hijaz quadrangle (Brown and others, 1963) is located in northwestern Saudi Arabia (fig. 1). The quadrangle includes the coast line from 24° to 28° N. and extends inland to 39°E.

Yanbu' al Bahr, a port of entry for pilgrims near the southern edge of the quadrangle, is the largest town with an estimated population of more than 5,000. A paved road connects Yanbu' al Bahr with Medina and Jiddah. Other ports to the north, Umm Lajj, Al Wajh, and Duba, are reached by means of an unpaved road along the coast. Important date-producing centers in the eastern part of the quadrangle are Yanbu' al Nakhl, Al 'Ayn, Al 'Ula, and Tayma. Tayma is on a paved road, the other towns are reached by unpaved roads suitable for trucks or four-wheel-drive vehicles. The most important of these roads are from Yanbu' al Bahr to Al 'Ayn and Al 'Ula; from Al 'Ayn to Al Wajh; and from Al 'Ula to Al Wajh.

An abandoned railway that extended from Medina to Amman, in the Hashemite Kingdom of Jordan, passes through Al 'Ula. Rehabilitation of this railway is in progress.

Al Wajh has an airfield with a concrete runway and has scheduled air service. Yanbu' al Bahr and Duba have graded landing strips but do not have scheduled service.

Topography and relief

Brown (1960) has described three physiographic provinces in Western Saudi Arabia: the Tihama or Red Sea coastal plain, the scarp mountains, and a ramped plateau called the Hisma in Northwestern Arabia. The Tihama ranges from 5 to 30 km in width although locally the mountains rise directly from the sea with only a narrow beach. The mountain belt is 60 km wide in the north but widens southward to more than 200 km. The northeastern part of the quadrangle forms part of the Hisma Plateau.

The Hisma Plateau is bordered by an erosional scarp that is particularly impressive in the northern third of the quadrangle where the plateau in places reaches an altitude of 1,500 m and lies within 100 km of the coast. Only one road provides access to the plateau in a distance of more than 200 km. In the central part of the quadrangle, Wadi al Hamd and its tributaries have cut deeply into the plateau and its margin is not as well defined.

The western edge of the plateau forms the approximate drainage divide between wadis (dry washes) that discharge into the Red Sea and wadis that drain eastward into interior basins. Wadi al Hamd is by far the largest of the west-draining wadis; it and its tributaries drain more than one-third of the land surface of the quadrangle. Other large wadis that drain into the Red Sea are Wadi Tiryam, Wadi Dama, and Wadi Thalbah north of Wadi al Hamd and Wadi al Fara'ah to the south.

The topography is varied due to the different types of terrain. The surface of the plateau is cut by narrow shallow wadis with broad areas of gentle slopes and sandy plains. In places low, steep-sided hills rise above the plain, but in general the topography is subdued. The mountains are typical of those in desert areas. Steep rocky slopes rise abruptly from alluvium-filled valleys and basins. Locally, on divides between wadis or on top of some granite bodies the terrain is more rolling, but in most places the mountains are deeply dissected. The coastal area shows evidence of recent uplift and is now being dissected. A badland type of topography has developed on softer rocks. Elsewhere broad sand- or gravel-covered plains are cut by steep-sided wadis.

Local relief ranges from 100 m to more than 1,500 m. The greatest relief occurs in isolated mountain ranges near the sea such as Jabal Radwa in the south and Jabal Shar, Jabal Dibbagh and Jabal Harb in the north. Jabal Dibbagh is the highest point in the area with an altitude of about 2,300 m.

Climate and water supply

Arabia forms part of the low latitude desert that extends across northern Africa and east to Pakistan. Rainfall is sparse and irregular. No appreciable rain had fallen in most of the quadrangle for five years prior to 1965 with the result that many wells were dry and pasturage had disappeared; most of the Bedouin had left the area. Several heavy rains occurred during the winter of 1965-66, and in the spring of 1966 the Bedouin were already drifting back.

Daytime temperatures are high during most of the year, but, except near the coast, the temperature drops considerably at night. A diurnal variation of from 20 to 25°C is not uncommon. Winter temperatures of below 0°C are recorded in the higher parts of the area.

Vegation is limited to shrubs and grasses except along the larger wadis where scattered acacia may be found. Some trees are as much as 7 m high. The trees are being cut for charcoal and most will be gone in a few years.

Water for the coastal towns comes from local wells except for Yanbu' al Bahr where water is piped in from Wadi al Fara'ah above Suq Suwaiq, and Al Wajh whose water is brought in by truck from Bi'r Aba al Qazaz 70 km to the northeast. The interior towns are located where water is relatively abundant. Fresh water in pools and running streams is found in three places in the quadrangle. Water in Wadi Tubjah near the east edge of the quadrangle is mentioned by Doughty (1888). The authors' field party carried about a week's supply of water. Barrels were filled wherever possible and it seldom was necessary to make a special trip for water.

Previous work

Burton (1876, a, b) was one of the first Europeans to be interested in the mineral wealth of the Northwestern Hijaz. He made two trips into the northern part of the area looking for gold and other minerals. Doughty (1888) spent considerable time in the northeastern part of the quadrangle and made geological as well as archeological observations.

The Saudi Arabian Mining Syndicate (SAMS) carried on an intensive search for gold deposits in the late 1930s. Engineers of the company examined all of the ancient mines in the quadrangle that could be located. Exploration offices were maintained in the gold district near Al Wajh and at the Murayjib deposit north of Yanbu' al Nakhl. No published reports resulted from this work but assay data and descriptions of the deposits are on open file at the Directorate General of Mineral Resources in Jiddah.

H. St. John Philby (1956) made two trips into the area. His first trip in 1952 in company with Mustafa Sadiq, an Egyptian mining engineer, resulted in the discovery of boulders of iron formation north of Al Muwaylih. The following year, in company with R. G. Bogue of the U. S. Geological Survey, the iron deposits of Wadi Sawawin were discovered. Bogue (unpub. data) reported on various mineral deposits studied in the course of the trip.

Richter-Bernberg and Schott (1954) of the Amt Für Bodenforschung of Hanover, Germany, studied the Red Sea coast from the Yemen to the Gulf of Aqaba. They describe gypsum deposits in the area between Yanbu' al Bahr and Al Wajh. The economic possibilities for the exploitation of magnetite in beach sands was investigated by Short (1956).

Von Gaertner and Schürenberg (1954) of the Amt Für Bodenforschung visited the Wadi Sawawin iron deposits in the course of a journey through northern Arabia.

Several mineral investigations have been carried out in recent years by geologists and engineers of the Directorate General of Mineral Resources and by organizations under contract with them. Schaffner (1958-a) Bhutta (1960-a) and Shanti (1963) made regional studies. Kahr (1961) studied the chromite deposits of Wadi Al 'Ays; Kahr and Agocs (1962) reported on the Wadi Sawawin iron deposits; Khalek (1963-a) describes silica sand and kaolin south of Tayma; Okumi and others (1965) made a detailed study of the gold deposits near Al Wajh; and Shepherd (1966) discovered a radioactive granite in the Wadi Sawawin area.

An airborne magnetometer and radiometric survey of the Wadi Al 'Ays and the Wadi Sawawin areas (fig.2) was made in 1962 by the Hunting Survey Corporation Ltd.

The Bureau Recherches Géologiques et Minières began mineral investigations in the southern part of the quadrangle in 1966.

Brown and others (1963) compiled a geologic map of the Northwestern Hijaz based on their own and others field work and on photo interpretation. This map is the first to provide basic data on the entire region and is the only geologic map of the area that has been published.

Present work

The present work envisioned a rapid reconnaissance over the Precambrian rocks of the quadrangle to search for mineralized areas that could subsequently be examined in more detail. After the first trip it was obvious that any attempt to cover the entire quadrangle in the time available would be too superficial so certain areas were selected for study in the north, north-central, east, and south-central portions of the quadrangle as shown on figure 2. From 20 to 30 man-days were spent in each 30' by 30' area.

Vehicle traverses were made through most of the accessible wadis in the selected areas and vehicle and foot traverses were made to targets selected from the study of aerial photographs. Features of possible importance in the localization of mineral deposits were examined and were sampled for determination of their trace-element content. Special attention was paid to intrusive contacts, fault zones and fault intersections, dikes and quartz veins bleached or limonitestained areas, and unusually dark rocks. The lack of vegetation allowed anomalous features to be seen with relative ease.

The sites of ancient mining activity were examined wherever possible but inasmuch as most of them had been examined in considerable detail they were not made the object of a special study. The mine descriptions in table 1 are largely taken from reports of earlier workers.

Acknowledgements

The work was made possible through the wholehearted cooperation of the staff of the Directorate General of Mineral Resources. Dr. Fadil K. Kabbani, Deputy Minister for Mineral Resources and his liaison officer, Mr. Abdul Hamid Derhally, gave their full support to the program. The administrative officer of the Directorate, Mr. Hassan Y. Yassin, and his staff were most helpful in furnishing vehicles and field supplies. Mr. Matouq Bahijry, Director of the Laboratories, gave the party full laboratory support and also gave his attention to personal problems that indirectly expedited the work. Mr. Ghazi Sultan, Chief Geologist for the Directorate, accompanied the authors on the first field trip and his experience in working in the desert was a great help. Mr. Shahta Omar Khatieb, geologist, accompanied the authors on other trips. In addition to his field duties he provided liaison with the local officials. Field assistants, particularly the guide, Hatthal bin Maith al Moutari, and a laborer, Saleh Ali al Gheni, took an active interest in prospecting and found several mineralized localities on their own initiative. They also prevented the authors from making serious breaches of desert etiquette in contacts with the Bedouin.

Geology

A mineral reconnaissance was the primary purpose of the present work. An attempt is made to relate mineral occurrences to local or regional geologic features but little time was available to study details of the stratigraphy, structure, or the sequence of intrusions. Geologic observations made during the present work are compiled on photomosaic base maps, scale 1:100,000, of the areas selected for study. Reports that accompany the maps are listed in the references. The resume of the geology that follows can best be understood by reference to the map of Brown and others (1963).

Crystalline rocks of Precambrian age are exposed over about 65 percent of the land area of the quadrangle. Gneiss and schist that crop out in large wrench fault zones may be the oldest rocks in the area but their stratigraphic relations are not known. At least part of them appear to be metamorphosed equivalents of adjacent layered rocks and intrusives. The oldest layered rocks are slightly metamorphosed andesitic volcanic rocks with interbedded wacke, felsitic volcanic rocks, conglomerate, and recrystallized limestone or dolomite. Brown and others (1963) show these rocks as greenstone (gd) or as Halaban Andesite (ha). Argillite, sandstone, and conglomerate of the Hadiyah Formation (h) unconformably overlie the metavolcanic section and are themselves overlain unconformably by unmetamorphosed flows and sedimentary rocks of the Shammar Rhyolite (sr). Plutons of granite, granodiorite, diorite, gabbro, and peridotite have intruded the above rocks. Mafic, intermediate, and felsic dikes are abundant throughout the quadrangle.

Sandstone of Cambrian age was deposited on a bevelled surface of the Precambrian rocks and was followed by deposition of sediments of Ordovician, Silurian, and Devonian ages.

Sedimentary rocks of Tertiary age crop out along the Red Sea coast and flood basalts of Tertiary and Quaternary ages cover broad areas of the quadrangle.

The rocks of Precambrian age are deformed by both folding and faulting. Paleozoic rocks are only gently tilted and faults are not common. The Tertiary rocks along the Red Sea are deformed, possibly by movement along the Red Sea Rift.

Precambrian stratigraphy

Gneiss and schist.

Biotite and hornblende gneiss, amphibolite, quartz-mica schist, chlorite schist, and sericite schist crop out in a belt that crosses the quadrangle from the Hadiyah railway station northwesterly to Wadi Dama. The belt ranges from

5 to 30 km in width. The stratigraphic succession and origin of these rocks is not known as they are confined to a zone of intense faulting that appears to be the western extension of the Nejd Wrench Fault Zone described by Brown and Jackson (1960, p. 77). Rocks of different ages may well be represented in the fault zone as shown on the map of Brown and others (1963). Slightly metamorphosed rocks in places appear to grade into rocks of higher metamorphic rank where a major fault is approached, but elsewhere fault slices of garnet-bearing gneiss lie adjacent to slightly metamorphosed volcanic rock.

The use of the symbol (sc) should be restricted to rocks of the Nejd Fault Zone. Rocks shown with the symbol (sc) elsewhere in the quadrangle are commonly only slightly metamorphosed and the original rock type can be mapped.

Halaban Andesite and greenstone.

Volcanic and metavolcanic rocks with interbedded sedimentary rocks make up the Halaban Andesite (ha) and greenstone (gd) map units (Brown and others, 1963) and are the most widespread rocks in the quadrangle. The two units are at least in part correlative, the greenstone is slightly metamorphosed but the volcanic origin is evident and the stratigraphic sequence is similar.

Halaban Andesite and greenstone crop out throughout the quadrangle except in the northeast where they are covered by Paleozoic sandstone. Dark brown to greenish-black mafic flows and pyroclastic rocks predominate in the section. Felsitic rocks are common; some of the areas shown as Shammar Rhyolite on the map of Brown and others (1963) are felsitic rocks interbedded with the mafic volcanic rocks, rather than a younger unit. Dark green wacke is common and conglomerate and recrystallized limestone or dolomite are locally present. In places the section is dominantly sedimentary. With more detailed mapping the rocks can probably be subdivided into several formations.

The base of the volcanic section was not seen in the mapped area. The rocks are either in fault contact with schist and gneiss or appear to grade into schist along strike. Goldsmith (oral communication, 1966) has mapped what appears to be an unconformity between the Halaban Andesite and underlying metasedimentary rocks a few kilometers southeast of the Northwest Hijaz quadrangle.

Bogue (unpub. data) states that a sedimentary unit he calls the Silasia Formation contains the oldest rocks in the area. The Silasia Formation north of Wadi Sadr, at the north edge of figure 2, lies on metavolcanic rocks with no evidence of overturning or thrust faulting. The authors believe that at least the lower part of Bogue's Silasia Formation is a sedimentary section within the dominantly volcanic sequence. The area north of Wadi Sadr contains the Wadi Sawawin iron deposits and is now being mapped in detail by geologists of the Japanese Geological Survey working under an agreement with the Ministry of Petroleum and Mineral Resources. On completion of this work the stratigraphic relations should be resolved.

The volcanic rocks are unconformably overlain by argillite and conglomerate of the Hadiyah Slate, or, where this is absent, by unmetamorphosed volcanic and sedimentary rocks of the Shammar Rhyolite.

Hadiyah Slate.

Hadiyah Slate (h) is the name given by Brown and others (1963) to a sedimentary sequence they describe as green and maroon slate, arkosic sandstone, and conglomerate, that crops out near the Hadiyah railway station in the eastern part of the quadrangle.

The Hadiyah is exposed in a broad belt east of Jabal Radwa from about latitude 24°30'N., northward to the Nejd Fault Zone in Wadi al Hamd. The rocks are labeled "sc" on the map of Brown and others (1963). North of the fault Hadiyah type rocks crop out intermittently in a northwest trending direction as far north as Jabal Lawz in the adjoining Wadi as Sirhan quadrangle (Bramkamp and others, 1963).

Green, maroon, and gray beds of the Hadiyah Slate are only locally slaty. Commonly they are argillites without slaty cleavage but with sericite along bedding planes that gives a sheen to exposed surfaces. Metamorphism is not apparent in the sandstone or conglomerate except near intrusive contacts where the rock may be converted to a dark hornfels.

Hadiyah Slate appears to lie unconformably on the Halaban Andesite or greenstone but it is not known whether this is a true unconformity or represents deposition of Hadiyah sediments in a volcanic area against volcanic rocks with a high initial dip. Conglomerate near the base of the Hadiyah suggests an unconformity but at one locality a tongue of Halaban Andesite that extends out from a volcanic pile is interbedded with the lower beds of the Hadiyah Slate. The Hadiyah may have been deposited at the end of a period of volcanic activity rather than after an additional period of uplift and erosion. The upper contact with the Shammar Rhyolite is unconformable.

Shammar Rhyolite.

Unmetamorphosed flows of rhyolite, dacite, and andesite together with interbedded conglomerate, shale, and limestone make up the Shammar Rhyolite (sr) in the mapped area. These rocks are localized at or near the contact of the Paleozoic and Precambrian rocks. Outcrops of rocks elsewhere in the quadrangle shown as Shammar Rhyolite by Brown and others (1963) are either felsitic intrusions or felsitic volcanic rocks that appear to be interbedded with the Halaban Andesite and greenstone.

The Shammar Rhyolite lies unconformably on the older layered rocks, or on rocks intrusive into them, and is unconformably overlain by sandstone of Paleozoic age.

Conglomerate of unknown age.

Brown and others (1963) mapped an extensive area of conglomerate (rs) north of Al Wajh that they could not correlate with other units. They thought the conglomerate might be the same age as the Shammar Rhyolite or even younger. Cobbles and boulders of granite and volcanic rocks indicate that the conglomerate is younger than the Halaban Andesite and field relations confirm this. However the beds are intruded by granite and may well correlate with the Hadiyah Slate.

Intrusive rocks

All the Precambrian bedded rocks with the possible exception of the Shammar Rhyolite have been intruded by plutonic rocks of many kinds. Granitic rocks are the most abundant but syenite, diorite, gabbro, and peridotite are present. More than 250 separate intrusive bodies are shown on the map of Brown and others (1963), but in places several bodies are parts of one intrusive.

The relative age of the various intrusions is not yet well defined. Brown and Jackson (1960, pp. 71-73) give evidence for three widely separated periods of intrusive activity in the Precambrian and one in the Paleozoic. A two-fold separation is evident in the Northwestern Hijaz and three ages are possible. Some granite intrusions appear to be syntectonic or late tectonic whereas other granitic bodies are post tectonic. Some intermediate and mafic intrusive rocks are associated with the earlier granites, but other intrusive masses, including the largest body of peridotite, are late.

C. L. Hummel (oral communication, 1966) found a patial association between many mineral deposits and granite in the Northeastern Hijaz quadrangle but this relation was not so evident in the Northwestern Hijaz.

Older intrusives.

Plutons of granite, called cave granite by Bogue (unpub/ data) underlie broad areas near the Red Sea coast. These plutons consist mainly of biotite granite and hornblende granite with sparse muscovite granite and minor biotite or hornblende adamellite and granodiorite. They appear to fill preexisting structures and to have followed structural trends in the Halaban Andesite and greenstone, a relation interpreted to result from syntectonic emplacement.

Reddish biotite or hornblende granite rich in potassic feldspar intrudes the syntectonic granite and occurs widely throughout the quadrangle where they are shown with the symbol (gr) on the map of Brown and others (1963). These bodies of granite may represent more than one period of intrusive activity because they appear to be more abundant in the Halaban Andesite and greenstone than in the Hadiyah Slate.

Many of the dioritic intrusives and some masses of gabbro appear to predate the potassic-rich granite as shown by the presence of granite dikes cutting the diorite or gabbro.

No data on absolute ages for these rocks is available in the mapped area. Brown and Jackson (1960) cite the age of the syntectonic granite at about 1,000 million years and the calc-alkaline granite at about 700 million years. If the two granites described above show the same age difference they could not be related to the same orogeny.

Ophiolite complex.

Kahr (1961) mapped an ophiolite complex west of Wadi al 'Ays in the south-central part of the quadrangle. The complex is made up of serpentinized peridotite, gabbro, and diorite. Rocks of the complex intrude both the Halaban Andesite and Hadiyah Slate. Small bodies of chromite as well as veinlets of magnesite and chrysotile occur in the peridotite.

Younger granite and gabbro.

Large plutons of massive, light-colored, medium- to coarse-grained biotite or hornblende granite intrude the syntectonic granite, Halaban Andesite and greenstone, and the Hadiyah Slate. These plutons are most common in the north where they form the highest peaks in the quadrangle, Jabal Dibbagh and Jabal Harb. Contacts with the enclosing rocks are sharp with only a narrow zone of contact metamorphism. Two age determinations of the Jabal Harb intrusion are shown on the map of Brown and others (1963). One is 550 million years by the potassium/argon method and the other 660 million years by the rubidium/strontium method.

Stocks, ring dikes, and small plutons of syenite and alkali granite appear to be the youngest intrusive rocks. They commonly form circular intrusions with associated ring dikes of gabbro or diorite and ring-like internal structures. The intruded rocks may be turned up adjacent to the circular structures indicating forceful intrusion of the syenite, alkalic granite, gabbro, and diorite. A characteristic feature of these late alkalic intrusive rocks is an anomalously high content of trace amounts of beryllium, lanthanum, niobium, yttrium, and zirconium and, commonly, tin and molybdenu, Magnetite from these rocks has an abnormally high content of zinc.

Jabal Radwa forms part of the largest of these late intrusive masses. Ring dikes of gabbro crop out both north and south of the main granitic body. Small syenitic intrusions in the Hadiyah Slate 45 and 75 km north-northeast of Jabal Radwa are bordered by gabbroic dikes that locally contain as much as 35 percent magnetite.

Jabal Shar in the northern part of the quadrangle is composed of riebeckite granite with well developed graphic intergrowths of quartz and feldspar. It is mapped as a late alkalic granite by Brown and others (1963) and contains the characteristic suite of anomalous trace elements. The age shown on the map of Brown and others at Jabal Shar is from a specimen of riebeckite granite and is 1,175 million years. Either alkalic granite of widely disparate ages occurs in the quadrangle or the age determination needs to be reevaluated. Additional sampling for age determination is called for, but fresh samples from surface material are difficult to obtain.

Dikes.

Randomly oriented dikes and groups of sub-parallel dike swarms are abundant throughout the area underlain by rocks of Precambrian age. They are most common in the Halaban Andesite and greenstone and in the earlier intrusive rocks. Dike swarms that strike east or northeast are the most abundant but north- and northwest-striking swarms do occur. Except for aplite and pegmatite most of the dikes are porphyritic with a fine-grained groundmass. Many resemble the volcanic rocks with which they are probably related. They range in composition from rhyolite to peridotite. Felsitic dikes appear to be the most abundant, but this may be due to their light color and to their greater resistance to erosion. Attempts to relate the dikes of a particular type or orientation to mineralization were not successful.

Paleozoic and younger rocks

Paleozoic rocks.

Gently dipping reddish to pale colored sandstone and shale underlie the Hisma Plateau in the northeastern part of the quadrangle. The lower sandstones are cliff-forming and the contact with the Precambrian is marked by an imposing erosional scarp with outlying spires and stacks of red sandstone.

The Precambrian rocks were eroded to a surface of low relief before deposition of the Cambrian sediments. The Shammar Rhyolite and Hadiyah Slate were either largely eroded or were not deposited in some areas as the Paleozoic sandstone commonly lies directly on Halaban Andesite and greenstone or on intrusive rocks. Where Shammar Rhyolite is present, the contact is unconformable.

Brown and others (1963) describe the rocks of Paleozoic age. Only the basal portion was examined during the present study.

Tertiary and Quaternary rocks.

The Raghama (?) Formation (Brown and others, 1963) of probable Miocene age crops out in a narrow intermittent belt along the Red Sea. It is composed of conglomerate, sandstone, calcareous sandstone, limestone, and gypsum. Richter-Bernburg and Schott (1954) describe a section near Yanbu' al Bahr that is several hundred meters thick. Gypsum localities are shown on figure 2. The deposits about 50 km northwest of Yanbu' al Bahr appear to have the best commercial possibilities.

Flood basalts cover broad areas of the quadrangle. They include the Harrat ar Raha and Harrat al Uwaynid on the Hisma Plateau and the Harrat Lunayyir in the south-central part of the area. The flows are black scoriaceous olivine basalts. Cinder cones occur either singly or in groups aligned along fractures. Volcanic activity has continued since the late Tertiary. The latest recorded eruption took place near Medina in historic time.

Structure

Only the major structural features of the quadrangle can be described as time limitations did not permit working out the complexities of folding and faulting. Faults were examined for evidence of mineral deposits, but not enough is known of the stratigraphy in most areas to permit determination of either the magnitude or direction of fault movements.

Folds.

The varied lithology and color of the Hadiyah Slate serves to emphasize the folds. Many are small and a complete fold may be seen in places in a single hill. The Hadiyah Slate northeast of Jabal Radwa (labeled sc on the map of Brown and others, 1963) is folded in a northerly trending synclinorium with many subsidiary folds. North of the Nejd Wrench Fault Zone the belt of Hadiyah Slate is intermittent but appears to be in a northwesterly trending synclinal structure.

Whether the older metavolcanic rocks were folded previous to the orogeny that affected the Hadiyah Slates is not known. The older rocks commonly dip at high angles but the uniform appearance of the weathered surface masks the attitude and direction of folding.

Faults.

The fault pattern in the quadrangle is dominated by faults associated with the western portion of the Nejd Fault Zone and by much younger faulting associated with the Red Sea rift. The Nejd Fault Zone trends northwest and in the eastern part of the quadrangle lies in the depression followed by Wadi al Hamd and Wadi al Jizl. Near the junction of the two wadis the fault zone turns westward and splits. One set of faults can be traced westward to the coast near Al Wajh and the other northwestward to the vicinity of Duba. Individual faults are well marked topographically by linear wadis and by aligned gaps between them. Bedding is contorted in the vicinity of the faults and in places mylonite is exposed. The north side of the fault zone is believed to have moved west relative to the south side (Brown and Jackson, 1960, p.77). Movement in the opposite sense was noted but may only represent relative displacement between blocks within the fault zone.

East-trending faults are common near the northern and southern borders of the quadrangle and also occur as splits off the Nejd Fault Zone. Wadi Tiryam in the north follows a major fault that may cut off the Nejd Fault Zone. North- and northeast-trending faults are less common than the east-trending faults, but deep linear valleys as much as 30 km long are cut along north-trending faults in the mountains north of Umm Lajj and strongly emphasize their presence.

Both northwest and northeast faults have offset the base of the Paleozoic sandstone indicating at least some post-Precambrian movement. Overstreet (oral communication, 1966) states that movement on the Nejd Fault Zone in the eastern part of the Shield had apparently ceased by Permian time.

The faults associated with the Red Sea Rift are much younger and have offset the beds of the Raghama(?) Formation.

Economic geology

Introduction

The date that mining began in the Arabian Peninsula is lost in antiquity. Gold from Arabia is one legendary source of Solomon's treasure. Inscriptions in stone at several ancient mining sites show that the period of the Abbasid Caliphate, about 1100 to 1000 years ago, was one of intense mining activity and most of the known ancient mines date from this period.

Modern activity began in the 1930s when the Saudi Arabian Mining Syndicate (SAMS) obtained a concession to prospect for gold and silver. SAMS reopened the Mahd adh Dhahab gold mine (Ministry of Petroleum and Mineral Resources, 1965, p.21) and in addition maintained an active exploration program. Their activities in the Northwestern Hijaz were carried on from two centers, the Murayjib mine 90 km north-northeast of Yanbu' al Bahr and the Umm al Qurayyat mine near Al Wajh. Assay laboratories were operated at both places. Most of the ancient workings listed in table 1 were relocated and sampled by SAMS engineers. Trenching, test pitting, and diamond drilling were used to explore the deposits. Not enough ore was found to support a gold mining operation under the conditions prevailing at the time of exploration. It should be noted that, in general, conditions for gold mining were much more favorable in the 1930s than they are at present.

Exploration for minerals other than gold began in 1950 and has continued with increasing momentum until the present. Appreciable amounts of iron formation, gypsum, chromite, and glass sand have been discovered as well as small occurrences of mica, asbestos, magnesite, and marble.

The present study is one of four major mineral exploration projects currently underway in the quadrangle. Geologists of the Directorate General of Mineral Resources are studying gypsum deposits north of Yanbu' al Bahr. Geologists and topographers from the Geological Survey of Japan, working under the terms of an agreement with the Ministry of Petroleum and Mineral Resources, are making a detailed study of the iron deposits of Wadi Sawawin in the northern part of the quadrangle. Geologists of the Bureau des Recherches Géologiques et Minières, also working under the terms of an agreement with the Ministry of Petroleum and Mineral Resources, are mapping the geology and searching for minerals in the southern half of the quadrangle.

Mineral deposits

Gold.

Nearly all of the ancient workings shown on figure 2 and listed in table 1 were for gold. The mode of occurrence of the gold deposits is similar throughout the area. Gold is associated with quartz veins emplaced along faults or fractures. Bogue (unpub. data) distinguished three varieties of quartz that were deposited in sequence over a short period of time. First is a white granular quartz that is associated with a small amount of pyrite. This quartz was fractured and the second variety, grayish gold-bearing quartz, was introduced as veinlets seldom more than 5 centimeters thick. The gold is fine-grained but can be seen with a hand lens. Chlorite, serpentine, and hydromica accompany the gold. The third variety is barren white massive quartz that commonly was emplaced as thick veins adjacent to the earlier quartz and was not mined by the ancients.

Nearly all of the gold deposits occur in three discrete areas. The greatest number lie in a belt parallel to and within 50 km of the Red Sea, from Umm Lajj north to Wadi Dama. Another group of workings lie in a belt extending north from Yanbu' al Nakhl to Wadi al Hamd. The third group consists of a few workings south of Al 'Ula in Wadi Matran and Wadi Dha'a.

Similarity in the mode of occurrence of the gold deposits suggests that they are of the same general age. If so, the deposits can only be dated as post-Hadiyah Slate, because age relations with the Shammar Rhyolite are not known. Brobst (1972) suggested that there may be mineral deposits associated with faulting on the Red Sea Rift, but the alignment of gold mines roughly parallel to the Rift is thought here to be only coincidental. Many of the gold-bearing veins at Murayjib and nearby mines clearly fill tension fractures on the crest of an anticline in the Hadiyah Slate and Halaban Andesite. The folding appears to be pre-Shammar and the veins must have formed at the same time. The Rerga lead deposit near Yanbu' al Bahr is reported to be associated with chalcedony and may be related to the younger deposits described by Brobst.

Engineers of SAMS examined nearly all of the ancient workings listed in table 1. Trenches and test pits were dug on the most promising prospects and at least five areas were drilled in order to sample the veins below old workings. Schaffner (1958b) sampled a quartz vein 1.2 m thick at the Hammam deposit (No.42, fig. 2) that contained 0.08 ounce of gold per ton. Marginal to the vein, he sampled a lens of brecciated iron-stained quartz and gouge which assayed 3.77 ounces per ton. Obviously this was the material sought by the ancients but in most prospects it has been entirely removed.

SAMS did not find any deposit in the Northwestern Hijaz that would sustain a mining operation. A recent restudy of the Al Wajh gold district (Okumi and others, 1965) confirmed the earlier findings.

Iron.

Iron deposits of three types occur in the quadrangle: banded iron formation, magnetite segregations in mafic rocks, and magnetite beach sands. The banded iron formation of Wadi Sawawin near the north edge of the quadrangle is the most important. The iron formation is composed of alternating layers of red jasper and iron oxides (specular hematite and magnetite). Slate is locally interbedded within the iron formation, and dikes and sills of diorite are common. Garnet-epidote rock takes the place of jasper in some beds. The proportion of jasper to iron oxides and of hematite to magnetite differs at different outcrops. Some iron formation is not attracted to a hand magnet whereas other layers are strongly magnetic.

The most detailed study of the deposits was made by Kahr and Agocs (1962). They estimated 912 million tons of iron formation in an area 2 km wide and 26 km long. The present authors' estimate is considerably less, about 200 million tons of iron formation. The iron content of most of the material appears to range from 30 to 40 percent Fe. A detailed study of the deposits is now underway and will furnish reserve and grade estimates that can be used for future development.

The deposits are within 80 km of the coast but are scattered over a wide area. Scarcity of water, complete lack of facilities and labor, and the absence of direct-shipping ore has inhibited the development of the deposits up to the present time.

Isolated bodies of iron formation occur northwest and west of Wadi Sawawin in the Al Bad' quadrangle (Trent and Johnson, 1968). The largest bodies, west of Jabal Harb, contain several million tons of iron formation. Magnetite seems to be more common in these bodies but the jasper content is also higher. The iron formation is in pendants in the older granite. Small pendants may be in part converted to massive specular hematite. These bodies appear to be too small to be mined separately but may be of interest when the Wadi Sawawin deposits are developed.

Bogue (unpub. data) reports the presence of iron formation 10 km east of Bi'r Aba al Ajjaj, about 50 km easterly from Al Wajh. Hematite and jasper are in metamorphosed sedimentary rocks close to a granite intrusion. The extent of the deposit is not known.

The largest deposits of magnetite in gabbroic rocks found in the course of the work lie in the middle reaches of Wadi Hayyan at about 27°N. A ring dike structure of diorite and gabbro contains numerous lenses of massive magnetite which range in size from a few hundred to several thousand tons. The lenses appear to be concentrated near the margin of the intrusion. A sample from one body contains 48.75 percent Fe.

Gabbro with more than 30 percent magnetite crops out on the margin of the circular peralkaline intrusion (gp) northeast of the Murayjib gold mine in the southern part of the area. Massive magnetite float was seen in a wadi draining a similar intrusion 30 km further north but the outcrop was not located.

Magnetite sand derived from gabbro occurs along the coast road south of Wadi Thalbah, between Al Wajh and Duba. Bogue (unpub. data) chip sampled the gabbro to test for gold and platinum. The sample was analyzed by F. W. Millsap of SAMS who reported 3.12 percent Fe, 0.07 ounce of gold and no platinum. There is not enough magnetite sand to be of interest.

Schaffner (1958) reports the presence of magnetite at Twal al Bi'r about 8 km east of Bi'r Nabt, northwest of Yanbu' al Bahr. The largest body of magnetite is less than 30 m long and ranges from 2 to 3 m wide. Two smaller bodies are nearby but Schaffner spent a day in the area and failed to find any more. This is probably the same locality as the one described by Von Gaertner and Schurenberg (1954, p.96).

Magnetite in beach sand constitutes the third type of iron deposit. Short (1956) sampled beaches from Jordan to the Yemen border in a search for magnetite or other heavy minerals such as zircon, scheelite, or radioactive material. He reported three beaches in the Northwestern Hijaz that he thought had economic possibilities. A beach at the mouth of Wadi Tiryam is 3 km long and is stated to contain 13 percent magnetite. A beach 10 km north of Wadi al Hamd is 4 km long and is said to contain 26 percent magnetite. A third beach 2 km south of Umm Lajj is reported to contain 15 percent magnetite over a length of 10 km. Schaffner (1958) reexamined the beach near Umm Lajj and reported the magnetite to be in thin lenses. He estimated 1 percent magnetite for the entire beach. None of the beaches contained other heavy minerals in enough quantity to be of interest.

Copper.

Secondary copper minerals are widespread in the quadrangle but the occurrences commonly consist of single fractures or quartz veinlets with small amounts of copper minerals coating fracture surfaces or disseminated in the quartz. Malachite and chrysocolla are the most common copper minerals in the area but chalcocite is locally present. Primary chalcopyrite is less common but does occur at some outcrops. Bogue (unpub. data) reports disseminated limonite with traces of chalcopyrite in granitic rock near Bi'r Nabt, southeast of Umm Lajj, and near Shawaq in the northern part of the area. He recommended further work to investigate the possibility of disseminated copper deposits. The localities are only vaguely described. Schaffner (1958) and Von Gaertner and Schurenberg (1954, p.96) were not able to locate the Bi'r Nabt deposit and the present authors were unable to locate either deposit in the limited time available.

The ancient workings called Shizam or Shism at Tasa, 40 km southwest of Al 'Ula, were mined for copper. Workings follow two northwest-striking shear zones as much as 3 m wide. Stopes are as much as 20 m long and at least 10 m deep. Samples from pillars and from the ends of the workings contain traces of gold and from 0.2 to 1.5 percent copper. A well in the mine area contains green copper-bearing water. This well is mentioned by Doughty (1888) who writes that the Bedouin used the water for medicinal purposes. An estimated 2,000 tons of slag and the ruins of a village lie at the base of the hill below the mine. The mine was examined by engineers from SAMS but they were interested only in the gold content.

Chromite.

Fakhry (1941-a) reported the presence of serpentinite in the area west of Wadi al 'Ays. Kahr (1961) mapped the area and described an ophiolite complex made up of serpentinized peridotite, gabbro, and diorite. He discovered two chromite lenses in the peridotite, each containing about 5,000 tons of ore, as well as numerous pods of a few tons each. Subsequent work by the authors resulted in the discovery of additional small pods of chromite. Geologists of the Bureau des Recherches Géologiques et Minières are presently remapping the ophiolite complex in more detail.

Asbestos.

Serpentinite in the ophiolite complex west of Wadi al 'Ays commonly contains hairlike seams of chrysotile asbestos and more rarely veinlets as much as 1 mm thick. Much of the serpentinite is highly sheared with cobble-size fragments of massive serpentine in a gouge-like matrix. Chrysotile is recognizable only in the massive rock.

Kahr (1961) describes two localities that contain higher than normal amounts of chrysotile. The best deposit is near Jabal Wask (near 25°18'N.x 38°03'E.) and consists of fractures filled with slip-fiber chrysotile and magnesite. Kahr thought the deposit of marginal economic value. Bhutta (1960) also visited the area and thought the deposits too small to be of interest. The present authors think that it may be possible to find enough material to support a small-scale local industry when the need arises.

The other deposit farther north in Wadi Osman contains only a small amount of chrysotile mixed with brittle picrolite.

Magnesite.

Veins and veinlets of magnesite are common in the serpentinite but do not appear to be large enough or abundant enough to be mined. Locally veins may be more than 1 m thick but the average is only a few centimeters. Bhutta (1960-c) describes a magnesite body in the Jabal al Wask area that he thought warranted further investigation.

Marble.

Lenses of recrystallized limestone or dolomitic limestone form a minor part of the sedimentary rocks included in the Halaban Andesite and greenstone. Several lenses crop out near the railroad at Qala'at Zumurrud and Jabal Aba ad Dud. The rock is fine- to medium-grained and light colored. Commonly the marble crops out as fairly pure isolated hills but at one place volcanic rocks are interbedded with the marble. Other deposits lie near the coast, those near Al Wajh are described by Okumi and others (1965), and a deposit near Umm Lajj was sampled by Khalek (1963-b). Khalek found the deposit near Umm Lajj to be dolomitic with 29.97 percent CaO and 9.37 percent MgO.

Mica.

Muscovite in pegmatites has been described by Shanti (1960) from the head of Wadi Madhar, north of Wadi al Hamd at about 37°30'E. Books of muscovite occur in pockets as much as 10 cm wide and 30° cm long in a quartz-orthoclase pegmatite. About 20 pockets were found in 80 m of pegmatite. The muscovite near the surface is not of good quality.

A very coarse-grained mass of muscovite granite crops out in the low hills east of Wadi Azlam where the wadi leaves the mountains at about 26°59'N.x36°12'E. Centimeter-size books of muscovite are abundant in the granite; thus, it may be worth while to look for sheet-muscovite-bearing pegmatites in the area.

Kyanite.

Garnetiferous mica schist with scattered blades of kyanite crops out as a pendant in sheared granite in the Nejd Fault Zone about 6 km southwest of Bi'r Aba al Qazaz, northeast of Al Wajh. A boulder of nearly pure kyanite about 15 cm in diameter was found in the same area but the outcrop could not be located and a search in adjacent wadis failed to disclose any more kyanite.

Sulfur.

Considerable interest has been shown in the past in sulfur occurrences near the Red Sea southeast of Al Wajh and near Al Muwaylih. Burton (1876-a, p.300) visited the deposit near Al Muwaylih and obtained specimens that contained sulfur. Bogue (unpub. data) investigated three of these deposits and found only traces of sulfur which he believed were derived from adjacent gypsum-bearing beds. He concluded that the sulfur deposits have no economic potential.

Gypsum.

Gypsum may be the most readily exploitable mineral commodity in the quadrangle. Large deposits are known along the coast from Yanbu' al Bahr to Duba. Richter-Bernberg and Schott (1954, p.26) describe gypsum-bearing beds 100 m thick near Yanbu' al Bahr. The beds are Tertiary in age and form part of the Raghama (?) Formation. Studies to determine the amount and quality of the deposits near Yanbu' al Bahr are now underway by geologists of the Directorate General of Mineral Resources.

Trace-element studies

Visual field reconnaissance was the principal technique used in the present search for evidence of mineral deposits, but samples of wadi sediment were collected in the course of the work in order to obtain additional information on the abundance of various trace elements in the basins drained by the wadis. Abnormal amounts of one or more of the trace elements could either confirm the results of the visual examination or could indicate areas that warranted more detailed investigation.

Systematic sampling of this type is called geochemical prospecting and the method has been used successfully in the discovery of ore deposits in many parts of the world. The Northwestern Hijaz was too large an area for systematic sampling in the time available and all that was hoped for was to delineate smaller areas that should be sampled systematically.

Samples were collected from wadis with drainage basins of only a few square kilometers and, in most places, from wadis that drained intrusive contacts, fault zones, areas with quartz veins, or areas that showed evidence of hydrothermal activity. Except for the size of the basin these are all features that are potentially favorable for the presence of mineral deposits.

The samples were sieved at the sample site so as to yield about 100 g of material in the size range from 0.175 to 0.495 mm (30 to 80 mesh). Samples were then sent to the laboratories of the Directorate General of Mineral Resources in Jiddah where a 5 to 10 g portion was taken for analysis. Magnetite for analysis was separated from the remainder of the sample. The samples were analyzed for the following 27 (table 2) elements using a semiquantitative spectrographic method developed by the U. S. Geological Survey. Mr. Charles A. Thompson of the U. S. Geological Survey analyzed all but 22 of the samples. The latter were analyzed by Mr. Kamal H. Shahwan of the Directorate General of Mineral Resources. Check analyses for copper, molybdenum, and zinc were run by standard colorimetric methods by L. Al Dugaither of the Directorate General and by J. Goldsmith of the U. S. Geological Survey.

Table 2. List of elements reported by spectrographic analysis.

Silver	(1) _/	Gallium	(10)	Tin	(10)
Boron	(10)	Lanthanum	(20)	Strontium	(50)
Barium	(20)	Manganese	(20)	Titanium	(10)
Beryllium	(2)	Molybdenum	(2)	Vanadium	(20)
Bismuth	(20)	Niobium	(50)	Tungsten	(50)
Cadmium	(50)	Nickel	(5)	Zinc	(100)
Cobalt	(5)	Lead	(10)	Germanium	(20)
Chromium	(10)	Antimony	(200)	Yttrium	(10)
Copper	(10)	Scandium	(10)	Zirconium	(20)

_/ Numbers in parenthesis show the lower limit of detection in parts per million (ppm).

The magnetite fraction of the samples was analyzed for copper, molybdenum, and zinc by wet laboratory procedures by L. Al Dugaither. The significance of abnormal amounts of these elements in magnetite is not well understood but high zinc in magnetite is, in places, related to zinc deposits (Theobald and Thompson, 1962, p. C72).

Results of the spectrographic analyses are shown by means of histograms in figures 3-6, and samples with anomalous trace-element content are shown on figure 2. Sixteen elements were detected in enough samples to furnish meaningful histograms. Bismuth, cadmium, antimony, tungsten, and germanium did not occur in detectable amounts in any samples. Silver, beryllium, niobium, tin, and zinc did not occur in detectable amounts in enough samples to be shown graphically. Gallium showed so little variation that the results did not appear to be meaningful. Figure 2 shows the locations of samples that contained elements in higher than average amounts together with the symbols of the anomalous elements.

The term 'higher than average' is roughly correlative with the term 'anomalous' as used by Hawkes and Webb (1962, pp. 26-31). These authors consider anomalous element content to be that above the upper limit of normal background or 'threshold'. For limited data they suggest that the threshold be exceeded by 2.5 percent of the samples which could be considered anomalous. It was not possible to make a division at the top 2.5 percent, and the elements listed as anomalous on figure 2 range from the top 3 to 8 percent of the samples shown on the histograms.

Interpretation of the results is difficult because of the sparse sample density. The significance of anomalous samples must be determined in relation to the type of rock in the drainage basin represented by the sample. For example, anomalous barium in a granitic terrane may well be due to the common presence of barium in potassic feldspar and thus would not be a significant anomaly. Anomalous nickel and chromium in an area of ultra mafic rocks is another example well shown in the mapped area.

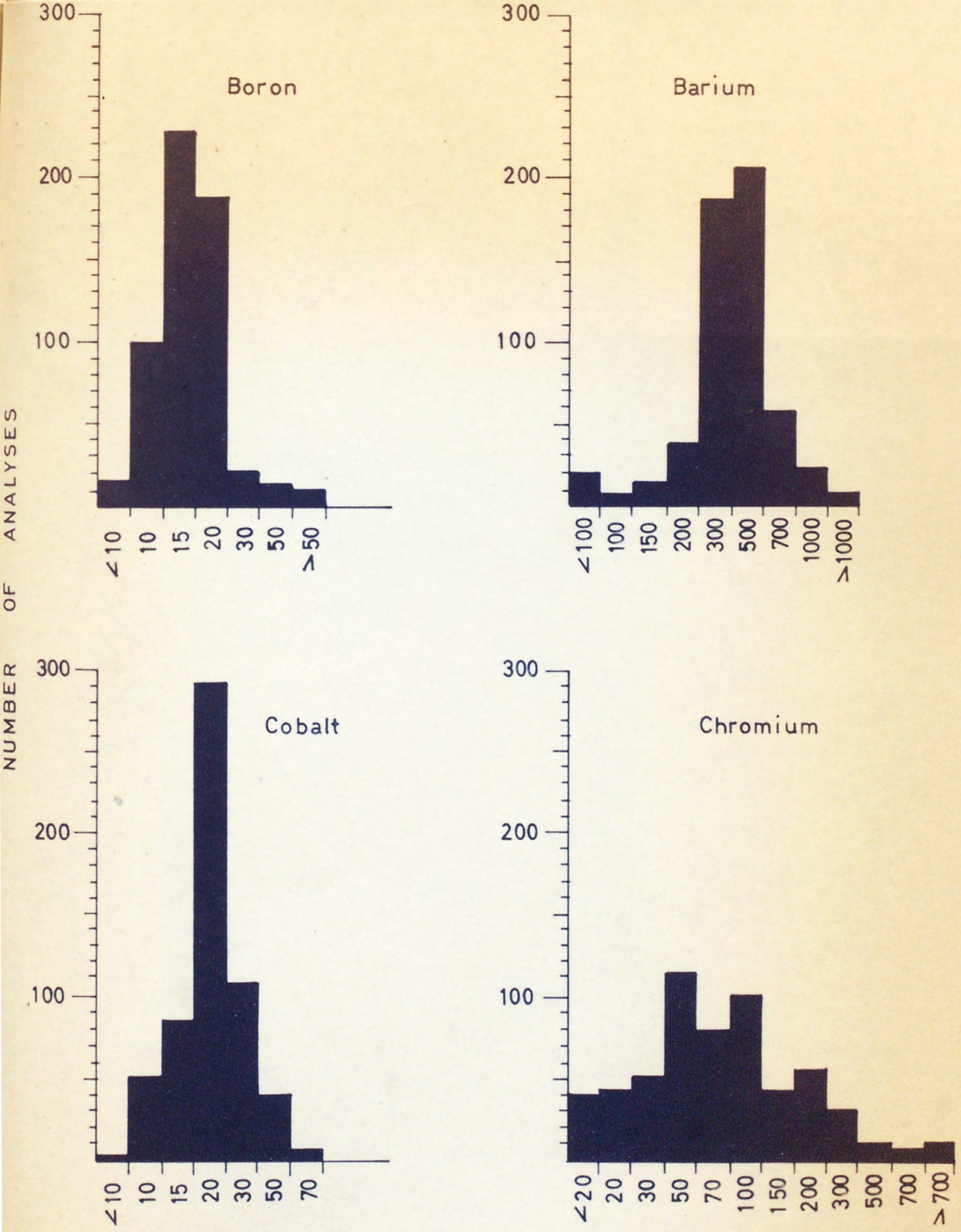


Figure 3. Histograms showing amounts of boron, barium, cobalt, and chromium in samples of wadi sediment

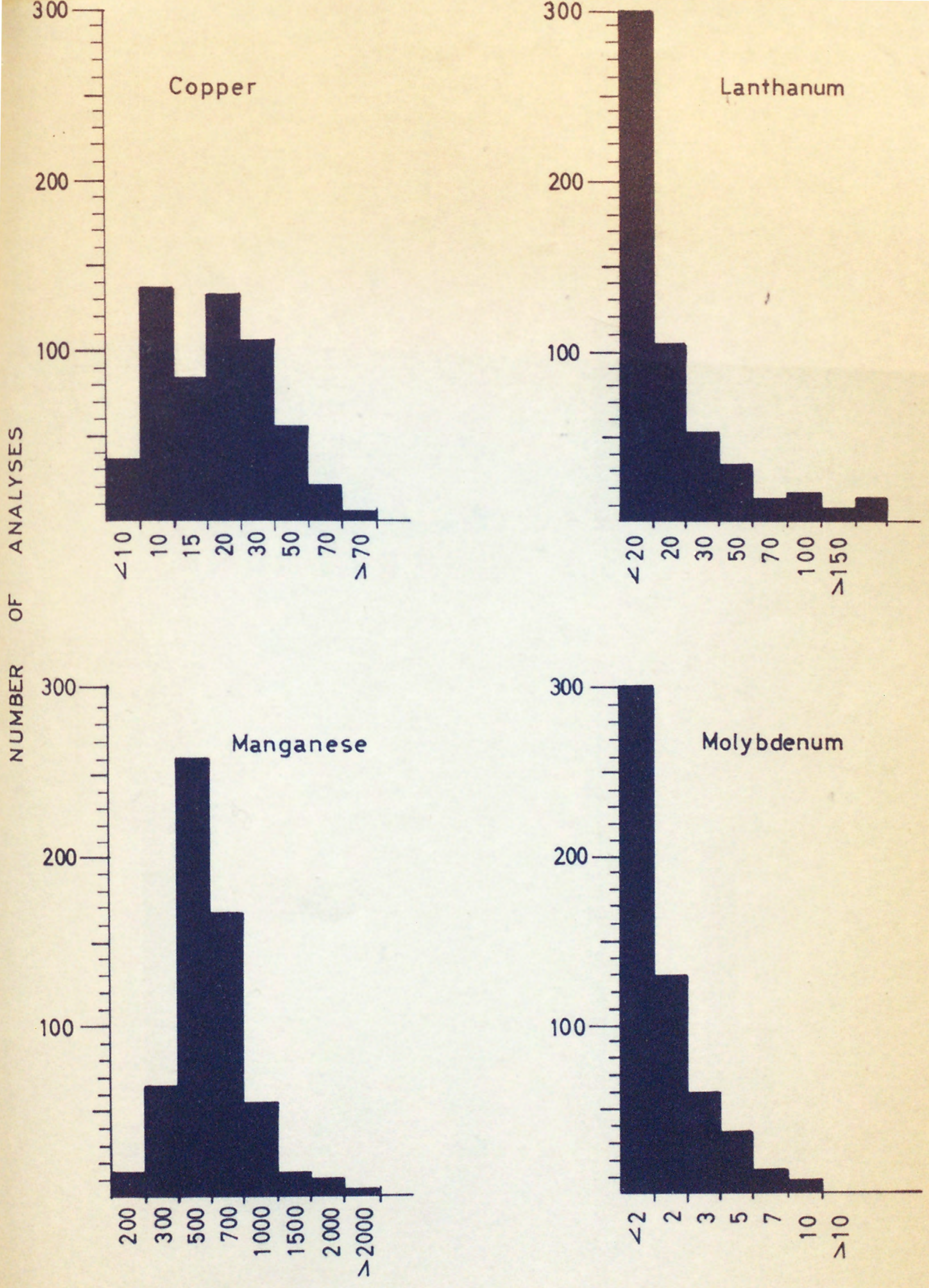


Figure 4. Histograms showing amounts of copper, lanthanum, manganese, and molybdenum in samples of wadi sediment.

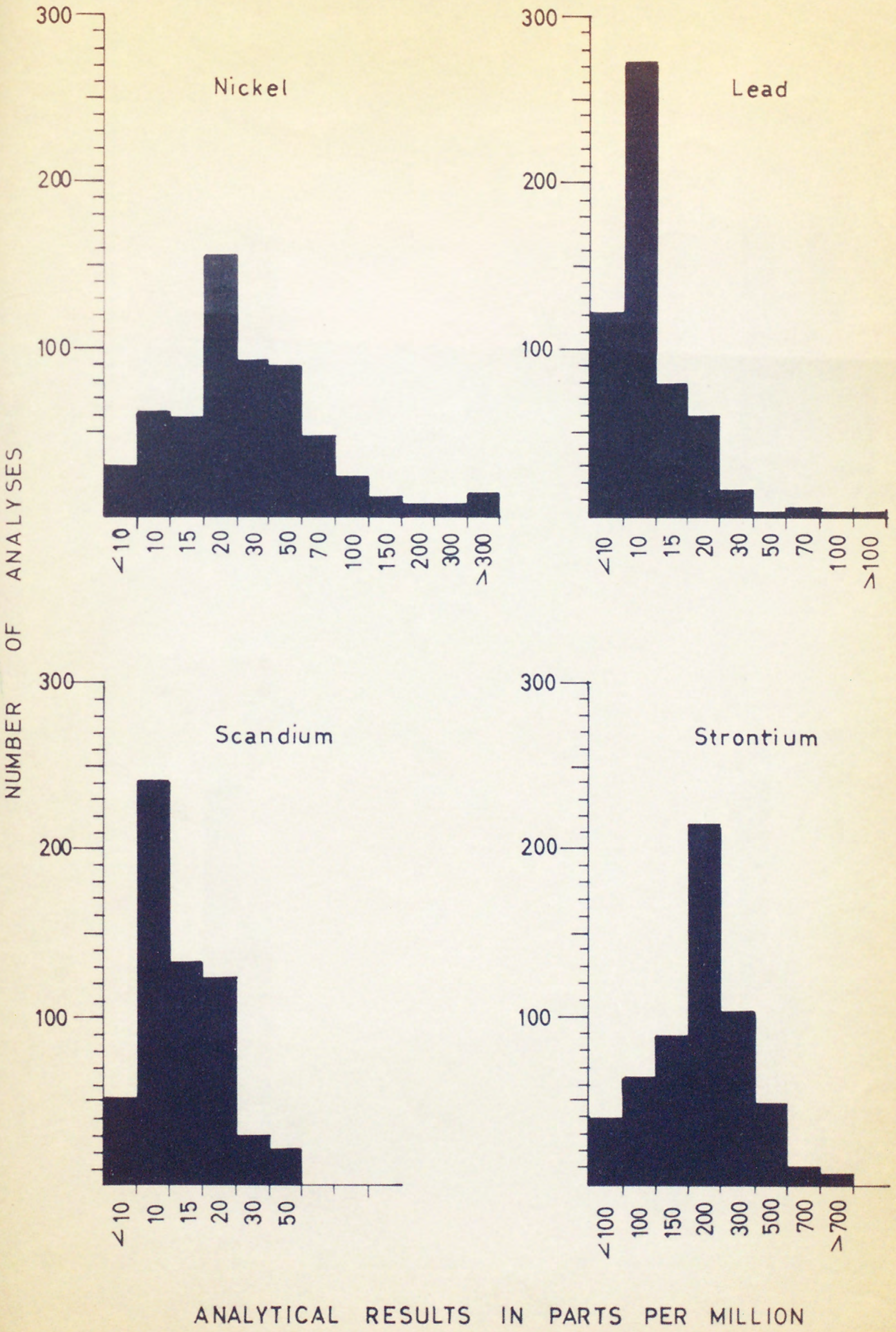


Figure 5. Histograms showing amounts of nickel, lead, scandium, and strontium in samples of wadi sediment.

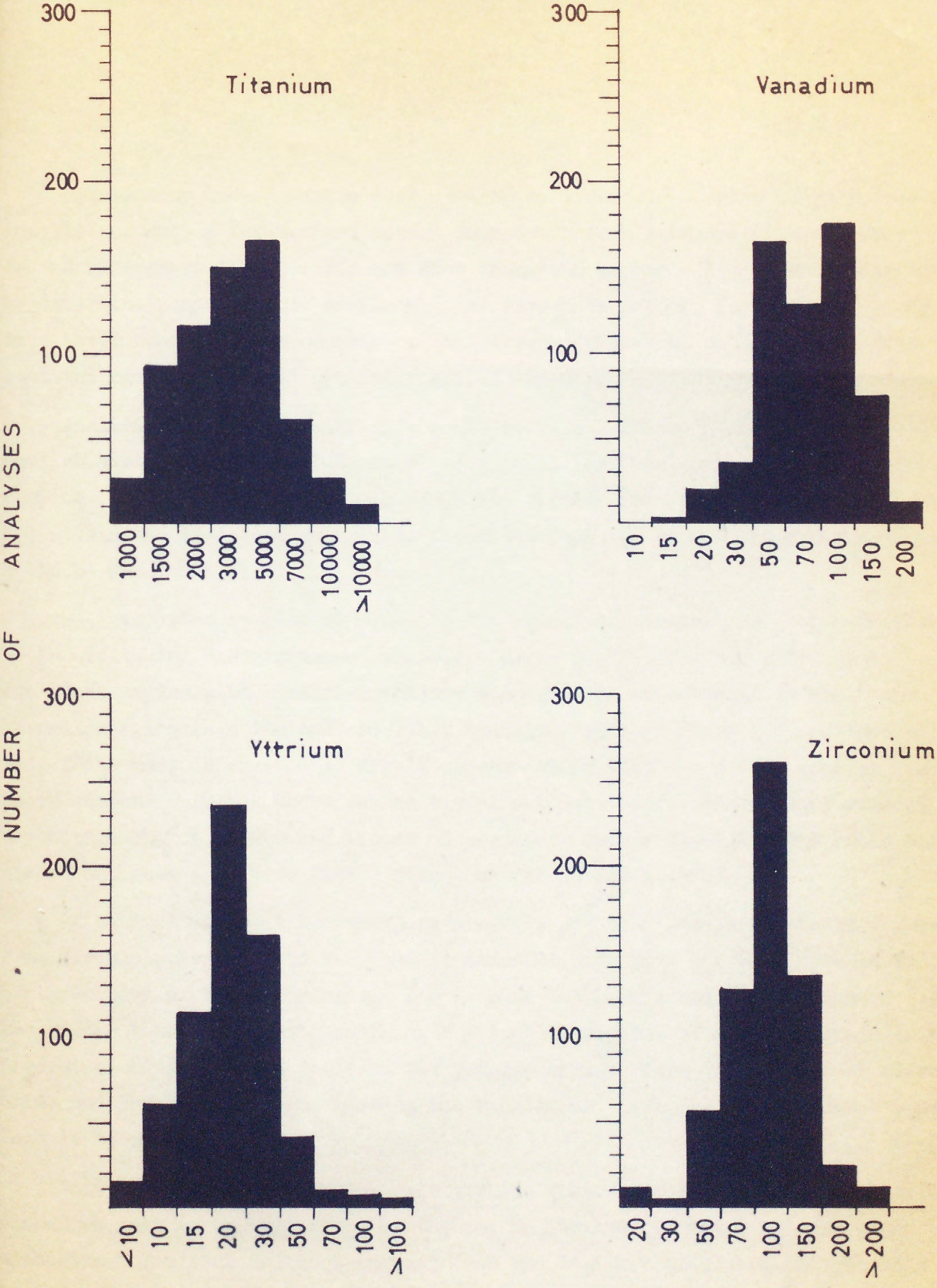


Figure 6. Histograms showing amounts of titanium, vanadium, yttrium, and zirconium in samples of wadi sediment.

Dilution by wadi alluvium must also be considered. Samples taken in two localities, each a few hundred meters downstream from outcrops with visible secondary copper minerals, did not show anomalous copper. It may be impossible to determine from a single sample whether anomalous copper, for example, is due to a small nearby copper deposit or to a larger deposit at some distance that contains enough copper to partially offset the effects of dilution.

Analytical error may also affect the results. Theobald and Thompson (1965) publish histograms showing the range of results in 39 determinations of a single sample. Nearly all of the anomalies in the samples from the Northwestern Hijaz are within the limits of analytical error although, of course, only a few anomalies could be due to this.

Most isolated samples with one or two anomalous elements are not considered in the following description of anomalous areas for the reasons cited above. Isolated samples with several anomalous elements are of possible interest and several samples in a limited area that contain a similar suite of anomalous elements are of the most interest. It should be emphasized that except for samples taken below ancient workings there was no visual evidence of the presence of mineral deposits. Sparse pyrite and traces of secondary copper minerals were noted in places but seemed to have little effect on the sample results.

An unusual array of 10 anomalous elements are contained in a single sample from a radioactive granite near the junction of Wadi Sadr and Wadi Sawawin in the northern part of the quadrangle. The granite has been examined by Shepherd (1966) who states that the granite contains a columbite deposit of marginal grade (0.4 percent niobium oxide). Parts of the granite contain more than 1 percent zirconium oxide and Shepherd suggests testing the wadi sands below the granite for a possible deposit of zircon.

Rock samples from the riebeckite granite that underlies Jabal Shar contain anomalous amounts of beryllium, lanthanum, molybdenum, niobium, yttrium, and zirconium. Two wadi sediment samples from the southern slopes of the mountain contain anomalous amounts of silver, manganese, molybdenum, and titanium; one contains anomalous copper and the other yttrium. Several samples taken east and northeast of the mountain contain anomalous copper (50 to 70 ppm) and molybdenum (5 to 7 ppm) and one contains 100 ppm of lead, one of the four highest leads in the quadrangle. The area from the west end of Jabal Shar east to Wadi Sulaysiyah should be sampled systematically and examined in more detail. Large northwest-trending faults cross the area (Johnson and Trent, 1966) and Hummel (oral communication, 1966) believes that faults with this trend are related to mineralization in the Northeast Hijaz. The northwest-trending Nejd Fault Zone is barren in the Northwest Hijaz but parallel faults on the northeast side, such as those near Jabal Shar, do show geochemical anomalies.

One of the most promising mineralized areas lies in the basin of Wadi Hayyan about 80 km north of Al Wajh. A ring-dike complex of gabbro and diorite containing small bodies of massive magnetite (see p.25) is cut by a northwest-trending fault. Traces of secondary copper minerals occur along the fault. Wadi sediment samples contain anomalous amounts of cobalt (50 to 70 ppm), chromium (300 ppm), molybdenum (5 ppm), titanium (10,000 ppm), vanadium (200 ppm), and zinc (300 to 500 ppm). All but the molybdenum and zinc could be related to the presence of gabbroic rocks and therefore are not significant, but the latter two could well be significant. The sample results together with visual evidence of hydrothermal activity indicate that the area between Wadi Hayyan and Wadi Jarasah should be examined in more detail.

Another area of possible interest lies southeast of Bi'r al Bayda' where wadi sediments from granitic and monzonitic terrane contain anomalous amounts of chromium (300 ppm), nickel (100 to 150 ppm), barium (1000 ppm), and strontium (700 to 1,000 ppm). The barium and strontium may be included in the feldspar lattice in the granite, but the presence of anomalous nickel in granitic rocks is unusual and may be significant.

The lack of anomalous elements in the Nejd Fault Zone is well illustrated in this same general area. The gneiss and schist of the Fault Zone underlie a northwest-trending belt whose width extends from Bi'r al Qurr to Wadi as Sirr. Sample density in the fault zone is comparable to that northeast of the zone but the scarcity of samples containing anomalous elements is clearly shown on figure 2.

A fairly large area that contains anomalous copper in samples of wadi sediment is located in the vicinity of the Shizam copper deposit 40 km southwest of Al 'Ula (no. 13 on fig.2). The anomalies are not large (50 to 70 ppm) but are constant. The Shizam deposit itself is not as impressive as the amount of slag derived from it. Samples contaminated by the slag are highly anomalous.

Samples from the area west and north of Qala'at as Sawrah (26°N.x 38°30'E.) contain anomalous zinc (300 ppm), molybdenum (10 ppm), and cobalt (70 ppm). Magnetite from the same samples and from others nearby contains from 1,000 to 2,500 ppm of zinc. Theobald and Thompson (1962, p. C72) believe that detrital magnetite with more than 1,000 ppm of zinc is probably derived from areas containing zinc deposits. Nearby marble deposits and two ancient gold workings also merit further study.

The significance of molybdenum in magnetite is not known but the anomalous amounts of molybdenum (40 to 150 ppm) found in several samples southeast of Qala'at as Sawrah may be of interest. Magnetite from two samples in the same area contain 1,000 ppm of zinc and two other wadi sediment samples contain anomalous lead (30 ppm). The only visible evidence of mineralization noted was at the sample locality at 26°N.x 38°45'E. where a rhyolite dike with sparse pyrite and adjacent apparently barren quartz veins crop out. The wadi sample at this locality contained beryllium (3 ppm), copper (70 ppm), molybdenum (7 ppm) and lead (30 ppm).

Samples from the area of ultramafic rocks west of Wadi al 'Ays in the south central part of the quadrangle contain high amounts of cobalt (50 ppm), chromium (700 to 7,000 ppm), and nickel (300 to 1,000 ppm). Only the highest of these could be considered significant anomalies and they are probably related to small pods of chromite that crop out in areas of peridotite. Copper anomalies (50 to 150 ppm) also occur in wadi samples from the ophiolite complex.

Samples with anomalous copper (50 to 70 ppm) are common east of Wadi al 'Ays. Most anomalous samples are from wadis that drain areas of Hadiyah Slate. Samples from wadis that drain areas of Halaban Andesite only rarely contain anomalous copper.

Wadis that drain the granite at Jabal Radwa were sampled in some detail (Johnson and Trent, 1965) as magnetite from the granite commonly contains from 1,000 to 1,500 ppm of zinc. A trace element suite was found similar to that in late alkalic granites (gp). No visible evidence of mineral deposits was seen and the significance of the high zinc in magnetite is not known.

Conclusions and recommendations

Iron formation, gypsum, and possibly chromite will probably be mined in the Northwestern Hijaz within a few years. The Wadi Sawawin iron deposits are of moderate size and low garde. The authors do not believe that the deposit will be developed commercially under present conditions but the rapidly changing technology in iron ore mining can make it attractive in the future. This opinion is not shared by others. Some mining engineers who have seen the deposit are even more pessimistic (Wendel, 1966), whereas geologists tend to be more optimistic. All agree that the deposits need further study and this is now being done.

The gypsum deposits along the Red Sea are also being evaluated. They will certainly be mined for local use if not for export.

Two lenses of chromite of about 5,000 tons each are reported by Kahr (1961). Additional studies have not disclosed any more large lenses but exploration is continuing. Even if no more is found one of the lenses may be mined when an internal market has developed. It is easily accessible and only requires blasting and loading into trucks. Small pods of chromite have been mined in California for use in local foundries, and with the continuing development of Saudi Arabia a similar market may develop.

The following areas should be studied in more detail. Surface indications of mineral deposits are unimpressive or lacking but the trace-element anomalies should be investigated.

A search for magnetite in the ring-dike structure of Wadi Hayyan and prospecting the surrounding area by means of a systematic geochemical survey seems to be the most promising investigation. An airborne magnetometer survey may indicate the presence of additional larger bodies of magnetite. This could be followed by ground magnetometer surveys as needed. A geochemical survey of the ring-dike area and the area to the east as far as Wadi Jarasah may indicate targets for additional work. Quartz veins should be examined. A rock sample from a quartz vein with limonite-filled cavities in Wadi Jarasah contained anomalous silver (15 ppm), beryllium (15 ppm), molybdenum (30 ppm), and lead (200 ppm).

A small mass of granite intruded into diorite at the north edge of the map at 35°50'E., is cut by numerous narrow quartz veins. Some veins, particularly near the contact between granite and diorite, contain copper minerals. The veins seen were too small to be of interest but additional work seems warranted.

A search for pegmatites on Jabal Shar is recommended. Some of the anomalous trace elements found in the granite could be concentrated in pegmatite minerals such as beryl, columbite, and zircon. The area surrounding Jabal Shar should be sampled systematically for a geochemical survey.

Systematic geochemical surveys are also recommended in the area of the Shizam copper deposit; the area west of Qala'at as Sawrah; and the area with anomalous copper east of Wadi al 'Ays. The limits of these surveys are indefinite but they should include the areas of anomalous samples shown on figure 2.

A regional study of the Jabal Radwa granite would be of interest to attempt to explain the presence of high zinc in the magnetite.

The deposit of glass sand described by Khalek (1963) was not visited by the writers but should be evaluated. A sample collected by Khalek contained 98.48 percent SiO_2.

Immediate results should not be expected from any of the above recommendations, but they could be considered as starting points for a continuing investigation of the mineral potential of the Northwestern Hijaz. As the work progresses additional areas of interest will probably be discovered.

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