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MINERAL DEPOSITS AND GEOLOGY OF NORTHERN OMAN AS OF 1974

By R. G. Coleman and E. H. Bailey

U. S. Geological Survey

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Prepared on behalf of the Directorate General of Petroleum and Minerals, Ministry of Development, Sultanate of Oman

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Frontispiece. Headquarters building of the Directorate of Petroleum and Minerals, Ministry of Development, Muscat, Sultanate of Oman.

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MINERAL DEPOSITS AND GEOLOGY OF NORTHERN OMAN AS OF 1974

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R. G. Coleman and E. H. Bailey

SUMMARY

An investigation of the mineral resources of northern Oman was carried out under an agreement between the U. S. Geological Survey and the Ministry of Development, Sultanate of Oman, during late 1973 and early 1974. The purpose of the investigation was to provide an evaluation of the mineral potential of northern Oman and produce recommendations leading toward the utilization of any viable mineral deposits that were found. The widespread copper deposits located within the Semail volcanics appear to be mineable, the iron-nickel laterites developed upon the weathered surface of the Semail ophiolite have economic potential. Manganese and chromite deposits investigated have only a marginal value and are not likely to be of economic importance in the near future. Discovery of economic copper and iron deposits warrants further geologic mapping and mineral exploration in northern Oman. In addition to this, recommendations regarding the organization of a geological and mining group within the Directorate of Petroleum and Minerals are presented.

INTRODUCTION

Negotiations for this investigation were initiated early in 1971 by the Government of Oman in discussions with the U. S. Department of State, and the final agreement was made in May 1973. The agreement provided that a U. S. Geological Survey team would carry out field investigations during the winter field season of 1973-1974 and would produce a written report within six months of the completion of the field work. This is the report so specified.

Staff

The U. S. Geological Survey team consisted of Dr. R. G. Coleman and Dr. E. H. Bailey. Dr. Coleman conducted the initial planning and logistics of the operation beginning early in 1973 while in Menlo Park, California. In late November 1973, Dr. Coleman arrived in Oman and remained there until the end of February 1974. Dr. Bailey reached Oman on January 15, 1974 and remained until February 23, 1974. The U.S.G.S. team spent 125 man-days in Oman with 90 man-days in the field. Writing, typing, drafting, and chemical analyses for the final report entailed at least another 100 man-days during the period May-July 1974. Dr. G. F. Brown of the U.S.G.S. also contributed considerable time to the early phases of planning and organizing the Oman Project. Our field work was facilitated by assistance given to us by Mr. Mohammed Kasim of the Directorate of Petroleum and Minerals, and by Dr. Ismail El Boushi, Geologic Advisor to the Directorate.

Methods of Investigation and Logistics

To assess the mineral potential of Oman it was necessary to investigate the known ore occurrences and to also search for unrecorded deposits. In addition, time had to be spent doing reconnaissance mapping to learn the geologic relations where mineral deposits were known in order to appraise what other areas were also favorable for the discovery of new deposits. The most expeditious way to do this was to work out of field camps, examining known deposits, mapping the terrain within a limited distance from each camp, and inquiring of the local inhabitants and wali's about the occurrence of ancient mines or slag piles. We were assisted by Mr. Salim Makki, Director General of Petroleum and Minerals, in these contacts with the local wali's and the Omani people. These contacts provided valuable information regarding sites of ancient mines and possible areas of mineral deposits.

The Directorate provided us with three Land Rover vehicles (two station wagons and one pick-up), a driver-interpreter, a cook, and a watchman (photo 1). Most of our camping equipment was sent to Oman by the U.S.G.S.; however, some essential items were loaned to us by the Directorate. In making our field examinations approximately

Photo 1. Land Rover caravan of U.S.G.S. team near Yangul, Oman.

8000 km (5000 miles) were covered by Land Rover traverse, and although no mileage figure was kept of traverses on foot, the distance probably was in excess of 160 km (100 miles). In addition, we had approximately four hours of helicopter time through the courtesy of Prospection Limited.

Two series of maps that cover Oman were available, one at 1:500,000 and the other at 1:100,000, printed and distributed by the Ministry of Defense, United Kingdom. We also were provided with approximately 1000 RAF* aerial photographs (1:60,000) of the Oman Mountains through the Directorate of Military Surveys, Ministry of Defense, United Kingdom. Our field observations were recorded on 1:60,000 RAF photos, 1:100,000 maps, and on larger scale sketch maps we made ourselves. Rock and ore samples were collected from selected areas, and some of these materials were chemically analyzed in order to ascertain the amount of economic metals contained. Basic to such an investigation is the acquisition of as much data as possible from previous geologic studies. In this we were particularly fortunate to have had the full cooperation of the Petroleum Development Company (OMAN) Ltd. (PDO), which has done most of the geologic mapping in Oman. Their maps were made available to us during our investigations.

Acknowledgements

We are indebted to Mr. Salim Makki, Director General of Petroleum and Minerals, for the support and cooperation he freely provided. Dr. Rudy Jackli, General Manager, PDO, generously provided us with much valuable unpublished geologic and geophysical data, and other members of the PDO staff also helped with our geologic work on numerous occasions. Mr. C. C. Huston and Mr. Alan Hutchinson of Prospection Limited kindly provided us with information on their operation as well as a copy of their 1973 field investigations report. Mr. C. J. Quinlan and Mr. Fred McEldowney of the American Embassy in Muscat were a great help to us in establishing our field project in Oman. Mr. J.S. Townsend, Economic Advisor to the Oman Government, provided encouragement and also greatly facilitated our operation in Oman.

GEOGRAPHY

The area covered in this agreement is wholly within northern Oman and extends from Ras Al Hadd to the southern border of the Union of Arab Emirates, an area of about 41,000 sq. km (16,000 sq. miles). Most of the area is within the Oman Mountains, which form a crescent shaped range extending 600 km (360 mil) parallel to the coast from Muscat to the northern tip of the Musandam Peninsula. Northwest of Muscat, a narrow coastal plain 10-40 km (6-24 miles) wide, known as the Batinah, separates the mountains from the Gulf of Oman, but to the east of Muscat the coastal plain disappears and farther southeastward to Ras Al Hadd the coast is rugged and steep with some parts drowned to form an intricate shoreline. The Oman Mountains form a barrier between the Batinah coast and the western interior of Oman. The

* Royal Air Force

highest part is in the mid-section of the mountains at Jabal Akhdar, which rises to 2980 meters (9800 feet). Northward from Jabal Akhdar the mountains become subdued, and in the United Emirates section the average elevation in the mountains is less than 900 meters (2970 feet). Continuing northward to the Musandam Peninsula the elevations rise to over 2000 meters (6600 feet) at Ruus Al Jibal. South of Jabal Akhdar the mountain range is cleft by the Semail Gap providing a natural passageway across the Oman Mountains. The mountains to the south (Al Hajar Ash Shargi) are extremely rugged with many elevations in excess of 2000 meters (6600 feet).

The Oman Mountains are dissected by numerous wadies that form deep canyons cutting into the core of the mountain range. The wadies flowing northeastward into the Gulf of Oman are steeper than those wadies flowing south into the great interior basin (Umm as Samim) at the edge of the empty quarter (Rub Al Khali) and have locally advanced their headwaters southwestward beyond the crest of the range. The southwestern foothills of the Oman Mountains are marked by an almost continuous pediment that forms extensive gravel plains cut only locally by southwestern flowing wadies. South and east of the Oman Mountains the Wahiba sands cover the southwestern slope and only a narrow plain separates the mountains from the migrating sand dunes.

The positions of the main road systems of Oman are strongly influenced by the physiography. Along the Coastal Plain a new paved road extends northward from Muscat to Sohar allowing easy access to all coastal towns, but south of Muscat there is no coastal road nor is there any road crossing the Al Hajar Ash Shargi. The main access road to the interior is a graded gravel road across the mountains at Semail Gap. North of the Semail Gap road only two poor roads cross the Oman Mountains: 1) Wadi Jizzi from Sohar to Buraimi; 2) Wadies Zallah and Hawasina from Al Khabura to Ibri. The inaccessibility of much of the Oman Mountains by road makes geologic work time consuming when carried out by Land Rover and foot traverses, and access is particularly difficult on the northeastern slope of the Oman Mountains where incised wadies produce deep canyons that cannot be traversed by Land Rover. Because the accessibility of many parts of the Oman Mountains is so difficult, large areas remain unexplored geologically, and this fact should be taken into account when making an evaluation of their mineral potential.

The most important copper district of northern Oman has been called the "Bowling Alley" by Prospection Ltd. (see photo 3 and figure 6) as it forms a narrow corridor (3 km x 17 km) on the east side of the Oman mountains approximately 32 km due east of Sohar.

GEOLOGY

Previous Work

Geologic studies of northern Oman have been directed mainly toward the search for petroleum and reflect that influence. As a proper background for this report a short review of previous work is presented. The earliest geologic report on Oman was made by Pilgrim (1908) as part of a larger study of the Persian Gulf area for the Geological Survey of India. Pilgrim's report was mostly descriptive and provided few details. During the winter field season of 1924-1925, G. M. Lees (1928a) carried out an extensive exploration of northern Oman and the southeastern coast, and his observations form the basis for some of the stratigraphic nomenclature now used. Nearly 25 years later, increased interest in the petroleum potential of the Arabian peninsula brought forth a series of summary papers on Oman geology: Hudson, Browne and Chatton (1954), Hudson, McGugan, and Morton (1954), Morton (1959), Hudson and Chatton (1959), Hudson (1960), and Tschopp (1967a). Much of this data was a distillation of work carried out by oil companies, and very little basic data was published. The first published geologic map of Oman, at the scale of 1:2,000,000 resulted from a joint effort of the U. S. Geological Survey and Arabian American Oil Company (1963).

More recently Shell Research N.V., The Hague, and the Petroleum Development (Oman) Ltd. have carried out extensive geological studies of Oman, and summary reports have been published by Wilson (1969), Glennie and others (1973), and Reinhardt (1969). A summary detailed report, including a geological map (1:500,000) of northern Oman will be published in the near future (Glennie and others, 1974, Konink. Nederlandsch Geol. Mijnboukundig Genootschap Verh.). Besides these reports on Oman generated by PDO, a few other publications: that also discuss the geology of the Oman Mountains are Moseley (1969), Allemann and Peters (1972), Greenwood and Loney (1968), and Beydoun (1964). The mineral resources of the Oman Mountains are considered only in the published report by Greenwood and Loney (1968); however, PDO has an unpublished report on mineral resources of Oman that was an outgrowth of their geologic studies. Figure 1 shows the areas covered by geologic mapping in Oman, along with mapping we propose.

Considerable unpublished geophysical work that has been done in Oman is summarized in figures 2 and 3. All the geophysical information was obtained from PDO, who collated and synthesized the results to delineate subsurface structures favorable for the accumulation of petroleum. Release of this data could, however, provide information of value in understanding the geologic history of Oman.

As mentioned earlier the only modern prospecting for metallic and non-metallic deposits prior to 1971 was that carried out rather incidentally by the PDO team that mapped the Oman Mountains in 1963-1969. These data were made available to us, but were not generally encouraging regarding the mineral potential. Beginning

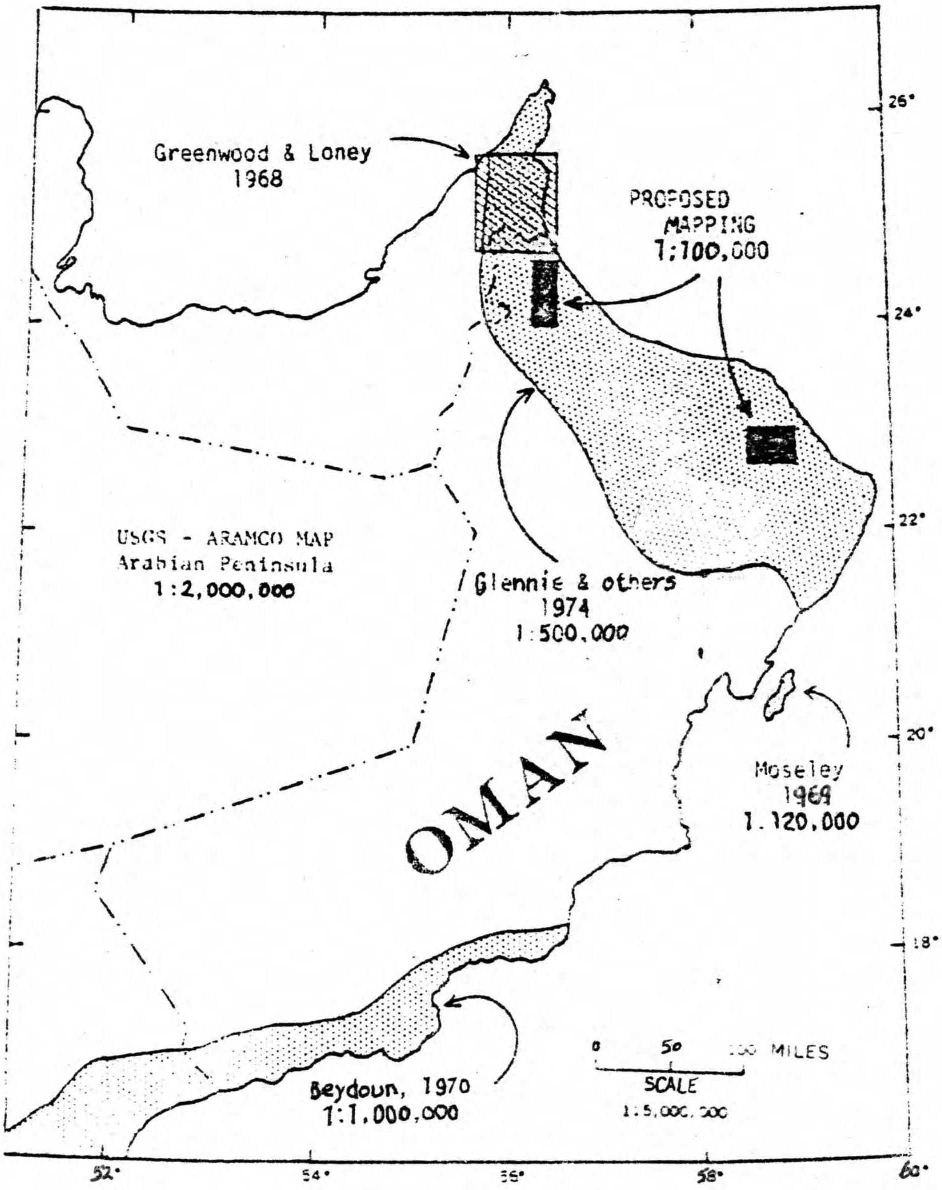

Figure 1. Map of Oman showing by dotted pattern status of published geologic maps by 1974, and by solid pattern, the proposed mapping.

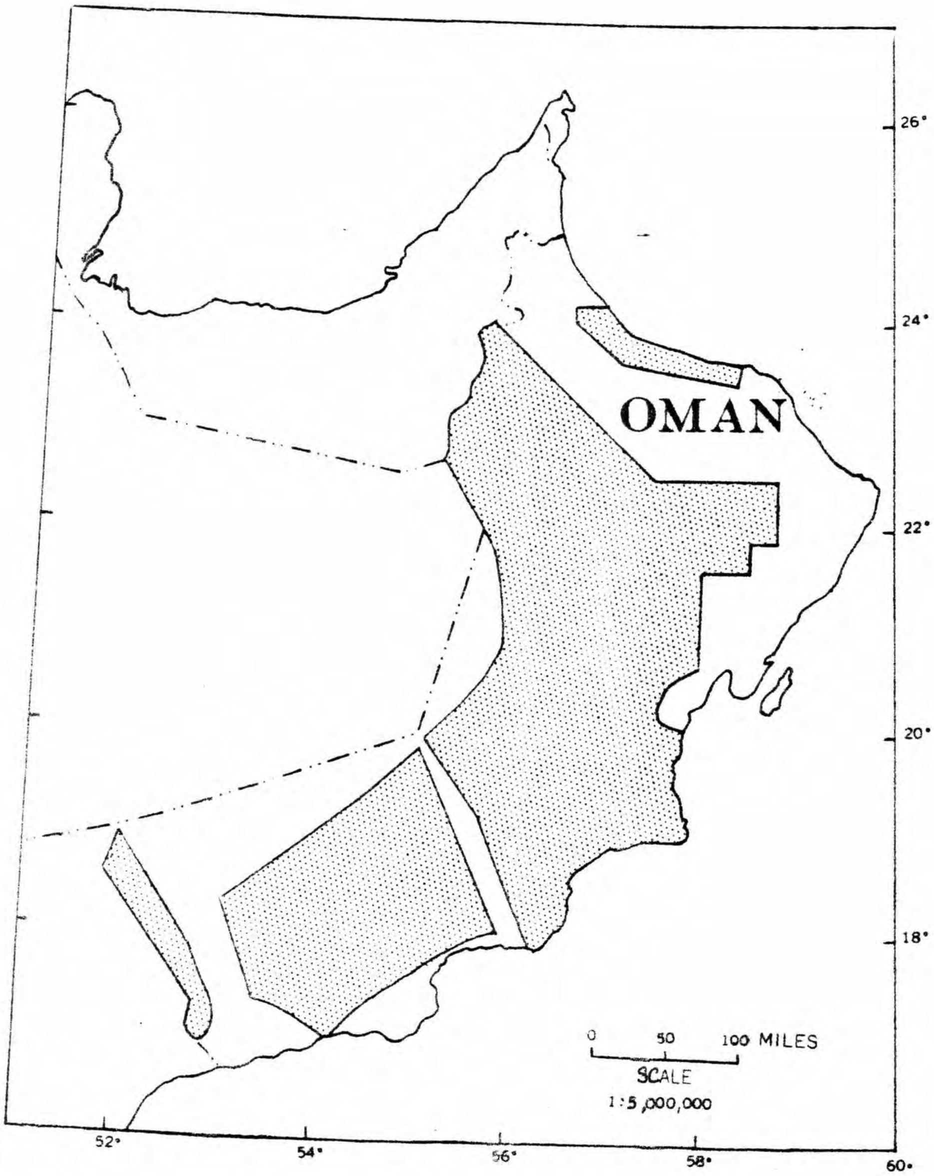

Figure 2. Map of Oman showing by dotted pattern area covered by gravity surveys through 1973.

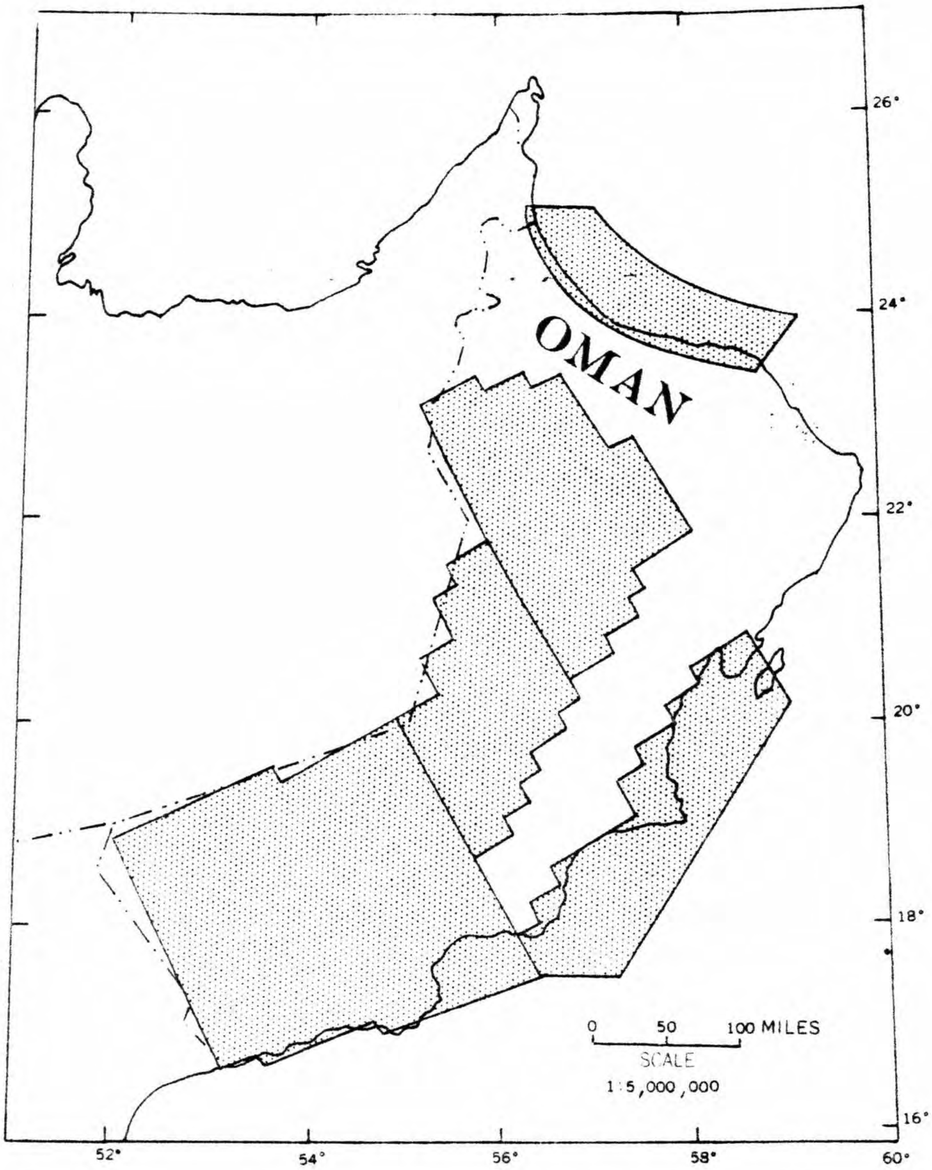

Figure 3. Map of Oman showing by dotted pattern area covered by aeromagnetic surveys through 1973.

in 1972, much more serious prospecting for minerals was begun by the Canadian firm of Prospection Limited under an agreement with the Sultanate of Oman. The area covered by this agreement was confined to the Oman Mountains, and this Prospection team has done geological and geochemical reconnaisance in a highly efficient manner over much of the area. By the beginning of 1974, Prospection Limited had focussed on a zone of gossans related to copper-bearing massive sulfide deposits they discovered in the Wadi Jizzi area, and during our examination in early 1974 they were chiefly drilling and doing geophysics in order to determine the extent and grade of these deposits. A summary report of Prospection Limited's field investigations for the period March to June 1973 of concession area no. 1 was made available to us on July 1, 1974, too late to allow incorporation of their data in this report.

Geologic Overview

The geologic framework of northern Oman can best be understood by dividing the rock units into three main groups: (I) The basement autochthonous rocks, represented by Paleozoic and possibly Precambrian meta-sedimentary and meta-igneous rocks overlain by a thick sequence of shallow water shelf carbonates, which characterize most of the eastern part of the Arabian Peninsula. (II) The Semail ophiolite, a thick sequence of ultramafic and mafic rocks thought to represent ancient oceanic lithosphere, and the Hawasina unit of deep water chert, shales, and limestone. These are allochthonous rock units that were emplaced by low angle thrusting or gravity sliding and now rest above the Arabian Shelf carbonates. Emplacement of the Hawasina and Semail ophiolite has produced chaotic masses of mélange containing huge exotic blocks of Permian limestone. Metamorphic zones were formed at the base of the Semail ophiolite at the beginning of emplacement. (III) Thick shallow-water marine limestones of Late Cretaceous to middle Tertiary age deposited directly on top of both the allochthonous and authochthonous rock units.

All of these units have been involved in middle Tertiary folding and late Tertiary normal faulting. Recent uplift along the axis of the Oman Mountains brought about active erosion and is responsible for the present configuration.

Within the short period of three months devoted chiefly to the search for mineral deposits in an area of approximately 41,000 sq. km (16,000 sq. mi.) it was not possible for us to generate much new geologic data. However, to provide background for the discussion of the mineral deposits in this report, a brief summary of the major rock units that make up the Oman Mountains, along with an explanation of the structure, follows.

Basement Rocks (Autochthon)

Pre-Permian Rocks

Within the Oman Mountains low-grade metamorphic rocks are exposed in erosional window at Jabal Akhdar, Sayah Hatat, and Jabal Ja'alan. These rocks can be divided roughly into carbonate sedimentary rocks and fine-grained clastic sediments with minor amounts of volcanic rocks. All have undergone greenschist facies metamorphism and show at least two periods of deformation. Within the Sayah Hatat, numerous quartz reefs have developed in the metasediments; however, as shown by the analyses included in Table 12 in the appendix, these do not contain economic concentrations of metals. There are no cross-cutting leucocratic intrusions within this series, and the only geologic event that could have produced mineral concentrations was the metamorphic event dated at 327 m.y. by PDO.

Arabian Shelf Carbonates (Permian to Cretaceous autochthonous rocks)

Resting unconformably on the folded and metamorphosed Pre-Permian basement are the Arabian Shelf carbonates, see photo 2. The rocks consist mainly of limestone, dolomite, and mudstone whose fossils indicate shallow water deposition. Near the top of the autochthonous section the Late Cretaceous Muti Formation is made up of marl, shale, lenses of limestone, conglomerate, and sandstone flysch. The total thickness of this section is approximately 2700 meters. These rocks represent the source beds and traps that contain most of the petroleum in Oman; however, they are not known to contain metallic mineral deposits. The pure limestones in the section afford an almost unlimited supply for the manufacture of cement.

Ophiolite and Related Rocks (Allochthon)

Semail ophiolite

Economically the most important rock unit in the Oman Mountains is the Semail ophiolite, because nearly all of the ore deposits are associated with it. We consider the ophiolite to be ancient oceanic crust which has been thrust over the Hawasina, and we accept the hypothesis of Reinhardt (1969) that it formed at a spreading center within the Tethyan sea during Mesozoic time. The Semail is a classic example of ophiolite, perhaps containing 30,000 cu. km, and offers the most extensive exposure of this kind of rock to be found anywhere in the world (photo 3).

The ophiolite is divided from base to top into the following major rock units: (1) Peridotite, containing rocks composed chiefly of olivine, orthopyroxene, and clinopyroxene. It crystallized in the upper mantle, and now forms the thickest and most widespread part of the ophiolite, see photo 4. Parts of the peridotite, particularly near its base, have been converted to serpentinite by hydration;

Photo 2. Folded flanks of Jabal Akhdar north of Izki. Thick section of autochthonous Arabian Shelf carbonate rocks forming dip slope in background. Hawasina red cherts and gray limestones form mélange within ridge of the foreground.

Photo 3. Hawasina mélange containing exotic blocks of Permian-Triassic reefal limestone in middle distance. Exposure is within "Bowling Alley" a few kilometers north of Wadi Jizzi. Cloud-covered hills in the background are composed of Semail ophiolites.

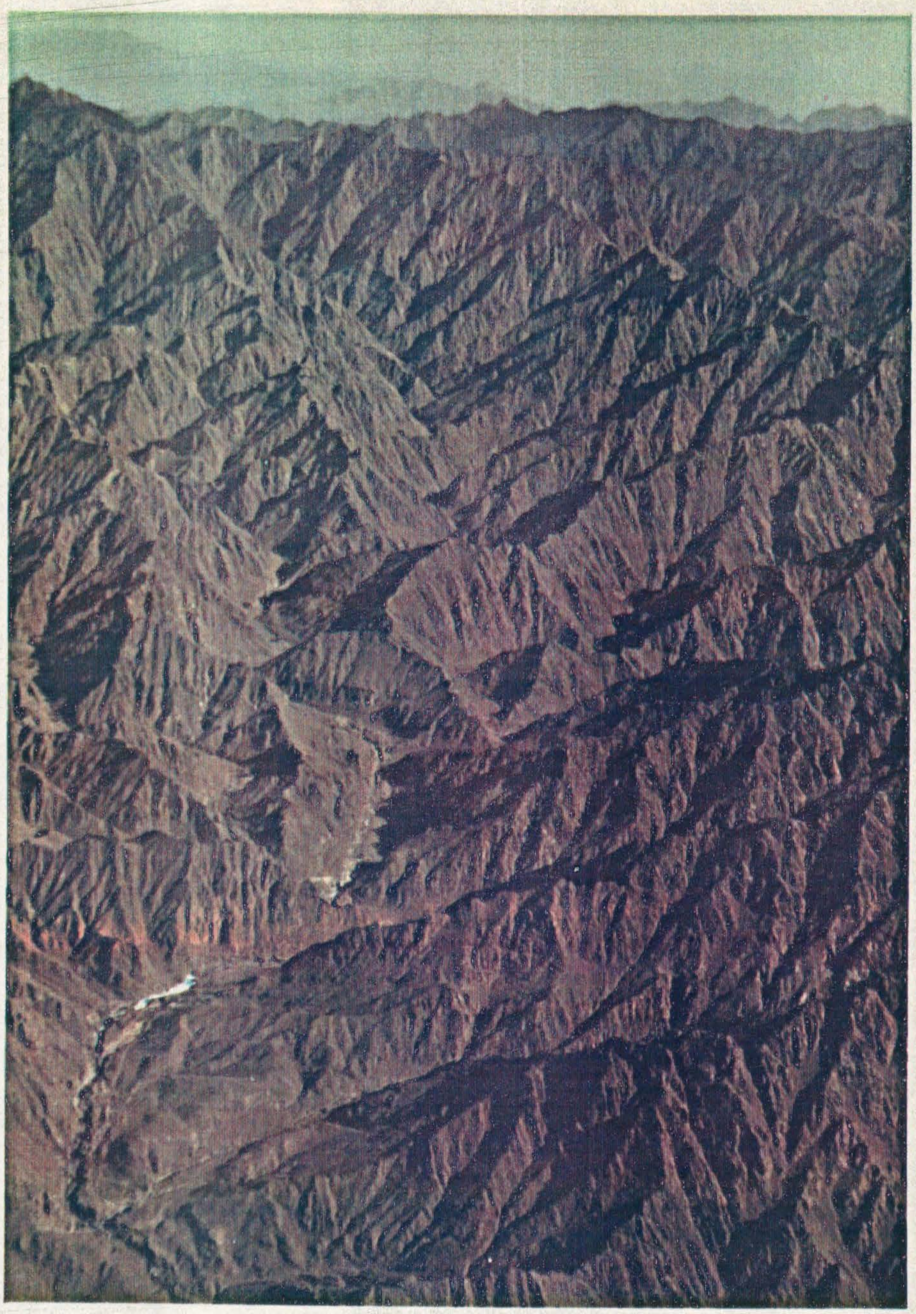

Photo 4. Typical exposure of Semail peridotites in the mountainous part of northern Oman. Area of white and blue along wadi is typical calcium hydroxide spring with accompanying travertine apron.

(2) Gabbro, which is coarse to medium grained and consists of the minerals of the peridotite plus plagioclase and hornblende. It crystallized in shallow magma chambers above the peridotite, and because of crystal settling may be strongly layered, see photo 5; (3) Diabase, with the same minerals as the gabbro but a medium grained texture. Most of the diabase crystallized as dikes formed by magma injection into fractures repeatedly opened at an active spreading oceanic rift zone. The resulting unit, commonly referred to as a sheeted complex, consists of nearly parallel dikes with little or no intervening country rock, see photo 6. Diabase also occurs as dikes in the upper part of the gabbro and in lava that overlies the sheeted complex; (4) Plagiogranites, consisting of coarse to medium-grained quartz, plagioclase, and hornblende rocks, crystallized as small intrusives in the upper parts of the gabbro or within the sheeted complex; (5) Basalt, a fine-grained or aphanitic rock of gray to black color, occurs as a thick uppermost unit in the ophiolite. It represents voluminous and repeated submarine extrusion of mafic lava at the spreading rift zone, and much of it exhibits pillow structure, see photo 7. This thick pile of igneous rocks, therefore, developed at the spreading center within the ancient Tethyan sea prior to the thrusting of the Semail ophiolite upon the Hawasina. During emplacement, imbricate thrusting, folding, and overturning resulted in complicating the structure and introducing local repetitions of parts of the sequence.

Massive sulfide copper deposits are present within the pillow basalts and diabase of the ophiolite sequence, and copper mineralization also occurs along high-angle thrust faults and normal faults in the gabbro and peridotite. Chromite deposits are present within the peridotite and most often are concentrated in dunite. Asbestos developed locally in parts of the peridotite during late stage serpentinization. Widespread weathering of the exposed surface of the Semail ophiolite in early Tertiary time produced extensive laterites that are rich in Fe, Ni, and Cr.

Hawasina unit, exotics, mélange, and metamorphics (Permian to mid-Cretaceous.

The Hawasina includes a series of six tectonically-bounded units, each of which contains rocks which range in age from Jurassic to mid-Cretaceous. The individual tectonic units range from 60 to 900 meters (198 to 2970 feet) with a total tectonic thickness of 1900 meters (8910 feet). The lower units of the Hawasina are mainly lithoclastic limestones and quartz sand turbidites. Thin-bedded red cherts with shales predominate in the upper sections, and pillow lavas are commonly interbedded with them. The environments indicated by the lithology and faunas of the Hawasina allochthonous units suggest transgression from shallow to deep water, seemingly contemporaneous with the shelf carbonates of the autochthon. Deep ocean sedimentation below the carbonate

Photo 5. Layered gabbro within Semail ophiolite exposed along Wadi Jizzi. Light bands consist mostly of plagioclase and dark bands contain abundant olivine and pyroxene.

Photo 6. Diabase dike swarm in Semail ophiolite near Ibra illustrating result of repeated injection of magma along parallel fractures forming a series of dikes with no intervening country rock. At the time of injection the dikes doubtless were nearly vertical.

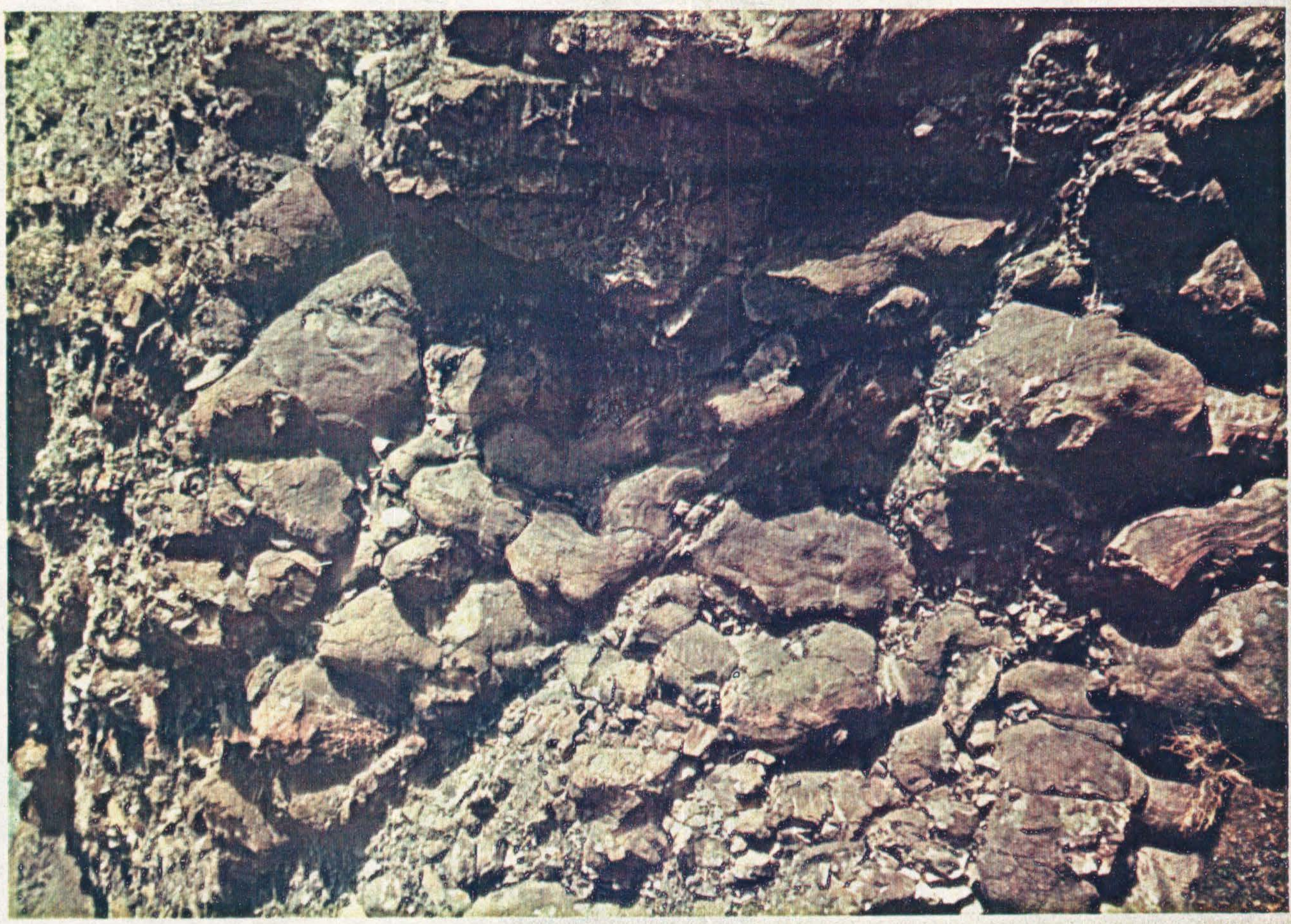

Photo 7. Pillow lavas from the upper part of the Semail ophiolite. Many of the best copper deposits are concentrated in similar layers of pillow lava.

compensation level is indicated by manganese ore beds occurring locally with the cherts. No mineralization has been detected within the volcanics interlayered between the cherts.

In the highest structural units of the Hawasina occur isolated exotic blocks of white recrystallized reefal limestones (Permian-Triassic), ranging in size from small isolated hills to large mountains resting on, or in, a mélange, see photo 3. The mélange itself consists of a tectonic mixture of Hawasina chert, shale, limestone and locally serpentine and amphibolite. Both the mélange and exotic blocks are considered to result from the tectonic emplacement of Semail ophiolite on top of the highest units of the Hawasina. Extensive mineral deposits are not expected to occur within the mélange, although silica-carbonate rock related to the low-angle thrusts was observed in two places. This silica-carbonate rock shows that some hydrothermal alteration was developed during thrusting or perhaps shortly thereafter.

Sedimentary Rocks Lying On Semail Ophiolite

Shallow-water marine limestone (Late Cretaceous to Middle Tertiary).

During the Late Cretaceous (Maestrichtian) both the autochthonous Mesozoic carbonates and the allochthonous Hawasina and Semail ophiolite were covered by a transgressive sea that deposited limestone and marl. These limestones characteristically contain rudists and orbitoid Foraminifera in the Late Cretaceous deposits and alveolinid and nummulitid Foraminifera in the Lower Tertiary deposits. They attain thicknesses up to 2500 m (8250 ft) in the eastern Oman Mountains, and thicknesses up to 2000 m (6600 ft) are found west of the northern Oman mountains. They provide a virtually unlimited supply of nearly pure limestone that could be utilized for the manufacture of cement or other industrial products where an unusually pure limestone is required. Miocene rocks resting on top of these marine limestones in the vicinity of Sur are reported to contain coal.

Pliocene-Holocene deposits.

Beginning in the Oligocene or early Miocene the eastern Arabian continental margin was deformed. This resulted in folding and uplift of the Oman Mountains, causing erosion and deposition of extensive alluvial deposits on their northern and southern flanks. To the south these deposits filled the large interior basin centered around Umm as Samim, and to the north much of the alluvium deposited on the Batinah coastal plain was derived in this period of erosion. Information from drill sites 222 and 223 of the Glomar Challenger located near the east coast of Oman indicates that during the middle Miocene greatly accelerated sedimentation rates coincide with the uplift and deformation of the Oman Mountains (Whitmarsh and others, 1974). Detrital minerals characteristic of the Oman ophiolites were found in these offshore sediments.

Recent tectonic movements have arched the Oman Mountains, rejuvenating particularly the streams flowing northward. These down-cutting streams have produced interfluve terraces containing many boulders of peridotite and gabbro. Such terraces are very resistant to erosion because they are generally cemented by calcium carbonate, and characteristically canyons cut into them develop unusually steep walls. Placer deposits of chromite may possibly exist within these sediments, and reworking along the coastlines could perhaps develop black sand deposits. It is also possible that evaporite deposits containing Li or K salts may be concentrated within the large interior playa of Umm as Samin.

Structural History

The Oman Mountains reveal five major tectonic events that can be tied to their geologic evolution: 1) Metamorphism and folding along N-S axis is recorded within the Pre-Permian basement rocks of the Sayah Hatat and Jabal Akhdar windows. K-Ar ages of 327 m.y. indicate that this event was late Paleozoic and not Precambrian. 2) The late Paleozoic breakup of Pangaea into Gondwanaland and Eurasia created the Hawasina ocean (Tethys), and the production of the Semail ophiolite at a spreading ridge within this ocean. The Arabian Peninsula is considered to have drifted southward with Gondwanaland, and during the period from late Paleozoic to late Mesozoic shelf carbonates of the autochthon were deposited along the east margin of the Arabian shield and deep water chert and limestone of the Hawasina formed in the sea northeast of the present coast line. 3) During the Campanian, the Hawasina sea began to close as the Afro-Arabian continent moved towards Eurasia, and parts of the Hawasina and Semail ophiolite moved southwestward over the Arabian shelf carbonates. This emplacement was accompanied by gentle folding and imbricate thrusting within both the Hawasina and Semail ophiolite. Metamorphics (85 m.y.) developed at the base of the Semail ophiolite, and during the final emplacement, mélange zones developed under the Semail ophiolite. 4) During the middle Miocene, uplift and folding of the Oman Mountains formed the N- to NW-trending fold belt that is characterized by the huge antiforms of Jabal Akhdar, Sayah Hatat, and Musandam Peninsula. The middle Miocene folding further complicated the internal structures of the ophiolite and perhaps also produced some gravity sliding away from the crests of the antiforms. 5) After middle Miocene, normal faults striking NE and NW have cut the northwesterly trending mountains. Within the Batinah coastal plain and offshore, normal faults parallel to the coast have dropped the Tertiary and Mesozoic sediments downward to the north into the Gulf of Oman. During recent times the middle portion of the Oman Mountains from Fujaira southward to the Semail Gap has been gently arched. This uplift rejuvenated the north-flowing streams whose increased sedimentary load soon covered most of the block faults along the Batinah coast. During this period of arching in the midsection of the Oman Mountains, the Musandam Peninsula sank nearly 300 meters (1000 ft) forming its characteristic drowned topography. Less intense subsidence is also recorded along the north Oman coast from Muscat southward to Ras al Hadd.

In general, in this structural interpretation, we agree with the geologic interpretation of Glennie and others (1973), even though some seem to strongly oppose their views (Wilson, 1973; Moody, 1974). Much contrary discussion involves stratigraphic paleontology and is beyond the scope of our studies. The crux of the controversy regarding the geologic history is whether the Semail ophiolite and the Hawasina rocks are in normal stratigraphic sequence or whether they are separate thrust sheets (nappes) now imbricated on top of the carbonates that make up the Arabian platform. Morton (1959), Tschopp (1967a), Wilson (1969, 1973) and Moody (1974) all have stated that the Hawasina Series and Semail ophiolite are autochthonous (remain at site of their origin) and of Late Cretaceous age. Furthermore, they visualize that the Semail ophiolite has formed as huge extrusions of mafic lava _in situ_. Contrary to this, Glennie and others (1973) and Lees (1928a) visualize that the Hawasina rocks represent deep water deposits formed contemporaneously with the Arabian Shelf carbonates but deposited within an ocean situated along the axis of the present Gulf of Oman. At the same time, new oceanic crust constituting the Semail ophiolite was being formed at a spreading ridge within the ocean. During the Late Cretaceous southwesterly directed over-thrusting of the Hawasina and Semail ophiolite onto the Arabian continental margin produced the present imbrication. As the Semail ophiolite contains most of the potential ore deposits within the Oman Mountains, the present geologic distribution of its component rocks, and perhaps the faults within them, is of overriding economic concern.

ECONOMIC GEOLOGY--METALLIC MINERALS

Summary

The following section of this report describes in some detail all the metallic mineral deposits we were able to locate in Oman. Some were listed in the reports of the PDO, many were also found by Prospection Ltd., who made a search similar to ours, and some are located and described here for the first time. Each deposit is plotted and numbered on the 1:500,000-scale mosaic map accompanying this report, figure 4, and a listing of deposits is included as table 1. In the table the deposits are numbered as on the map and also located by reference to the UTM* grid zone printed on the scale 1:100,000 British military sheets and on the ERTS** mosaic (fig. 4). Every deposit is described and evaluated in the text in the order of numbering. Following the name of the deposit, we list the grid locations and the title of the 1:100,000-scale sheet of the Ministry of Defense, United Kingdom, where the deposit can be located. Especially significant analytical data is given in the text with the mine descriptions, and supplementary chemical and spectrographic analyses are included as an appendix.

The 41 metallic deposits discussed include 29 copper, five iron, three chromite, three manganese, and one lead-zinc deposit. Some of the copper deposits that have already been drilled by Prospection Ltd. are known to be mineable, and others may prove to be viable. The iron deposits could be of great importance, but more study is needed to evaluate them. The known chromite deposits are noneconomic, the manganese has potential only for limited small-scale mining, and the lead-zinc deposit is not mineable.

Metallic mineral deposits were found throughout northern Oman from the Fujayrah border on the northwest to the vicinity of Ras al Hadd at the eastern extremity. Most of those discovered are near the borders of the mountains, perhaps partly indicating less search in the areas of more difficult access. Geologically, all of the copper, chromite, and lead deposits are in the Semail ophiolite, and the most promising iron deposits are in the laterite developed on the ophiolite. Manganese occurs with chert in the allochthonous Hawasina formation. The large expanses of underlying autochthonous rocks exposed chiefly in Jabal Akhdar, Jabal Aswad, and Sayah Hatat are not known to contain mineral deposits, but they have also been much less thoroughly examined. The post-Cretaceous marine sedimentary rocks and the younger alluvial sediments are unmineralized, and also little examined. The young gravels doubtless in some places blanket ore deposits, and more careful mapping, geochemical, and geophysical work is needed for the discovery of these covered deposits.

Our investigation, combined with that of Prospection Ltd. has demonstrated that there are mineable metallic mineral deposits, chiefly copper, in northern Oman. There is no doubt that further

* Universal transverse mercator
** Earth Resources Technology Satellite

Table 1. List of deposits investigated in northern Oman

No.	Name	Grid Location 1/	Evaluation 2/	Host Rock	Type of Deposit	Former Activity
				Copper Deposits		
1	Semda	DC 418 193	+	Basalt - diabase	Pipe - Gossan	Pits - Slag
2	Lushil	DC 404 115	-	Basalt - diabase	Pipe - Gossan	
3	Zabin	DC 358 098	-	Basalt	Lenses - Gossan	
4	Fizh	DC 345 068	-	Basalt	Lenses - Gossan	
5	Khabiyat	DC 397 013	-	Basalt	Gossan	
6	Bayda	DB 408 939	±	Basalt	Pipe - Gossan	Cuts - Shaft
7	Aaria	DB 402 925	+	Basalt	Pipe - Gossan	Cuts - Slag
8	Ghayth	DB 428 905	±	Basalt	Lens - Gossan	
9	Lasail	DB 422 843	+	Basalt	Pipe - Gossan	Slag
10	Jabah	FB 247 002	-	Tuff	Bed	
11	Rakah	DB 570 182	+	Basalt	Stockwork - Gossan	Shaft - Slag
12	Maydan I	DB 390 334	-	Gabbro - Peridotite	Vein Zone	Slag
13	Maydan II	DB 380 343	-	Gabbro - Peridotite	Vein Zone	Slag
14	Bu Kathir	DB 374 149	-	Gabbro - Peridotite	Vein Zone	Cuts - Slag
15	Hawirdit	DB 384 169	-	Peridotite	Veins	Cuts - Slag
16	Tawi Ubaylah	DB 147 776	±	Gabbro - Peridodite	Vein Zone - Gossan	Cuts - Slag
17	Ghayl	DB 042 788	-	Gabbro - Peridotite	Veins	Cuts - Slag
18	Muden	EA 513 955	-	Diabase - Gabbro	Vein Zone	
19	Luzak	FA 155 782	-	Gabbro	Veins	Slag
20	Tabakhat	EA 480 340	-	Peridotite	Veins	Adits - Mine
21	Khafifah	FA 464 320	-	Gabbro	?	Slag
22	Masakivah	FA 454 125	-	Gabbro	Veins	
23	Inah	FA 700 337	-	Peridotite	Veins	Adits - Slag
24	Eedah I	FA 173 446	-	Gabbro	Veins	Slag
25	Eedah II	FA 171 439	-	Gabbro	?	Slag
26	Hoowasi	FA 090 378	-	Peridotite	Veins	Cut - Slag
27	Khara	FA 772 108	-	Peridotite	Vein Zone	Cuts - Slag
28	Zahir	FY 866 986	-	Gabbro	Vein Zone - Gossan	Cuts - Slag
29	Shwayi	FA 075 188	±	Gabbro	Stockwork - Gossan	Cut - Slag

1/ Refers to coordinates used on 1:100,000 maps of Ministry of Defense, United Kingdom, and on fig. 4, this report

2/ + Probably useable

± Possibly useable

- Not useful

Table 1. List of deposits investigated in northern Oman--Continued

No.	Name	Grid Location [1]	Evaluation [2]	Host Rock	Type of Deposit	Former Activity
				Iron Deposits		
30	Kalahay Niba I	FA 597 149	±	Laterite		
31	Kalahay Niba II	FA 787 215	±	Laterite		
32	Salaht	FA 822 143	-	Sandstone	Reworked laterite	
33	Wasit	EA 589 338	-	Peridotite		Cut
34	Fanjah	FA 137 944	±	Laterite		Cut
				Chromite Deposits		
35	Masakirah	FA 597 149	-	Dunite	Stringers	
36	Mudi	FA 958 025	-	Peridotite	Layer	
37	Aka Keya	DB 026 786	-	Dunite	Stringers	
				Manganese Deposits		
38	Hammah	FV 681 871	-	Chert	Pods	
39	Jaramah	GV 791 841	±	Chert	Layer - Pods	
40	Wasit	EA 589 338	-	Chert	?	
				Lead-Zinc Deposit		
41	Nujum	FA 205 880	-	Silica-carbonate	Veins	Mine
				Hot Springs		
42	Gallah	FB 413 025	+	Serpentine	Spring	
43	Rustag	EA 420 867	+	Limestone	Spring	Falag
44	Al Khadra	EA 312 839	+	Limestone	Spring	

1/ Refers to coordinates used on 1:100,000 maps of Ministry of Defense, United Kingdom, and on fig. 4, this report

2/ + Probably useable

± Possibly useable

- Not useful

work will find other deposits that are either more remote, less well exposed, or entirely covered by a shallow layer of aluvium.

Copper Deposits in the Semail Ophiolite

Copper deposits occur throughout the vast thickness of the Semail ophiolite, but those situated in the pillow lavas, especially those near the top of the pillow lavas, have the greatest potential. The position of the deposits within the ophiolite is shown diagrammatically on figure 5, which also gives added data regarding features of mineralization that vary according to their position and host rock.

The better copper deposits in the basaltic pillow lavas are accompanied by large amounts of iron sulfide (pyrite), which where very concentrated may be a saleable product even without the copper. Through oxidation, the pyrite has given rise to sulfuric acid waters and colorful, extensively leached, gossan outcrops. These gossan zones, and doubtless the underlying ore bodies, are small in areal extent, being generally elliptical in plan with major axes of from 30-150 m (100-500 ft). A downward extent for an ore body to at least 225 meters (750 ft) has been proved by drilling at one deposit, and it is likely others may extend to comparable depths. Some ore bodies, like Ghayth, are not elliptical but elongate and obviously deposited along a fault, whereas others show by a straight marginal segment partial fault control. Typically, little primary alteration exists about the deposits in basalt, although there is some evidence of zeolite alteration.

The bright orange, red, brown, or yellow colors of the gossan makes the exposed deposits easy to find, especially if searched for from the air, see photos 15 and 17. However, distinguishing gossans over sulfide deposits containing copper from those containing just pyrite can be difficult. Where there are secondary copper minerals in the outcrop, the deposits have invariably been found and worked in ancient times, perhaps more than 3000 years ago. Black slag piles dot the landscape surrounding the deposits, and in some places there are extensive ruins of old reduction furnaces. But, where the leaching of the gossan has been most intense the original copper sulfides have been dissolved and no secondary copper minerals are left behind. As a result, in some promising deposits secondary copper minerals can be seen in the less altered periphery but not in the most mineralized core. For example, the intensely altered surface gossan in the core of the Lasail deposit shows virtually no copper, but drilling revealed the underlying sulfide zone contained several percent of copper ore as chalcopyrite in veins and disseminated crystals in massive pyrite. In some places, copper leached from a gossan is redeposited at the base of the leached zone, but as far as we are aware, no zone of secondary enrichment has been noted in the Lasail deposit. Some other deposits, for example, Ghayth, Zabin, and Fizh, exhibit strong gossan with no secondary copper minerals showing

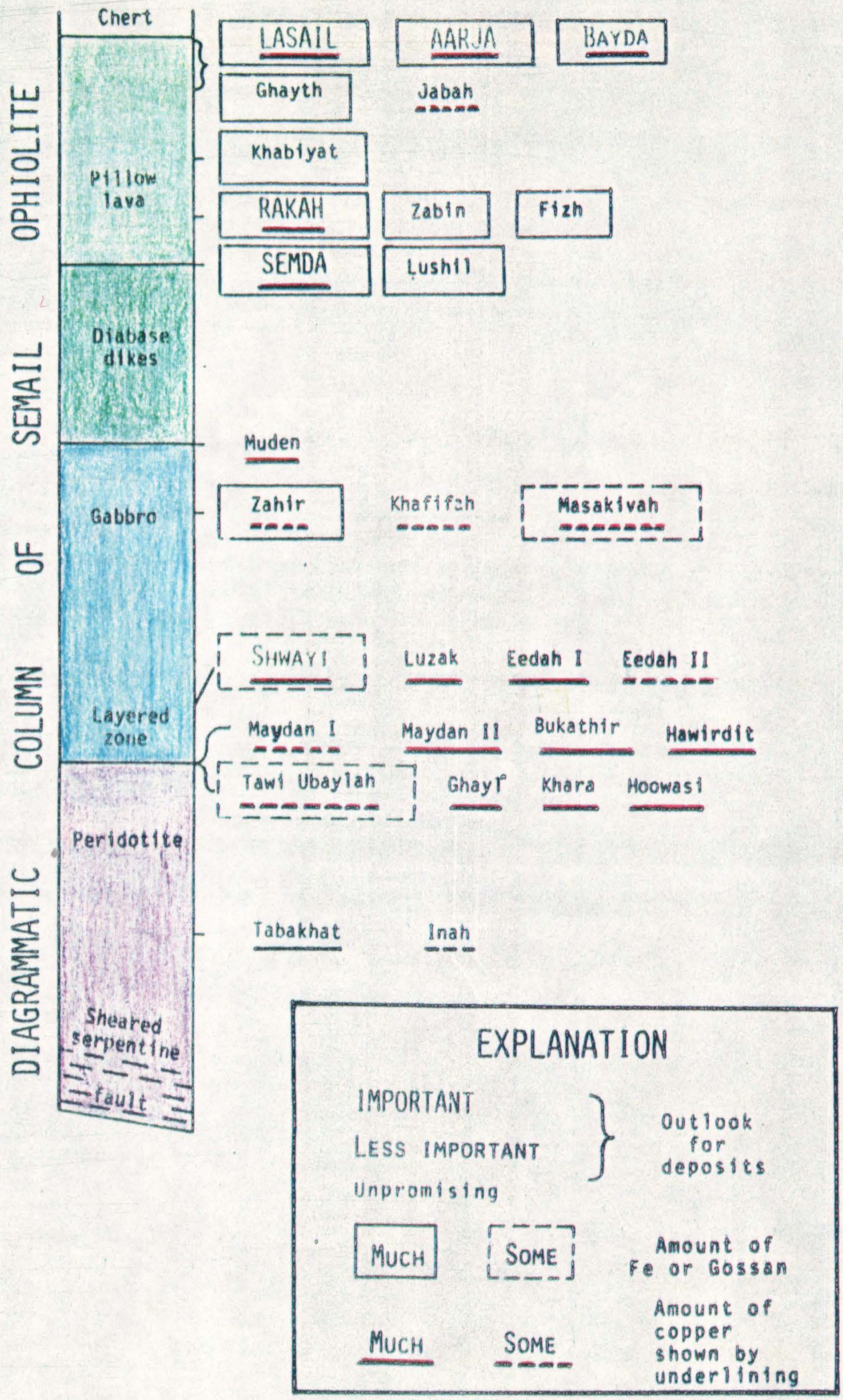

Figure 5. Diagram showing distribution and other features of 29 copper-iron sulfide deposits in the Semail ophiolite.

either in core or periphery; we suspect these contain little or no primary copper sulfide but one cannot be sure without drilling.

It can be safely predicted that some of the copper-bearing massive pyrite deposits in the pillow lavas will prove to be of sufficient grade and size to be mineable, even though all facilities for mining and transport of ore to market must be installed. If it proves to be as expected, the ore of the Lasail deposit alone seems to be able to carry the cost of getting into operation. If some of the other deposits in the "Bowling Alley" can also be proven to be viable, as seems likely, mining them concurrently with the Lasail deposit will of course result in significant lowering of the installation and operating costs on a per-ton basis. The massive sulfide deposits in the pillow lava in Oman are much like the intensively mined deposits in the Lower Pillow Lavas in the Troodos ophiolite on Cyprus, which also were mined in ancient times (2500 B.C.?) (Searle, 1972). The Cyprus deposits consist of several ore bodies of 1-10,000,000 tons of massive pyrite containing 1-4 percent copper occurring as chalcopyrite. Other deposits of similar type occur in Greece, Turkey, and Newfoundland (Upadhyay and Strong, 1973).

The diabase dike, or "Sheeted Intrusive," part of the Semail ophiolite lying below the pillow lavas contains at its top only two known deposits, see figure 5. Both have well-developed gossan and are in all respects like the previously described deposits in the basaltic lavas.

The lower gabbro and peridotite parts of the Semail ophiolite contain more than half of the copper deposits so far discovered in Oman, figure 5. Many of these were mined in ancient times, but only the Shwayi deposit seems to have any potential for modern mining. Most of the deposits are along a contact, generally a steep fault contact, between peridotite and gabbro. The mineralized zones are narrow, usually less than 8m (26 ft) wide, have lengths of less than 300m (1,000 ft), and generally are poorly exposed. Primary chalcopyrite was found in some places, but the usual ore in outcrop contained only secondary copper minerals along shears and fractures. In one deposit we found pieces of chalcocite in veins of apparently primary origin. In contrast to the ores in the lavas, these deposits typically contain minor amounts of pyrite, and they generally exhibit only a little iron staining rather than heavy gossan. Their surface exposures are not prominent, but assays indicate several really contain copper ore as rich as found in the massive sulfide deposits.

Most of these deposits in gabbro or peridotite are too small to be mined today. However, the Shwayi deposit, containing two ore bodies comparable in size to those in basalt, warrants some exploration to determine if the mineralized rock is of ore grade. We are not too optimistic about it being mineable, however, as copper deposits in gabbro and peridotite in other parts of the world generally have not been economic.

The origin of the copper deposits in the Semail ophiolite deserves further study, both as a guide to where to search for additional ore and as a scientific contribution. At this state in their exploration, with almost no knowledge of the primary ore mineralogy or paragenesis, tentative conclusions are best drawn from what is known of their localization and comparison with better explored ore bodies of similar type found elsewhere.

As mentioned before, the mineable massive sulfide ores in the lavas in the upper part of the ophiolite are much like Cyprus ores, whose genesis has been studied by several geologists (Bear, 1963; Kinkel, 1966; Constantinou and Govett, 1972; Searle, 1972). However, the less promising chalcopyrite vein deposits found lower in the ophiolite are not well represented in Cyprus. There is general agreement that the Cyprus ores are ultimately derived from the ophiolite itself, but processes leading to their formation are debatable. The most generally accepted theory postulates that the sulfide deposits are formed at an oceanic spreading center about submarine springs, with deposition at the lava-water interface and also in the underlying channelways by fracture filling and some replacement. The source of the copper, and generally also the iron, is believed to be either from leaching of underlying basalt, differentiation in a gabbroic magma chamber within the ophiolite sequence, or "exhalations" from the mantle itself. In some deposits of the Cyprus type, post-mineral faulting and remobilization of the sulfides has been proposed.

In Oman, the massive iron sulfides occur only in the upper part of the ophiolite, mostly in the basalt, and it seems likely that the iron was extracted from the iron-bearing rocks lower in the pile but above the peridotite. As copper mineralization is found throughout the ophiolite, the copper seems to have had a mantle origin. However, its greatest concentration is near the very top of the ophiolite, and the search for mineable copper deposits should give greatest priority to the examination of the pillow lavas, especially those at the very top of the lava pile. Overlying copper-rich sedimentary umbers, such as occur at Cyprus, have not been found; however, in the "Bowling Alley" somewhat similar sedimentary ironstones occur interlayered with the uppermost pillow lavas. These ironstones are discontinuous and are nowhere more than 1 meter (3.3 feet) thick. Spectographic analysis show they contain high iron and manganese contents with only a little copper and nickel. Somewhat similar appearing ironstones have been dredged from the Red Sea hot brine areas, but the Oman ironstones contain much less copper, lead, zinc, and silver.

The time of mineralization is unknown, and some evidence suggests that the final emplacement of the ore did not coincide with the period of volcanism and sea-floor spreading but came later. Some deposits in the "Bowling Alley" by their shape indicate fault control to the mineralization, for example, the Ghayth and Semda deposits (figure 6). Others seem to lie along northwest-trending faults related to younger tectonics, for example, the Lushil, Fizh, Bayda, and Ghayth deposits. In addition, the northern trend of the "Bowling Alley" projected southward coincides exactly with the Maydan, Bukathir, and Hawirdit deposits in the peridotite, suggesting perhaps some deep-seated fracture is responsible for the gross distribution of most of the better copper deposits. Curiously, far to the north in Iran, the spectacular Sher Cheshmeh porphyry copper deposit is also along the extension of this line. While not enough is known about why the ore is related to these structural trands they can be used as guides in exploration.

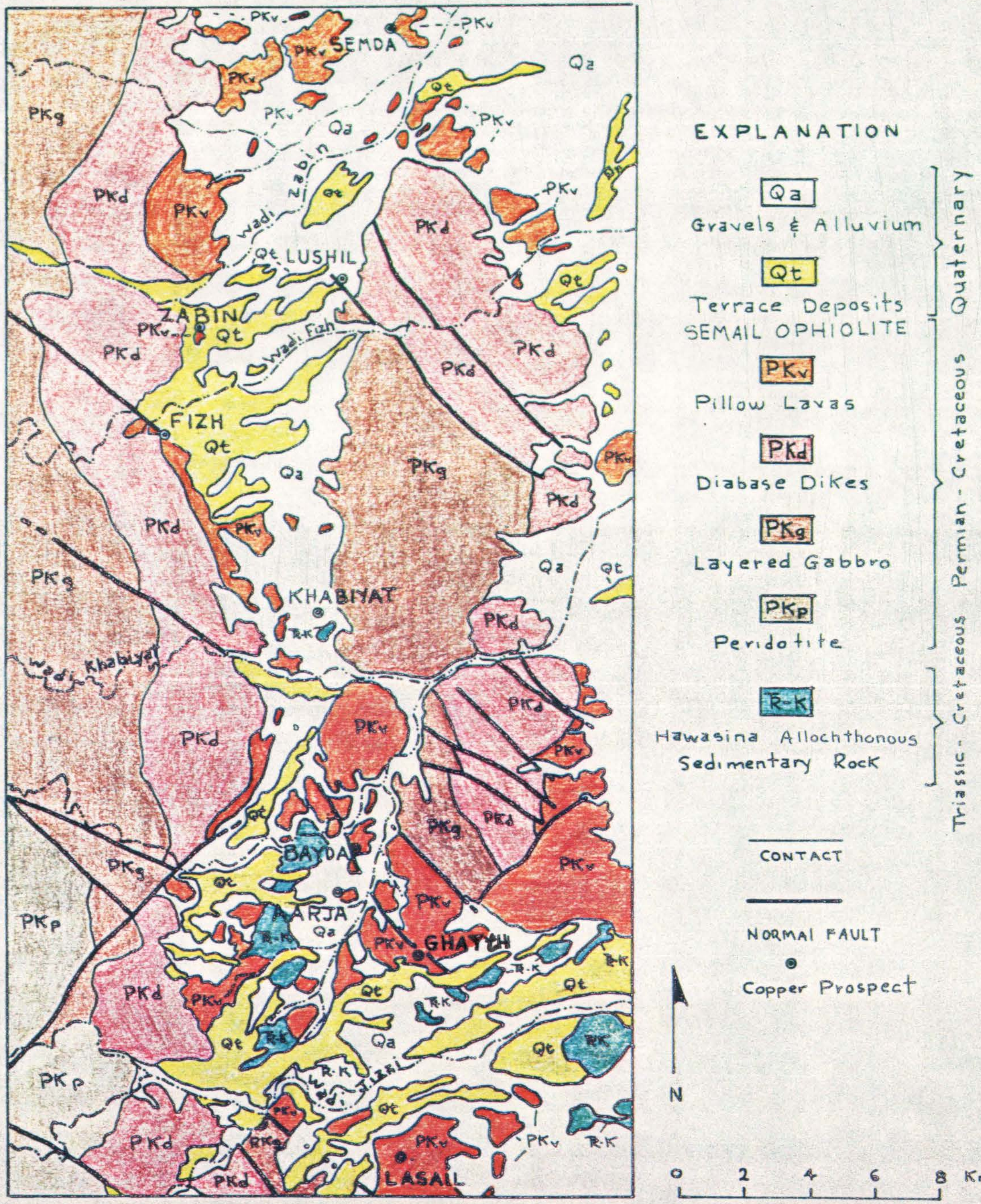

Figure 6. Geologic map of the "Bowling Alley" area showing the relation of copper-iron sulfide deposits in volcanic rock in the upper part of the Semail ophiolite to northwest-trending faults.

Descriptions of copper deposits in volcanic rocks

(1) Semda (DC 418-193 Fizh)

The Semda deposit is located on isolated interfluve between two wadies within low hills of Semail ophiolites 9.5 km (6 mi) north of the village of Fizh. Part of the ore is clearly developed in diabase dikes, and the occurrence of pillow lavas nearby suggests that the deposit may be in the transition zone between pillows and sheeted dikes. A thick mantle of pediment gravels whose level upper surface is about 90 m (300 ft) above the valley floor surrounds the mineralized of area on three sides and could be concealing other similar deposits.

The mineralized zone is very conspicuous because of the bright yellow and redish brown colors of its intensely altered gossan, see photo 8. It is elliptical in shape with a long axis of 150 m (500 ft) and a short axis of 115 m (375 ft), as shown in figure 7. Its southern limit is partly covered by alluvium, but we believe the float here is adequate to permit an accurate estimate of its extent. Its northeastern boundary is locally straight and includes a tail-like extension, perhaps suggesting some fault control for the mineralization. Centrally located in the gossan is a nearly circular depression about 60 m (200 ft) in diameter whose flat floor is 2 m (7 ft) below the level of the surrounding alluvial plain. Within this area all the material is a copper-free(?) powder of secondary iron oxides, sulfates, and gypsum, which forms a thin mud when wet. Perhaps the level here has been lowered somewhat by mining in ancient times, but small step faults visible in the walls indicate that the depression of the central area is mostly due to subsidence. This is doubtless the result of removal of material in solution, which indicates that the underlying fresh material is chiefly soluble sulfides with a minimum of insoluble silicates. Surrounding the central core is a slightly less altered area pock marked by shafts or pits only a few feet deep and connecting short tunnels. Much green and blue copper "stain," in the form of both hydrated oxides and sulfates, is still visible in the walls, and it was doubtless from this less leached zone that the ancients obtained most of the ore now represented by the extensive piles of slag found all about the mine area.

We believe the surface indications at the Semda deposit reflect a buried massive sulfide pipe with slightly less, but still intense, mineralization extending out from it for a distance of several hundred feet. Although at the surface the leached gossan over the central core is virtually copper free, the presence of considerable copper in the less leached periphery suggests the core also may have a high copper content, and perhaps even a zone of secondary enrichment. There is no way to be sure, however, without drilling to obtain samples for analysis. To us this appears to be the most promising deposit we examined, and it should be promptly explored

Photo 8. Semda gossan viewed looking northeast. Central depression is in area of complete oxidation and has collapsed owing to removal of copper and iron in solution. Foreground area covered by pits from which copper ore was mined in ancient time. Flat skyline is on surface of old, elevated pediment gravel.

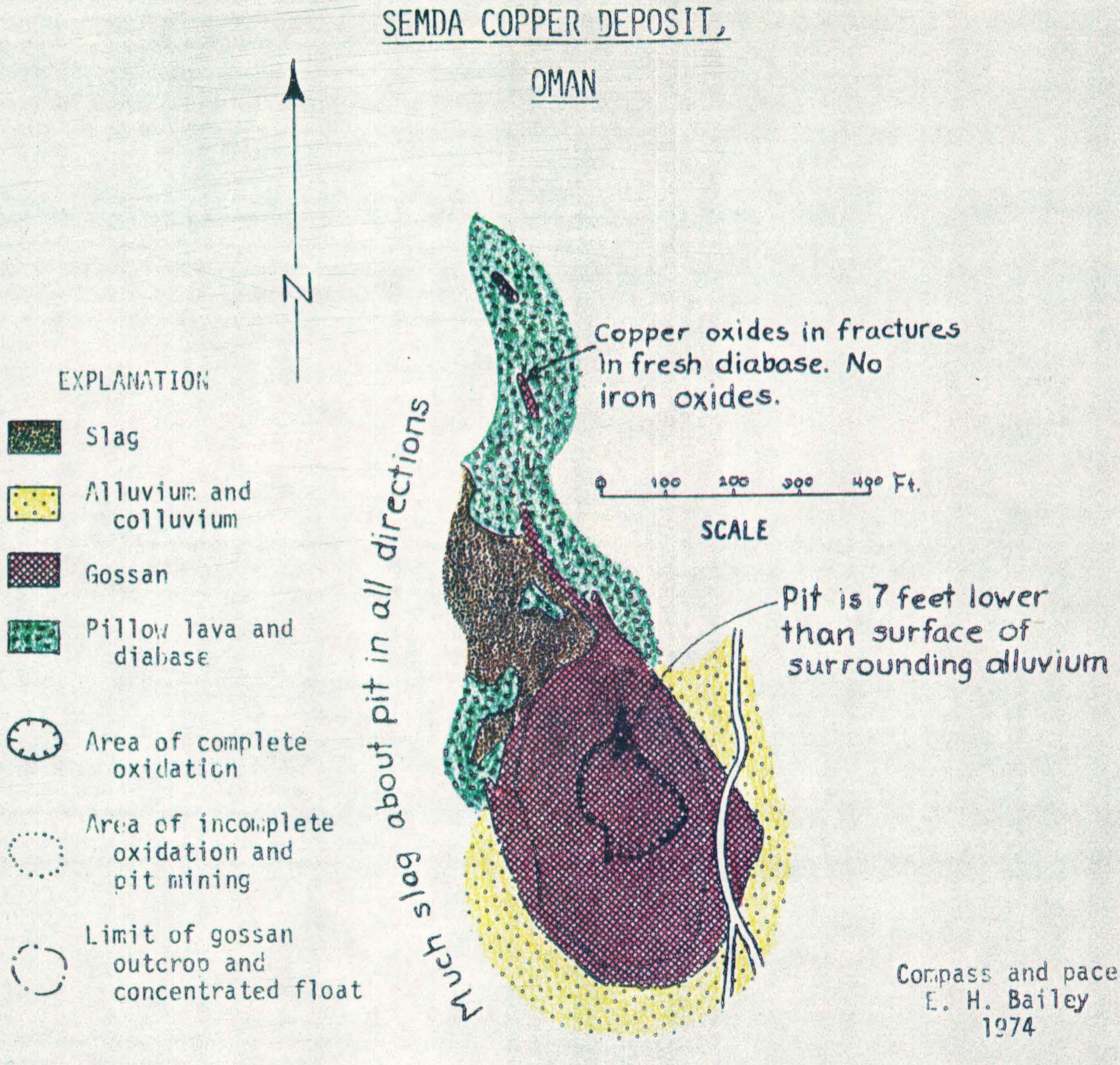

Figure 7. Geologic map of the Semda copper deposit.

by drilling. If it comes up to our expectations it is quite likely to be a mineable deposit.

About 120 m (400 ft) north of the main gossan is a low hill of fresh diabase traversed by a shear zone containing copper "stain" along fractures. Still farther north is another weakly mineralized parallel zone. No iron mineralization seems to have been present in either of these places. The direction of the mineralized fractures parallels the northeastern boundary of the main gossan, and reinforces our belief that the main ore body is at least in part fault controlled. Although a little digging has been done, these occurrences north of the main pit seem to offer no chance for serious mining.

(2) Lushil (DC 404-115 Fizh)

The Lushil deposit lies in a small flat at the intersection of two minor valleys 1.7 km (1 mi) east of the village of Lushil and near the road from the village to Fizh. It is in an area of rather subdued topography west of a bold outcrop of diabase dikes that are vertical and trend northerly. Just west of the deposit are low hills of mafic pillow lava. Although the diabase nearby is cut by northwest-trending faults, we have no evidence suggesting a fault between the diabase and lavas that might have aided in localization of the ore deposit.

The exposure of the deposit consists of a ground-level circular area about 30 m (100 ft) in diameter of strongly oxidized gossan, see photo 9 and figure 8. We saw no copper minerals or "stain" in the gossan, and no piles of slag indicating it had ever been mined. The surrounding rocks are unmineralized and surprisingly unaltered. The gossan probably has developed over a small pipe of massive iron sulfides, but its small size and lack of any sign of copper mineralization indicates further exploration is unwarranted.

The area about the deposit also seems unfavorable because of the lack of alteration or mineralization in the exposed rocks. In the valley a few hundred feet northeast of the gossan, however, there is an area of powdery soil containing some gypsum in which the geophysicists for Prospection Ltd. report a slight geophysical response. We believe the lack of surface alteration or the development of a good iron-stained gossan indicates little chance for the discovery of covered ore in this area.

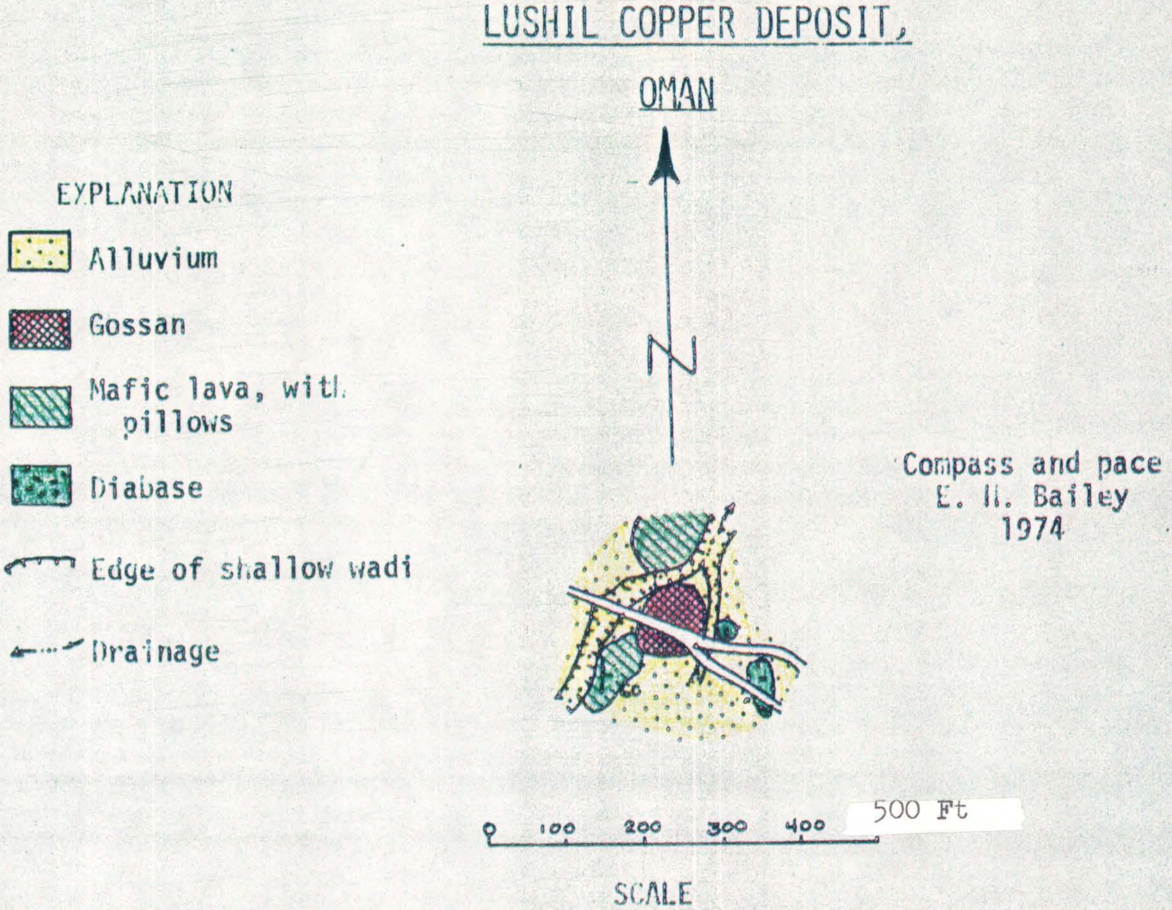

Figure 8. Geologic map of the Lushil deposit.

Photo 9. Entire area of exposure of Lushil gossan, viewed looking north.

(3) Zabin (DC 358-098 Fizh)

The Zabin deposit is 1.1 km (0.6 mi) S22°E of Zabin village and 8 km nearly due west of Fizh. It is exposed as several hills of iron-stained gossan and an intervening low area of bleached rock, see photo 10. The deposit is at the erosional boundary between an upper tableland floored by old gravels at least 9 m (30 ft) thick and a new pediment being established at a level that is 75 m (250 ft) or so lower. Small hills of mafic volcanic rock exposed on the flank of the erosional scarp contain the main deposit, and other minor shows of mineralized volcanics can be seen through the new pediment along the edge of incised wadies to the north. On the north side of a major wadi 500 feet north of the main deposit is exposed a contact between the volcanic rocks and underlying diabase dikes, suggesting that the deposit is near the base of the volcanic flows. The attitude of the dikes suggests backward rotation of this part of the Semail ophiolite.

Three main areas of mineralized rock exposed at the Zabin deposit are nearly surrounded by alluvium, see figure 9. The southern two, separated only by alluvial cover, could be parts of one continuous mineralized mass, and the main northern exposure also might extend northwestward beneath cover to the small exposures shown along the wadi bank on figure 9. Between these two clusters of mineralized rock is fresh volcanic rock, which makes it improbable that the north and south deposits are exposures of a single ore body. A projection of the S. 49° E. trend of the mineralized zone to the southeast reaches fresh volcanics in the next wadi to the south, indicating the mineralization does not extend far beneath cover in that direction.

The most intense mineralization, as indicated by a well-developed deep-red gossan of iron oxides in a silicate framework, comprises the most southerly gossan mass shown on the map. It forms the western part of a prominent hill, which has little-altered pillow lava in its eastern part. Although the gossan is striking because of its color, much initial silicate remains, indicating the unoxidized rock below is only partially replaced by sulfides. Neither here nor elsewhere in this area did we observe any copper mineralization, and there is no slag or other evidence of ancient mining about these prominent exposures. The gossans probably overlie pyrite mineralization with little or no copper. The surface showings are not encouraging enough to warrant further exploration.

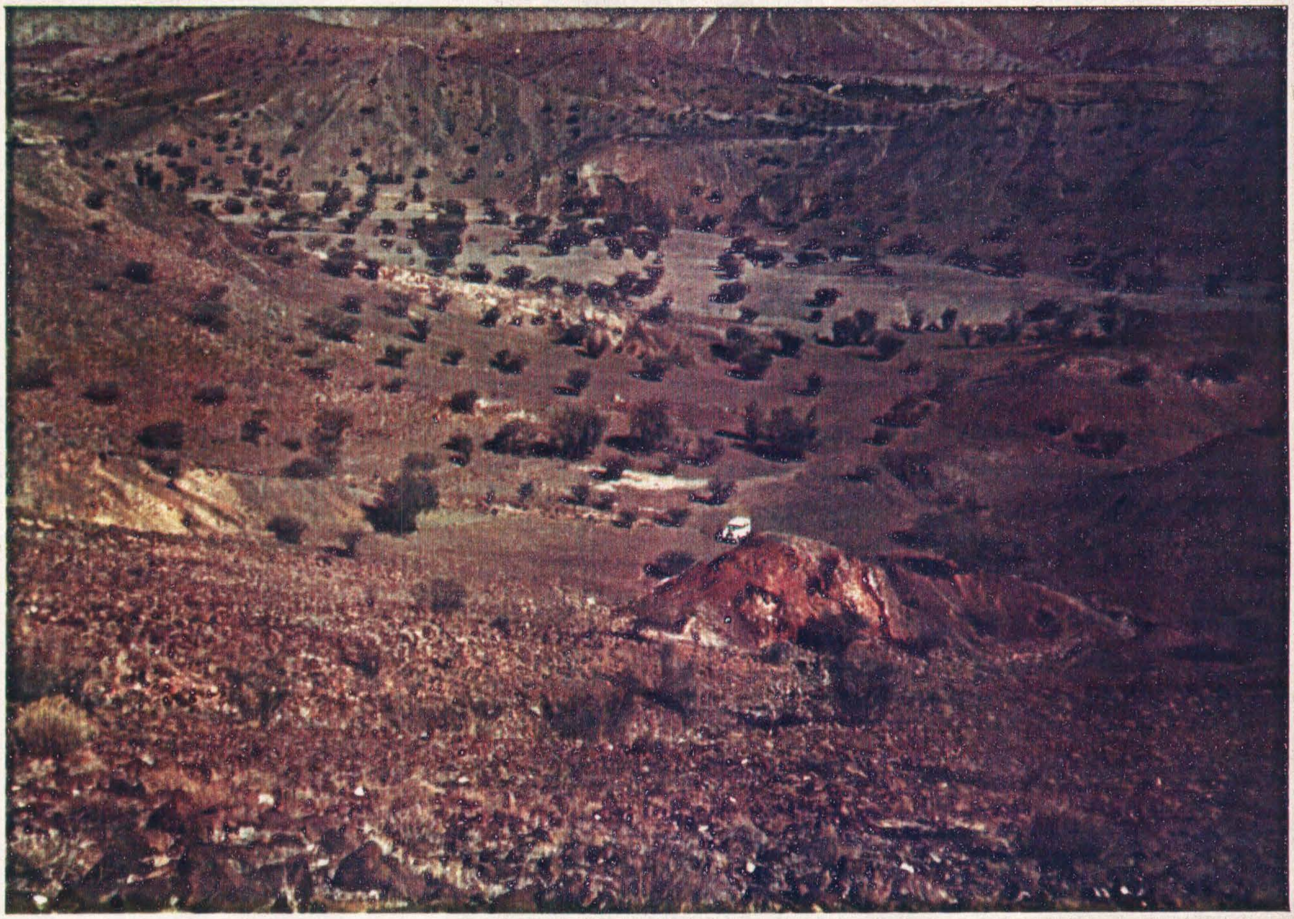

Photo 10. Area of Zabin deposit viewed looking northwest. Intense alteration extends from colorful hill this side of Land Rover to bleached zone just this side of broad, alluvial-filled wadi. However, a little alteration is found along the trend of the zone on the far side of the wadi.

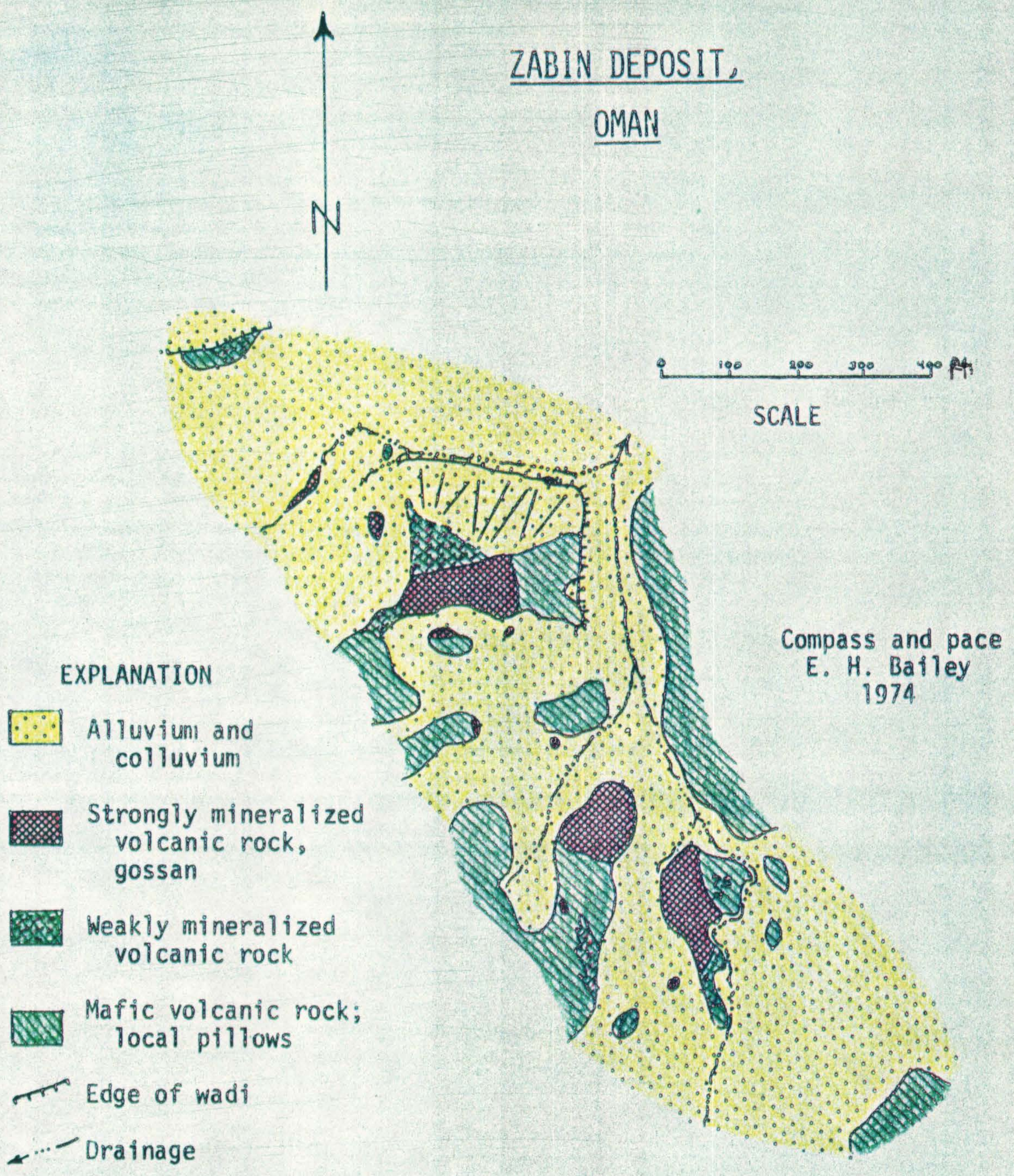

Figure 9. Geologic map of the Zabin deposit.

(4) Fizh (DC 345-068 Fizh)

The Fizh deposit is 0.3 km south of wadi Fizh and 1.8 km (1.1 mi) east of the village of Mahjal. It is easily found as it consists of two unusually dark hills rising from a broad pediment surface, which is cut down about 3 m (10 ft) into an older alluvial terrace, see photo 11. A mountain front nearby consists of northerly trending diabase dikes, but the deposit itself is in altered mafic pillow lava. The lava appears to lie about 45 m (150 ft) above the contact with the zone of dikes; thus, the geological setting here is identical with that of the Zabin deposit.

The deposit forms two parallel mounds having a narrow connecting band at their northern end, see figure 10. The mounds consist of gossan made up chiefly of deep brown, locally black, goethite, yellowish brown limonite, and deeply stained silica. Some very black siliceous material is thinly layered and perhaps is mineralized chert. There is a vague suggestion that the hard gossan is a cap extending little below the pediment level. No copper minerals were seen, and no evidence of former mining was observed.

The pair of mineralized hills is surrounded by alluvium, but there are enough small patches of unaltered volcanic rock sticking up through the alluvium on all sides to eliminate any speculation about the area of mineralization extending much farther beneath the cover. Also, the small exposure of volcanic rock on the inside edge of the eastern lobe, see figure 10, suggests the mineralization is not continuous between the two lobes beneath the intervening cover. The Fizh deposit does not appear to us to warrant further exploration.

(5) Khabiyat (DC 397-013 Fizh)

The Khabiyat deposit is 4.5 km (2.8 mi) S. 29° W of Jabal Shaykh and 0.3 km (0.18 mi) west of the main road up the east side of the "Bowling Alley". It lies on a flat alluvial surface between the main Oman Mountains and a smaller range of hills comprised of Semail gabbro and diabase. The only exposures in the mineralized area are seven small isolated patches of gossan that protrude above the alluviated plain. The gossans are strongly leached and consist mostly of residual silica with some yellow and brown iron oxides. They contain no visible copper minerals, and apparently were not mined in ancient times. Owing to the advanced degree of alteration of the rocks in these few exposures we are uncertain about the nature of the host rock, but it probably was a mafic volcanic rock. The limited showings do not appear to us to merit further exploration.

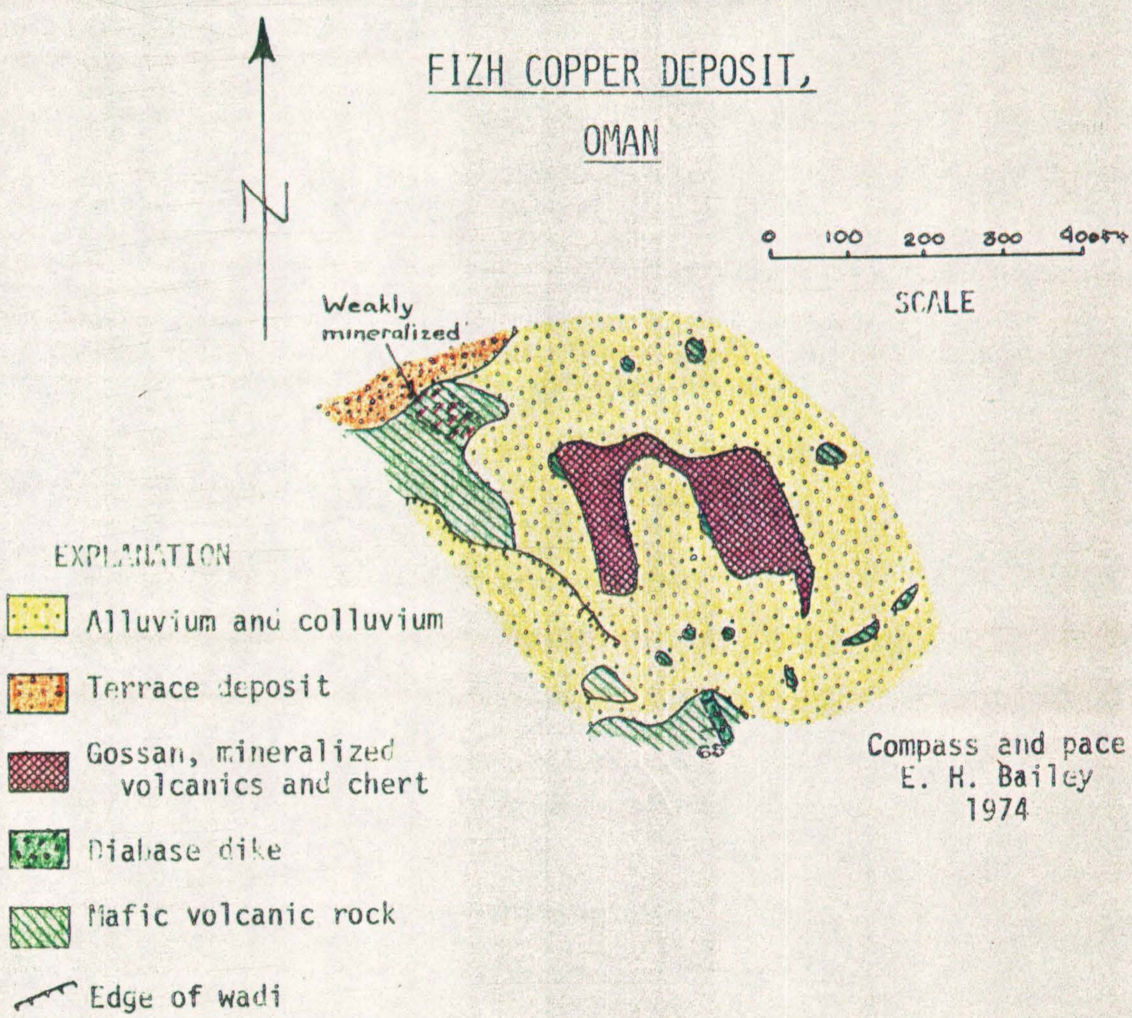

Figure 10. Geologic map of the Fizh deposit.

Photo 11. Gossan hills of the Wadi Fizh deposit, viewed looking southeast. Rock in right foreground is nearly fresh basalt.

(6) Bayda (DB 408-939 Fizh)

The Bayda copper deposit is on the east side of the "Bowling Alley" about 1.1 km (0.6 mi) S. 54° E of the village of Bayda. It occupies a slope leading up from an area of low hills of mafic volcanic rocks to a high-level flat blanket of old gravels. The mineralized zone is intermittently exposed through a mantle of talus broken from the gravel above, see photo 12.

The ore deposit is a zone of slightly to intensely altered volcanic rock extending for about 180 m (600 ft) in a northerly direction and having an average width of about 45 m (150 ft), see figure 11. The alteration is the most intense along the west side of the zone, where some local areas are so leached that only white silica remains. In other parts there has been less acid leaching and the rocks are deep brown to yellow in color owing to the abundance of iron oxides and sulfates. A little copper "stain" can be seen throughout but is most common along the western margin where some mining was done in open cuts and perhaps through a shallow shaft. Jasper is exposed above the west edge of the ore zone, and a hill on its southern end is mostly jasper. We are not certain if the jasper is a cherty sediment or is the result of silicification related to the ore genesis; however, local layering suggests at least part is primary.

The deposit contains some copper and has been mined on a small scale. We saw no slag, but perhaps some of the slag about the nearby Aarja deposit represents ore carried from here. Although the sulfide mineralization does not seem to be intense through the entire width of the altered zone, we believe the showing is of sufficient size and merit to warrant at least a couple of exploratory drill holes. We also noted some iron staining in the hills across the wadi about 1 km (0.6 mi) to the north, but did not have time to inspect it closely.

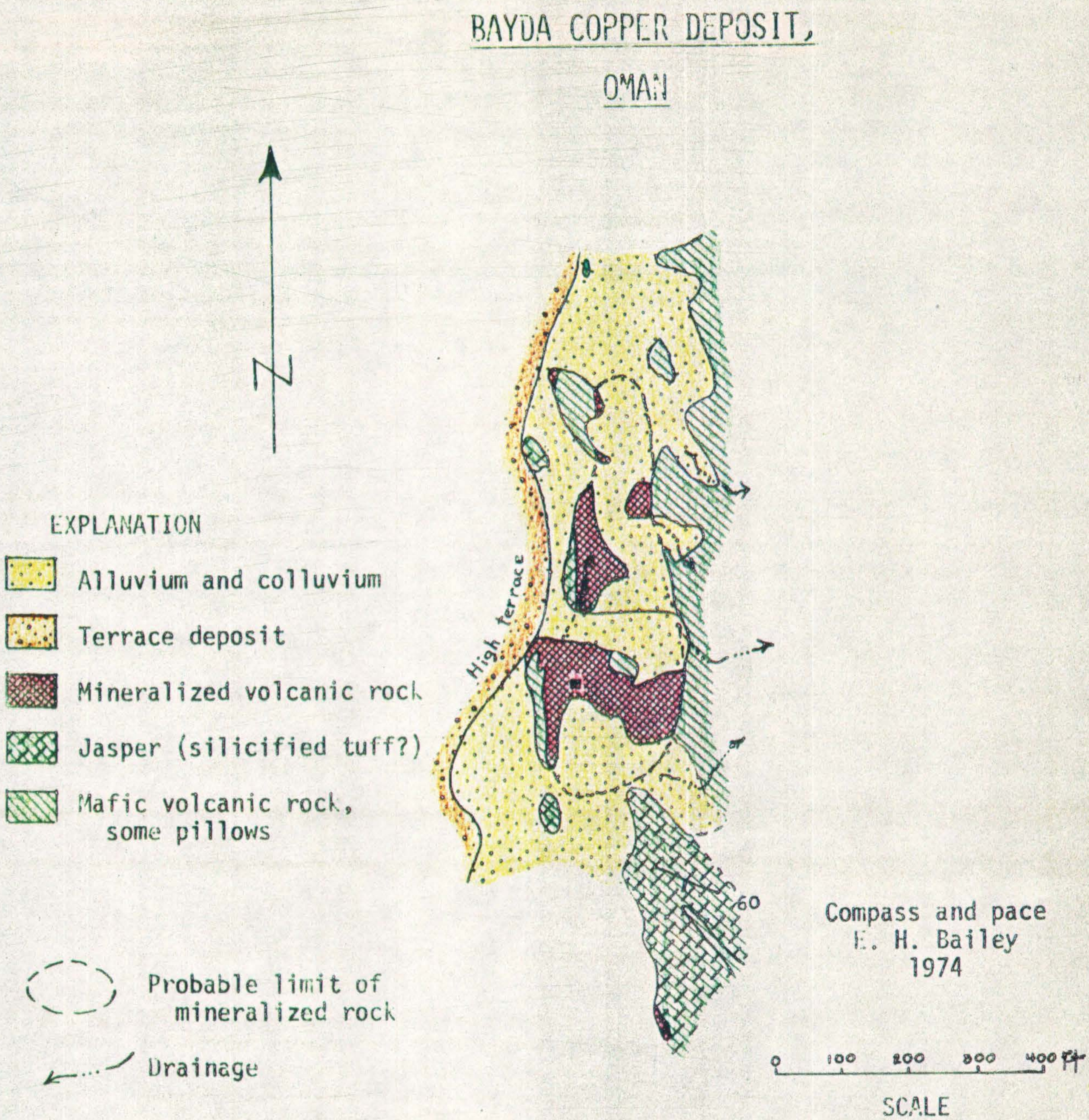

Figure 11. Geologic map of the Bayda copper deposit.

Photo 12. Bayda copper deposit viewed looking north. In upper left are old workings in area of gossan and bleached volcanic rock. Center skyline is cap of older alluvium. Low hills to right of central area of white beached rock are composed of unmineralized pillow basalt.

(7) Aarja (DB 402-925 Fizh)

The Aarja deposit lies among low rolling hills surrounded by alluvium in an interfluve between two large wadies 2 km (1.2 mi) south of the village of Bayda and 1 km west of the "Bowling Alley" road. The country rocks are mafic pillow lavas, locally cut by a few diabase dikes. The deposit is probably near the top of the Semail ophiolite as beds of cherty ironstone 0.5-1 m (2-3 ft) thick occur with the ore, and some silicified tuffs were also noted nearby.

The deposit is exposed as a brightly colored hill about 25 m (85 ft) high composed of intensively altered gossan of iron-stained silicates, white silica, limonite, geothite, and other typical products of intense sulfide mineralization and subsequent acid leaching, see photo 13. Secondary copper minerals are fairly common, especially near the top of the hill and along the base of its western slope, where there has been considerable mining. The extent of mining is indicated by the widespread piles of slag, which in the aggregate amount to more than 25,000 tons.

The prominent gossan exposure measures 120 by 60 m (400 by 200 ft), but abundant float suggests that the ore body is larger than this, see figure 12. We believe it is elliptical in shape with lengths of major and minor axes of 165 and 100 m (550 and 350 ft). It is elongated in a northwesterly direction, parallel to the prevalent direction of faulting in the "Bowling Alley" area. However, we saw no surface expression of a fault here, and are not able to relate the structure to the fault along which is developed the nearby Bayda deposit.

Because of the size of the gossan and its copper content it may represent a minable deposit, although the sulfide replacement does not appear to have been as complete as at the Lasail or Semda deposit. We recommend that it be further explored by at least three drill holes to determine the grade of the primary ore and its extent beneath the alluvial cover.

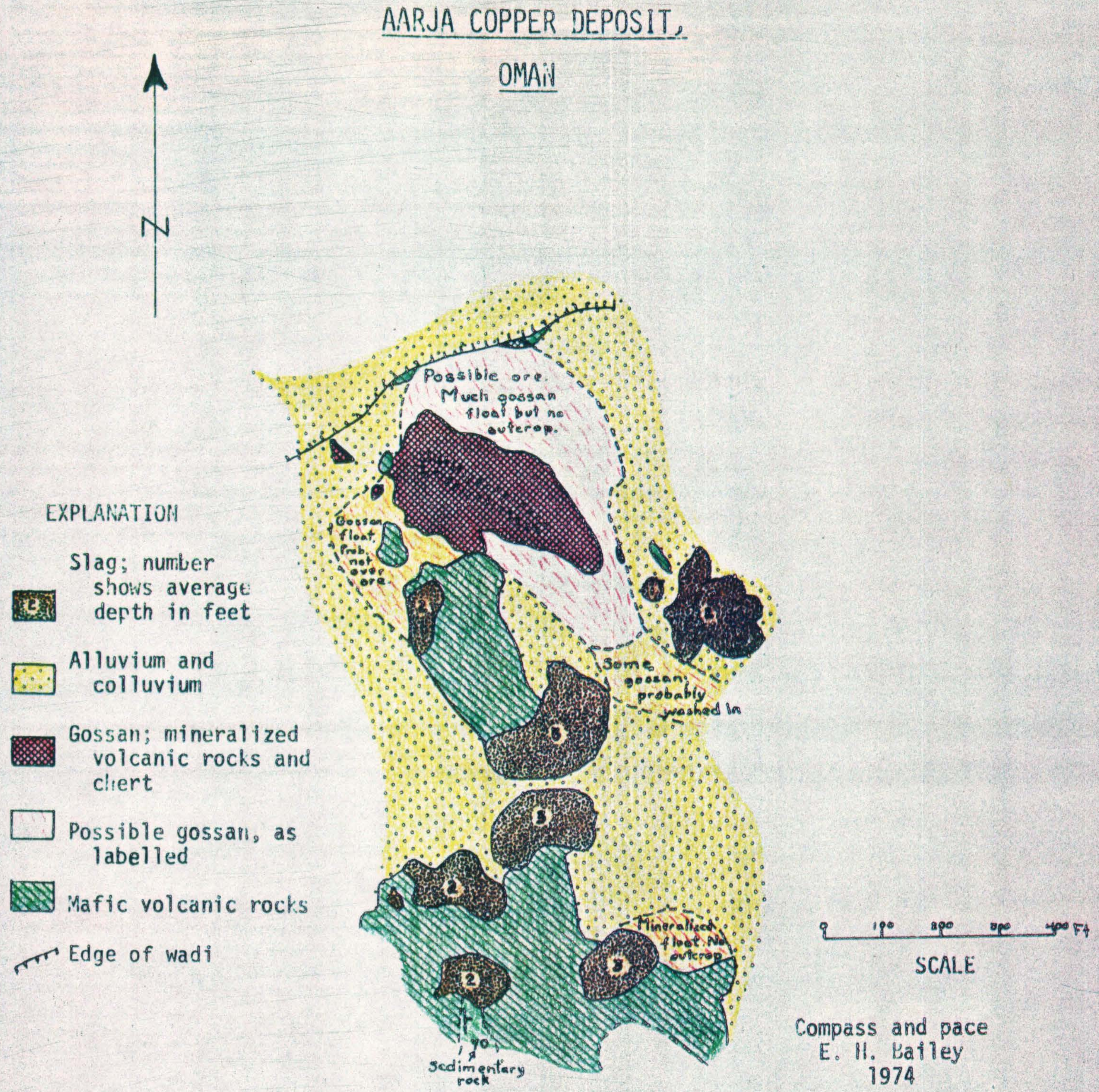

Figure 12. Geologic map of the Aarja copper deposit.

Photo 13. Aarja copper deposit, viewed looking southeast. The highest parts of the prominent gossan hill contain mineralized chert. Flat skyline on left is surface of overlying old alluvium deposited in a prior cycle of erosion.

(8) Ghayth (DB 428-905 Wadi Al Jizzi)

The Ghayth deposit extends along a narrow alluviated valley between low hills about 4 km (2.5 mi) N. 23° E. of ruins of Mulayyinah on the bank of Wadi Jizzi. The valley is bordered by hills of mafic volcanic rock, locally showing pillow structure, and to the southwest other hills contain cherty ironstone beds 0.6 to 1 m (2 to 3 ft) thick.

The exposure of the deposit consists of brick-red, orange, and locally black gossan cropping out as low mounds or as near-ground-level patches along a zone extending N. 14° W., see photo 14 and figure 13. This zone developed along a vertical fault that may be the southern extension of the fault on which occurs the Bayda deposit.

The Ghayth deposit is exposed over a length of a little more than 400 m (1,400 ft). Its northern end is about at the limit of exposure, as a short distance farther north along the strike of the fault fresh volcanic rock can be seen. To the south, the deposit might extend farther under cover, as its projection goes under a capping of thick terrace gravels. The northern part of the gossan zone has an exposed width of about 30 m (100 ft), but the southern part, which is less well exposed, appears to be less than 15 m (50 ft) wide.

The gossan has not been mined and we saw no copper minerals in it. From the leached surface exposures we judge that it overlies a narrow vein of massive pyrite with borders of volcanic rock containing varying amounts of disseminated pyrite. Owing to the total absence of copper "stain" it appears to have no economic potential, but its extent is sufficient to warrant a single exploratory drill hole to obtain samples of the unoxidized ore. Mineralized areas shown on figure 13 to the east of the main ore zone represent weak alteration and are not worth further attention.

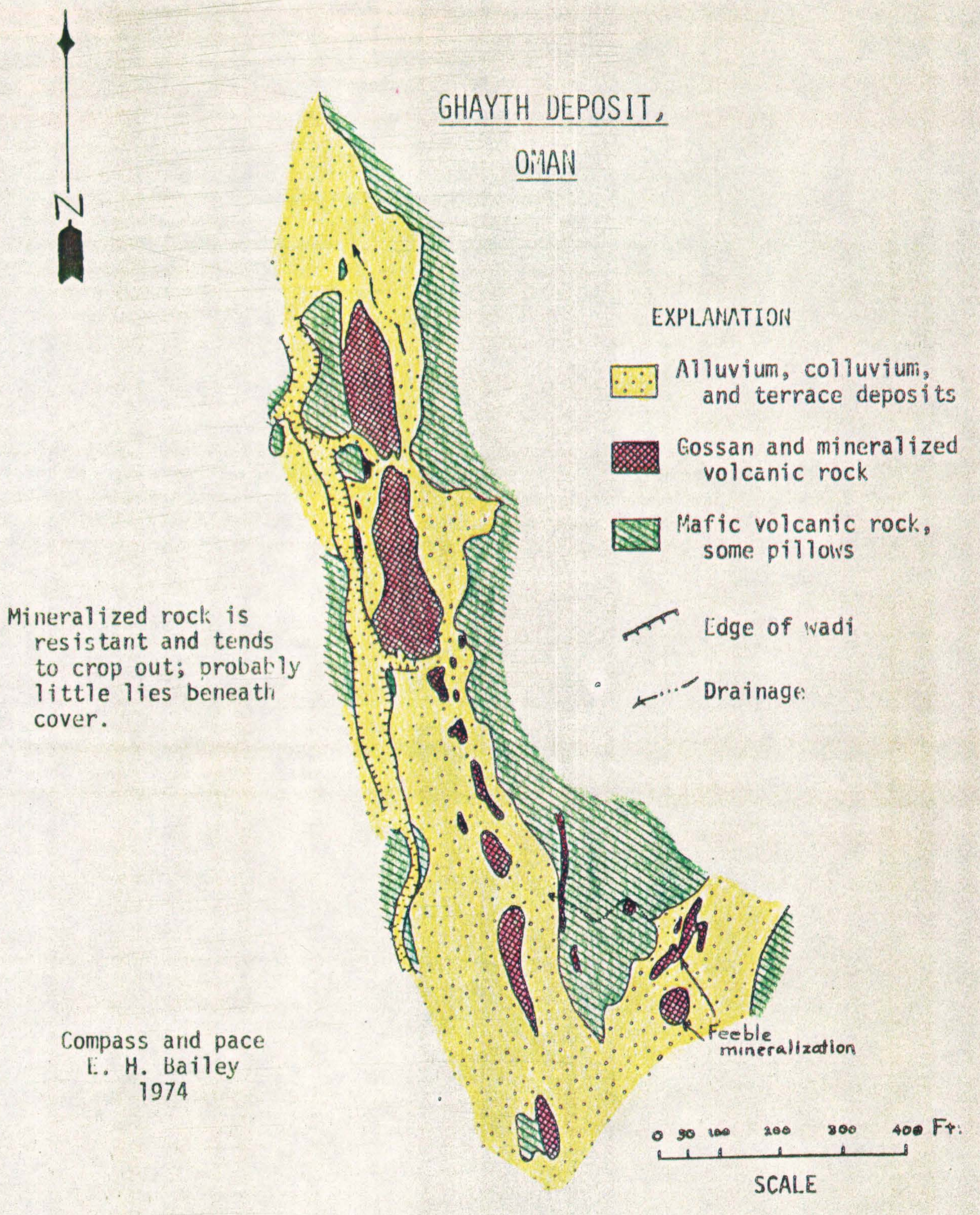

Figure 13. Geologic map of the Ghayth deposit.

Photo 14. Ghayth gossan zone viewed from southern end looking north. Virtually the full extent of the mineralized zone is shown in the photo. Bordering rocks are mafic pillow lava and hills beyond are gabbro.

(9) Lasail (DB 422-843 Wadi Jizzi)

The Lasail deposit occupies a depression within low hills of pillow lavas, dikes, and sills 2.7 km (1.7 mi) S. 14° E. of the ruins of Mulayyinah on Wadi Jizzi. The area appears to be synclinal, and the occurrence of dark, iron-rich sediments overlying pillow lavas suggests that the ore body lies at the top of the Semail ophiolite pile. Local diabase dikes trend northward and dip at moderate angles westerly. Because of the advanced study made here by Prospection Ltd., who believe this to be the most promising ore body yet discovered in Oman, we made no attempt to map the deposit.

The exposure of the ore body consists of a flat low area of striking orange, red, and brown powdery gossan said to measure 270 m (900 ft) by 135 m (450 ft), see photo 15 and 16. Diamond drilling by Prospection Ltd. has shown that the gossan has formed over a pipe of massive sulfide ore having a vertical extent of at least 210 m (700 ft), the depth of penetration by the equipment available. Little data on the content of copper in the drill core is available to us. But substantial sections are said to assay 2-3 percent copper, occurring as chalcopyrite veins and crystals in massive pyrite. With only partial knowledge of the preliminary drill data we estimate the known amount of ore may be between 5 and 10 million tons of massive pyrite ore containing 2 1/2 percent copper. Cost calculations indicate this deposit can be mined at a profit under present conditions if the potential tonnage and grade are as indicated.

Copper "stain" and relics of copper in vesicles in the lava can be seen at the deposit. This was the site of the most extensive ancient mining we saw, and the slag heaps lying all about the gossan have been estimated to contain 100,000 t* of roasted ore.

*t, metric tons

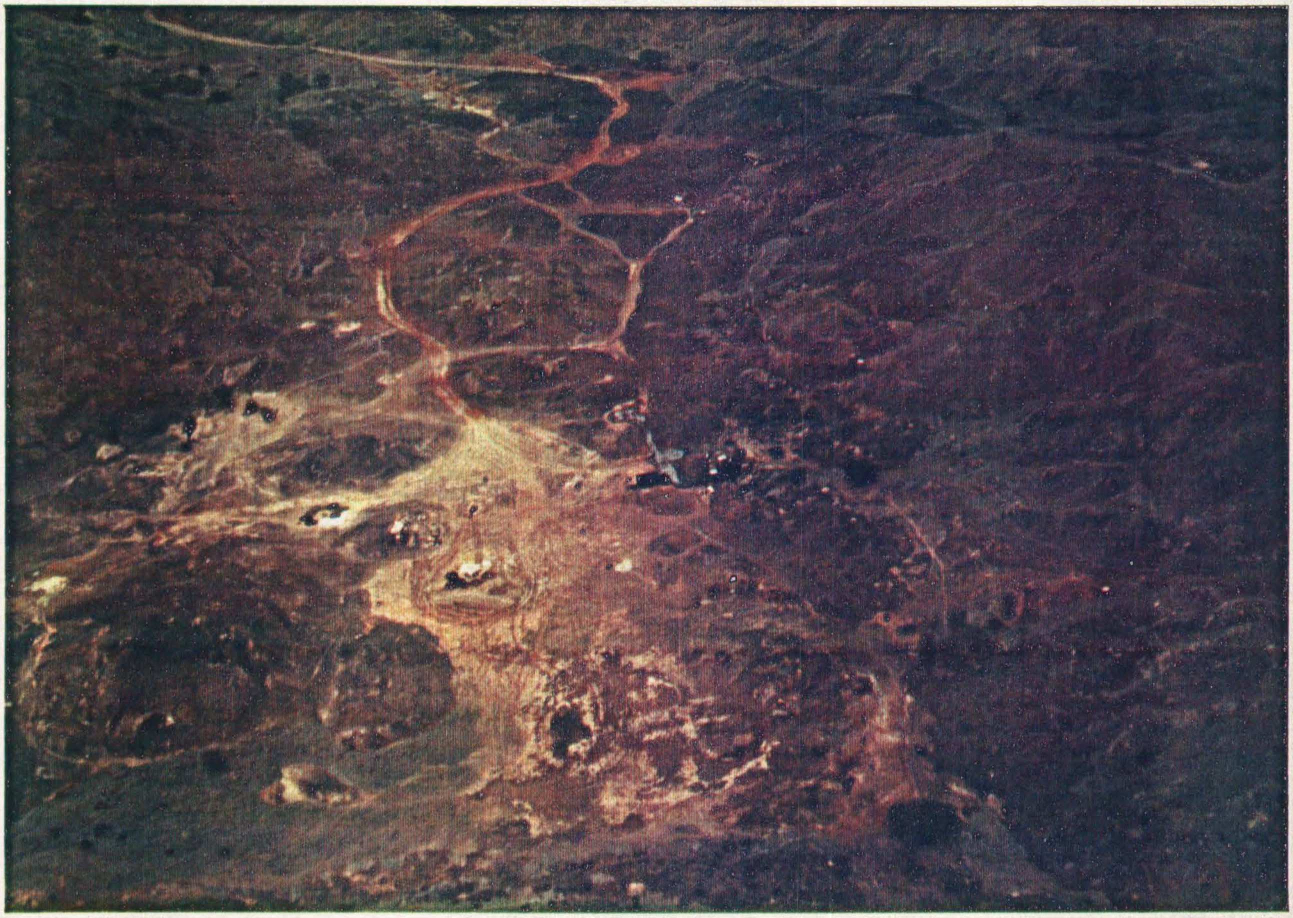

Photo 15. Lasail copper deposit as viewed from the air looking due north. Black, pock-marked, areas surrounding gossan are ancient slag piles, which are estimated to contain at least 100,000 tons. Drill rig in center of photo to right of wet area is set up at Prospection Ltd. DDH-2.

Photo 16. Central part of gossan over the Lasail ore body looking west. Conical piles of various colors to left of Land Rover represent material from pits at 0.5 (1.63 feet)-meter intervals of depth and indicate rapid downward changes in kind and degree of alteration of the massive sulfide ore. Although the sulfide ore averages more than 2 percent copper, the gossan at the surface generally contains less than 0.1 percent, indicating the necessity for drilling to obtain samples from the sulfide zone for proper evaluation of the gossan outcrops.

(10) Jabah (FB 247-002 Udhaybah)

The Jabah occurrence lies among low rolling hills along Wadi Jalsa approximately 5 km (3 mi) S. 43° E. from the village of Rusayl on the main road to Muscat. The area is underlain by pillow lava which is capped by 1 m (3.3 ft) of silicified leucocratic tuff containing plagioclase phenocrysts. At the contact a thin bed of chert separates the tuff and pillow lava, and secondary copper minerals occur sporadically at the chert-tuff interface. Although an analysis of tuff in the mineralized zone shows 2.9% copper (see table 6 in Appendix), we recommend no further work here.

(11) Rakah (DB 570-182 Miskin)

The Rakah copper deposit is exposed as a group of low hills partly covered by alluvium 11.2 km (7 mi) N. 21° E. of Yanqual Fort, from which it is readily accessible. The main mineralization is in mafic volcanic rocks, but in adjacent diabase and nearby gabbro there has also been some mineralization along fractures. Boundaries between the different kinds of rock are apparently northeasterly trending faults, and it is likely that here the Semail ophiolite is also overturned.

The deposit is exposed as a colorful gossan of brown, yellow, and orange iron oxides and white silica, with other products of secondary alteration and acid leaching, see photo 17 and 18. Locally, however, a little pyrite still remains in the outcrops. The surface area of the mineralized zone is rectangular in shape and about 240 m by 120 m (800 by 400 ft) in dimension, see figure 14. Secondary copper minerals can be seen in several parts of the gossan, and mineralization is particularly intense along northeast-trending shear zones in the central area and near the northwestern margin where cuts, and some underground workings, attest to ancient mining. Scattered about the deposit are many piles of slag which in the aggregate are estimated to contain about 20,000 tons. Also in the area are several well-preserved fire pits where the copper was roasted out of the ore.

The size of the Rakah deposit and the prevalence of some copper minerals in its gossan requires that it be explored by a few drill holes. However, the surface showings do not appear as in some of the deposits in the "Bowling Alley", and the remoteness of this deposit from all others of merit would make it difficult to operate it as one of several supplying a single concentrating plant.

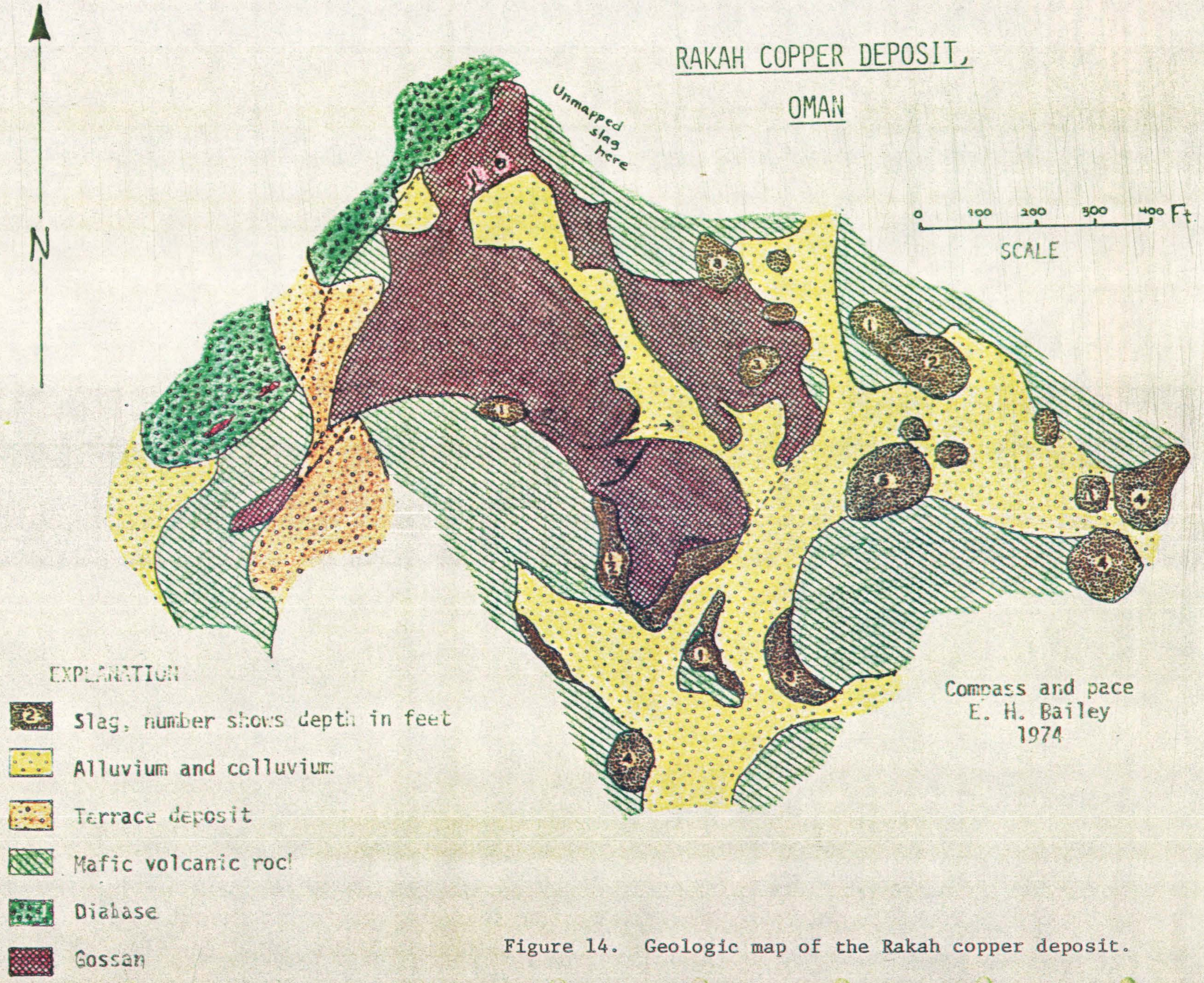

Figure 14. Geologic map of the Rakah copper deposit.

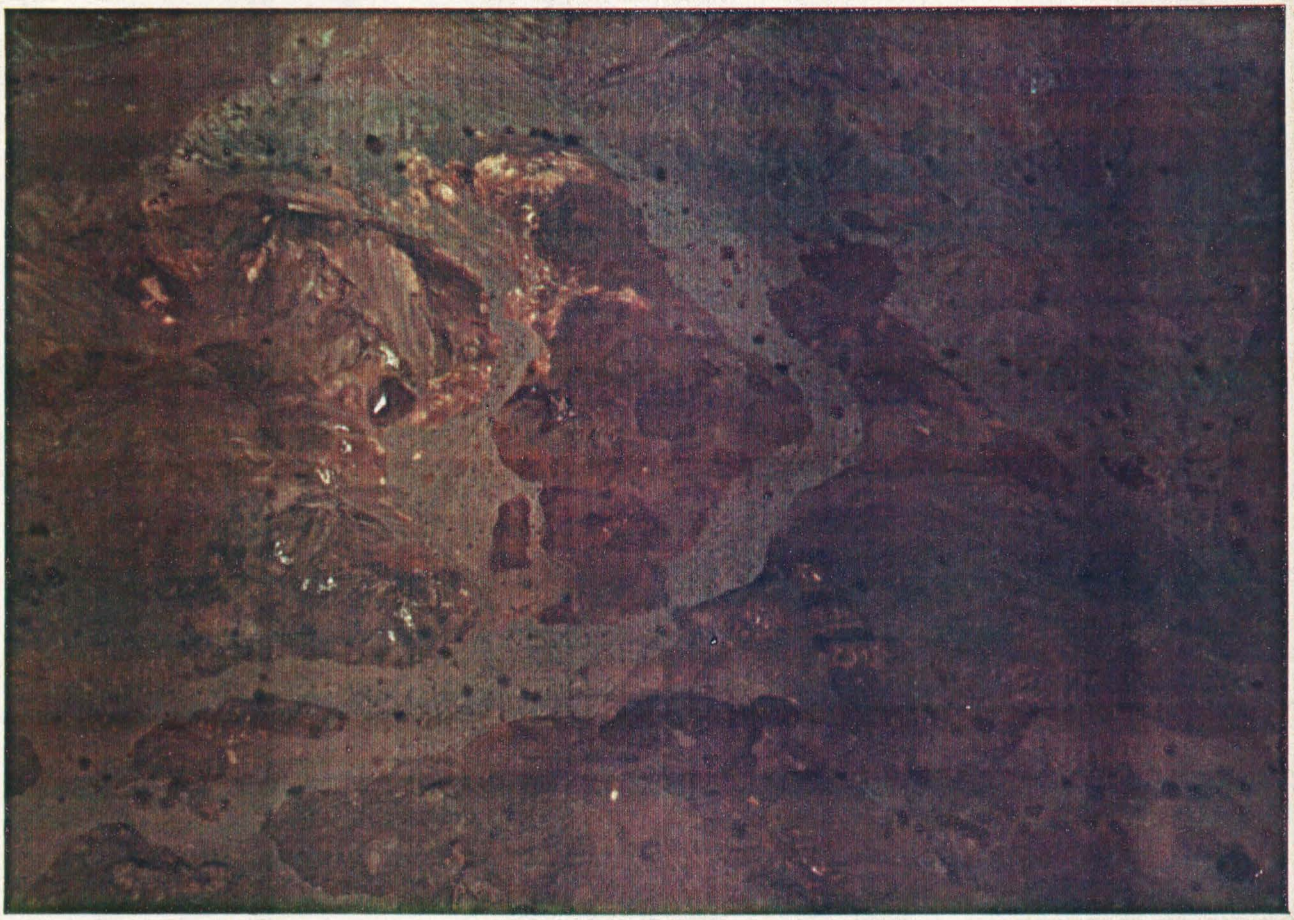

Photo 17. Rakah gossan zone viewed from the air looking northwest.

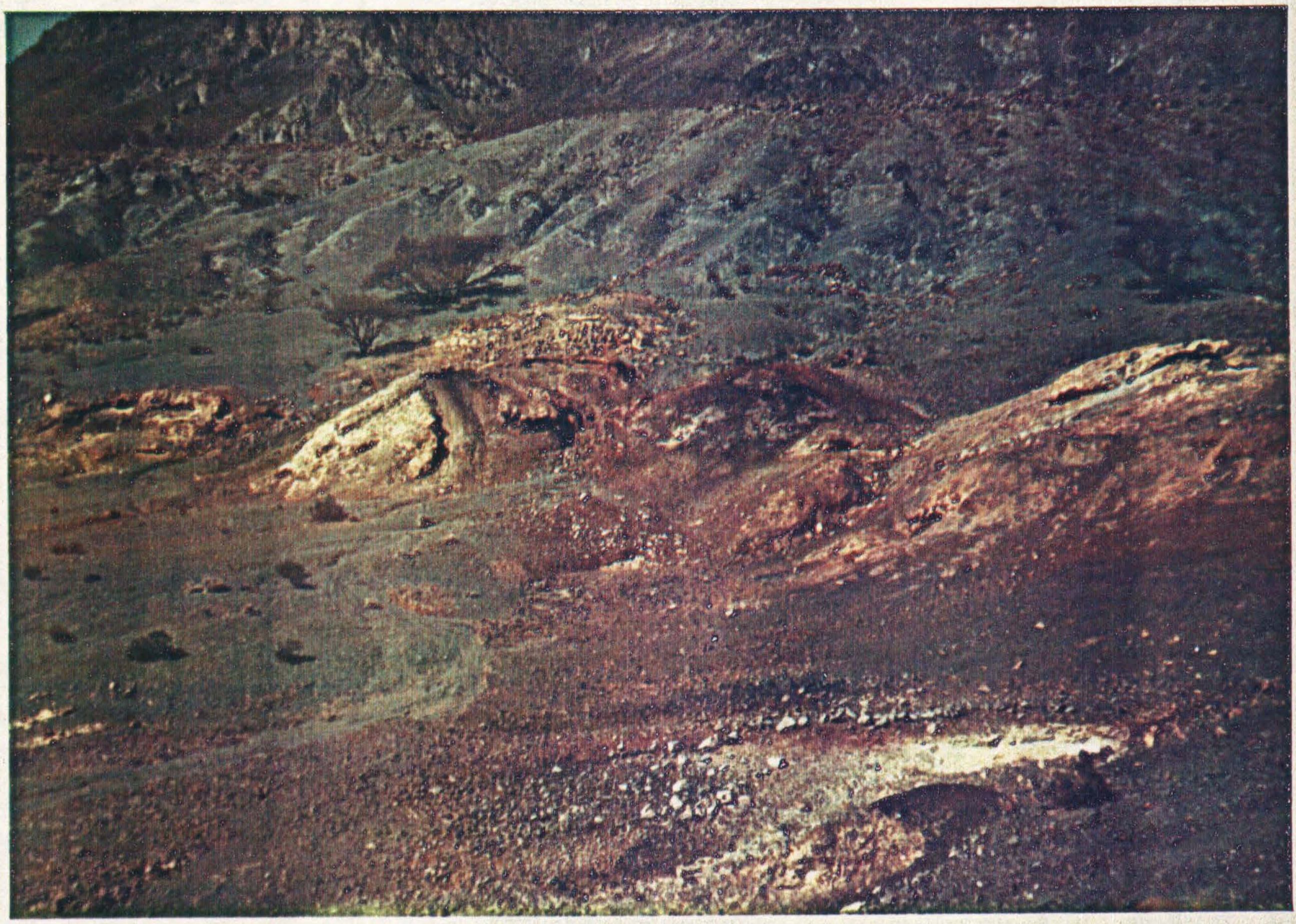

Photo 18. Northern part of the Rakah gossan zone where a little underground mining has been done, viewed looking west. Low greenish-gray slope beyond ore zone is composed of diabase dikes; high range beyond is chiefly gabbro.

(12) Maydan I (DB 390-334 Qumayrah)

The Maydan I deposit is in a narrow wadi about 1.5 km (1 mi) east of Tawi Salamah, which is in Wadi Ahin. Here for 450 m (1,500 ft) along an easterly trending shear zone in a peridotite screen in gabbro occur scattered veinlets of malachite, see figure 15. The mineralization is most intense in two zones near the margins of the peridotite, and in them generally copper stains were seen over widths of only a few feet. Although small slag piles indicate some ancient mining here, the deposit seems to have no potential for modern mining.

(13) Maydan II (DB 380-343 Qumayrah)

This deposit, which is also known as the Salama deposit, is less than 1 km (0.6 mi) west of the village of Maydan in Wadi Ahin and about 2 km (1.6 mi) northwest of the Maydan I deposit. As shown in photo 19 and figure 16, copper mineralization occurs in a shear zone separating cumulate peridotite from coarse-grained, locally pegmatitic gabbro. Across a small wadi 210 m (700 ft) to the south are prominent exposures of diabase dikes which strike almost due north and dip steeply eastward. The mineralized shear zone forms a bench 6-9 m (20-30 ft) wide on a southwest-facing slope and is in most places covered with talus. At its east end is a good exposure of the ore zone, but here chalcopyrite and secondary copper minerals are confined to a zone only 1 foot wide. The debris-covered bench is largely the result of ancient mining, and perhaps the ore zone was somewhat wider in this part. The scale of ancient mining is indicated by the size of the slag piles found on each side of the wadi and estimated to contain about 7,000 t. The deposit is too small to be of interest today.

(14) Bu Kathir (DB 374-149 Dank)

The Bu Kathir deposit is about 16 km (10 mi) west of Yanqul and 2.1 km (1.3 mi) south of the village of Bu Kathir in a small canyon that can be reached only on foot. Most of the rocks in the canyon wall are layered gabbro, but the ore showings occur in a fault-bounded screen of serpentinized peridotite. Secondary copper minerals are scattered on shear surfaces in a zone trending N. 60° W. and dipping 70° S. Copper "stain" occurs erratically over a width of generally less than 2 feet for a length of about 500 feet, and there are minor shows even beyond this. Selected pieces of mineralized rock from the ore zone gave 11.0 percent copper. The zone was formerly mined through one adit near its center and several small open cuts, but two slag piles noted in the area contain probably less than 1,000 t of roasted ore. In spite of the richness of the selected pieces, the showings do not warrant additional work.

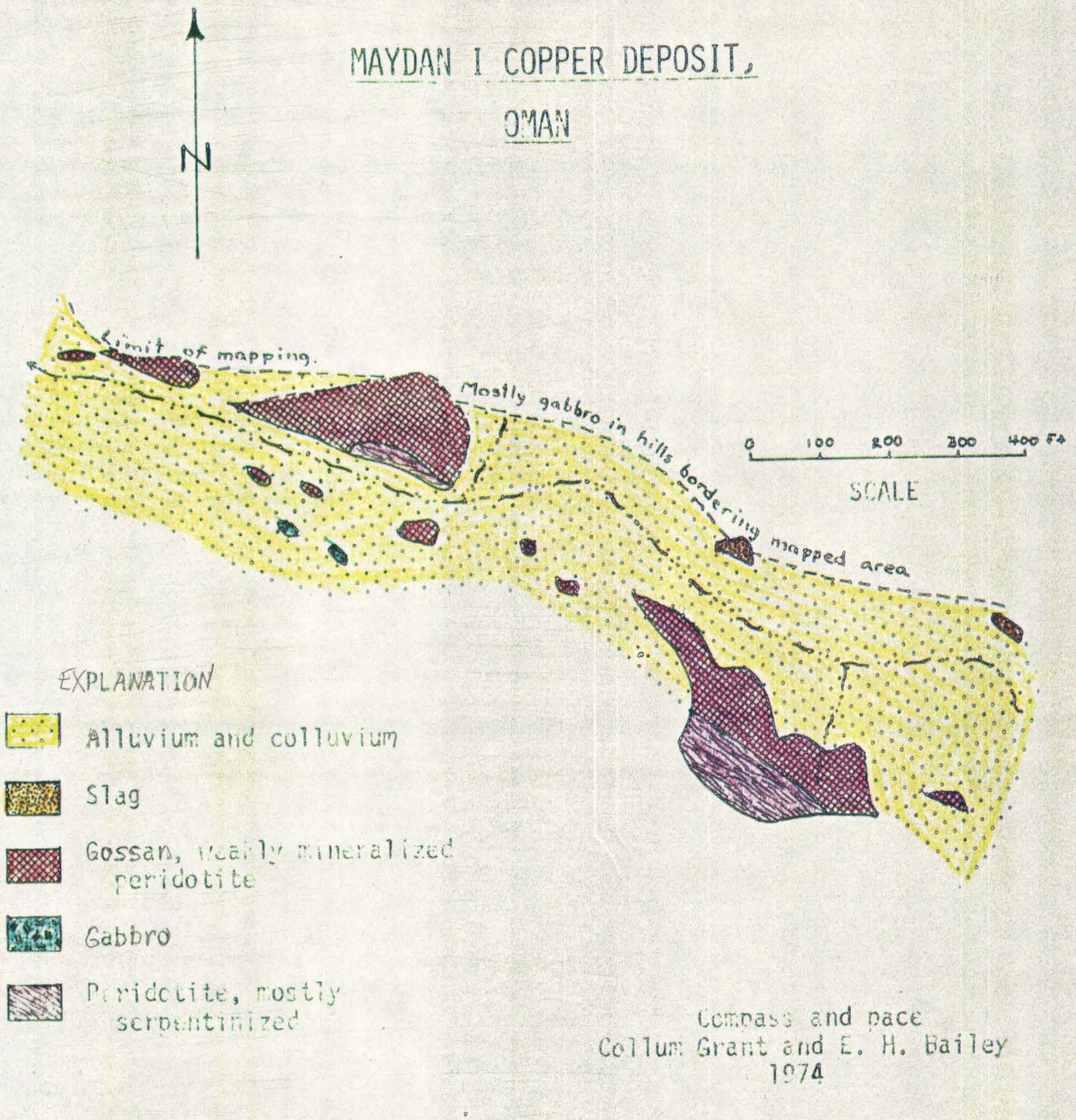

Figure 15. Geologic map of the Maydan I copper deposit.

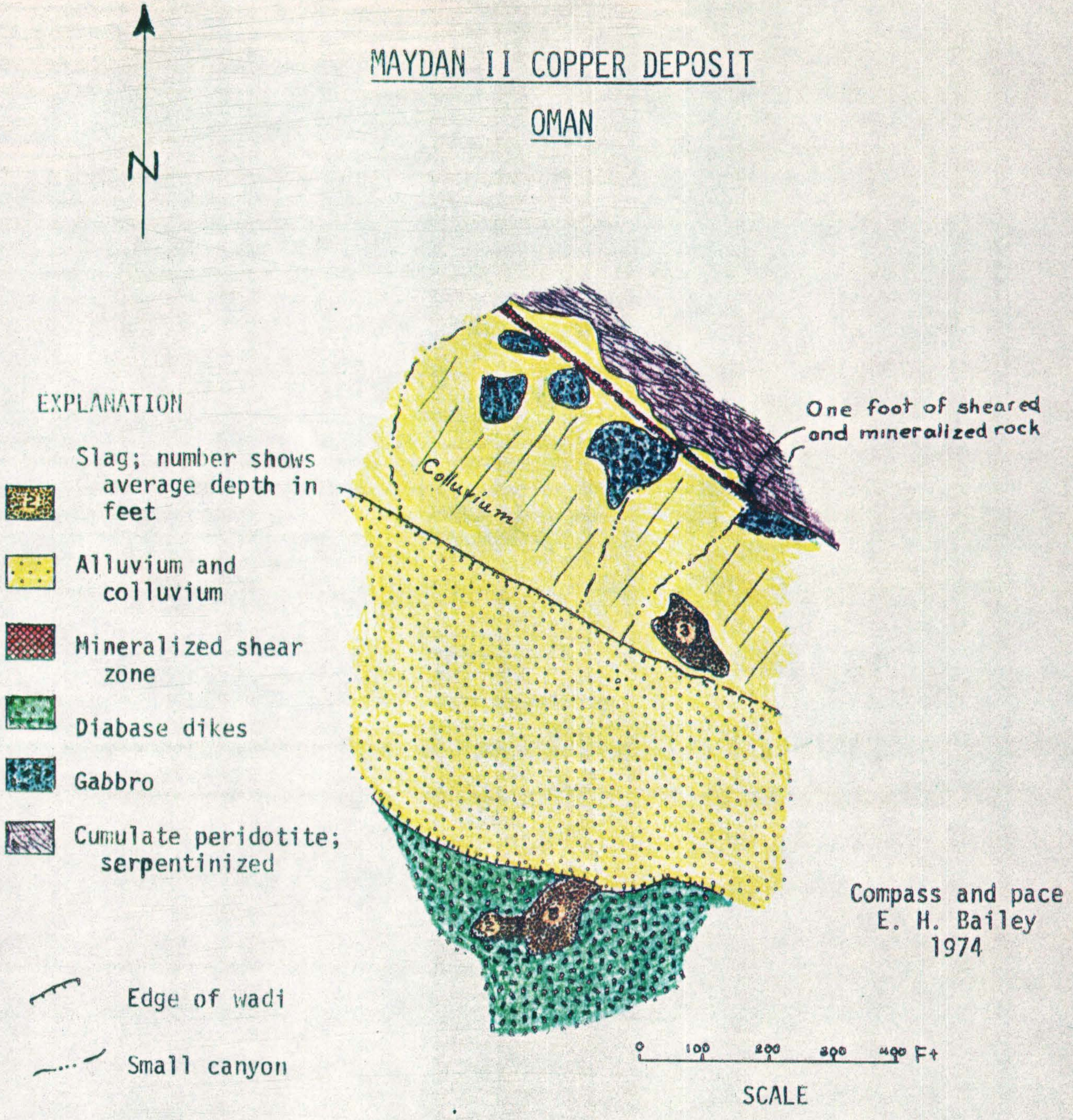

Figure 16. Geologic map of the Maydan II copper deposit.

Photo 19. Maydan II ore zone, viewed looking north. Rough rocks above ore zone are cumulate peridotite, and subdued rocks below zone are gabbro, which is locally altered. Most of brown gossan seen in photo is waste dumped down hill from mining along ore zone. Dark pile in center of base of photo is slag, and a little more can be seen above its right edge on the far side of the wadi.

(15) Hawirdit (DB 384-169 Dank)

The Hawirdit deposit is 3 km (2 mi) south of the small village of Ahdyah, from which it is accessible only by foot trail. Near the base of a south-facing hill are several dumps, eroded ancient cuts, and a small cave, see figure 17. The low ground is serpentinized peridotite but the upper parts of the surrounding hills are gabbro. In the east edge of the mineralized area the gabbro appears to be separated from the underlying peridotite by a more or less flat fault.

At the Hawirdit deposit we saw no real exposures of ore in place, but the material on the dumps, as well as the locations of the pits, indicate that the ore consists of secondary copper minerals in sheared peridotite. Some of the sorted ore on the dump is of good grade, but the quantity available is small. Extensive ruins of ancient buildings and slag heaps attest to former copper recovery; however, the deposit has no potential for mining today.

(16) Tawi Ubaylah (DB 147-776 Wadi Jizzi)

The Tawi Ubaylah copper deposit is 0.7 km (0.4 mi) southeast of the village of Tawi Ubaylah, a short distance south of the drainage divide of the Oman Mountains and east of the road between Wadi Jizzi and Buraimi. The ore zone extends along the side of a south-facing ridge about 25 m (80 ft) above the wadi at its base for a length of at least 210 m (700 ft), see photo 20. The upper part of the hill is gabbro and the lower part is highly sheared serpentinized peridotite containing blocks of gabbro. The contact is a steep fault trending N. 75° E. Ancient dumps and diggings form a narrow bench along the faulted contact, and although a gossan zone is locally exposed we could find no good exposure showing copper minerals in place. Pieces of sheared serpentine containing secondary copper minerals, azurite and malachite, are common as float or in dumps, and we found one piece showing a 1-inch vein of chalcocite. Samples of the gossan analyzed by Prospection Ltd. contained about 1 percent copper, and a grab sample from a gossan pile gave us a value of 3.0 percent copper (see table 6 in Appendix). In the wadi at the foot of the hill sheared peridotite is entirely unmineralized.

Across the wadi are extensive slag piles, at least 20 old furnaces, and ruins of numerous ancient rock buildings. This is the only place in Oman where we found pieces of copper matte and bowl-shaped chunks of slag, indicating the use of an advanced copper recovery process. Probably the ore zone at the Tawi Ubaylah deposit is too small to be mined today, but if the chalcocite zone is well developed it might have some potential. A drill hole or two into the ore zone would be interesting.

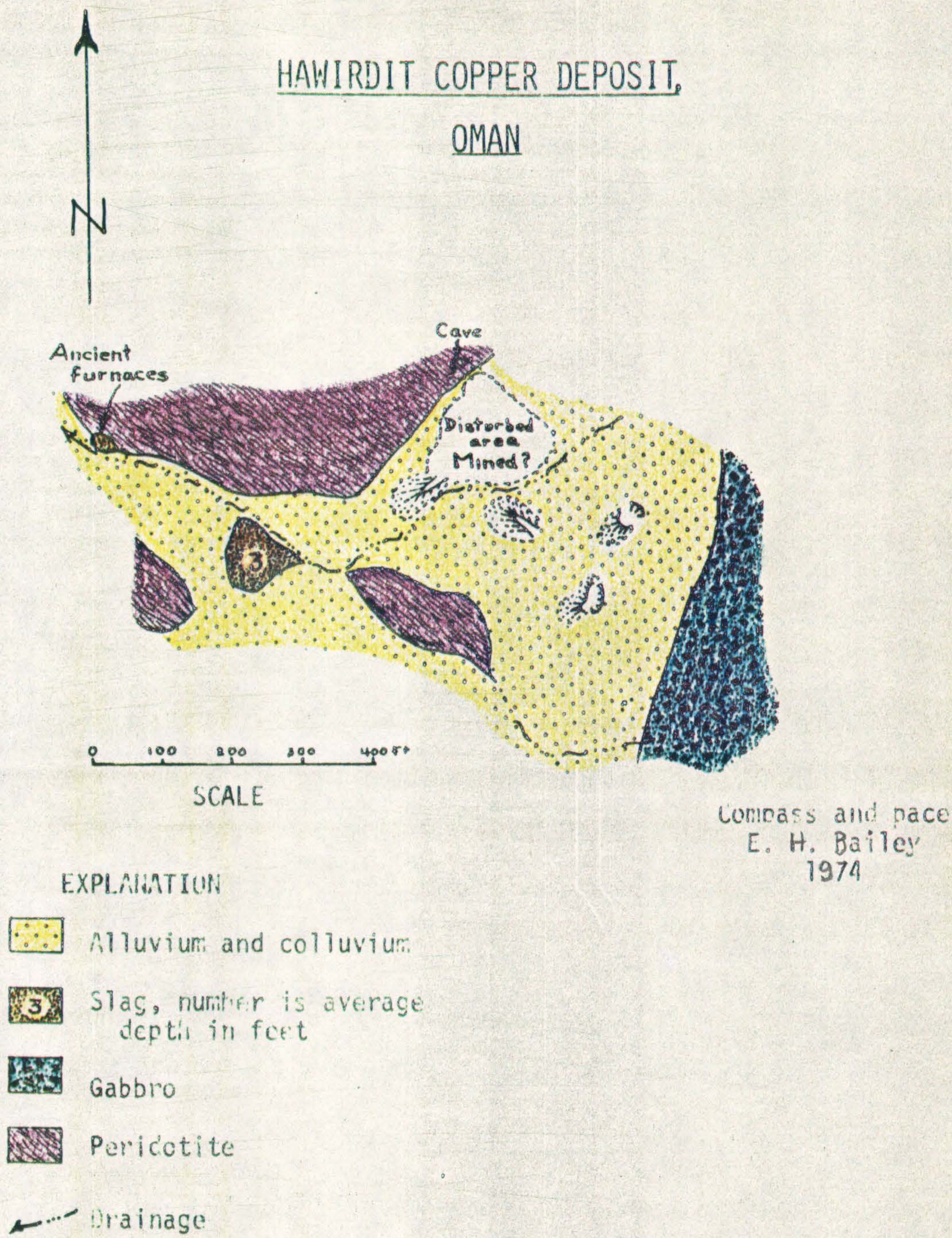

Figure 17. Geologic map of the Hawirdit copper deposit.

Photo 20. Mineralized shear zone of the Tawi Ubaylah copper deposit, viewed looking north. Rock lying above the ore zone is gabbro, and below is mostly serpentinized peridotite. Thin reddish-brown gossan cover on the slope below the ore zone is largely dumps resulting from ancient mining along the zone.

(17) Ghayl (DB 042-783 Wadi Al Jizzi)

The Ghayl copper deposit lies in an open valley about 13 km (8 mi) west of the Tawi Ubaylah deposit and 7.2 km (4.3 mi) southeast of Jabul Umm Dhawan. The ore zone is poorly exposed in a few low hills surrounded by alluvium and locally overlain by higher level terrace gravel. The deposit is in peridotite, but local gabbro dikes and layers near the deposit suggest that it is in the transition zone between peridotite and gabbro. Secondary copper minerals occur in sheared peridotite in an area 50 m (165 ft) long in a N. 20°W. direction over a maximum local width of 20 m (66 ft). The area contains some spots of good ore but is so churned by digging and covered with waste that it is impossible to tell how much of the zone shows significant mineralization. A grab sample of better ore in a waste pile assayed 3.2 percent copper. Because of the alluvial cover it is difficult to estimate the total length of the mineralized zone. It may go farther to the south, but along strike to the north of the deposit about 30 m (100 ft) are exposures of unmineralized peridotite. In the mined area are the ruins of at least 10 furnaces, and less than 1,000 t of slag is piled in the valley below. In spite of ancient mining the deposit does not appear worthy of additional exploration or sampling.

(18) Muden (EA 513-955 Nakhl)

The Muden occurrence of copper mineralization is on the north edge of the Oman Mountains 11.4 km (6.8 mi) S. 30° W. of Jammah. It consists of a mineralized shear zone between layered gabbro and diabase dikes along the north side of Wadi Muden. Disseminated copper sulfides and secondary copper minerals occur over a width of about 40 cm (16 in.), and the mineralized zone can be traced 90 m (300 ft) northwest of the wadi bank. An assay of a selected piece from the mineralized zone shows 12.2 percent copper (see table 6 in Appendix). No mining was done here in ancient times, and the occurrence is too limited to be of interest today.

(19) Luzak (FA 155-782 Tayin)

The Luzak deposit borders a wadi cutting gabbro hills about 5 km (3 mi) south of the village of Luzak. The site is by ruins of at least 25 houses and a shallow slag pile extending along the north side of the wadi for about 45 m (150 ft). At the east edge of the pile are pieces of gabbro containing a little chalcopyrite and secondary copper minerals along fractures. The source of the mineralized gabbro is uncertain, but about 300 m (1,000 ft) up the canyon northwest of the slag pile there is a possible cut in sheared and bleached gabbro. On the ridge above are other bands of bleached rock following shear zones trending a few degrees east of north. We are not sure we found the deposit from which the ore for smelting was originally mined, but there seem to be no promising outcrops in the area.

(20) Tabakhat (EA 480-340 Bahla)

The Tabkhat deposits are 6 km (3.5 mi) west-southwest of Nizwa, from which they can be reached by driving up a wadi for 5 km (3 mi) then parking and hiking southwestward up through a saddle some 60 m (200 ft) higher to reach the south slope of the ridge. The deposits consist of chalcopyrite and secondary copper minerals occurring in shear zones in peridotite, see photo 21. Locally, the peridotite contains veins of magnesite, but those are unrelated to the copper mineralization. The greatest mining was done in the underground workings shown in figure 18. Here there were two parallel zones, trending nearly east and dipping 65° N., that were mined to a known depth of at least 18 m (60 ft), and one shaft is reported to have reached a depth of nearly 60 m (200 ft). The mine is difficult to enter because of its steepness, and it is quite hot owing to the oxidation of the sulfides and lack of through circulation. Two chip samples taken in these workings by Prospection Ltd. gave 2.86 and 5.21 percent copper. Sample 621, taken by the writers across 1 foot of the ore zone underground as shown on figure 18 contained 2.1 percent copper. A grab sample from the dump gave 1.1 percent copper (see table 6 in Appendix).

High on the ridge to the south of the mapped mine is another tunnel which extends more than 50 m through the ridge. It is driven in peridotite and follows a mineralized shear zone about 1 foot wide along a fault trending N. 80° W. and dipping 80° W. Slickensides on the fault plunge 48° to the east. Twenty feet below the tunnel portal on the west end is another adit following the same zone, and in the general area are still other minor cuts and short underground workings.

In spite of the widespread mineralization and extensive underground workings, we found no slag in the area and none was known to our Omani guides. Possibly the ore was hauled to Nizwa for processing. The mineralized zones are too narrow and too inaccessible to be potentially minable now.

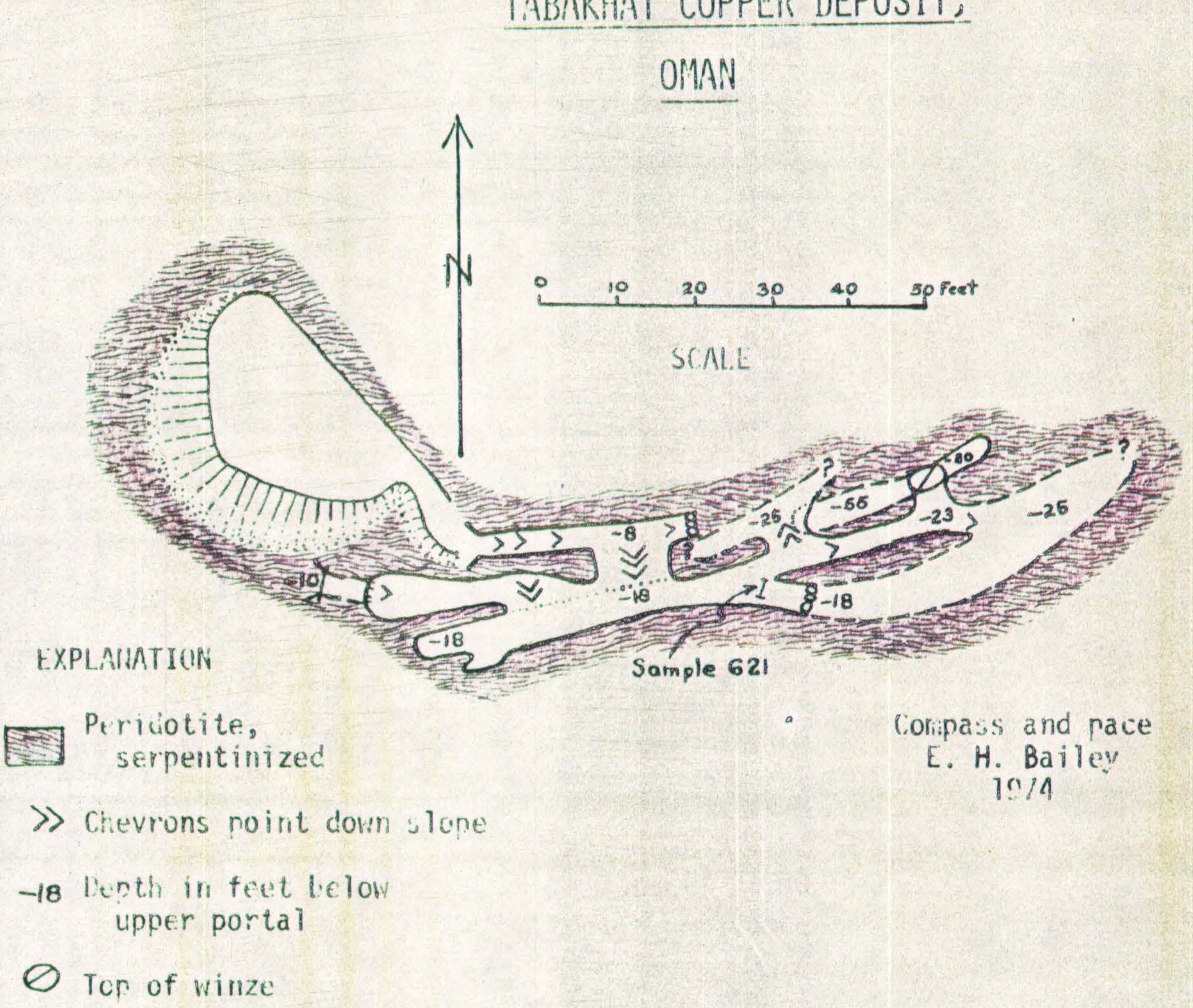

Figure 18. Sketch map of one of the underground workings at the Tabakhat copper deposit.

Photo 21. Peridotite hillside containing the main underground workings at the Tabakhat mine. Area in lower left of photo is the ancient dump which was sampled. The upper portal of the workings shown on figure 18 is a little more than one inch from the right margin of the photo and a little above the middle. The lower portal is in the shadow area directly below. Other workings are over the ridge beyond the figure on the skyline.

(21) Khafifah (FA 464-320 Samad)

Next to several houses on the edge of the village of Khafifah just before the road crosses Wadi Khafifah into the main part of the village is a slag pile in excess of 5,000 tons. The area is one of layered gabbro that is in fault contact with peridotite. No zone of mineralization was found, but in the gabbro west of the road a zone of hydrothermal alteration was seen. Assay of slag from this locality shows about 5 percent copper and a trace of silver (see table 7 in Appendix). We recommend no further work on this occurrence.

(22) Masakivah (FA 454-125 Samad)

The Masakivah occurrence is in the foothills of Jabal Haymah about 12 km (7.2 mi) N. 80° W. of Ibra. Here layered gabbro strikes northwest and dips 60° SW. near a contact with pendolite. In the gabbro a mineralized zone containing secondary copper minerals in shear planes extends less than 2 m (6.6 ft) and is not more than 10 cm (4 in.) wide. The occurrence is too small to deserve further attention.

(23) Inah (FA 700-337 Ibra)

The Inah deposit, which is 14.2 km (8.5 mi) N. 8° W. of Batin at the headwaters of Wadi Batin, can be reached only on foot after crossing the plain north of Batin. At the divide between Wadi Batin and Tayin numerous small adits have been driven into serpentinized pendolite. The mineralization appears to be disseminated chalcocite in sheared serpentine along a large northwest-trending fault. Numerous slag heaps totalling perhaps 5,000 t indicate it was a fairly active mine in ancient time. The showings are too small and scattered to warrant further work on this prospect.

(24) Eedah I (FA 173-446 Wadi Tayan)

The Eedah I deposit is reached by driving 12.8 km (8 mi) north up Wadi Andam northeast of Mahaliyah and turning off eastward to go up a ravine 1 km (.6 mi). It also can be reached from the Ibra-Muscat road at the Wadi Andam crossing by driving southwest for 7 km (4 mi). Here in the foothills of a gabbro range are prominent slag dumps containing a little less than 5,000 t and several old ruins. Bleached gabbro up the canyon to the east contains local copper "stain" but we found no definite excavation. The feeble showings do not warrant additional investigation.

(25) Eedah II (FA 171-439 Wadi Tayin)

The Eedah II deposit is east of Wadi Andam, and about 0.8 km (0.5 mi) southwest of the Eedah I deposit but in the next wadi to the south. The rocks on both sides of the canyon are gabbro which for 300 m (1,000 ft) along the wadi bank has been hydrothermally altered to a snowy white clay. A sample of an 8-cm (3-in.) iron-stained zone cutting the clay contained less than 0.05 percent copper (see table 6 in Appendix). On the hillside above, gabbro overlies the bleached rock with an abrupt, though apparently unfaulted, contact. It shows good cumulate texture and prominent N. 85° W., 45° N. layering. Although on a bench by the Wadi there is a slag measuring 60 m x 9 m (200 x 30 ft), we could find no copper mineralization in place.

(26) Hoowasi (FA 090-378 Samad)

On a west-side bench above Wadi Andam less than 3 km (2 mi) north of Mahaliyah are two small piles of slag containing only a few hundred tons. Some of the slag contains copper staining, but no pieces of ore were found. Across the wadi, on a sharp point between it and a tributary, is what is apparently an ancient cut, now much caved and eroded, about 25 m (80 ft) long and 2.5 m (8 ft) wide. The cut is in peridotite, and the presence of gabbro a short distance up the wadi indicates it is near the contact. Although there is considerable iron oxide along fractures, we found no copper mineralization here.

(27) Khara (FA 772-108 Ibra)

The Khara copper deposit is 5.5 km (3.3 mi) southeast of the village of An Niba and 19 km (12 mi) east-northeast of Ibra near the head of a northwestward-draining wadi. The surrounding hills have gabbro in their upper half with serpentinized peridotite containing some large blocks of gabbro below. The contact in a regional sense is nearly horizontal although undulatory, but in the mineralized area is a nearly vertical fault trending northwestward. Locally along the fault are ancient cuts in sheared peridotite containing thin veinlets of secondary copper minerals, and on dumps we also found some scattered chalcopyrite. The largest cut, which in its present eroded condition is about 9 m (30 ft) wide and 18 m (60 ft) long, follows N. 10° E. fractures up into the gabbro. By this cut is a pile of mineralized rock, presumed to be unprocessed ore rather than ore rejects, which yielded a grab sample that analyzed 4 percent copper (see table 6 in Appendix). At the base of the hill is an extensive slag pile and the ruins of at least 16 houses. An assay of the slag shows 5.9 percent copper. The antiquity of the mining is suggested by erosion of the miners' hillside trail by a gully that has cut into it to a depth of 8 feet.

In a canyon about half a kilometer to the northeast we also observed some copper "stain" along a northwest-trending shear zone in peridotite.

These deposits are not rich enough or extensive enough to have present-day mining potential.

(28) Zahir (FY 866-986 Al Mintirib)

The Zahir deposit is 1.8 km (1.1 mi) S. 52° W. from the village of As Zahir and can be reached easily by crossing the wadi and approaching the southern tip of Jabal Suwadiyah. The mineralized zone is in a saddle on top of a hill consisting mainly of Semail gabbro. A shear zone 1-3 m (3-10 ft) wide contains primary copper sulfides along with extensive gossan consisting of secondary silicates, sulfates, and iron oxides. The mineralized zone trends northwest and has an exposed length of 42 m (142 ft). An analysis of mineralized gabbro within the ore zone gave 1.2 percent copper, and iron-rich gossan material had 1.7 percent copper (see table 6 in Appendix). Ancient mining produced a single dump near the mineralized zone and numerous slag heaps that would aggregate less than 1,000 t. The small number of ancient building foundations and the small smount of slag indicates the production of this mine was small. We recommend no further work on this deposit.

(29) Shwayi (FA 075-188 Samad)

The Shwayi copper deposit is about 4.5 km (2.7 mi) east of the village of Majazah in the Wadi Andam, or about 32 km east of Izki. The main mineralization is in an area of very low hills nearly engulfed in alluvium, and as there is no prominent development of colored gossan, the deposit would be difficult to locate were it not for the extensive piles of black slag bordering it.

The deposit consists of two separate ore bodies developed in gabbro, see figure 19. The northern ore body, which is very poorly exposed, is elliptical in shape with a length of 210 m (700 ft) and a width of about 60 m (200 ft), see photo 22. In its western half is an undrained depression 1 m (3 ft) lower than the general ground level and blanketed with washed-in detritus. Probably its depressed level is a result of ancient mining, but no evidence of this other than the depression itself remains. In its eastern part, small irregular pits are cut into leached and iron-stained gabbro locally containing secondary copper minerals. On a small hill at its southern margin is an inclined shaft, which is now inaccessible but probably not very deep.

The second ore body is a few hundred feet south of the first, see figure 19. It is roughly circular with diameter of about 75 m (250 ft), but because the western limit is an alluvium boundary it might extend farther west. The mineralization is less intense than in the northern ore body, and the gossan area as mapped includes some weakly mineralized gabbro.

About a kilometer north of these deposits along the foothills of a low range is a prominent steep eastward-trending fault separating serpentinized peridotite on the north from gabbro on the south. The path of the fault is marked by extensive terraces of white aragonitic tufa deposited by calcium hydroxide springs having a pH of 11.2. Along the fault are several dumps containing secondary copper minerals, but the mineralization does not anywhere seem to be extensive. Analysis of mineralized gabbro from one of the dumps yielded 2.0 percent copper (see table 6 in Appendix).

The main Shwayi deposit cannot be properly evaluated, as surface leaching makes it impossible to ascertain the copper content of the primary ore. Because oxidation at the surface is incomplete, we assume the depth to primary ore is not great, and deep trenching or bulldozing across the largest ore body might be adequate to determine its grade. Drilling would be more satisfactory but also more costly. It is probable that the deposit is not of commercial grade, as deposits of this type in gabbro generally are not, but it cannot be entirely dismissed without further physical exploration.

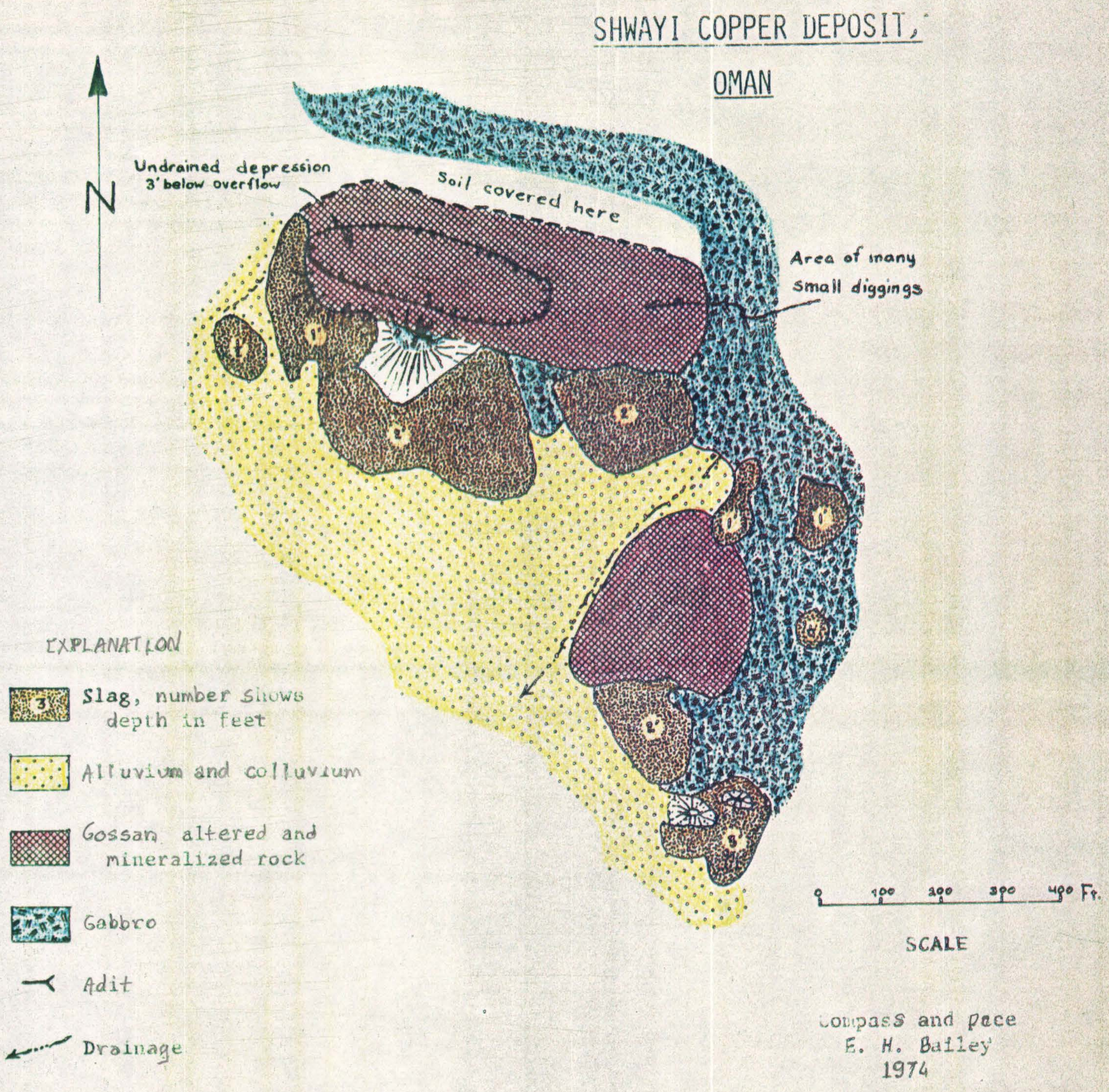

Figure 19. Geologic map of the Shwayi copper deposit.

Photo 22. Shallow depression believed to overlie the northern ore body of the Shwayi copper deposit, looking east. Toward the far end of the depression to the right of the trees colors due to iron staining can be seen in some of the less altered gabbro.

Iron And Nickel(?) Deposits In Laterite

Summary

Ancient residual and reworked laterites lie on the Semail ophiolite in several places throughout Oman. They have been found at Jabal Fanjah where Wadi Semail enters a narrow gorge before flowing onto the Batinah coast, and extensive laterites underlie protecting bluffs of shallow marine limestones in the vicinity of Kalahay Niba northeast of Batin in the Ash Shargiyah country. The laterite is believed to have formed as a result of tropical, or perhaps submarine, weathering of the ophiolite and, as the surface on which it formed cuts at low angles across the sequence, in some places it was derived from peridotite and elsewhere from gabbro or volcanic rock. Because the Semail ophiolite contains particularly high contents of iron, nickel, and chromium, the weathering process has concentrated these elements in the residual laterite, and locally further concentration has been brought about by reworking. One can expect the laterites formed on the different rocks to have different mineral potential; for example, laterites formed on peridotite might be rich in nickel or even chromium, but are less likely to have as high content of iron as those formed from gabbro. However, we have not had time to make a study of their variations in relation to the parent rock.

As compared to vein or lode deposits, laterite deposits are generally widespread and have the potential to yield very large tonnages of ore. Many of the large iron-nickel laterite deposits of the world have developed on peridotite similar to those in the Semail ophiolite, so it is possible major deposits exist in Oman. However, the Oman deposits in most places are overlain by massive limestone which presents a formidable barrier to mining unless places can be located where the limestone is thin or stripped off by erosion.

The laterite formed during latest Cretaceous time (Maestrichtian), soon after the generation of the Semail ophiolite, probably in late Campanian time, and before the deposition of the Paleocene shallow-water marine limestone that overlies the laterite in the Kalahay Niba area. Laterite in southwestern Saudi Arabia (Overstreet and others, 1973), and also those in Ethiopia (Mohr, 1962), are considered to have formed during the same time period, suggesting that a large area of tropical weathering then extended across the southern Arabian Peninsula and eastern Africa. The oolitic iron deposits within the Shumaysi Formation east of Jeddah, Saudi Arabia, are considered to be Late Cretaceous or Paleocene in age, and conceivably they may also be reworked laterite similar to the Oman laterite (Shanti, 1966).

The section following provides more detailed descriptions of the laterite deposits we have examined, but there are many miles of contact between the Paleocene limestone and ophiolite that we have not had time to examine, see figure 20. To properly assess the iron and nickel potential of the laterite in Oman, all of these areas should be carefully inspected, and sampled where the outcrops warrant this.

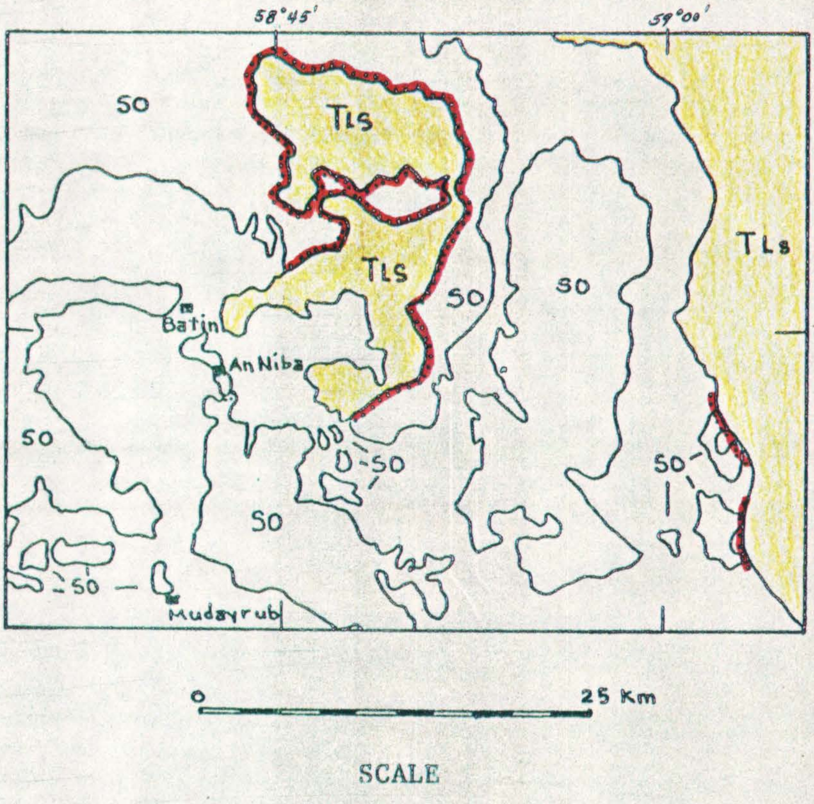

Figure 20. Sketch map showing area of potential iron deposits in the laterite (dots) developed on Semail ophiolite (SO) and overlain by Tertiary limestone (Tls). Unlabelled areas are young alluvial deposits.

(30, 31) Kalahay Niba I (FA 597-149) and II (FA 787-215 Ibra)

The Kalahay Niba iron-rich laterite deposits are 7-9 km (4-5.5 mi) northeast of the village of Batin and easily reached from it by following up the drainage of Wadi Batin to the limestone bluffs. The deposits occur directly under the limestone cliffs that here have a thickness of 25-30 m (83-100 ft), as shown in photo 23. We found no exposures of laterite without the protective capping of limestone. The laterite is quite variable in thickness 15-30 m (50-100 ft) as it appears to follow channels, and sedimentary bedding within it also suggests some reworking. The iron-rich laterite is locally pisolitic and reddish-brown in color, as shown in photo 24. Some layers appear to be nearly pure hematite and geothite with only minor amounts of residual silicates. Chemical and spectrographic analyses of eight selected samples reveals a range from 30 to 51 weight percent iron, with surprisingly high chromium values of 1.18 to 12.53 percent (see table 8 in Appendix).

The distribution of the iron laterite faithfully following the exposed cliff-forming contact of the marine limestone is shown in figure 21. Assuming that the now known exposed laterite has an average thickness of 15 m (50 ft) and extends at least 150 m (500 ft) behind the limestone bluff with a total outcrop distance of 5.5 km (3.3 mi), a value of approximately 50 million metric tons of an average grade of 40 percent iron has been calculated. However, considerable more work is required to fully characterize the grade and tonnage of the actual reserves available. During our investigation we were not able to inspect all of the contacts between the limestone and Semail ophiolite, and so all of these contacts should be considered as having a possible laterite preserved under the limestone.

(32) Salaht (FA 822-143 Ibra)

The Salaht iron occurrences are 9 km (5.4 mi) east of the village of An Niba. Here resting on top of the Tertiary limestone of Jabal Salaht is a 60 m (200 ft) section of cross-bedded sandstone interlayered with thin beds of shale. Within the sandstones are several lenses up to 15 cm (6 in) thick of sandstone in which hematite forms an interstitial cement. These lenses are continuous, and within the section there are five separate iron-rich beds.

Analyses at one layer shows > 10 percent iron and 0.3 percent chromium. The high chromium indicates that the iron in these sediments maybe reworked from the laterite produced on the Semail ophiolite. As the exposure of this iron-bearing sandstone is less than 3 sq km and the volume of the iron-bearing lenses very small, we recommend no further work on this occurrence.

Photo 23. Kalahay Niba I iron laterite exposed directly under Tertiary limestone. Material in foreground is Semail volcanics. Viewed looking southwest toward OM-114 where channel samples were obtained.

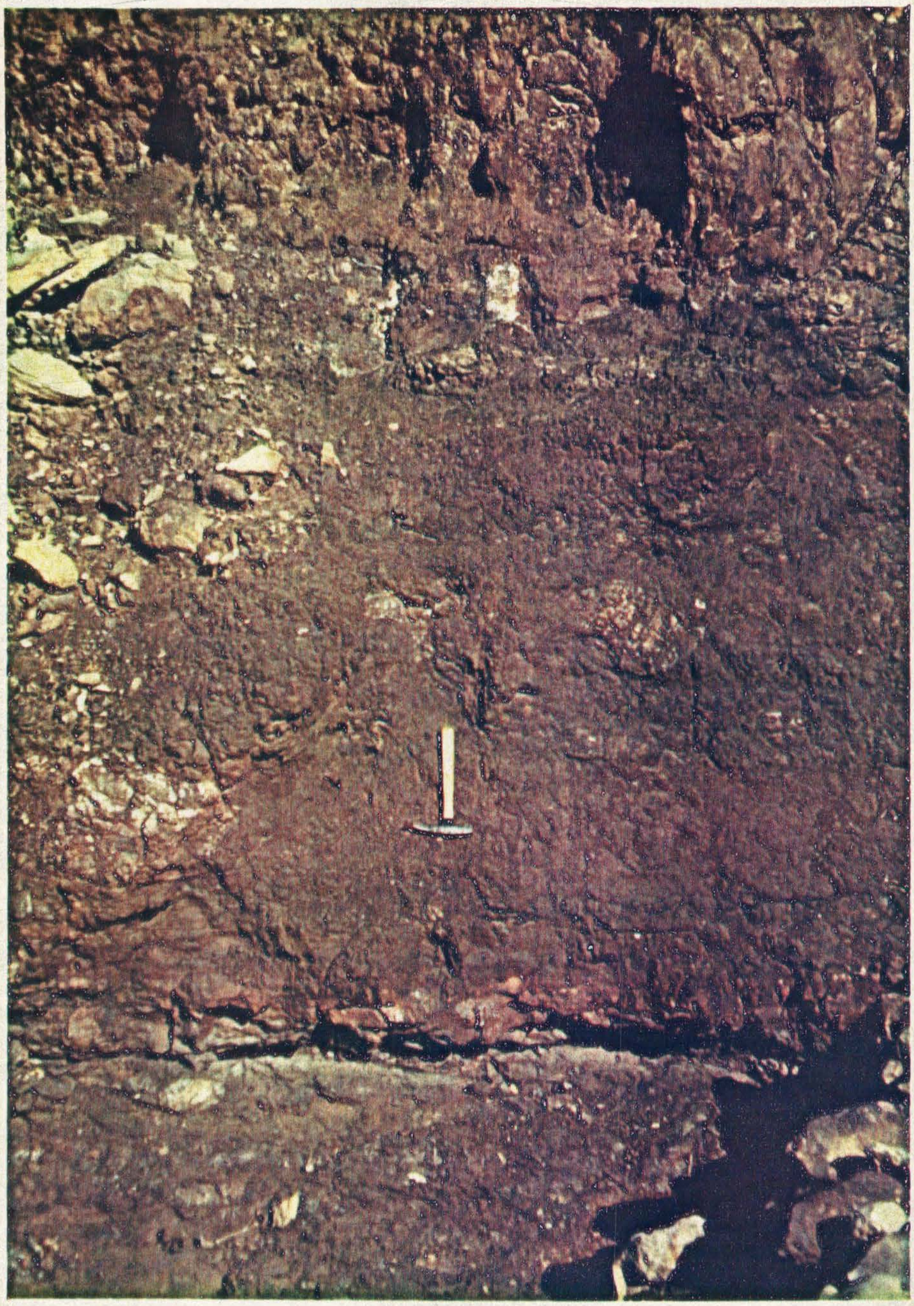

Photo 24. Exposure of pisolitic iron ore at Kalahay Niba I. Assay of representative material from this ledge is 44.6% iron.

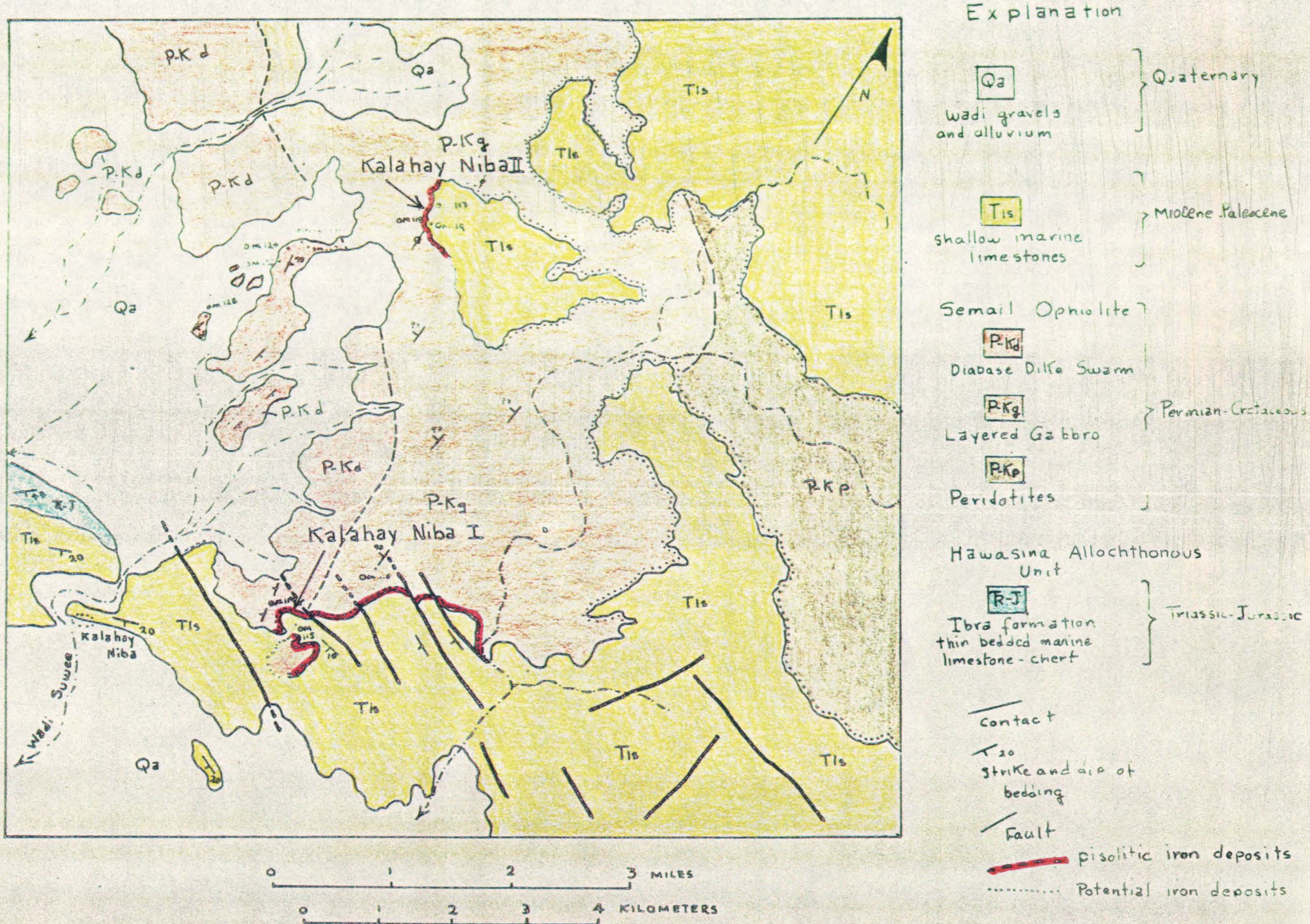

Figure 21. Map showing locations of the Kalahay Niba iron deposits in laterite below Tertiary limestone, and unexamined extensions of the laterite that have equally good potential.

(33) Wasit (EA 589-338 Birkat Al Mawz)

About 5 km (3 mi) east of Nazwa on the east side of Jabal Al Hawrah, and reached by driving north from Nazwa road near Wasit, is what appears to be an ancient open pit or quarry. It is cut into a deeply weathered peridotite, and much secondary carbonate occurs in the upper part of the weathered profile. It may have been dug to extract the carbonate for use in making a form of mortar but no direct evidence for this was found. Spectrographic analysis of material from the top part of the laterite showed 0.07 percent nickel, 0.15 percent chromium and less than 5 percent iron. This mysterious ancient cut warrants no further attention as a potential source of ore.

(34) Fanjah (FA 137-944 Ibra)

Along the high ridge of Jabal Fanjah 2 km (1.2 mi) S. 76° E. of the village of Fanjah is a red laterite developed on Semail peridotite and exposed over an area of approximately 18 sq km (7 sq mi). Middle Miocene folding has steeply tilted both the laterite and an overlying protective limestone, and rapid erosion has removed much of the exposed soft, rich upper part of the laterite. The weathering profile within the peridotite consists of approximately 30 m (100 ft) of massive brown-weathered peridotite, containing iron oxide accumulations on fracture surfaces at the base, overlain by laterite approximately 18 m (60 ft) thick. The basal part of the red altered peridotite is cut by silica-rich cross-cutting veins, and this grades upward into a red jasper and hematite zone having hard parts that form the ragged outcrops of the upper reaches of Jabal Fanjah. Hematite-rich areas 15 x 30 m (50 x 100 ft) are present as pockets within the jasper, and at the top of the section, we found a small pit in soft, bright red, ochreous material that suggested this may have been the site of an ancient mine.

Analyses of a sequence of samples from the unaltered peridotite into the laterite are given below (see also table 9 in the Appendix):

Sample Numbers	Height above base in feet	Materials	Weight Percent Fe	Ni	Cr	Si
OM-276	225	Top of laterite. Soft iron ore	31.6	.1	.2	22.5
OM-274C	165	Hematite-rich laterite	55.0	.3	.1	6.3
OM-274B	165	Laterite, red jasper	11.7	.07	.1	37.1
OM-274A	165	Laterite, iron-rich peridotite	13.9	.15	.2	.5
OM-272	120	Completely weathered peridotite	5.0	.29	.2	15.1
OM-271	70	Brown weathered peridotite	5.2	.24	.2	17.8
OM-270	0	Fresh peridotite	4.9	.24	.2	16.8

The laterite zone at Fanjah contains hematite-rich zones that are ore grade, but the red jasper which predominates in the laterite is too low in iron and too high in silica to provide a useable source of iron ore. Furthermore, the concentration of silica in the laterite zone produces a very hard and resistant rock, which would be costly to grind or to process metallurgically.

We recommend further work in this area to estimate the total tonnage of the hematite-rich soft ores available in the hard red jasper zone. Our work was conducted along only one vertical profile, and so may be biased with respect to the potential of this deposit.

Chromite Deposits in Semail Peridotite

Chromite is a common accessory mineral in the Semail peridotites, and although the crystals are commonly small it can be detected in almost any specimen by using a hand lens. Two representative samples of Semail enstatite peridotite analyzed by PDO contained between 0.4 and 0.45 percent Cr_2O_3. However, only locally within the great expanse of the Semail peridotite is chromite found in masses large enough to be of potential economic significance. All the concentrations of chromite we saw in the peridotite were in dunite rather than in the more abundant harzburgite, which is also generally true in other parts of the world. The chromite occurs as layers or stringers, and in some places it exhibits cumulate texture, such as is normally associated with direct crystallization from an igneous melt. Previous workers (Greenwood and Loney, 1968; Peters and Kramers, 1974) have noted for the chromites in Trucial Oman habitats different than we describe above. They refer to podlike bodies extending up to 100 m in length and containing up to 100,000 metric tons of ore. Smaller sacklike bodies of less than 1,000 metric tons are described as generally parallel to primary igneous layers. The chromite prospects in Northern Oman appear to be concentrated in a layered zone in peridotite 100-200 m below the contact with the overlying gabbro. Those we have seen are cut by abundant faults and "pull-aparts" which disrupt the continuity of the ore layers and make both mining and tonnage estimates difficult.

The value of chromite ore depends on both the quantity of chromite present and the ratio of chromium, iron, and aluminum in the chromite mineral itself. Compositionally, three general kinds of chromite ore are recognized: (1) high-chromium, which contains 46 percent or more Cr_2O_3 and has a chromium/iron ratio of 2:1 or more; (2) high-iron, which contains 40-46 percent Cr_2O_3 and has a chromium/iron ratio of less than 2:1; and (3) high-aluminum, which contains more than 20 percent Al_2O_3, and more than 60 percent Al_2O_3 and Cr_2O_3 combined. High-chromium ores are used for metallurgy, and high-aluminum ores are used mostly for refractories. Only high-iron ores are used for making chemicals, and they are also of major importance for making alloys and refractories (Thayer, 1973).

Chemical analyses of the Oman chromites, together with some previously published for Trucial Oman, are given in table 2 and additional chemical data is given in table 10 of the Appendix. The Oman samples represent chips across the ore zone and are not pure chromites. The Cr_2O_3 values on our samples are less than 37 percent Cr_2O_3 and the chromium/iron ratios are below the minimum generally required for metallurgical grade which brings a price about twice that for refractory-grade ore. However, the samples from Trucial Oman have a higher chromium content and more suitable chromium/iron ratio. Considering the similarity of geology, it is likely that in central Oman specimens and even small lenses of commercial-grade chromite ore also can be found. However, we do not recommend a specific search be made in the peridotite for chromite deposits, as the chances of finding an overlooked deposit of commercial size and grade seem to be too small to justify such a search.

Table 2.--Chemical analyses of chromites from Oman and Trucial Oman

		Cr_2O_3	Al_2O_3	FeO	MgO	Cr/Fe
Oman*						
Masakirah	OM-110	36.5	21.4	15.6	11.6	2.05
Mudi	OM-138	33.3	27.7	12.6	16.5	2.33
Aka Keya	OM-356	37.9	--	14.15	--	2.68
Trucial Oman (Greenwood and Loney, 1968)						
Masfut No. 1		52.52	11.22	17.91	14.11	--
Masfut No. 1		56.5	11.9	18.9	12.9	2.63
Masfut No. 1		48.25	10.45	16.59	16.65	2.56
Masfut No. 1		54.4	10.8	16.9	14.0	2.8
Manama No. 1		45.01	17.93	15.01	16.82	--
Manama No. 1		48.77	18.75	15.32	15.30	--
Manama No. 1		50.7	19.4	15.7	14.2	2.84
Masfut No. 5		46.43	--	14.39	--	2.84
Masfut No. 10		47.64	--	16.59	--	2.53
Masfut No. 12		51.99	--	16.08	--	2.85
Siji		34.70	--	15.44	--	1.98
Al Fujairah (Peters and Kramers, 1974)						
F 315		45.1	18.2	13.7	15.2	2.91
F 326		47.9	19.4	13.7	14.0	3.09
F 313		38.5	22.8	14.2	14.4	2.39
F 316		45.2	18.2	13.7	14.7	2.91
F 385		40.6	21.7	17.0	13.5	2.10
F 291		61.3	8.0	13.5	13.0	4.01
F 286		55.3	10.3	14.4	13.4	3.38
F 216		59.0	11.4	15.4	13.0	3.37
F 121		51.0	16.0	15.4	13.8	2.90

*Analyses by Sarah T. Neil, U.S. Geological Survey, Menlo Park, Calif.

Descriptions of chromite deposits

(35) Masakirah (FA 597-149 Ibra)

The small Masakirah chromite deposit is exposed on an open low surface 6 km (3.6 mi) N. 23° E. of Ibra. The chromite ore occurs as discontinuous elongate stringers, some measuring 7 x 3 m (23 x 6.6 ft) within dunite surrounded by harzburgite, see figure 22. The contact between the chromite stringers and dunite is diffuse as the chromite occurs as a cloud of individual grains imbedded in the olivine rock. The area of chromite occurrences extends through a narrow elongate lens of dunite and a rough estimate of the quantity available is about 5,000 tons. Analyses of the chromite ore given in table 2 indicate it to be only of refractory grade, and we recommend no further work on this deposit.

(36) Mudi (FA 958-025 Al Mintirib)

The Mudi deposit is 8.5 km (5.1 mi) N. 71° E. from the village of Az Zahir. It consists of a vertical layer of chromite about 1 m wide and extending approximately 15 m along a very steep inaccessible gully in harzburgite. The abundance of float in the gully suggests that a much larger body previously exposed has been largely washed away. The texture within the layer indicates primary cumulus origin; however, no other layered rock or gabbro was seen near this occurrence. The chemical analysis of chromite from this deposit is given in table 2. We estimate only about 900 metric tons of chromite ore could be obtained here and recommend no further work.

(37) Aka Keya (DB 026-786 Wadi Al Jizzi)

At the Aka Keya locality, which is 6.4 km (3.8 mi) S. 32° E. from Jabal Umm Dhawan, chromite stringers follow a dunite zone in Semail peridotite for a distance of 700 m (2,310 ft), see photo 25. They show some cumulate texture but are discontinuous and pinch out over distances as short as 10 m. As the entire dunite zone has undergone folding and faulting it is difficult to estimate the possible amount of chromite ore available, but it is believed to be less than 1,000 metric tons. A chemical analysis of chromite from this deposit is given in table 2. Owing to the small size and broken nature of the deposit we recommend no further work be done on it.

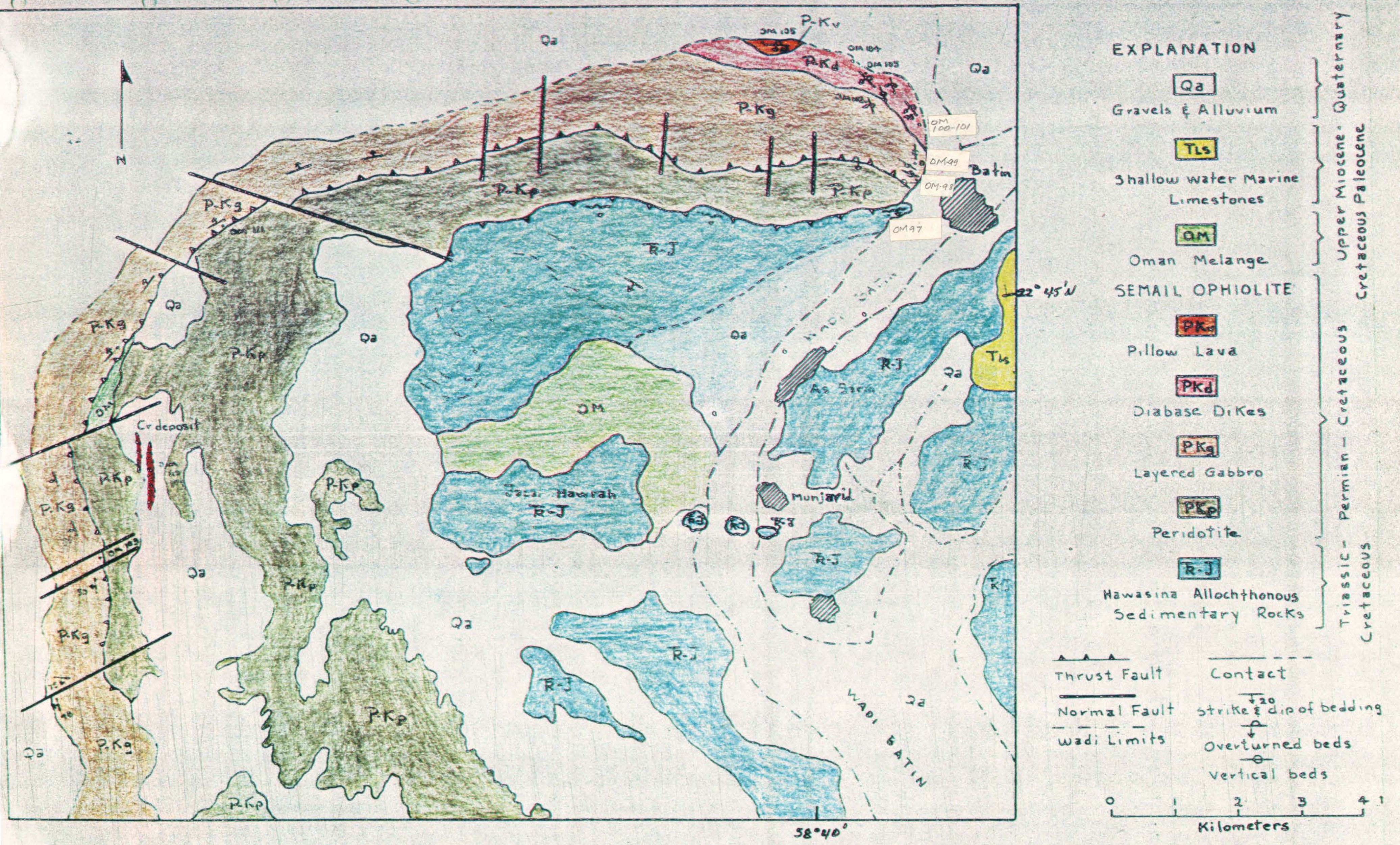

Figure 22. Map showing location and geologic setting of the Masakirah chromite deposit.

Photo 25. Aka Keya chromite deposit showing light brown dunite zone within darker brown peridotite. Dark material in foreground is chromite rubble derived from a single stringer. Orthopyroxenite forms ribs crosscutting the dunite.

Manganese Deposits in Hawasina chert

Scattered manganese deposits have been found in the Hawasina cherts in several areas. These deposits represent direct accumulation of manganese oxides on the ocean floor during the deposition of deep-water cherts that characterize the Hawasina Formation. As a general rule, the manganese ore forms thin lenticular beds, blebs, or pods which as deposited have limited continuity. In addition, local disharmonic folds and minor faults interrupt the ore beds. We believe the Jaramah deposits near Ras al Hadd might be mined on a small scale, but all the other occurrences we saw were too small to be of interest.

Descriptions of manganese deposits

(38) Hammah (FV 681-871 Al Mintirib)

The Hammah deposit lies in low rolling hills 5.7 km (3.4 mi) S. 38° W. from Tawi Silaim, which is situated on Wadi al Batha. The manganese ore, consisting of fine-grained pyrolusite, forms small pods and lenses within gently folded beds of Hawasina chert. All the lenses we saw were very small, and none extended for more than 1 m or had a width of more than 30 cm (1 ft). We did not have time for an extended search for additional manganese occurrences in this area, but no further work is warranted.

(39) Jaramah (GV 791-841 Sur)

The major Jaramah manganese deposits are in low rolling hills 11.8 km (7 mi) S. 41° W. from the fort at Ras al Hadd in the northeastern tip of Oman. The manganese ore forms prominent black outcrops along several 10-meter-high ridges where it is interbedded with red and tan Hawasina chert, see photo 26. The manganiferous horizon can be easily followed as discontinuous outcrops for more than 7 km (4.2 mi), and because of its color shows up prominently on airphotos. Locally the ore beds exhibit some minor folds, but the regional strike is northwesterly.

Results of an examination made in 1973 by L. E. Carlson for Granges International Mining of Stockholm were made available to us. Our work chiefly corroborates his findings and adds additional analytical data.

Photo 26. Exposure of black chert containing pyrolusite within red cherts and shales of the Hawasina Unit at the Jaramah manganese deposit. This is one of the least interrupted beds but it shows some local folds and breaks due to minor faults.

The main ore mineral is pyrolusite. It occurs as apparently nearly pure beds 3 cm to 50 cm thick and in places as much as 330 m (1,000 ft) long. It also impregnates even more extensive chert beds coloring them jet black. The rich ore, which is heavy and partly crystalline, in places contains 50 percent manganese; but the equally black chert beds are deceptive, as they may contain less than 10 percent manganese. In places in the black chert there are pods of rich crystalline pyrolusite less than a meter long. Beds and pods are scattered through parts of a Hawasina red chert sequence locally as much as 30 m thick, and in most places dipping steeply into the low ridges. The rich ore comprises only a few percent of the width of the entire ore zone. A columnar section of one of the richest zones is given in figure 23.

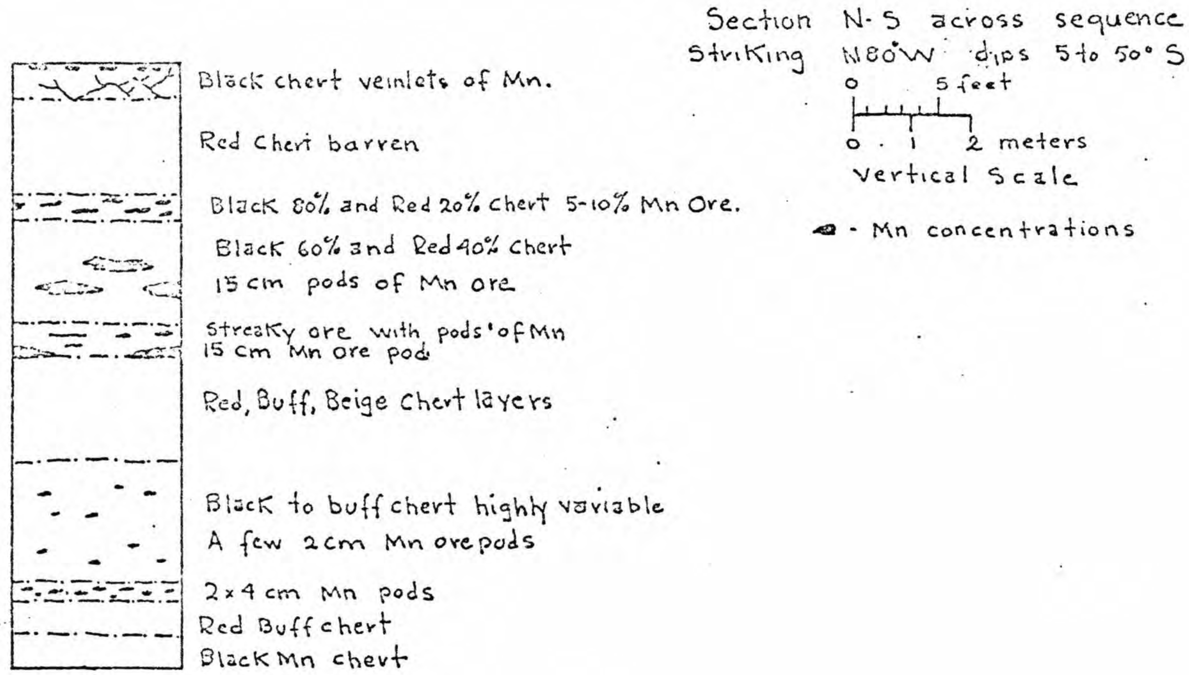

Figure 23. Measured section through one of the ore zones of the Jaramah manganese deposit near Ras al Hadd.

Because of both vertical and lateral variation it is difficult to get meaningful samples of reasonably small size. Previous analyses of weighted composite samples from two separate zones showed 23.6 percent and 24.8 percent manganese. A 1.3 m (4.3 ft) channel sample we took from one of the richer zones gave only 11.33 percent manganese, but a handpicked sample of rich ore contained 49.88 percent manganese. This and other analytical data is given in table 3.

Table 3.--Chemical and spectrographic analyses of manganese samples from the Hawasina Unit

Map No.	39	39	40
Field No.	OM-193	OM-198	OM-250
	Chemical Analyses		
Mn %	49.89	11.33	--
	Spectrographic Analyses		
Si %	7.	>10.	7.
Ai	.3	.3	.7
Fe	.05	.15	.1
Mg	.03	.07	.2
Ca	.3	.2	.5
Na	.15	.15	.7
Ti	.003	.015	.003
Mn ppm	150000	50000	>150000
B	20	50	1500
Ba	2000	2000	3000
Be	3	--	--
Co	100	20	15
Cr	50	7	15
Cu	1000	70	100
Ga	--	--	--
Mo	500	200	500
Ni	200	30	70
Sr	700	70	700
V	200	70	150

Chemical analyses by Sarah T. Neil and
Spectrographic analyses by R. E. Mays, U. S. Geological Survey, Menlo Park

OM-193 Small pod of ore from interbedded black and red chert, Jaramah.

OM-198 Channel sample 1.3m (4.3ft) of manganese ore zone in chert, Jaramah

OM-250 Manganese boulder from Hawasina cherts near Wasit.

We located at least four main manganese ore zones, which may be unrelated or may be outcrop belts of fewer horizons that have been folded. Other belts probably exist, as we found manganese float in wadis over a very extensive area but had insufficient time to follow up on the discoveries. We believe, however, we saw the best areas, as did also the geologist for Granges International Mining.

It is our opinion that the Jaramah manganese deposits are marginal, and it is unlikely that better manganese deposits in the area have escaped notice. Chemical-grade (50% Mn) and battery-grade (45% Mn) ore occurs in the deposits and probably could be recognized and removed by hand sorting. The deposits appear to us to have no potential for large-scale mining, but perhaps could be operated on a small scale to provide income for local residents of a relatively unproductive part of Oman. The occurrence of the ore is such that it could be dug up in the low hills, at least down to valley level, at low cost by a bulldozer and this could be followed by recovery of the rich ore by hand sorting. However, the total tonnage available seems to be barely adequate to justify the cost of bulldozer, truck, and storage facilities.

(40) Wasit (EA 589-338 Birkat Al Mawh)

About 5 km (3 mi) east of Nazwa on the east side of Jabal Al Hamrah we found in an exposure of Hawasina chert several loose boulders of nearly pure pyrolusite. The Hawasina here is mostly covered by terrace gravel and we were unable to find the ore in place. A spectrographic analysis of one of the loose pieces of ore is given in table 3.

Lead-Zinc Deposit

(41) Nujum (FA 205-880 Udhaybān)

The Nujum deposit is the only lead-zinc deposit we found in Oman. It is about 13 km (8 mi) southeast of Hadadibah, and is reached from a point near Bidbid by driving eastward from the PDO pipeline road up Wadi Nujum about 5 km, parking, and walking half a kilometer.

The deposit consists of a single long vein zone that parallels the wadi near the base of the mountains on the southwestern side. The vein is in hard silica-carbonate rock formed by the hydrothermal alteration of serpentine, which comprises a rather thin zone at the base of the Semail ophiolite. Underlying Hawasina rocks, here metamorphosed to a schist, are exposed in several places only a few tens of meters below the mineralized silica-carbonate rock. Where exposed, the Hawasina is entirely unmineralized.

The vein zone containing the lead-zinc ore trends N. 10° W. and dips steeply to the east. It is intermittently exposed over a length of about 300 m (1,000 ft) and has been explored or mined in three main workings. Near its center it was mined in an open cut 36 m (120 ft) long and in places 9 m (30 ft) deep, see photo 27. From the deepest part of the cut, level workings have been driven, but they are now inaccessible. The main vein was variable in width but locally it was over 1.5 m (5 ft) wide, and with a parallel vein was mined over a width of 5 m (16 ft). The mineralized zone has vague margins, as it consists chiefly of hard siliceous rock formed by replacement of the rather similar silica-carbonate rock. It is stained brown by oxidation of iron sulfides, and contains local pods and disseminated crystals of galena, sphalerite, anglesite, cerussite, mimetite, and the rare, bright red, lead oxide, minium. An analysis of a chip sample across a 1.35 m (4 1/2 ft) width gave the following percents:

Copper	3.8 %
Lead	15.0
Zinc	7.5
Arsenic	3.0

Another sample representative of a dump below the mine contained 4.8% lead, 4.7% zinc, 1.8% percent copper. Fire assays of two samples gave silver values of .004 and .01 percent or 1-3 oz/ton. Additional semiquantitative spectrographic data on ore samples from the Nujum deposit is given in Table 11 in the Appendix of this report.

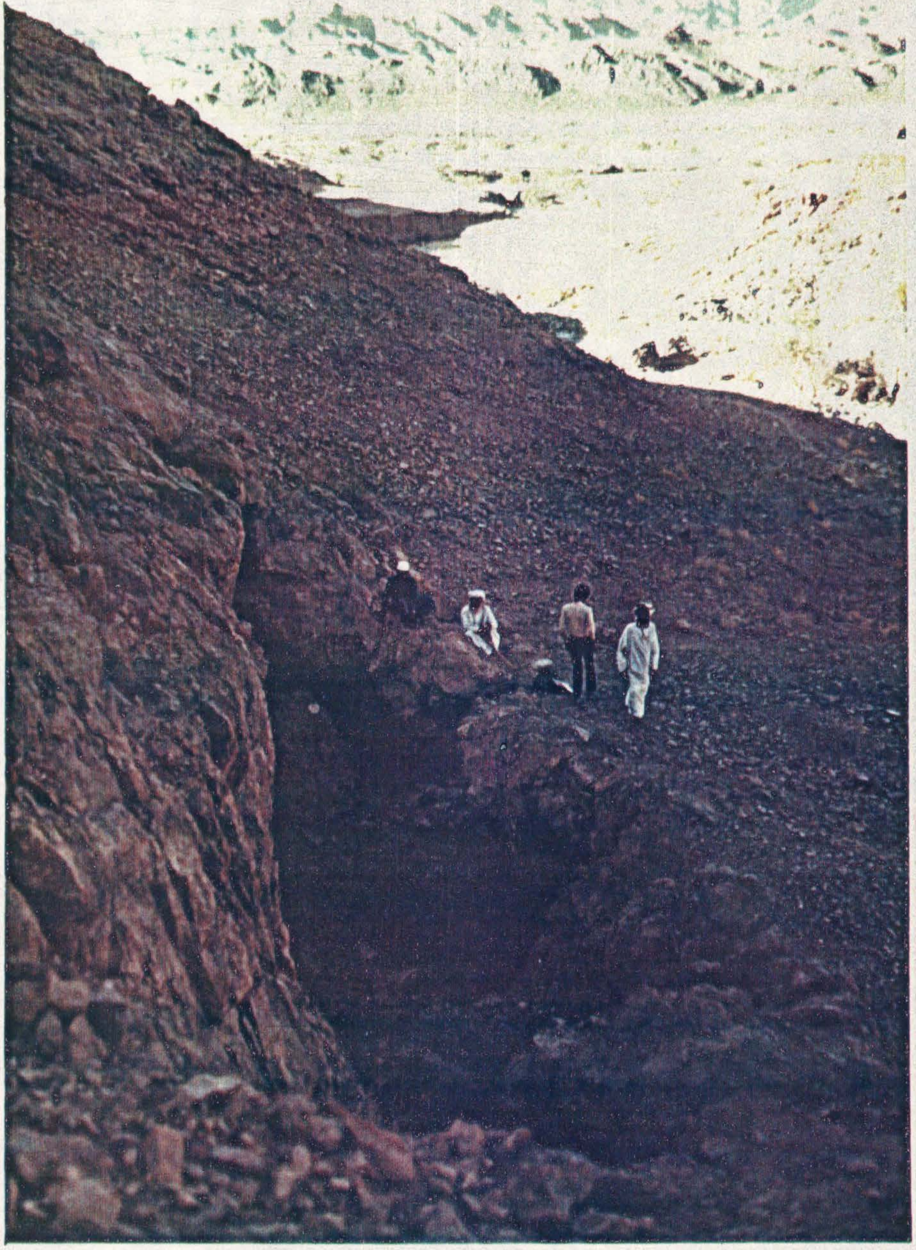

Photo 27. Ancient workings in the central part of a vein of lead-zinc-copper ore at the Nujum deposit, looking west. The vein cuts silica-carbonate rock formed from serpentine at the base of the Semail ophiolite.

North of the cut a little less than 150 m (500 ft) is a narrow inclined working following downward along the vein, which here is only about 5 cm (2 in) wide. The working is so small one must lie flat and go headfirst into it, and after going in about 9 m (30 ft) we gave up because of the lack of ventilation. It appeared to go down at least another 9 m (30 ft), but seems to have been driven only for exploration.

About 150 m (500 ft) south of the main cut is another adit driven northward along the mineralized zone. Here there are two adits with a common portal; one going slightly upward and the other inclined downward. The lower follows the vein, which here trends N. 25° W., for a distance of 27 m (90 ft). The upper level was penetrated almost as far to where it was partly filled with rubble. Both adits were unusually tall and doubtless they were used for removal of ore as well as exploration. At the portal here, as well as below the main cut, were piles of ore that had been sorted out from other rock removed in mining. However, we saw no slag in this area, and can only surmise from the extent of the work done that probably metals were recovered from this ore. Also unknown, is whether lead or zinc was extracted, or whether all the mining was done solely to recover the silver present in the lead ore.

The vein although mineralized over a reasonable length and width probably has no potential for modern mining. It occurs in the silica-carbonate rock, and probably does not penetrate into the Hawasina schists believed to lie less than 10 m (33 ft) below the old workings. However, without a drill hole or winze into this area immediately below the mined portion of the vein, deeper mineralization cannot be positively ruled out. The relations here seem to indicate that the formation of the silica-carbonate rock from the serpentine came later than the emplacement of the ophiolite by thrusting, and certainly the lead-zinc mineralization post-dates the silica-carbonate rock. The lead mineralization is thus younger than the Late Cretaceous deformation, and perhaps much younger.

Insufficient time was available for the proper evaluation of nonmetallic mineral deposits. We record here some of our observations and ideas as a guide to future work, but this report should not be considered as a final word regarding the real potential of these less glamorous, but often very lucrative, deposits.

Limestone-Dolomite

A considerable part of the Oman Mountains is made up of limestone and dolomite, some of which certainly can be utilized domestically and, where favorably located, might be exported. Examples of carbonates that might be used are mentioned here only briefly. A large supply of low-magnesium limestone is necessary for the establishment or expansion of the cement industry. Certain limestones within the Hawasina develop excellent flagstones that might be used as ornamental stone. Tertiary shallow-water limestones may locally be pure enough to be used as metallurgical-grade material. Certain parts of the recrystallized limestones that make up the huge exotic blocks in the mélange have the potential of being excellent sources of polished marble. To assess the usefulness of these rocks, we recommend that a careful study be made of the chemical and mechanical properties of the various types of carbonate sediments.

Asbestos

The large area of serpentinized Semail peridotite may contain potential sources for asbestos fibers, as chrysotile, the main source of fibrous or spinning-grade asbestos, is one of the common constituents in peridotite. We were shown some specimens of ore-grade cross-fiber crysotile from near Rustag; however, during our limited traverses within the peridotite we saw no zones of asbestos large enough to be of commercial interest. The short-fiber (Grade #7) asbestos commonly occurs in highly sheared serpentine, and the unusual lack of shearing in the serpentine of Oman is a discouraging feature. Early work by Greenwood and Loney (1968) in Trucial Oman has revealed no commercial asbestos deposits.

Magnesite

Veins of magnesite ($MgCO_3$) are abundant within the serpentinized peridotites of Oman. Some veins reach thicknesses up to 1 m (3.3 ft) and may extend up to 100 m (330 ft), see photo 28. All the veins, however, are too small to be considered as a deposit of magnesite, which now is not greatly in demand. Should there be an increased interest in the mining of magnesite, Oman has the potential of becoming an important producer.

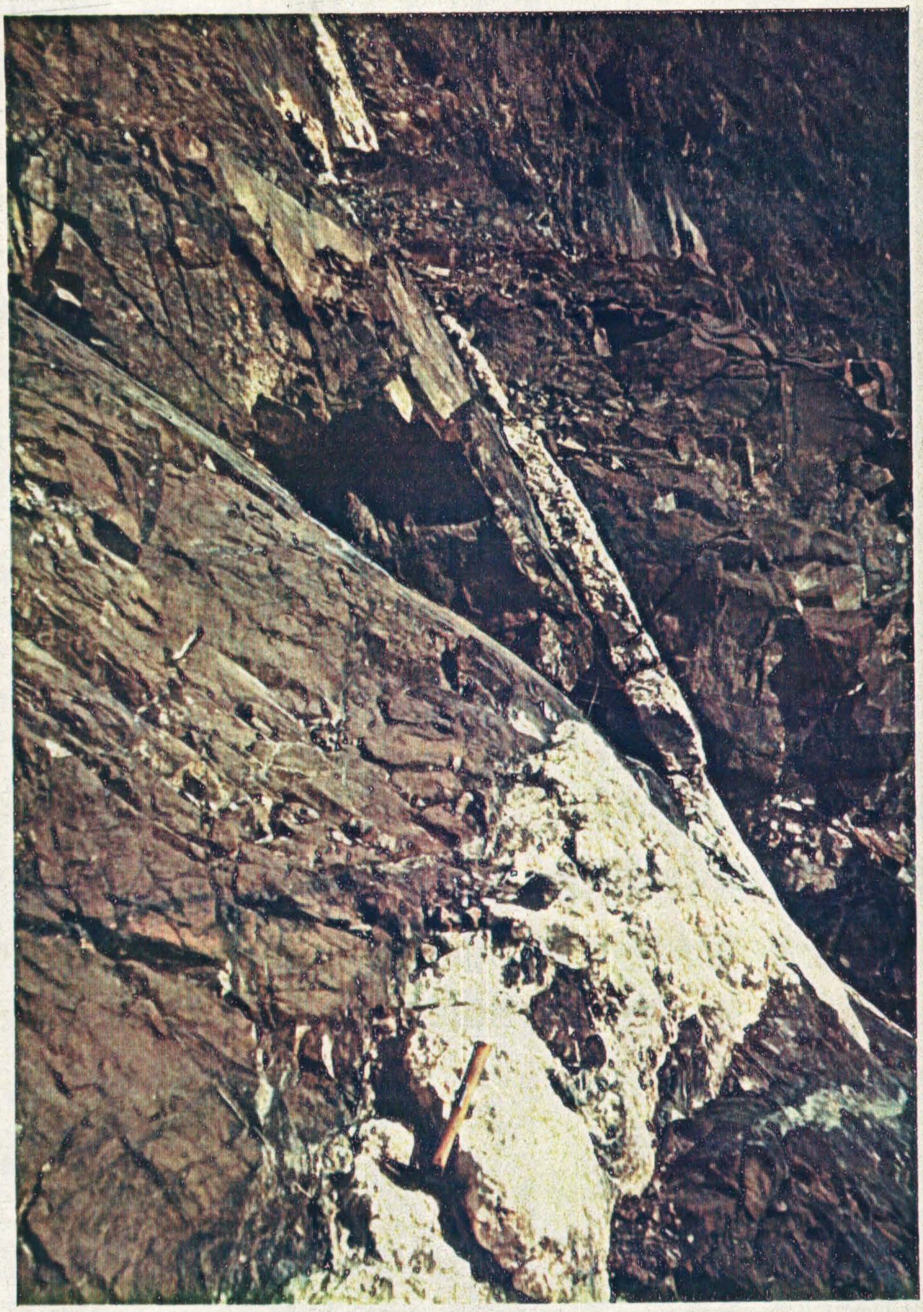

Photo 28. Magnesite vein cutting partially serpentinized peridotite along wadi Bani Ghafir, north of Rustag.

Clay

The use of clay in Oman has been restricted mainly to small potteries turning out utilitarian utensils used mainly for the storage of water. However, utilizing excess natural gas now being flared-off at the wellheads within the interior of Oman, a ceramic industry making products for both domestic use and export may be feasible where an adequate supply of natural clay is available. In the area north of Bahala there is a surface, or near-surface, layer of clay, perhaps deposited in a Pleistocene lake, which has provided an adequate supply of clay for adobe bricks and a local pottery industry. A detailed study of these clay beds should be attempted to ascertain the clay reserves of this deposit, and their feasibility for greater use.

Evaporites

The large interior drainage area centered around Umm As Samin has been an area of deposition of evaporites over a long period of time. It is possible that economic concentrations of alkali salts and alkaline earths (including lithium) may have been concentrated within this interior basin. Churn drilling accompanied by assays is necessary to establish the nature of the evaporites in this basin.

Hot Springs

Three major hot springs investigated during this study issue along normal faults in carbonate rocks on the north side of the Jabal Akhdar antiform. Their positions are marked by ancient travertine aprons at the Gallah and Rustag Springs, but no travertine was found at Al Khadra. Chemical analyses show these waters to be normal bicarbonate waters of very high quality. They have surface temperature ranges from 44° to 51° C. The possible maximum subsurface temperatures for the springs, estimated by using the Na/K ratios, are 123° C, see table 4. This value suggests that the water issuing from the hot springs is normal meteoric water that has percolated down along normal faults, has been heated up several kilometers below the surface, and has risen again to the surface as hot water. The data indicate they have no potential for geothermal power, but the steady supply of water of high quality could be utilized as an excellent source for bottled water. Further facilities constructed at the sites of these hot springs could provide the basis for health spas. Individual descriptions of the hot springs we examined follow .

(42) Gallah (FB 413-025 Udhavbah)

The springs are located at the foot of the mountain just south of the village of Gallah, which is 5.8 km (3.5 mi) south of the main blacktop highway near Azaiba. The series of four springs issuing here have a total flow estimated as 40 gal/min. They are alined along a low-angle thrust fault between overlying carbonate rocks and underlying serpentine mélange, but on both sides of the spring area normal faults displace the thrust plane. Locally developed silica-carbonate rock formed from the serpentine in the mélange suggests that the hydrothermal alteration here is clearly related to the hot springs. An extensive travertine apron, up to 4 m (13 ft) thick, has developed along the spring line forming a prominent terrace; however, the water is not now depositing calcium carbonate. An analysis of the water is given in table 4.

(43) Rustag (EA 420-867 Rustag)

The important Rustag hot spring is located 1.7 km (1 mi) west of Rustag castle and can be reached by a road that starts at the west entrance of the village market place. Geologically the spring lies along a normal fault that extends southward into the Jabal Akhdar antiform. It is a large spring supplying a surface pool that is approximately 14 m in diameter and 10 m deep. The pool has a manmade protective wall around it, and the overflow water is diverted along an open canal to be used for household and irrigation purposes. According to the local people this hot spring maintains a steady flow the year round. At the time of collection the estimated flow was about 400 gal/min. A well-developed travertine apron is exposed around the spring, but no $CaCO_3$ is being deposited now. Analyses of the water are given in table 4.

(44) Al Khadra (EA 312-839 Rustag)

On Wadi Sahtan 4 km (2.4 mi) south of the village of Tabaqah, and reached by driving up the wadi from Tabaqah, is a single spring issuing from a horizontal cleft in carbonate rocks. No travertine was found at this locality, however, rapid erosion within Wadi Sahtan may prevent the accumulation of such deposits. It was estimated that the flow at this spring was approximately 100-200 gal/min, and local residents indicate that the flow is steady throughout the year. A chemical analysis is presented in table 4.

Table 4.--Chemical analyses of Oman hot springs, concentrations in mg/l.

	1 Gallah	2 Rustag	3 Al Khadra
pH	8.0	7.8	7.9
Temperature °C	48	51	44
Ca^{+2}	84	66	70
Mg^{+2}	38	26	27
Na^{+1}	94	97	80
K^{+1}	3.8	4.2	3
Cl^{-1}	130	150	130
SO_4^{-2}	170	85	91
HCO_3^{-1}	220	230	220
Li^{+1}	.03	.17	.08
SiO_2	23.5	24	26.5
Calc. max sub-surface Temp. °C	118.2	123	114

Analyst T. S. Presser, U.S.G.S., Menlo Park, Calif.

1. Sample OM-80A hot spring near village of Gallah, grid location FB 412 029.
2. Sample OM-170 hot spring near village at Rustag grid location EA 420 867.
3. Sample OM-171 hot spring on Wadi Sahtan, grid location EA 312 839.

Cold Springs

Cold springs with extensive white travertine aprons are conspicuous along normal faults within the dark-colored Semail peridotite, see photo 4. None of these springs has a large volume of flow, and most are small seeps whose restricted pools are coated with a thin scum of newly precipitated aragonite. In spite of their limited flow, similar travertine-depositing springs in partly serpentinized alpine-type ultramafic bodies in the western United States have been extensively studied (Barnes and O'Neil, 1969). Their waters are characterized by high pH, usually greater than 11, and their analyses are similar to the three new analyses of Oman spring waters given in table 5. Their unusual character is believed to result from low-temperature near-surface serpentinization of peridotite by meteoric waters.

Table 5. Chemical analyses of Oman calcium hydroxide spring waters concentrations in mg/l.

	1 Kafifah	2 Hahwalah	3 Rustag
pH	11.2	11.5	11.3
Temperature °C	28	25	28
Ca^{+2}	62	60	120
Mg^{+2}	0.2	0.1	0.2
Na^{+1}	110	230	110
K^{+1}	4.8	8	6
Cl^{-1}	140	280	170
SO_4^{-2}	2.9	8.6	4.8
SiO_2	.1	.1	.2
(Calc) OH^{-1}	37.3	60.6	47.8
Li^{+1}	.03	.01	.02

Analyst T. S. Presser, U.S.G.S., Menlo Park, Calif.

1. Sample OM-166 spring along vertical fault in peridotite near village of Kafifah, grid location FA 460 331. (see photo 29)

2. Sample OM-318 spring along vertical fault in peridotite at Hahwalah along wadi Jizzi, grid location DB 301 801.

3. Sample OM-44 spring along vertical fault in peridotite near village of Rustag, grid location EA 445 884.

Photo 29. Kafifah calcium hydroxide spring along fault zone separating gabbro in background and peridotite of foreground. White travertine apron consists of aragonite ($CaCO_3$) which also cements stream mortar beds in foreground.

RECOMMENDATIONS

Our conclusions resulting from the field investigation of the geology and mineral resources of Oman are summarized in a series of recommendations. They are made chiefly to provide guidelines for the orderly and full development of the mineral potential within the economy of the Sultanate of Oman. For some resources, such as copper, recommendations regarding immediate utilization of known deposits can be made. For the development of other resources additional short-term investigation is required, either to learn more about the grade and extent of known deposits, or to search further for similar deposits more amenable to use. To achieve the ultimate utilization of the Oman resources requires longer term geologic, geophysical, and geochemical investigations aimed primarily at the discovery of accessible deposits that are not now exposed at the surface, chiefly because they are blanketed by alluvium or other surficial material. Their discovery generally requires years of study by teams of specialists, and, although perhaps only partly within the capability of present-day Oman, some suggestions preparing the way for this type of work in the future are included.

Metallic Ore Deposits

The combined result of the Prospection Ltd. and U.S.G.S. investigations in the mountainous portion of Oman during 1972-1974 clearly reveals that this area does have economic deposits of copper, potentially economic iron deposits, and less encouraging occurrences of chromium, lead-zinc, and manganese. Of these, the copper deposits are the most promising, and exploration of some of them is in an advanced stage. We recommend that continued effort should be made to determine the real ore potential of each known copper prospect by diamond drilling and geophysical investigation where warranted. This investigation of known deposits is now in the hands of Prospection Ltd., and we feel that they are doing a very competent and professional job. However, because of their requirement to be rigidly cost conscious, they may not adequately explore some of the more promising deposits in gabbro or peridotite or the more remote Rakah deposit.

All of the most promising copper deposits are in the "Bowling Alley" and southern extension in Wadi Jizzi, and detailed geologic mapping of the area is a necessary adjunct to the work now being carried out by Prospection Ltd. Such mapping will provide answers to the genesis of the ore and nature of features responsible for its localization, from which one develops control for use in mining of these deposits and search for new ones. Prospection Ltd. is not doing this kind of detailed mapping, nor do they have geologists experienced in such studies. We recommend that modest scale geologic mapping of the entire "Bowling Alley" ore zone be started as soon as possible to assist in the most orderly development of this important mineralized area.

The laterite deposits discovered in Oman during this study may have a potential to produce significant quantities of iron, and perhaps also nickel and chromium, but they are so little known that the potential cannot be properly assessed. To provide the basis for a steel industry they must satisfy several major requirements, which the deposits as now known cannot do though perhaps they have the potential. To be useful, iron ore must be available in large amounts, reasonably accessible, preferably amenable to low-cost open-cut mining, and of proper metallurgical content and grade. The richest deposit is not nessarily the best for exploitation. For proper evaluation detailed maps depicting topography, geology, structure, and sample locations with assay values are a basic necessity.

We recommend that a detailed study of the area containing the laterite deposit be made in order to ascertain if any deposits are mineable, to locate the deposits most suitable for mining, to determine their tonnage and grade, and to prepare adequate maps to permit evaluation and proper development of this resource. This will require examination of an area of 625 sq km, followed by large-scale mapping accompanied by the collection and analysis of numerous channel or larger samples. If deposits of commercial promise are located, further metallurgical tests and feasibility studies will be required.

Prospecting for chromite should be continued in the ultramafic parts of the Semail peridotite. Only small unmineable deposits have been found, but the geologic setting is the same as in parts of Turkey, Iran, and Russia where chromite is being mined. Chromite deposits are most likely to occur in masses of dunite, but this mineral is perhaps best sought by observing the stream pebbles or concentrations of black sands in the drainage areas in the peridotite, which encloses local masses of dunite. The chances for success do not warrant the cost of a geologist searching specifically only for chromite, but if mapping is being done for other purposes he should be watching for its occurrence. The search for chromite could best be done by prospectors, goatherders, villagers, or wandering bedouins if they could be shown pieces of the distinctive black ore and told of its value.

Known deposits of manganese ore in the Hawasina cherts are marginal. It is possible that the Jaramah deposit might be mined by local villagers on a small scale to provide income in an area with almost no other resources. The ore, however, is too limited and too difficult to mine on a large scale to warrant major development. If a market is available, we recommend mining by bulldozing across the ore zone to yield broken rock from which pieces of very high-grade ore could be readily sorted by unskilled laborers. Cost of such an operation could be kept very low as the only requirement in addition to local labor would be an informed director for the operation, a bulldozer, a single truck for mining and haulage, and construction of ore bins for storage, perhaps at Sur.

Elsewhere in the Hawasina we found loose, out-of-place pieces of high-grade manganese ore, and geologists working in the area should be alerted to possibility of discovery of other manganese deposits.

Nonmetallic Ore Deposits

The main emphasis of our field study was metallic ore deposits, and we had neither the time or competence to make a valid appraisal of the nonmetallic deposits of potential value. In most countries the value of nonmetallic production greatly exceeds that of metallic ore deposits, and a study of Oman's nonmetallic resources is likely to be worthwhile in planning for its expanded economic development. Potentially useful nonmetallic mineral resources include: carbonate rocks as sources for cement, metallurgical limestone, and building or ornamental stone; clay deposits for building and ceramic products; evaporites as sources of potash and lithium; and possible sedimentary phosphates. As Oman is now constructing roads at a rapid pace, some effort might also be directed toward studies of sources and properties of major road building materials. We recommend that the Oman Government have a knowledgeable geologic group make a survey of the nonmetallic mineral potential of Oman. This should be initiated as a limited appraisal carried out by a small team of geologists, as was done during this U.S.G.S. investigation of the metallic mineral potential.

Water Resources

Our investigation did not touch on the larger problems of water resources in Oman and we did not collect enough field data to make specific recommendations except for the hot springs. We did however sense the need for one central governmental agency to have authority over the use and development of the water resources in Oman. The development should start with a survey of the water potential within Oman by a competent group which has had experience both in surface and ground water geology. The government agency that controls the use of water should be made aware of the results of such a study and also retain a professional groundwater geologist on its staff.

Mapping

The basis for most geologic decisions regarding mineral resources, civil engineering for roads and dams, and water resources is a proper geologic map. For the consideration of different problems, maps of different scales are needed so that each problem is properly focused. A map of the Arabian peninsula (1:2,000,000) which included Oman was published by the U.S.G.S. in 1963. More recently northern Oman has been mapped geologically at a scale of 1:250,000 by P.D.O. as part of their oil-related studies, and this map will soon be published and available to the Oman Government. The P.D.O. map is an excellent start as it provides a broad overview of the geology, and it was used by our investigative team to great advantage. However, for detailed knowledge of specific areas, such as the "Bowling Alley" copper district near Wadi Jizzi, the P.D.O. map scale is much too small and the geology too generalized. We recommend that the Oman government support geologic mapping of the "Bowling Alley Copper District" at a scale of 1:50,000 and mapping of the Kalahay Niba laterite iron deposits at a similar scale.

The 1:100,000 British military maps which are available could be used as a basis for the above mapping, and for a countrywide geologic mapping program at a scale useful for most purposes. Approximately fifty 1:100,000 sheets cover northern Oman, and twelve cover the coastal area of Dohfar. As a basic long-term geologic project for Oman, we recommend geologic mapping of all these areas, with priority of mapping given to those areas that would most benefit the economic development of the country. An experienced geologist (5-6 years) with proper support can map one 1:100,000-sheet in one field season of 3-4 months, and with proper office and laboratory facilities could write a report and finish compiling the map in the remainder of the year. Therefore to carry out such a project would entail 62 man-years, and with a staff of 5 field geologists the task could be completed in approximately 12 years. This admittedly is a very ambitious program, but it could be started on a modest scale with outside cooperation until Oman had developed a geological staff capable of doing this work. In addition, it is likely that some areas are of sufficient interest that foreign geologists might map them, without pay, as a scientific study if provided some logistic support. The benefits of such work would be in development of ore deposits; help in large civil engineering projects; development of additional water supply; and would provide a geologic basis where needed for planning the economy of Oman.

Open-Door Science Policy And Arab Cooperation

Lastly, we recommend that the Oman Government actively encourage scientific investigations within the country. As shown earlier, Oman has within its borders one of the best exposed areas of on-land ancient oceanic crust to be found anywhere in the world. At the present time, there is much interest in these rocks, and many geoscience groups would like to have the opportunity to fully investigate this ancient oceanic crust. Generally such work would entail no expense to the Oman Government but would be an important prestige item to the country. Most visiting geologists would require help in the form of interpreters and transportation, but they could pay for this assistance. If an open-door policy prevails, there is no doubt that results of such scientific expeditions would benefit the country from several standpoints. Added scientific information will lead to a better understanding of the geology of Oman, and perhaps lead to the discovery of additional mineral resources. Exchange of ideas between visiting scientists and Omani government representatives could also provide guidance in developing these resources. In addition, there would be a small inflow of capital.

SELECTED REFERENCES

Alleman, F., and Peters, T., 1972, The ophiolite-radiolarite belt of the North Oman Mountains: Eclogae Geol. Helvetiae, v. 65, no. 3, p. 657-697.

Barker, P., 1966, A reconnaissance survey of the Murray Ridge: Royal Soc. London Phil. trans., series A, V. 259, p. 187-197.

Barnes, Ivan and O'Neil, J. R., 1969, The relationship between fluids in some fresh Alpine-Type ultramafics and possible modern Serpentinization, Western United States: Geol. Soc. Amer. Bull. v. 80, p. 1947-1960.

Bear, L. M., 1963, The mineral resources and Mining Industry of Cyprus: Geol. Surv. Cyprus Bull. No. 1, 208 p.

Beydoun, Z. R., 1964, The stratigraphy and structure of the Eastern Aden Protectorate: Overseas Geology and Mineral Resources, No. 5, p. 1-107.

Beydoun, Z. R., 1970, Southern Arabia and northern Somalia: Comparative Geology: Royal Society of London, Philosophical Transactions, Series A, v. 267, p. 267-292.

Brown, G. F., 1971, Tectonic map of the Arabian Peninsula: Saudi Arabian Directorate General of Mineral Resources, Arabian Peninsula Map AP-2, scale 1:4,000,000.

Brown, G. F. and Coleman, R. G., 1972, the tectonic framework of the Arabian Peninsula: Intern. Geol. Congr., 24th Proc., Montreal, Sec. 3.

Bugenstock, Herwald, 1966, Seismische Untersuchunger im mördlichen Teil des Arabischen Meeres (Golf von Oman): Erdöl und Kohle-Erdgas-Petrochemie, v. 19, p. 237-243.

Constantinou, G., and Govett, G. J. S., 1972, Genesis of sulfide deposits, ochre and umber of Cyprus: Trans. Inst. Mining and Metal. (Sect. B: Applied earth Sci.) v. 81, p. B34-B46.

Davis, A. G. 1950, The radiolaria of the Hawasina Series of Oman: Proc. Geol. Assoc. v. 61, p. 206-217.

Glennie, K. W., Boeuf, M.G.A., Hughs-Clarke, M.W., Moody-Stuart, M., Pilaar, W.F.H., and Reinhardt, B.M., 1974, Geology of the Oman Mountains: Part 1 (text), Part 2 (tables and illus.), Part 1 (text), Part 2 (tables and illust.), Part 3 enclosures), Kon. Nederlands Geol. Mijb, Gen. Ver. Verh., 31, 423 p.

Glennie, K. W., Boeuf, M. G. A., Hughes-Clarke, M. W., Moody-Stuart, M., Pilaar, W. F. H., and Reinhardt, B. M., 1973, Late Cretaceous nappes in Oman Mountains and their geologic evolution: Amer. Assoc. Petroleum Geol. Bull. v. 57, p. 5-27.

Glennie, K. W. and Hughes, N. W., 1973, Late Cretaceous nappes in Oman Mountains and their geologic evolution: reply: Am. Assoc. Petroleum Geologists Bull., v. 57, no. 11, p. 2287-2290.

Glennie, K. W. and Reinhardt, B. M., 1974, Late Cretaceous nappes in Oman Mountains and their geologic evoluation: Reply to J. D. Moody: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 5, p. 895-898.

Greenwood, J. E. G. W., and Loney, P. E., 1968, Geology and mineral resources of the Trucial Oman Range, Great Britain Inst. Geol. Sci. Overseas Div., 108 p.

Hudson, R. G. S., 1960, The Permian and Trias of the Oman Peninsula, Arabia: Geol. Mag., v. 97, no. 4, p. 299-308.

Hudson, R. G. S., Browne, R. V., and Chatton, C., 1954, The structure and stratigraphy of the Jebel Qamar area, Oman (abs.): Geol. Soc. London Proc., no. 1513, p. xcix-civ.

Hudson, R. G. S. and Chatton, M., 1959, The Musandam Limestone (Jurassic to Lower Cretaceous) of Oman, Arabia: Paris, Mus. Nat. d' Histoire Naturelle Notes et Memoires Moyen-Orient, t. 7, p. 69-93.

Hudson, R. G. S., McGugan, A., Morton, D. M., 1954, The structure of the Jebel Hagab area, Trucial Oman: Geol. Soc. London Quart. Jour., v. 110, pt.1, no. 438, p. 121-152.

Kinkel, A. R., Jr., 1966, Massive pyritic deposits related to volcanism, and possible methods of emplacement: Econ. Geology, vol. 61, p. 673-694.

Kühn, O., 1929, Beiträge zur Paläontologie und Stratigraphie von Oman (Ost. Arabian): Ann. Nat. Mus. Wien, v. 43, p. 13-18.

Lees, G. M., 1928a, The geology and tectonics of Oman and parts of Southeastern Arabia: Geol. Soc. London Quart. Jour., v. 84, pt. 4, p. 585-670.

______ 1928b, The physical geography of Southeastern Arabia: Geograph. Jour., v. LXXXI, No. 5, pp. 441-470.

Mohr, P. A., 1962, The geology of Ethiopia: Univ. College of Addis Abbaba Press.

Moody, J. D., 1974, Late Cretaceous nappes in Oman Mountains and their geologic evolution: discussion: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 5, p. 889-895.

Morton, D. C., 1959, The geology of Oman: 5th World Petroleum Cong. Proc., New York, Sec. 1, p. 277-294.

Moseley, F., 1969, The upper Cretaceous ophiolite complex of Masirah Island, Oman: Geol. Jour. v. 6, pt. 2, p. 293-306.

Overstreet, W. C., Overstreet, E. F., and Goudarzi, G. H., 1973, Mineralogical and Chemical investigations of the laterite in the As Sarat Mountains, Asir Region, Kingdom of Saudi Arabia: Directorate General of Mineral Resources Open-file report, 66 p.

Peters, Tj., and Kramers, J. D., 1974, Chromite Deposits in the Ophiolite Complex of Northern Oman: Mineral Deposita (Berl.) 9, p. 253-259.

Pilgrim, G., 1908, Geology of the Persian Gulf and adjoining portions of Persia and Arabia: India Geol. Survey Mem., v. 34, No. 4, p. 1-77.

Pohn, H. A., Offield, T. W., Watson, K., 1974, Thermal inertia mapping from satellite discrimination of geologic units in Oman: Jour. Research U. S. Geol. Survey, v. 2, No. 2, p. 147-158.

Reinhardt, B. M., 1970, On the genesis and emplacement of the ophiolites in the Oman Mountains "Geosyncline": Geologie En Mijnbouw, v. 49, no. 2, p. 161-163.

______ 1969, On the genesis and emplacement of ophiolites in the Oman Mountains geosyncline: Schweizer. Mineralog. U. Petrog. Mitt., v. 49, no. 1, p. 1-30.

Ricou, L. E., 1971, Le croissant ophiolitique peri-arabe une ceinture de nappes mises en place an cretace superieur: Rev. Geographie Phys. et Geologie Dynamique, v. 13, no. 4, p. 327-350.

Searle, D. L., 1972, Mode of occurrence of the cupriferous pyrite deposits of Cyprus: Inst. Mining and Met. Trans., Sect. B, v. 81, no. 792, p. B 189-197.

Seibold, Eugen, 1970, Zur bodengestalt des nordwestlichen Golfs von Oman: "Meteor" Forschungsergehnisse, Reihe C, no. 3, p. 1-14.

Shanti, M. S., 1966, Oolitic iron ore deposits in wadi Fatima between Jeddah and Mecca, Saudi Arabia: Saudi Arabia Min. Res. Bull. No. 2, Jeddah, Saudi Arabia.

Sultanate of Oman, 1973, Map of Petroleum concessions and oil fields of Oman and Adjacent countries; 1:2,000,000: Centre for economic planning and development, Directorate of Petroleum and Mineral Resources.

Thayer, T. P., 1973, Chromium, in Brobst, D. A., and Pratt, W. P., eds., United States Mineral Resources: U. S. Geol. Survey Prof. Paper 820, p. 111-121.

Tschopp, R. H. 1967a, the general geology of Oman: 7th World Petroleum Cong. Proc., Mexico, v. 2, p. 231-242.

______ 1967b, Development of Fahud field: 7th World Petroleum Cong. Proc. v. 2, p. 243-250.

Upadhyay, H. D., and Strong, D. F., 1973 Geologic setting of the Betts Cove copper deposits, Newfoundland: An example of ophiolite sulfide mineralization: Econ. Geology, vol. 68, pp. 161-167.

U. S. Geological Survey and Arabian American Oil Co., compilers, 1963. Map of the Arabian Peninsula 1:2,000,000: U. S. Geol. Surv. Misc. Geol. Inv. Map I-270, B-2.

U. S. Geological Survey and Arabian American Oil Co., compilers, 1963. Geologic map of the Arabian Peninsula 1:2,000,000: U. S. Geol. Surv. Misc Geol. Inv. Map. I-270A.

Wilson, H. H., 1969, Late Cretaceous eugeosynclinal sedimentation, gravity tectonics, and ophiolite emplacement in Oman Mountains, southeast Arabia: Am. Assoc. Petroleum Geologists Bull., v. 53, no. 3, p. 626-671.

______ 1973, Late Cretaceous nappes in Oman Mountains and their geologic evolution: discussion: Am. Assoc. Petroleum Geologists Bull. v. 57, no. 11, p. 2282-2287.

Whitmarsh, R. B., Weser, O. E., Ross, D. A., et al., 1974. Initial Reports of the Deep Sea Drilling Project, volume 23, Washington (U. S. Govt. Printing Office) p. 497 to 499.

APPENDIX

Chemical and Spectrographic Analyses

Table 6.--Chemical and spectrographic analyses of copper prospects in the Semail Ophiolite.

Map No.	10	10	11	13	13	14	15
Sample No.	OM-13A	OM-13B	OM-287	OM-291A	OM-291B	OM-631	OM-304
				Chemical Analyses			
Cu %	2.9	--	0.05	1.1	--	11.0	3.4
Ag ppm	--	--	--	--	--	--	--
Au ppm	--	--	--	--	--	--	--
Ni %	<.04	--	<.04	<.04	--	0.32	0.33
				Spectrographic Analyses			
Si %	>10.	>10.	>10.	>10.	7.	10.	>10.
Al	5.	.3	.3	5.	1.5	2.	.5
Fe	10.	10.	1.5	3.	2.	5.	7.
Mg	2.	.03	.1	5.	2.	7.	>10.
Ca	1.5	.15	.5	7.	7.	7.	1.5
Na	2.	--	--	1.	--	.07	--
K	--	--	--	--	--	--	--
Ti	1.	.03	.03	.1	.01	.01	.005
Mn ppm	2000	50	70	700	1500	1000	500
Ba	10	15	15	--	3	7	--
Co	50	7	--	30	300	200	300
Cr	3	5	20	700	700	3000	3000
Cu	20000	200	700	1000	>20000	>20000	>20000
Ga	20	--	--	7	--	--	--
Ni	15	7	15	200	1000	1500	1500
Pb	--	--	50	--	--	--	--
Sc	50	--	--	50	15	--	--
Sr	100	30	--	100	20	300	--
V	200	100	--	100	30	--	20
Y	50	--	--	--	--	--	--
Zn	--	--	1000	--	700	1000	--
Zr	100	--	--	--	--	--	--
Ag	--	--	15	--	--	7	--
Mo	--	--	--	--	--	--	--

Table 6.--(cont'd)

Map No.	16	16	18	20	20	25
Sample No.	OM-632	OM-634	OM-60	OM-621	OM-622	OM-629
			Chemical Analyses			
Cu %	--	3.0	12.2	2.1	1.1	<.05
Ag ppm	--	--	--	<20	<20	--
Au ppm	--	--	--	0.08	0.27	--
Ni	--	<.04	<.04	0.23	0.21	0.11
			Spectrographic Analyses			
Si %	7.	5.	>10.	>10.	>10.	>10.
Al	3.	3.	5.	.2	3.	3.
Fe	>10.	>10.	>10.	10.	>10.	10.
Mg	1.5	1.5	2.	>10.	10.	10.
Ca	3.	.2	.7	.3	2.	2.
Na	.3	--	.2	.1	.15	.2
K	1.5	--	--	--	--	--
Ti	.05	.02	.015	.003	.1	.03
Mn ppm	500	300	700	500	300	1500
Ba	20	--	10	--	20	30
Co	1500	700	70	300	300	150
Cr	150	100	50	1000	1500	500
Cu	>20000	>20000	>20000	15000	10000	150
Ga	--	--	15	--	--	--
Ni	300	200	70	1500	1500	700
Pb	--	--	--	150	200	150
Sc	15	15	10	7	10	15
Sr	1500	--	15	15	100	100
V	--	30	200	20	50	30
Y	30	--	--	--	--	--
Zn	3000	1000	--	700	--	--
Zr	--	--	--	--	--	--
Ag	--	--	--	--	--	--
Mo	20	30	--			

Table 6.--(cont'd)

Map No.	25	27	27	28	28	29
Sample No.	OM-630	OM-181A	OM-181C	OM-133A	OM-133B	OM-256
			Chemical Analyses			
Cu %	--	4.0	5.9	1.2	1.7	2.0
Ag ppm	--	--	--	--	--	--
Au ppm	--	--	--	--	--	--
Ni	--	0.17	0.04	0.09	0.04	--
			Spectrographic Analyses			
Si %	>10.	>10.	3.	>10.	1.5	>10.
Al	3.	.3	3.	7.	1.5	7.
Fe	10.	7.	7.	10.	>10.	>10.
Mg	10.	10.	2.	10.	.15	5.
Ca	2.	.5	>10.	.07	.5	.7
Na	.2	--	--	--	.15	.3
K	--	--	--	--	--	--
Ti	.03	.007	.02	.1	.05	.05
Mn ppm	1500	700	1500	500	100	1500
Ba	30	5	--	--	3	5
Co	150	300	150	200	300	150
Cr	500	2000	1000	1000	1000	200
Cu	150	>20000	>20000	10000	15000	15000
Ga	--	--	5	20	--	15
Ni	700	1500	300	500	300	150
Pb	150	--	--	--	--	--
Sc	15	--	30	50	50	15
Sr	100	15	70	--	30	20
V	30	15	30	100	300	70
Y	--	--	--	--	--	--
Zn	--	--	--	--	--	--
Zr	--	--	--	--	--	--
Ag	--	--	--	--	--	--

Chemical analyses by Sarah T. Neil and
Spectrographic analyses by R. E. Mays, U. S. Geological Survey, Menlo Park

Table 6.--(Cont'd)

Explanation

OM-13A	Copper mineralization in silicified tuff at contact with Semail pillow lava, Wadi Jabah.
OM-13B	Mineralized chert resting on top of Semail pillow lavas, Wadi Jabah.
OM-287	Silicified sulfide-bearing rock in gossan, Rakah.
OM-291A	Chalcopyrite in altered gabbro, Maydan II.
OM-291B	Malachite-rich gossan material, Maydan II.
OM-631	Selected pieces of mineralized rock, Bu Kathir.
OM-304	Selected pieces from dump, Hawirdit.
OM-632	Chalcocite ore from dump, Tawi Ubaylah.
OM-634	Gossan from dump, Tawi Ubaylah.
OM-60	Copper mineralization in shear zone, Wadi Muden
OM-621	Chip samples of mineralized rock, Tabakhat (Pb=05%, Zn=.04%)
OM-622	Dump sample, Tabakhat (Pb=.07%, Zn=.03%).
OM-629	Altered zone 7.5 cm (3 in), iron stained, Eedah II
OM-630	Altered and bleached rock. Eedah II.
OM-181A	High grade dump material, Khara mine.
OM-181C	Ore from mineralized zone, Khara mine.
OM-133A	Mineralized gabbro with malachite, Zahir mine.
OM-133B	Gossan, Zahir mine.
OM-256	Mineralized gabbro from dump, Shwayi mine.

Table 7.--Spectrographic analyses of ancient slag from Oman copper deposits.*

Map No.	21	23	23	27	28	16
Sample No.	OM-165	OM-88A	OM-88B	OM-181B	OM-133	OM-355
Si %	>10.	>10.	>10.	>10.	>10.	>10.
Al	5.	1.	.7	.7	5.	5.
Fe	>10.	>10.	>10.	>10.	>10.	>10.
Mg	7.	5.	5.	2.	3.	7.
Ca	2.	5.	5.	5.	5.	5.
Na	.1	.3	.2	.5	.2	.3
Ti	.1	.05	.05	.015	.15	.15
Mn ppm	500	500	500	500	500	1500
Ag	1	2	--	--	--	--
Ba	20	50	50	30	50	50
Co	700	300	1000	300	200	1500
Cr	1500	1500	2000	1500	50000	500
Cu	50000	20000	20000	10000	3000	>20000
Ga	15	15	10	--	15	10
Ni	2000	300	1000	200	300	700
Sc	20	15	20	--	20	70
Sr	150	700	700	700	700	500
V	150	30	30	15	200	150
Zn	200	--	500	--	500	1000
Zr	--	--	--	--	--	70

Analysts: R. E. Mays and Chris Heropoulos, U. S. Geological Survey, Menlo Park, California

OM-355 Tawi Ubaylah Slag.
OM-165 Khafifah Slag.
OM-88A Inah Slag.
OM-88B Inah Slag.
OM-181B Khara Slag.
OM-133 Zahir Slag.

*These slags are from copper deposits of gabbro-peridotite contacts and contain 0.3 to 5% Cu with minor amounts of Ag, An and Ni. Past experience on trying to rework the ancient slags on Cyprus has proven not to be economical and so we consider these ancient slags are not important as a possible source of copper.

Table 8.--Chemical and spectrographic analyses of Kalahay Niba I and II iron deposits.

Map No.	30	30	30	30	30	30	30	30
Sample No.	OM 114 A	OM 114 B	OM 114 C	OM 114 D	OM 114 E	OM 114 F	OM 117 A	OM 117 B
				Chemical Analyses				
Fe %	30.80	51.43	44.62	39.1	30.1	38.4	45.52	43.95
Cr	12.53	1.53	2.61	2.6	2.8	.87	1.18	2.94
Ni	--	--	--	0.33	0.36	1.1	--	--
				Spectrographic Analyses				
Si %	1	5.	5.	5.	5.	10.	1.5	1
Al	10	3.	7.	5.	5.	3.	2.	15
Mg	3	.3	.5	.5	.7	.7	.15	.2
Ca	1.5	2.	1.5	2.	2.	.3	5.	1.
Ti	.15	.15	.3	.1	.15	.1	.03	.2
Na	--	.1	.15	2.	5.	.15	.05	.03
Mn ppm	700	3000	700	500	200	1000	15000	2000
Ba	5	100	20	7	10	7	3	30
Co	300	150	200	150	150	500	700	500
Cu	150	150	100	300	300	100	300	100
Ni	2000	3000	5000	2000	2000	7000	3000	3000
Pb	15	30	--	20	--	--		--
Sc	50	70	100	70	70	70	100	100
Sr	20	100	70	500	500	50	1000	150
V	500	200	500	150	150	150	300	300
Zn	700	--	300	--	--	--	200	200
Zr	--	--	30	70	100	--	--	--

Chemical analyses by Sarah T. Neil and semiquantitative spectrographic analyses by Chris Heropoulus and R. E. Mays, U.S.G.S., Menlo Park

Kalahay Niba I

OM-114-A	High grade iron ore
OM-114-B	Medium grade iron ore
OM-114-C	Low grade iron ore
OM-114-D	Channel sample (9 feet) of iron ore
OM-114-E	Average sample from talus in iron ore
OM-114-F	Channel smaple (2 feet) of iron ore 100 feet east of D & E

Kalahay Niba II

OM-117-A	High grade iron ore
OM-117-B	Medium grade iron ore

Table 9. Chemical and Spectrographic analyses of iron laterite samples from Semail ophiolite

Map No.	33	33	33	33	33	33	33	33	32
Sample No.	OM 270	OM 271	OM 272	OM 274 A	OM 274 B	OM 274 C	OM 275	OM 276	OM 247
				Chemical Analyses					
Ni %	0.24	0.24	0.27	0.16	0.09	0.23	<.04	0.11	-
Fe %	4.9	5.2	5.0	13.9	11.7	55.0	1.9	31.6	-
Si %	16.8	17.8	15.1	.51	37.1	6.3	37.7	22.5	
				Spectrographic Analyses					
Si %	>10	>10	>10	1.	>10	7.	>10	>10	10
Al	.15	.15	.07	.3	.3	.5	5.	.7	.1
Fe	3.	5.	5.	>10	>10	>10	1.5	>10	2.
Mg	>10	>10	>10	5.	.07	.1	.2	.15	7.
Ca	1.5	.1	2.	>10	.1	.5	.3	.5	>10
Na	-	.15	1.	-	-	-	-	-	> 5
Ti	.001	.001	.0007	.003	.003	.005	.05	.007	.001
Mn ppm	700	700	500	2000	200	200	100	200	500
B	-	50	-	-	-	-	-	70	15
Ba	7	-	70	150	70	500	100	150	30
Be	-	-	-	2	7	7	-	2	-
Co	70	70	70	70	10	50	5	50	30
Cr	2000	2000	2000	2000	1000	1000	1000	2000	1500
Cu	100	50	30	50	50	70	30	50	50
Ga	-	-	-	10	10	-	7	10	
Ni	1500	1500	1500	1500	700	3000	200	1000	700
Pb	-	-	-	-	-	-	70	20	-
Sc	7	10	10	20	-	10	15	20	-
Sr	100	-	30	150	-	30	15	700	700
V	30	30	20	50	-	30	50	50	15
W	-	-	-	-	200	500	-	500	-

Chemical analyses by Sarah T. Neil and semiquantitative spectrographic analyses by R. E. Mays and Chris Heropoulos, U.S. Geological Survey, Menlo Park

Fanjah

OM 270 Base of laterite section, slightly weathered peridotite
OM 271 70 feet above base, massive brown weathered peridotite iron oxide on surface
OM 272 120 feet above base, completely weathered peridotite original textures preserved
OM 274 A 165 feet above base, completely weathered iron-rich peridotite
OM 274 B 165 feet above base, red jaspar with hematite veins cutting peridotite
OM 274 C 165 feet above base, lens of iron ore in red jaspar
OM 275 Shear zone within laterite containing green material
OM 276 Top of laterite soft iron ore from ancient mining pit

Wasit

OM 247 Weathered surface of peridotite near Wasit

Table 10. Chemical and spectrographic analyses of chromites from Semail Ophiolite

Map No.	35	36	37
Sample No.	OM 110	OM 138	OM 356
	Chemical Analyses		
Cr %	24.98	22.80	26.0
Fe	12.16	9.70	11.0
Al	11.3	12.0	-
	Spectrographic Analyses		
Si %	2.	5.	3.
Al	15.	15.	>10.
Fe	15	10.	>10.
Mg	7.	10.	10.
Ca	1.5	.15	.3
Ti	.2	.1	.05
Mn ppm	700	700	1500
Ba	5	7	7
Co	150	150	150
Cu	50	15	20
Ni	2000	200	1000
Sc	10	7	7
Sr	10	-	20
V	1000	700	1500
Zn	500	700	-
Zr	15	-	-

Chemical analyses by Sarah T. Neil and spectrographic analyses by Chris Heropoulos and R. E. Mays, U.S. Geological Survey, Menlo Park.

OM 110 Chromite ore from MasaKirah deposit

OM 138 Chromite ore from Mudi deposit

OM 356 Chromite ore from Aka Keya deposit

Table 11. Chemical and spectrographic analyses of Nujum lead-zinc deposit

Map No.	41	41	41	41	41
Sample No.	OM 615	OM 617	OM 618	OM 619	OM 620
		Chemical Analyses			
Pb %	15.0	4.8	-	-	-
Zn %	7.5	4.7	-	-	-
Cu %	3.8	1.8	-	-	-
Ag ppm	120	40	-	-	-
Au ppm	<0.05	0.05	-	-	-
		Spectrographic Analyses			
Si %	>10	>10	>10	>10	>10
Al	.2	.5	.2	.3	.3
Fe	5.	5.	2.	5.	3.
Mg	1.5	1.5	.2	3.	.5
Ca	3.	3.	.1	5.	.7
Ti	.002	.007	.001	.002	.003
Mn ppm	2000	2000	200	1500	2000
Ag	200	70	100	100	15
As	30000	>5000	>5000	7000	2000
B	7	10	10	7	10
Ba	300	200	100	50	50
Cd	1000	500	150	200	500
Co	1000	1500	500	500	500
Cr	700	700	700	700	1000
Cu	>20000	15000	10000	1500	300
Ni	5000	10000	2000	1500	3000
Pb	>50000	50000	>50000	>50000	2000
Sb	1500	700	700	-	-
Sc	5	-	7	-	10
Sr	200	100	10	200	20
Zn	>50000	50000	1000	15000	>50000

Spectrographic analysis by R. E. May. Chemical analyses by Sarah T. Neal and Claude Huffman, Jr., U.S. Geological Survey, Menlo Park and Denver.

OM 615 Chip sample of average ore
OM 617 Dump material
OM 618 Picked sample with visible galena
OM 619 Picked sample with visible galena
OM 620 Picked sample with secondary lead minerals

Table 12. Chemical and spectrographic analyses of miscellaneous samples from northern Oman

Map No.	9	8	-	32	-	-
Sample No.	OM 321	OM 324 A	OM 2	OM 185	OM 1	OM 4
			Spectrographic Anayses			
Si %	10.	>10.	2.	>10.	>10.	.7
Al	.7	3.	1.5	1.	.3	.1
Fe	>10.	>10.	>10.	>10.	3.	1.5
Mg	.3	.7	2.	.2	.7	.3
Ca	1.	7.	7.	.5	3.	10.
Na	-	.5	-	-	-	-
Ti	.015	.07	.05	.7	.0015	.003
Mn ppm	300	50000	200	150	2000	7000
B	-	50	-	-	30	-
Ba	20	70	-	70	20	10
Co	50	30	-	10	-	-
Cr	30	20	100	3000	7	7
Cu	1000	500	20	200	30	15
Ni	50	300	10	50	7	-
Pb	-	200	150	-	-	150
Sc	-	7	-	15	-	50
Sr	30	200	30	50	70	1000
V	200	150	150	200	-	-
Y	15	50	-	-	20	200
Zr	-	50	70	100	-	-

Spectrographic analyses by R. E. Mays, U.S. Geological Survey, Menlo Park

OM 321 Iron-rich sediment interlayered with pillow lavas, Lasail deposit

OM 324 A Iron-rich sediment interlayered with pillow lavas, Ghatyh deposit

OM 2 Iron-rich dolomite from the Hijam dolomite, Sayah Hatat

OM 185 Iron-rich Tertiary sandstone, Jabal Salaht

OM 1 Quartz vein with some mineralization, Sayah Hatat metamorphic rock

OM 4 Siderite-calcite in quartz vein, Sayah Hatat metamorphic rock

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