

## A Comparative Study of Five Volcanic-Hosted Sulfide Mineralizations in the Arabian Shield

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**ABSTRACT.** Investigation of five volcanogenic base metal sulfide occurrences in the Arabian Shield (Ash Shizm, Umm Ad Damar, As-Safra, Al Musayna'ah, and Umm Ash Shalahib) showed that they are located within Hulaifah calc-alkaline volcanic rocks or its equivalents. The investigations included field, petrographic, mineralogical and chemical studies.

Felsic, calc-alkaline rock assemblages host these occurrences, with a predominance of rhyolitic rocks and some andesites. Basalt occurs only in the vicinity of the Ash Shizm mineralization. These rocks were regionally metamorphosed to low greenschist facies grade. Deformation and contact metasomatism affected parts of these occurrences producing foliation and local skarn development. The intensity of metamorphism and deformation varies between localities. Later episodes of hydrothermal activity overprinted zones of mineralizations producing sericitization, chloritization and silicification.

Geotectonically, these mineral occurrences were formed in different settings. Ash Shizm bimodal volcanics were probably deposited in an extensional regime in a back arc basin. Umm Ad-Damar, As Safra and Al Musayna'ah calc-alkaline volcanics are interpreted as formed within an island arc environment, while Umm Ash Shalahib volcanics could be considered similar to Andean type deposits related to an active continental margin environment. Ore microscopic investigations of the mineral assemblages in the five occurrences indicated primary ores that have been coarsened and deformed to variable degrees giving the ores their characteristic brecciated nature reflected in the associated pyrite and other metamorphic texture present.

Despite the extensive exploration programs carried out in the five areas by DGMR, no economically worthwhile deposit has been recommended for exploitation. The quantity and/or grade of these deposits, besides their

occurrence in remote areas without the infrastructure to support mining operations, classifies these deposits as non-economic in the near future.

For further exploration for volcanogenic sulfide deposits, the upper parts of the Hulayfah Group rocks or its equivalents are recommended. The greatest percentage of known volcanogenic mineral occurrences of the Arabian Shield are located within their felsic volcanic and volcanoclastic rocks.

### Introduction

The selection of five occurrences of base metal sulfides in Saudi Arabia (Figure 1) for reinvestigation was based on the following considerations:

- a. They are geographically spread throughout the Arabian Shield, so they could represent various geologic and tectonic settings.
- b. They occur within the middle volcano-sedimentary cycle of the shield which is known to contain several other similar occurrences. Hence the selected ones are a fair representation of this population of occurrences. Several names were assigned to the products of this cycle of volcanic activity, namely Hulayfah, Halaban, Al Amar, etc.
- c. The similarity among the five occurrences in housing Cu as the main element and variations in the minor constituents (Zn, Pb, Au, Ag), also mean a possibility of variation of their tectonic setting.

Ash Shizm is an ancient mining site for copper. Workings include stopes and filled in-shafts. Slag dumps are widespread in Wadi Ash Shizm. Since the early 1930's, several investigations were carried out. The most recent of which are by Johan (1979), Donzeau (1980a and b) and Shanti (1982). The latest work in this area was by the DGMR, who studied the mineralization intermittently between the years 1973 and 1982. Four of the total of 14 drill holes intercepted rather rich sulfide zones of copper and zinc (Donzeau 1980a & b and Shanti 1982).

Investigations of the two ancient prospects at Umm Ad Damar were carried out by various agencies. The history of these investigations was reviewed by Ahmed (1979) and by J. Grootenboer (in Ransom, 1982). The most recent of these investigations were by Ahmed (1979), Ransome (1982 and 1984) and Howes (1984). Due to extensive cover, many trenches were excavated to expose the bedrock (Ahmed 1979). Several drill holes intercepted mineralized zones at depth.

The early investigations of the As Safra ancient prospect were reported by Twitchell (1936) and Schaffner (1956). Later investigations and exploration works were carried out by Conraux (1969), Conraux and Delfour (1970), Delfour (1970 and 1975), Duhamel (1971), Riofinex (1977) and El-Mahdy (1980). Between 1956 and 1966, airborne magnetic, scintillometric and electromagnetic input system surveys were conducted at As Safra by various agencies. Quinn (1963) reviewed previous work at this prospect. Data from seven drill holes were reported by Conraux and Delfour (1970) and by Delfour (1970). Due to poor exposures, several trenches were excavated at As Safra.

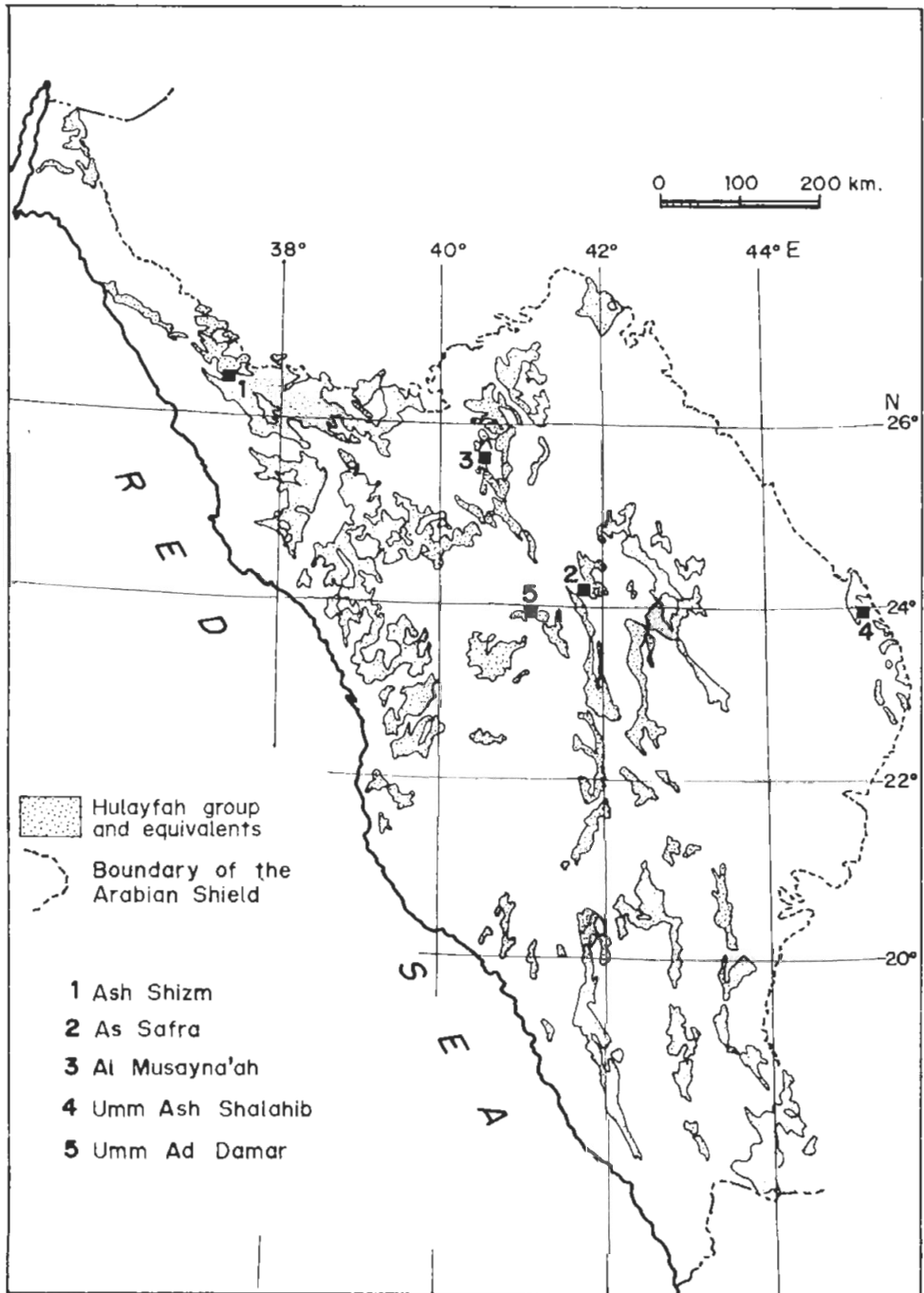


FIG. 1. Location map for investigated sulfide occurrences.

Al Musayna'ah was studied by many prospecting teams. The outcome is many open-file reports and published works that include: Shanks and Fakhry (1935), Kabani and Brown (1956), Schaffner (1956), Maclean and Al-Shanti (1958), Kahr (1962), Hummel *et al.* (1956), Delfour (1966, 1977 and 1979), Moore and Al-Shanti (1979), Tayib and Al-Shanti (1983) and Qadhi and Hussein (1984). Since its rediscovery in 1935, geologists were impressed by the size of ancient mining activities. Regional and detailed geological and topographical maps were prepared, and geochemical and geophysical surveys were carried out four times successively by DGMR and its agencies. Extensive trenching and drilling were also carried out, but the results indicated limited reserves as well as very low values of base metal content.

Umm Ash Shalahib was reinvestigated by BRGM which carried out geological mapping, trenching, geochemical and geophysical investigations and finally drilling. The area was mapped by Leca (1970) and Brosset (1972) and the maps were revised by Delfour (1975) to a scale of 1:10,000. Eijkelboom (1966) made an assessment of one of the mineralized zones. Letalenet *et al.* (1971) reported drilling results at Umm Ash Shalahib. The most recent development was reported by Smith *et al.* (1984).

### Geology

The host rocks in the studied occurrences are volcanic flows and volcanoclastic rocks of basaltic to rhyolitic composition. These are traversed by abundant dikes of variable composition and extent. The host rocks show the effects of regional metamorphism to various degrees, as well as of alteration associated with the mineralization. These alterations are manifested in the development of minerals of the greenschist facies such as epidote, chlorite and actinolite. These effects are more pronounced in the mafic and intermediate rocks than in the acidic rocks in general.

#### **Ash Shizm**

The area consists of a sequence of volcanic and volcanoclastic rocks (Figure 2) belonging to the Hulayfah group (Shanti 1982, Delfour 1975, Donzeau 1980a). This sequence strikes roughly ENE and dips between 40° to 70° to the west forming a homocline bordered on the south by a major E-W fault along which Wadi Ash Shizm was formed. The sequence is intensely faulted and fractured, and intruded by diorite, gabbro and granite.

In the mine area, along the southern slope of Jabal Ash Shizm, this sequence is broadly classified into three units. At the base, there is a basaltic flow unit which is locally pillowed and amygdaloidal. It contains some intercalations of rhyolitic flows and tuffs in its lower part. This basalt unit is overlain by a rhyodacite flow unit with subordinate intercalations of rhyolite tuff and breccia. Flow banding in rhyolites is well developed. The rhyolitic unit is overlain by another basalt flow unit, also locally pillowed and/or brecciated. The sequence is unconformably overlain by a multilithic conglomeratic bed containing well rounded granite pebbles and boulders. This conglomerate is considered to be the base of a younger group of rocks (Murdama?).

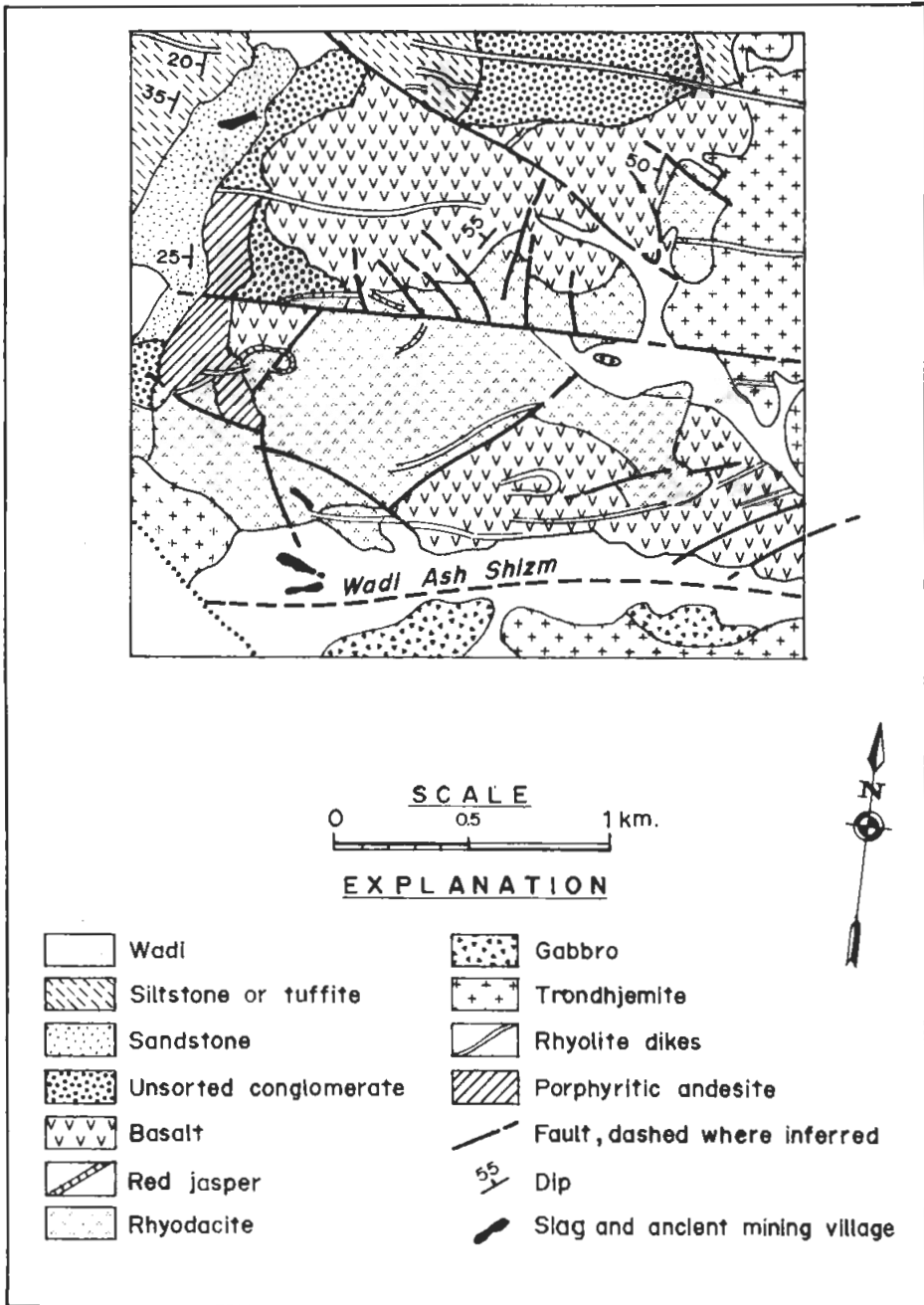
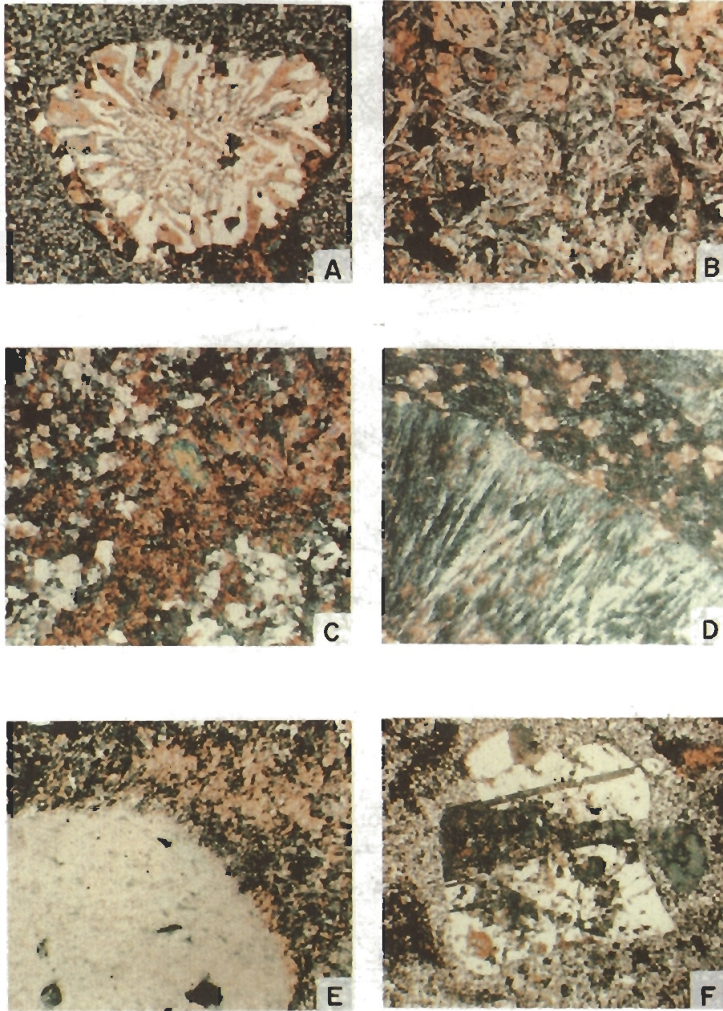


FIG. 2. Geologic setting of Jabal Ash Shizm prospects.  
Simplified from M. Donzeau (1980)



- FIG. 3A. Photomicrograph of a spherulite filled with quartz and alkali feldspar in rhyolite at Ash Shizm area. Transmitted light, crossed polars,  $\times 21$ .
- FIG. 3B. Photomicrograph showing intergranular texture between plagioclase, altered augite and opaque minerals in basalt from Ash Shizm area. Transmitted light, crossed polars,  $\times 21$ .
- FIG. 3C. Photomicrograph showing epidote replacing groundmass in rhyolite from Ash Shizm area. Transmitted light, crossed polars,  $\times 34$ .
- FIG. 3D. Photomicrograph of the border of a chlorite spherule showing fibrous chlorite surrounded by a matrix of microcrystalline chlorite and aggregates of very fine-grained epidote, chlorite, Ash Shizm area. Transmitted light, crossed polars,  $\times 34$ .
- FIG. 3E. Photomicrograph showing sericite and calcite replacing the matrix of rhyolitic tuff at the boundary of quartz porphyroblast, Umm Ad Damar area. Transmitted light, crossed polars,  $\times 34$ .
- FIG. 3F. Photomicrograph showing feldspar phenocryst partially replaced by sericite and chlorite in rhyolite crystal tuff, Umm Ad Damar area. Transmitted light, crossed polars,  $\times 34$ .

Basalt and rhyolite flows and their pyroclastic equivalents constitute the rock types of the Ash Shizm succession. The pyroclastics range from agglomerates to ash tuffs and laminated tuffs. Intercalations of rhyolitic rocks in the lower basalt unit, and intercalations of basaltic rocks within the middle rhyolitic unit are common. Generally, the rhyolites are more dominant than the basalts. Dikes of various compositions and extensions intrude the sequence.

The rhyolites of Ash Shizm show effects of regional metamorphism as well as alteration associated with mineralization. However, the original textures are still retained. Most common are intergranular, subophitic, spherulitic, porphyritic and amygdaloidal textures. Pyroclastic textures are also common. The original minerals are variably replaced by metamorphic minerals, especially augite in the basaltic rocks.

Feldspars are major constituent minerals in all rock types in Ash Shizm. They occur either as microlites in the ground mass, or as phenocrysts. All the feldspars encountered, both in basaltic and most rhyolitic rocks, are albitized ( $< An 10$ ). Feldspars of the basaltic rocks are also variably replaced by aggregates of greenschist facies metamorphic minerals. Epidote is the most common of these minerals. Prehnite may be present in some sections as shown by bow-tie aggregates. The second most abundant metamorphic mineral is chlorite, which varies from very minute flakes to coarse-grained aggregates. Other metamorphic minerals are actinolite, quartz, calcite and sericite. Quartz is more abundant than calcite and occurs as an alteration mineral in the form of chalcedony. Locally it forms spherulites (Figure 3A). The rock types identified here are basalts (Figure 3B), rhyolites (Figure 3C), basic lithic tuffs, acidic tuffs, greenstones, and chloritites (Figure 3D).

### ***Umm Ad Damar***

The mineralization at Umm Ad Damar occurs in the lowermost (felsic) unit of Bowden and Smith (1981) which conforms quite closely to the main features of the Hulaifah type rocks.

According to Ahmed (1979) and Ransom (1984), as well as our observations, the Umm Ad Damar prospects are dominated by rocks of rhyolitic composition, with lesser amounts of andesitic composition, both pyroclastics and flows (Figure 4). Cherty textured rocks and thin units of Jasper and Jasper-carbonate rocks occur within the pile, as well as a suite of distinctive white spotted shallow intrusive and flow rocks. Conglomerate, sandstone and siltstone of the Murdama Group occur in few outcrops to the southwest of the ancient mines. Bedding in these rocks strikes  $N20^{\circ}W$  and dips  $30^{\circ}W$ . The volcanoclastic rocks were intruded successively by massive dacite/rhyodacite sills and plugs, diorite plutons and finally mafic dikes. Stratigraphic and structural synthesis within Umm Ad Damar area and between it and its surroundings is very difficult. Lithological complexity and rapid lateral variations, as well as structural complexity make such an analysis highly subjective. Furthermore, metamorphism and alteration associated with mineralization add to this complexity.

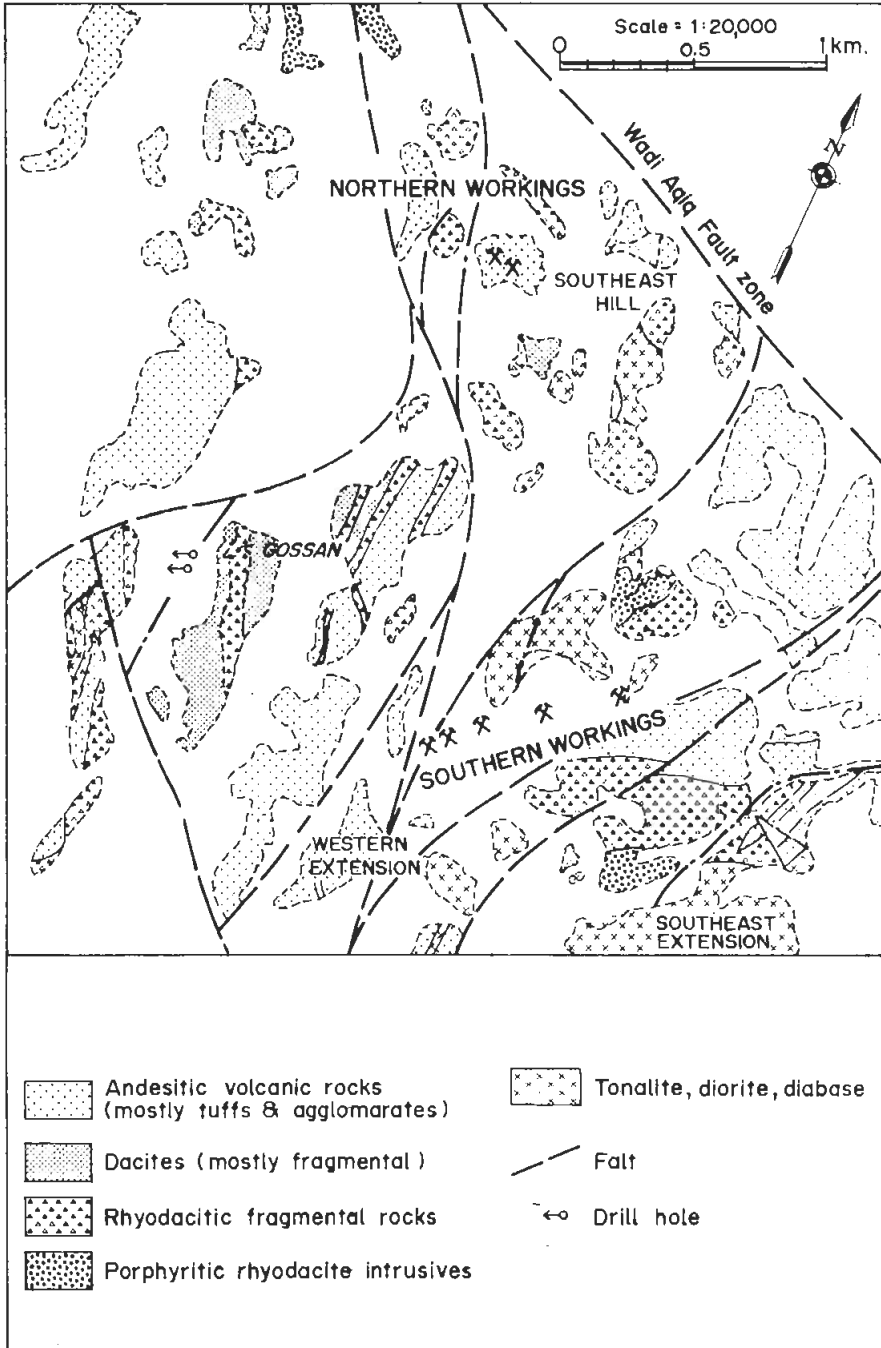


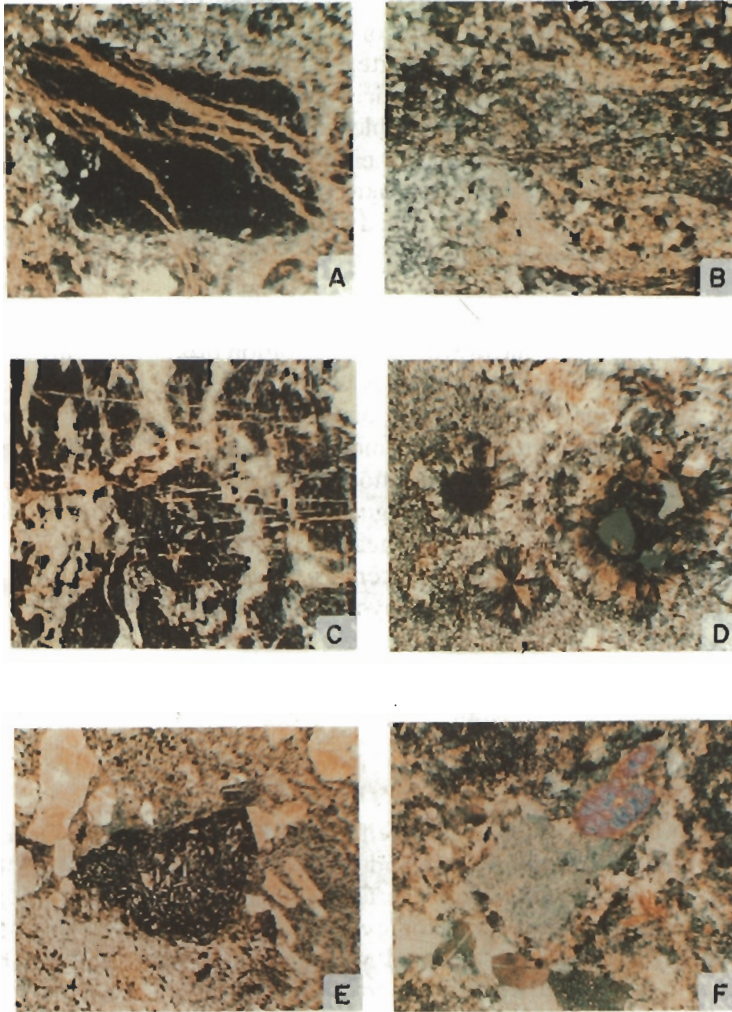
FIG. 4. Generalized geology of the Umm Ad Damar mine area (After Howes 1984).



The volcanic rocks at Umm Ad Damar are moderately to intensely affected by low grade regional metamorphism, but reconstitution or recrystallization is not advanced. Metamorphic minerals are chlorite, sericite, epidote, albite, quartz and calcite. Tremolite-actinolite is very local. Silicification is quite common as shown by the wide occurrence of secondary quartz. Chlorite and sericite are the most abundant metamorphic minerals. Chlorite occurs either in minute flaky aggregates in the groundmass, or as aggregates of large flakes pseudomorphic after earlier minerals. Sericite occurs also as minute flakes mixed with chlorite in the groundmass (Figure 3E), or replacing feldspar phenocrysts (Figure 3F). Ferruginous argillic material occurs along fractures or grain boundaries, or as irregular masses developed around pyrite cubes. Carbonates, mostly calcite, are very abundant as secondary minerals occurring as pseudomorphs alone or with other alteration products or earlier minerals. Carbonates also occur as irregular masses in the ground mass and as thin veinlets crossing the rocks (Figure 5A). Epidote occurs widely in the samples investigated from Umm Ad Damar, but in much less amounts than at Ash Shizm. It mostly occurs as very fine aggregates with other alteration products or as cryptocrystalline aggregates pseudomorphous after feldspar (Figure 5B). Shearing is common in Umm Ad Damar rocks with the development of shear planes on the microscopic scale which are also associated with wide scale replacement by alteration products (Figure 5B). The rock types at Umm Ad Damar are rhyolites, rhyolitic tuff (Figure 3F), quartzite (Figure 5C) and meta-andesite. This rock sequence represents a calc-alkaline volcanic suite. The alteration is more varied and more intense than at Ash Shizm. Shearing is common which causes the transformation of rhyolitic rocks into quartz-sericite rocks.

### **As Safra**

According to Duhamel (1971) and Delfour (1983), the As Safra Quadrangle is composed mainly of strongly folded and metamorphosed rocks of the Hulayfah group, overlying an ophiolitic complex. The ophiolitic complex and the Hulayfah group were both intruded by a syntectonic calc-alkaline granite. The Hulayfah group is unconformably overlain by deformed Murdama and Shammar formations that occur in a narrow elongated syncline trending NNW. All lithologic units are cut by the NW-trending Najd fault system. The As Safra mineral occurrence lies in a belt of Upper Hulayfah volcanic rocks, both flows and pyroclastics, which are intruded by a large body of synkinematic granite (Figure 6). The relief at the As Safra occurrence is very low and rock exposures are scarce. The pyroclastic beds strike N20°E. From east to west, the following sequence was recognised: andesite and microdiorite, bedded tuff, gray massive dolomitic marble, rhyolitic tuff (hosting the ore) which is intensely altered, and andesitic and rhyolitic tuffs. Numerous bodies of diorite, gabbro and diabase intrude these rocks and probably represent subvolcanic intrusives. A swarm of rhyolitic and microgranitic dikes striking N70°W traverses the prospect. These dikes post-date the mineralization. The rhyolitic host rocks (Figure 5D) are sheared and transformed to quartz-sericite and quartz-sericite-chlorite-rich rocks. The effects of metamorphism are similar to those observed at Umm Ad Damar, but the textures are better preserved here. The most common alteration products are



- FIG. 5A. Photomicrograph of plagioclase altered to microcrystalline epidote and crossed by calcite veinlets in altered rhyolite, Umm Ad Damar area. Transmitted light, crossed polars,  $\times 21$ .
- FIG. 5B. Photomicrograph of sericite, quartz and chlorite in altered sheared rhyolites, Umm Ad Damar area. Transmitted light, crossed polars,  $\times 38$ .
- FIG. 5C. Photomicrograph of quartzite at Umm Ad Damar area. Transmitted light, crossed polars,  $\times 21$ .
- FIG. 5D. Photomicrograph of spherulitic rhyolite from As Safra area. Transmitted light, crossed polars,  $\times 21$ .
- FIG. 5E. Photomicrograph of andesitic crystal tuff from Al Musayna'ah area showing fragments of andesite and feldspars in a fine-grained ashy matrix. Transmitted light, crossed polars,  $\times 21$ .
- FIG. 5F. Photomicrograph of calcareous rhyolitic tuff from Umm Ash Shalahib area showing fragments replaced by sericite and epidote and the matrix partly replaced by calcite. Transmitted light, crossed polars,  $\times 34$ .

sericite, chlorite, quartz, calcite and actinolite. Marble also occurs in the form of thin bands within the volcanic succession which are believed to be originally sedimentary carbonate layers. In some sections it is pure calcite marble, while in others it contains tremolite and brucite. Abundant oxidized pyrite cubes occur in the marble.

The rock types at As Safra are rhyolites, andesites, quartz-sericite schist and quartz muscovite schist and, like Umm Ad Damar, belong to a calc-alkaline volcanic suite.

### ***Al Musayna'ah***

The Al Musayna'ah area is made up mainly of rocks belonging to the Afna formation of the Hulayfah group, overlain unconformably by rocks of Ar Ragab formation of the Murdama Group, and in fault contact with the Bir Tuluha ophiolitic complex. The whole sequence is intruded by basic to acidic dikes and sills. The area hosting the mineralization is built up of a sequence of layered volcanic-volcaniclastic and sedimentary rocks with interlayered sill-like bodies of amygdaloidal porphyritic andesite (Figure 7), as well as some carbonate bands. The whole sequence strikes almost N-S and dips steeply eastwards. It is intruded by swarms of rhyolitic to dacitic dikes that are mostly parallel to the layering (Figure 7) and are not affected by mineralization. However, it seems that these dikes were accompanied by potash metasomatism which enriched the country rocks with potash feldspar.

The volcanic rock succession at Al Musayna'ah is composed mainly of andesitic flows with their volcaniclastic equivalents (Figure 5E) as well as subordinate rhyolites and rhyolitic pyroclastics. Both rhyolites and andesites exhibit porphyritic textures much more common than in the other occurrences. Andesites show the effects of metamorphism more than the rhyolites which are relatively fresher than in the other areas. In the rhyolites and andesites, the ferromagnesians are replaced by a mixture of chlorite, opaques and argillic material. However, primary hornblende and pyroxene (augite or hypersthene) were reported in the andesites as well as biotite in the rhyolites (Qadhi and Hussein 1984). The dominant feldspar in the rhyolites is anorthoclase.

### ***Umm Ash Shalahib***

Umm Ash Shalahib occurs in a belt of volcanic-volcaniclastic sequence of the Al Amar Group which is equivalent to the Halaban Group. The Al Amar major tectonic lineament separates the Al Amar Group to the east from the Abt schist to the west (Figure 8). The Umm Ash Shalahib area was mapped by Leca (1970) and Brosset (1972) and the maps were revised by Delfour (1975) on the scale of 1:10,000, and is reproduced here as Figure 9. These stratified rocks are intruded by masses of subvolcanic rhyolite with which the mineralization is spatially associated, being always within the rhyolite or at its contact with the country rocks (Tayib and Al Shanti 1983). According to Delfour (1975), three rhyolite masses were mapped. The northern most of them is an agglomeration of rhyolite dikes striking northeast and dipping 50° to the southeast. The central mass is of similar strike northeast and dipping 50° to the southeast. The central mass is of similar strike and dip and is mainly of rhyolitic intru-

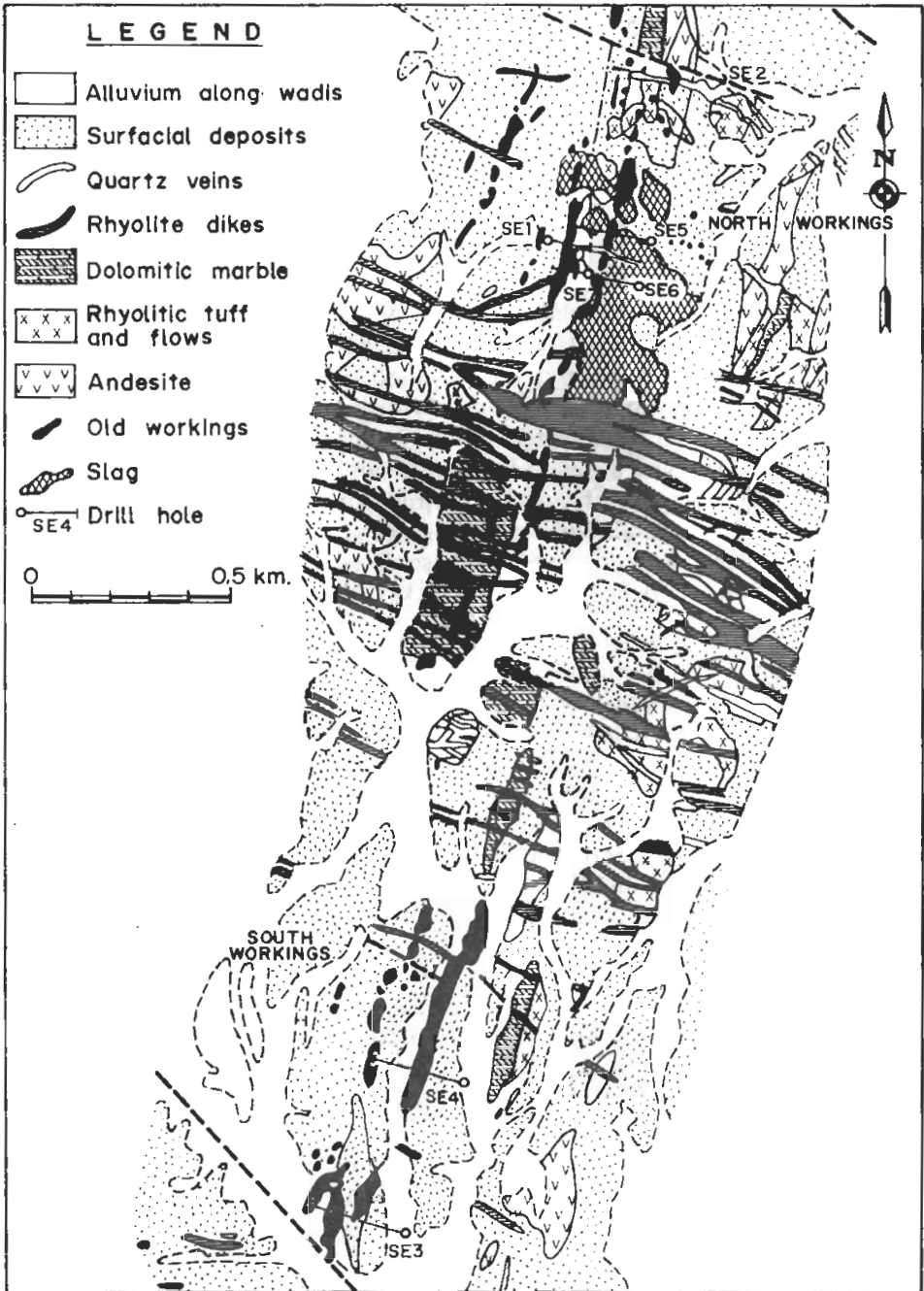


FIG. 6. Geologic map of As Safra area (After Duhamel, 1971).

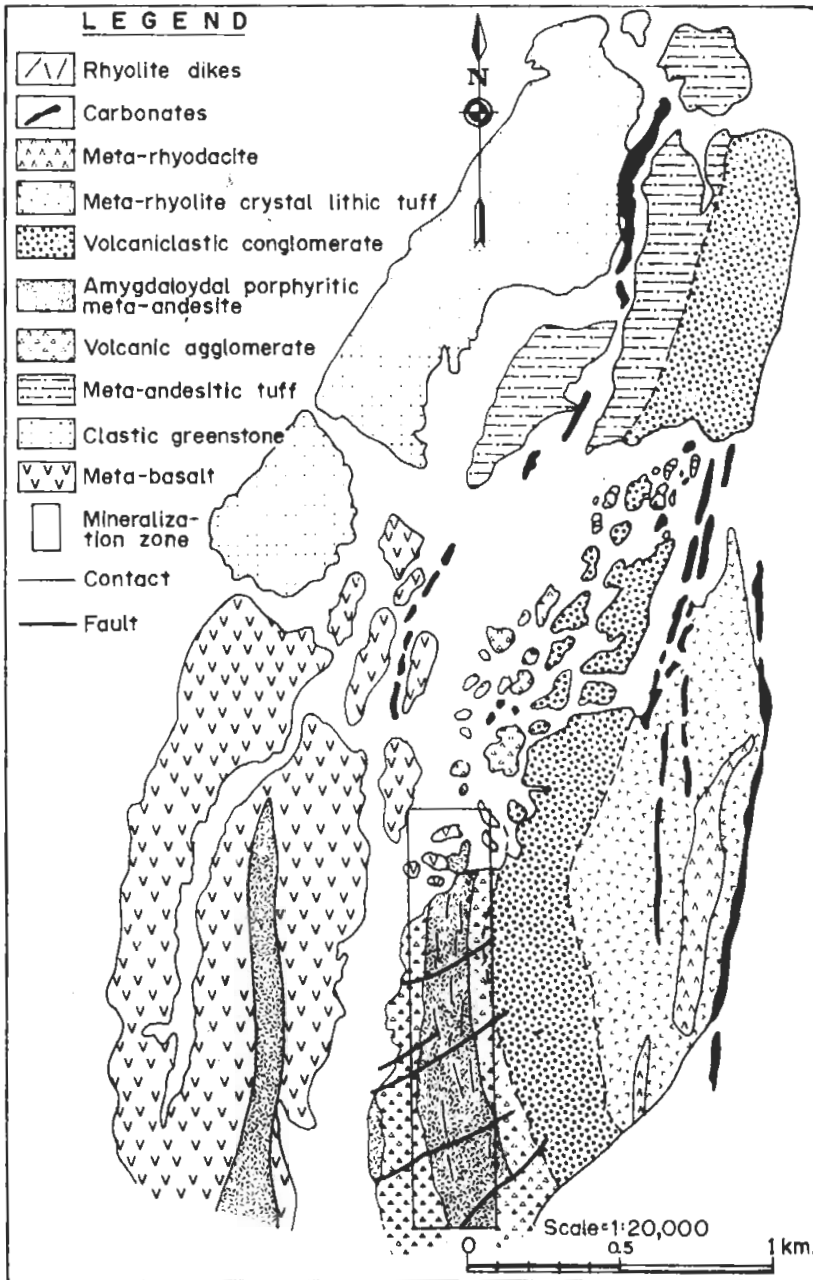


FIG. 7. Geologic map of North Al Musayna'ah area (After Tayib and Al Shanti, 1983).

sive breccia with stringers and veinlets of milky quartz. The southern rhyolitic mass is elongated in a north-south direction and is made up of intrusive breccia with a quartz cement. Diabase dikes are frequent in the area, and most of them seem to occupy northeast trending fault planes.

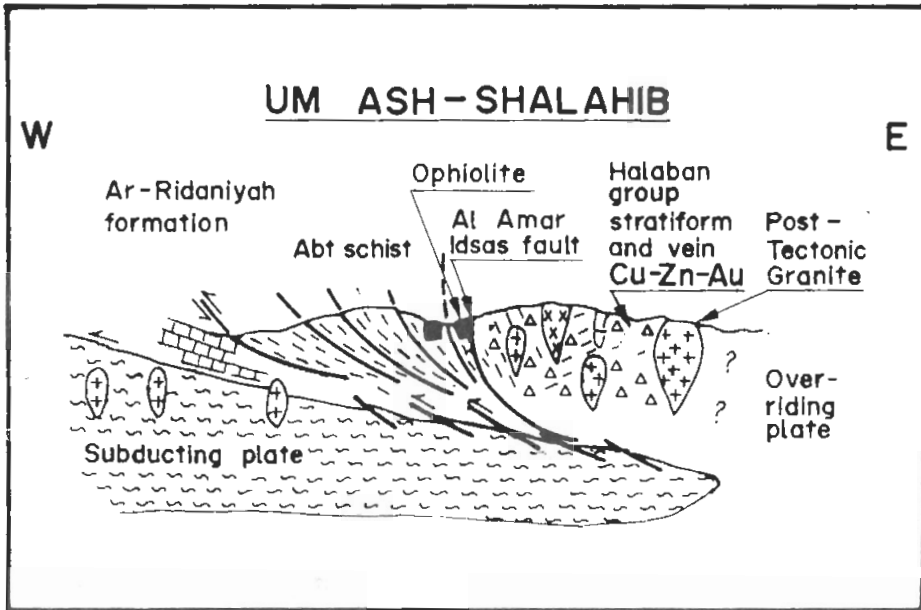


FIG. 8. Schematic cross section, Al Amar-Idsas belt, after Al Shanti and Mitchel (1976).

The host rocks of the mineralization at Umm Ash Shalahib are dominated by rhyolitic tuffs and flows. Shearing and alteration are common. The most common alteration is carbonatization, which produced calcareous rhyolitic tuff (Figure 5F). Epidote and quartz are also products of alteration and they form together epidote-quartz rock. Marbles and skarn rocks are common among the host rocks of Umm Ash Shalahib. The skarn minerals include calcite, epidote, actinolite, garnet, diopside and scapolite.

Umm Ash Shalahib rocks are also calc-alkaline in which pyroclastics are more abundant than flows. The proportion of interbedded sedimentary rocks, particularly carbonate rocks, is greater than in the other areas.

### Mineralization

Polymetallic sulfide deposits are known to occur within the Hulaifah Group type volcanic-volcaniclastic sequences of the Arabian Shield, sometimes referred to as type "B" lithostratigraphic sequence (Jackson & Ramsay 1980). These sulfides are generally characterized as being derived from submarine hydrothermal volcanic exhalations and deposited in the form of disseminated, stockwork and massive

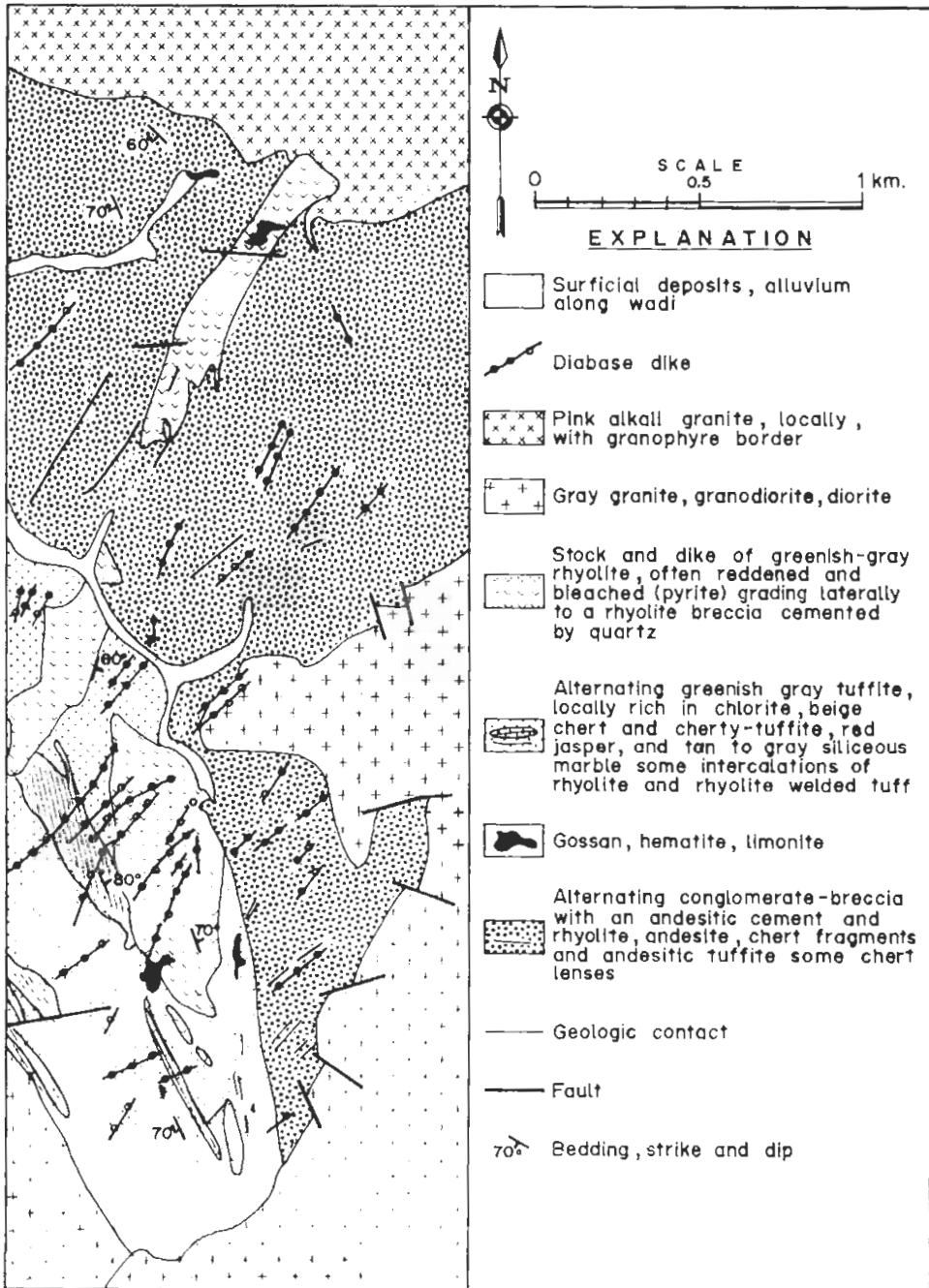


FIG. 9. Umm Ash Shalahib geologic map. Simplified from Leca (1970) and Brosset (1972).

forms. Post-depositional mobilization, due to thermal or dynamothermal events, occurred in most of these deposits. Additional epigenetic mineral assemblages were deposited along fractures and zones of weaknesses in some mineralization sites. The ore deposits have been invariably affected by metamorphism whereby recrystallization and metamorphic textures were superimposed on previous primary and alteration textures. Locally, new minerals developed as a consequence of metamorphism.

### **Ash Shizm**

The ancient Ash Shizm prospect was a site of ancient mining approximately 900 to 1000 years ago, probably for Au and Ag. The old workings follow zones of mineralization that are intimately and concordantly associated with the host volcanic rocks for a length of about 200 meters and a thickness of 2-3 meters.

The oxidation zone extends for a depth of approximately 35 m below the surface. These host rocks are composed of rhyolitic lavas and breccias that are highly chloritized. Numerous, criss-crossing small veinlets of secondary quartz traverse this zone. The oxidation minerals are mainly iron oxides (hematite and goethite) and minor amounts of secondary copper minerals that stain fractures and constitute about 5% of the rock. Red jasper overlies the mineralization.

The primary mineralization zone immediately underlies the oxidation zone. The host rocks are in the form of a pipe or funnel-shaped body about 150 m across and 300 m deep. The mineralization is in the form of stringers and disseminations that cluster together to form zones or bands of sulfides that vary in thickness from few cm to 15 m.

Primary ore minerals are, in a decreasing order of abundance, sulfides and sulfosalts, oxides, and tellurides. The sulfides and sulfosalts recorded are pyrite, chalcopyrite, sphalerite, galena, pyrrhotite, bornite, tetrahedrite, mackinawite, and cobaltite. The oxides are mainly magnetite and titanomagnetite. The tellurides are rare and comprise altaite, hessite, tellurobismuthite, and tetradyomite.

The mineralization at Ash Shizm exhibits the following characteristics:

1. It is confined to a certain lithologic assemblage composed essentially of highly chloritized rhyolite flow and breccia, of the upper Hulayfah. The host rock assumes the shape of a pipe and is capped by a zone of jasper.

2. No massive sulfide lenses are present. The mineralization is in the form of either disseminations or stringers. The stringers are always bordered by a selvage of chlorite containing disseminated sulfide minerals.

3. The mineral constitution of the stringers is not the same in all cases. Some stringers are composed mainly of pyrite, or of pyrite with subordinate sphalerite, some mainly of bornite with subordinate chalcopyrite and pyrite, and other stringers of about equal proportions of chalcopyrite and sphalerite with subordinate bornite and pyrite (Figure 10A).

4. In most of the stringers where chalcopyrite, bornite and sphalerite occur, the Zn/Cu ratio decreases downward.



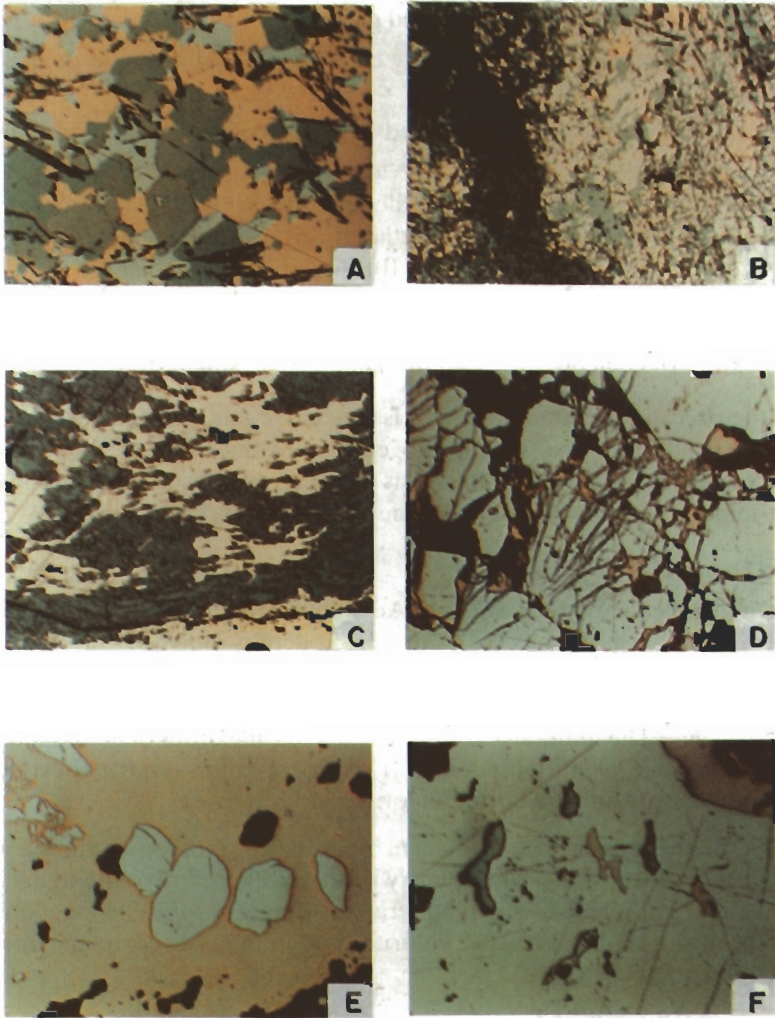


FIG. 10A. Photomicrograph showing two types of sphalerite, one with exsolution droplets, and the other free of exsolutions. Euhedral to subhedral crystals of magnetite (M) in contact with other sulfides. Galena contains minute inclusions of altaite (A) and hessite (H), Ash Shizm area. Incident polarized light, oil imm.,  $\times 138$ .

FIG. 10B. Photomicrograph of intense fracturing and brecciation of pyrite from Ash Shizm area. Incident polarized light,  $\times 85$ .

FIG. 10C. Photomicrograph showing streaking out of chalcopyrite as a result of directed pressure, Ash Shizm area. Incident polarized light,  $\times 21$ .

FIG. 10D. Photomicrograph of coarse- to medium-grained anhedral to subhedral, moderately fractured pyrite from Umm Ad Damar area. Fractures are filled by chalcopyrite. Incident polarized light,  $\times 85$ .

FIG. 10E. Photomicrograph of relic pyrite euhedra replaced by chalcopyrite, Umm Ad Damar area. Incident polarized light,  $\times 85$ .

FIG. 10F. Photomicrograph of anhedral crystals of hessite (H) and altaite (A) in pyrite, Umm Ad Damar area. Incident polarized light,  $\times 138$ .

5. The disseminated type of mineralization is composed principally of pyrite with subordinate chalcopyrite, sphalerite, and galena.

6. Associated gangues are principally chlorite with subordinate quartz and epidote.

7. The mineralization is characterized by its association with moderately to intensely chloritized zones of the host rocks.

8. The textural features suggest the deposit has been subjected to deformation and low greenschist-grade regional metamorphism. These features include slight fracturing and rare brecciation (Figure 10B) of ore minerals, development of porphyroblasts and parallel elongated pyrite crystals, the streaking out of ductile sulfides (Figure 10C) and the presence in some of them of pressure twinning and the mottled texture of chalcopyrite exsolution lamellae in sphalerite.

From the preceding characteristics, it is concluded that Ash Shizm sulfide deposit formed as a result of submarine volcanogenic exhalative processes. The mineralization is restricted to the rhyolitic unit and is capped by red jasper and carbonates. The age of the mineralization is nearly the same as the host rocks.

#### ***Umm Ad Damar***

There are two ancient mines at Umm Ad Damar area separated by 2.5 kms. Primary mineralization was intersected by drilling at depths ranging from 50 to 150 m by drilling. The gossan occurs in the southeastern part of the North Workings and covers an area of about 20,000 m<sup>2</sup>. The gossan outcrops exhibit intense development of fracture cleavage. The minerals present, in a decreasing order of abundance are iron oxides (mainly goethite and lepidocrocite), microcrystalline quartz (chert), clay minerals (mainly sericite and kaolinite), chlorite, and Mn oxides.

The oxidation zone reaches about 40 m below the surface, and attains a wider lateral extent than the gossans. The country rocks are altered rhyolitic to dacitic tuffs, meta-rhyolite, and rhyolite agglomerate. Minerals present are malachite, chrysocolla, bronchianite, sericite, chlorite, kaolinite, and secondary fine-grained quartz.

The primary mineralization occurs as disseminations of fine-grained euhedral to subhedral pyrite, locally with chalcopyrite, or as stringers composed mainly of chalcopyrite with minor pyrite, or quartz veinlets with chalcopyrite and pyrite. A few small zones of almost massive pyrite and chalcopyrite are also present. These modes are strata-bound and concordant with the enclosing rocks. The mineralization bands have the shapes of a lens or sheet, and their thickness varies from 2 to 10 cm. Each band may contain one or more modes of occurrence. It is emphasized that these mineralized bands are actually zones of country rocks that are more or less enriched in sulfides. The amount of sulfides in the bands varies from 1 to 50%, but the average is 2-3%. Other minerals present, in decreasing abundance are: sphalerite, magnetite, covellite, neodiginite, galena, pyrrotite, tellurides, and fahlore (tennantite-tetrahedrite). Gangue minerals include chlorite, quartz, calcite, sericite, and relic altered feldspars.

Lateral variations along the strike of the mineralized zones are expressed by transition from chalcopyrite-rich bands to zones where pyrite is the main sulfide mineral. In addition, the mineralization type changes from predominantly stringers, to disseminations, to stockwork types and vice versa, without apparent order. The first minerals to form were magnetite and titanomagnetite. These show an exsolution texture with spinal which indicates their formation at high temperature. Probably they are from the host rocks, i.e. igneous relics. Specularite developed by alteration of the earlier formed magnetite. During this stage, the environment of deposition was that of high temperature, oxidizing conditions.

Deposition of sulfides took place in successive pulses rather than in one continuous surge. The first sulfide to be deposited was pyrite. It formed in three generations, each characterized by its own texture (Pyrite I, II and III).

Sphalerite is the second sulfide to be deposited and it formed during two pulses of mineralization. The earlier, sphalerite I, formed at a slightly higher temperature than the later sphalerite II as indicated by the presence of exsolution texture of chalcopyrite in sphalerite I only. Chalcopyrite was the next sulfide to be deposited as revealed by its crosscutting relations, and by replacement texture with sphalerite and pyrite (Figure 10D-E). Three textural types of chalcopyrite are recorded. Covellite and neodiginite formed later than the other sulfides as a result of supergene alteration of chalcopyrite.

During one of the mineralization pulses, probably midway in the primary deposition phase, the bismuth minerals and tellurides were deposited (Figure 10F). Goethite, lepidocrocite, and amorphous hydrated ferric oxides developed as a result of supergene alteration of pyrite.

It could be concluded that the mineralization occurs in rocks belonging to the upper Hulayfah Group and is restricted to definite lithostratigraphic horizons consisting predominantly of rhyolitic to dacitic flows of calc-alkaline composition and their pyroclastic equivalents. The mineralized area is affected by faults trending NS-NNW. The deposit shows the effects of remobilization and metamorphism. Widespread replacement textures are recorded and suggest that more than one stage of sulfide formation occurred. The mineralization at Umm Ad Damar is believed to have resulted from submarine volcanogenic exhalative processes.

### ***As Safra***

Numerous ancient workings that occupy an area 4 km long and .05 km wide trending in a N20°E direction occur at As Safra area. The old workings are in two groups, the Northern, and the Southern which are one km apart. The oxidation zone extends for a depth of 35-40 m. The host rocks are sericitized and chloritized rhyolitic tuffs and breccia. Surface mineralization is in the form of abundant stains of malachite, chrysocola, and iron oxides. Occasionally remnants of pyrite and chalcopyrite associated with fragments of vein quartz are observed.

Four types of primary mineralization are recorded: massive, stringer, dissemination, and quartz stockwork. The stringer and the quartz stockwork types are by far

the most abundant. The mineralization consists of a series of interconnected and branching small lenses and irregular sheets lying concordantly in the schistose rhyolitic tuffs. However, stringers of sulfides locally crosscut the host rocks. The maximum width of the mineralized zones encountered in the drill holes are about 11 m, while in some places the mineralization is only 0.5 to 2 cm in thickness. Ore minerals are mainly pyrite with subordinate chalcocite, and minor amounts of sphalerite, magnetite, pyrrhotite, galena, cubanite, native bismuth, bismuthinite, fahlore, marcseite, covellite, tetradymite, hessite, emplectite, and wittichinite. Gangue minerals are dominantly quartz, chlorite, mica, epidote, plagioclase, and carbonates.

Pyrite exhibits three textural varieties. Pyrite (I) is fine- to very fine-grained cubes, pyrite (II) is coarse- to medium-grained cubes or sections thereof, while pyrite (III) is coarse-grained and anhedral to subhedral with abundant inclusions of gangues and minor ore minerals (Figure 11A). Chalcocite occurs either as cavity-fillings in pyrite (III), as clustered aggregates, or as inclusions in pyrite. It also replaces pyrite and contains inclusions of bismuth minerals, tellurides, galena, sphalerite and tetrahedrite.

A mineral of the tetrahedrite-tennantite group [ $\text{Cu}_3(\text{As}, \text{Sb})\text{S}_3$ ] is intimately associated with galena and chalcocite where it occurs as small, rounded grains or patches of the order of 0.01 mm in diameter. Bismuthinite is associated with bismuth and occurs as small columnar and radial crystals or forms xenomorphic clusters of frequently well rounded forms. Bismuthinite often replaces bismuth, and in many cases it envelops it as thin crusts; but sometimes it follows fractures and twin lamellae.

Lateral variations across the strike of the mineralized zones find microscopic expression in the transition from chalcocite-rich bands to zones where pyrite is the main sulfide mineral present. In addition, the mineralization type changes from predominantly stringer, to disseminations, and to stockwork in no apparent order. Vertical variations in mineralogy are erratic.

The mineralization at As Safra occurred in at least two phases. First, there was a primary deposition phase where sulfides were deposited in successive pulses. Pyrite was the first mineral to be deposited in three generations, each characterized by its own texture. Chalcocite was the second sulfide to be deposited, as revealed by its cross cutting relations and by replacement texture with pyrite. Sphalerite was deposited in two successive stages as indicated by the presence of exsolution texture. During one of the mineralization pulses, probably midway in the primary deposition phase, bismuth sulfosalts, hessite (Figure 11B) and other minor constituents were deposited (or exsolved).

During the successive mineralization pulses, a delicate balance existed between reducing and oxidizing conditions with the balance shifting mostly towards reduction. Oxidation conditions prevailed during relatively short spans of time during which magnetite was deposited.

The second phase was the result of metamorphic mobilization. During this phase,

the early formed ore minerals and their associated host rocks were subjected to metamorphic effects which resulted in changes in mineralogy and texture. Pyrite was recrystallized and formed elongated crystals parallel to the foliation planes. Chalcopyrite and the other ductile sulfides were streaked out to form stringers either parallel to the foliation or crosscutting it. Siliceous hydrothermal solutions permeated the country rocks and produced a stockwork of sulfide-bearing quartz veins situated in a vertical shear zone trending N20°E and intersecting the slightly folded formations.

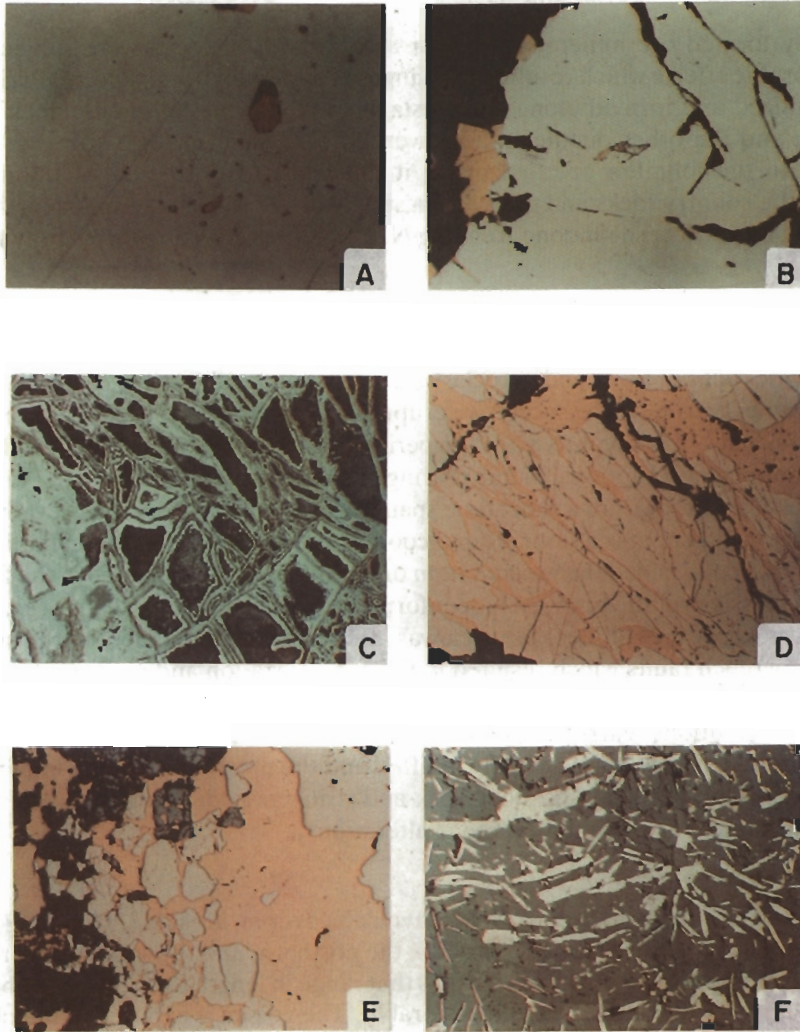
From previous data it could be stated that the As Safra area was subjected to a long period of mainly submarine volcanic activity during which the succession of Hulayfah Group type rocks of flows and pyroclastics interbedded with marble of the Hulayfah Group were deposited. The successive eruptions formed rocks that range in composition from andesite to rhyolite. During a period of quiescence, immediately following one of the volcanic eruptions, metal-bearing exhalates issued forth onto the sea floor and were deposited within a short time span through reduction by the prevailing reducing environment at sea floor. Rapid cooling and/or dilution of the metalliferous solutions probably aided the precipitation of the sulfides. This resulted in the formation of a massive sulfide body that is conformable with the surrounding rocks. After the deposition of the sulfides, the area was affected by regional metamorphism and the Najd wrench faults which resulted in the remobilization and recrystallization of the sulfides in secondary fractures trending N20°E. Late surges of epigenetic hydrothermal solutions carrying some sulfide mineralization caused widespread silicification. The area was gradually uplifted and the upper parts of the mineralization was eroded, exposing the stockwork and stringers underlying the massive sulfides, and subjecting them to supergene alterations.

#### ***Al Musayna'ah***

The ancient mine workings at Al Musayna'ah cover an area of 3.5 km long by 0.7 km wide. They are divided into two parts, the northern, and the southern workings. There are numerous old pits and trenches that range in length from few m to about 80 m and they vary in width from ½ to several m. The gossan is exposed in the old pits and trenches as well as low relief hills. The gossan exposures are highly sheared with intense development of fracture cleavage trending N-S and dipping steeply to the east. They exhibit examples of boxwork texture developed after pre-existing sulfides (Figure 11C).

The oxidation zone extends for a depth of about 40 m, with local deeper extensions. Minerals present are malachite, chrysocolla, goethite, lepidocrosite and amorphous hydrated ferric oxides. The host rock is moderately altered porphyritic andesite, rhyolite, porphyritic rhyolite and fine agglomerate. The primary mineralization occurs either as disseminations or patches of fine-grained anhedral to subhedral pyrite with minor chalcopyrite and magnetite or stringers of chalcopyrite and pyrite associated with magnetite (Figure 11D). A few veinlets of quartz and calcite with disseminations of pyrite and chalcopyrite are also present.

These modes of occurrences form thin bands conformable with the enclosing rocks



- FIG. 11A. Photomicrograph showing pyrite with rounded to oval inclusions of chalcopyrite, pyrrhotite, tetrahedrite and mixed chalcopyrite-pyrrhotite. As Safra area. Incident polarized light, oil imm.,  $\times 138$ .
- FIG. 11B. Photomicrograph of allotropic grains of emplectite (E) and hessite (H) in pyrite. As Safra area. Incident polarized light, oil imm.,  $\times 138$ .
- FIG. 11C. Photomicrograph showing boxwork texture developed after pre-existing sulfides. The walls are lined by hydrated iron oxides and the cavities are filled by silicate gangues. Gossan zone, Al Musayna'ah area. Incident polarized light,  $\times 85$ .
- FIG. 11D. Photomicrograph showing abundant veinlets and stringers of chalcopyrite traversing deformed pyrite and replacing it. Primary mineralization zone, Al Musayna'ah area. Incident polarized light,  $\times 85$ .
- FIG. 11E. Photomicrograph of medium-grained crystals of magnetite associated with matrix sulfides and gangue. Relic pyrite is replaced by chalcopyrite. Primary mineralization zone, Al Musayna'ah area. Incident polarized light,  $\times 85$ .
- FIG. 11F. Photomicrograph of acicular, fine- to medium-grained crystals of specularite disseminated within gangue. Primary mineralization zone, Al Musayna'ah area. Incident polarized light,  $\times 85$ .

and have the shapes of discontinuous sheets or attain irregular shapes. The thickness of the mineralized bands varies from 1-30 cm and are actually zones of country rocks enriched in sulfides. The content of sulfides in these bands ranges between 2-5%.

The mineralized veins trend mainly N40°-60°E and less dominantly in a N-S direction, particularly at rhyolite dike contacts with host rocks. Mineralization is restricted to fault zones and sheared wall rocks on both sides. Wall rock alteration minerals are quartz, epidote, chlorite, sericite and carbonates. The intensity of alteration fades away from sheared zones. Chloritization and silicification are closely associated with all forms of sulfide occurrences within faults and in host rocks. Epidotization, sericitization and carbonatization are well developed in host rocks but less associated with mineralization. Calcite veinlets traverse the host rocks and form local irregular patches with sulfides.

The primary mineralization zone contains mainly pyrite, chalcopyrite and magnetite, with minor amounts of sphalerite, specularite, chalcocite, neodiginite and covellite. Associated gangue minerals are calcite, quartz, potash feldspar, actinolite and chlorite. Pyrite is the most abundant sulfide followed by chalcopyrite. Both exhibit the same textural features observed at As Safra area. Magnetite and titanomagnetite occur as disseminated euhedral to subhedral, fine- to medium-grained crystals associated with sulfides and gangue (Figure 11E), and show various degrees of martitization. Specularite forms acicular fine- to medium-grained crystals disseminated within gangue (Figure 11F). Chalcocite, neodiginite and covellite occurs as small rounded inclusions in chalcopyrite. They also form veinlets traversing chalcopyrite or occur as rims around it (Figure 12A).

The paragenetic sequence of crystallization at Al Musayna'ah indicates that pyrite was the first mineral to form, and that it probably crystallized during three consecutive periods. Chalcopyrite and chalcocite developed at a later period and their crystallization probably terminated before the final crystallization of pyrite. Magnetite developed during a short later period when Eh conditions temporarily shifted towards a slightly oxidizing environment.

The ore minerals exhibit criteria suggesting a later period of cataclasis and regional metamorphism. Pyrite is frequently fractured to varying degrees, with the fractures either vacant or filled by gangue minerals or chalcopyrite (Figure 11D). The intensity of fracturing increases closer to faults and shear zones where pyrite exhibits extreme fracturing and brecciation. Anomalous anisotropism in pyrite is a common feature. Recrystallization and development of porphyroblasts were observed. Magnetite was also affected by deformational stresses, but it shows less fracturing than pyrite. Chalcopyrite grains are stretched and form parallel streaks of elongated crystals.

It is concluded that the mineralization at Musayna'ah belongs to the exhalative-volcanogenic type of deposits. The mineralized zones are represented by disseminations, stringers and veinlets within a sequence of volcanic-volcaniclastic rocks belonging to the Hulayfah Group type rocks.

It is suggested that the original mineralization was probably in the form of

stockwork feeders below a massive sulfide body. During periods of later deformation and regional metamorphism, the ore minerals were mobilized by circulating hydrothermal fluids and redeposited in available, easily accessible channels, namely faults and shear zones. Later reactivation of these faults caused brecciation of pyrite, and the introduction of magnetite, calcite and quartz veinlets in the existing mineralization.

### ***Umm Ash Shalahib***

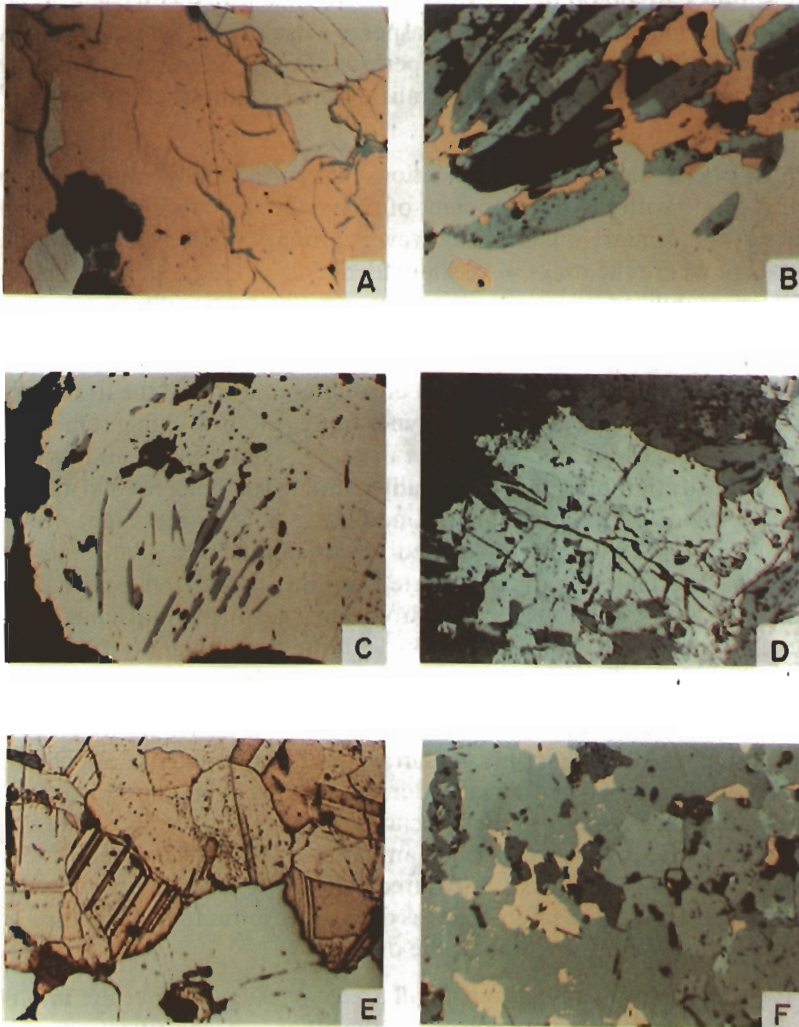
The old workings are centered around several gossan outcrops of which the main ancient ones are situated in the south. They consist essentially of open pits and trenches trending NNE that follows zones of oxidation. The gossans consist of brown to reddish brown ferruginous zones with siliceous, clayey matrix. Their width ranges from 50 cm to 10 m. The oxidation zone is exposed in the ancient trenches and in the drill cores to a depth of 40 m. The host rocks are altered rhyolite breccia and tuffs. Pervasive silicification is observed. Ore minerals in the gossan are mostly iron oxides and stains of malachite and chrysocolla.

The primary mineralization is in the form of small massive lenses trending NE, in addition to disseminations of sulfides and magnetite. It can be divided into four main modes that differ both in mineralogy and texture. These are massive sulfide-magnetite, disseminated sulfide-magnetite, massive magnetite, and disseminated magnetite (Figures 12B-C). Martitization is observed (Figure 12D) whereby lamellae of hematite form along the octahedral planes of magnetite and progressively invade the crystals from the margins and cracks. Martitization has advanced to such a degree that it almost completely replaced the magnetite except for sparse relics. It occurs exclusively in the upper part of the Hulayfah type rocks that consist of a succession of rhyolite, andesite, and their volcanoclastic derivatives. The subvolcanic rhyolite has the same trend as the mineralized zone and probably played a role in the formation of the deposit. The ore minerals consist of oxides and sulfides and are mainly pyrite, magnetite, sphalerite, hematite, chalcopyrite and some gold. The ore minerals exhibit several features of cataclasis subsequent to their recrystallization, but these mostly indicate mild deformation (Figure 12E). Recrystallization and remobilization textures are evident. The widespread replacement textures (Figures 12B,C,F) suggest that there are more than one stage of mineralization. The gangue minerals are mainly quartz, epidote, carbonate, actinolite, serpentine, talc, and chlorite. From the preceding characteristics, it is suggested that the mineralization is the result of submarine volcanogenic exhalative processes.

### **Summary and Conclusion**

The five mineralized localities investigated host mainly copper and zinc with either gold as in As Safra, silver as in Ash Shizm or gold and silver as in Umm Ash Shalahib, or with no gold and silver as in Umm Ad Damar and Al Musayna'ah. Gold and silver are present as tellurides in the form of microscopic inclusions within sulfide minerals, essentially pyrite and chalcopyrite, and are of little or no economic importance.





- FIG. 12A. Photomicrograph showing rims of covellite, neodiginite and chalcocite lining periphery of chalcopyrite and filling fractures in it. Primary mineralization zone, Al Musayna'ah area. Incident polarized light,  $\times 85$ .
- FIG. 12B. Photomicrograph of elongated laths of specular magnetite pseudomorph after specularite. Relics of specularite are still preserved. Umm Ash Shalahib area. Incident polarized light,  $\times 85$ .
- FIG. 12C. Photomicrograph of specular magnetite replaced by pyrite. Umm Ash Shalahib area. Incident polarized light,  $\times 85$ .
- FIG. 12D. Photomicrograph showing patches of coarse- to medium-grained martitized magnetite. Two types of martitization are present. Umm Ash Shalahib area. Incident polarized light,  $\times 85$ .
- FIG. 12E. Photomicrograph of etched surface of chalcopyrite exhibiting pressure twinning developed as a consequence of directed pressure. Umm Ash Shalahib area. Incident polarized light,  $\times 85$ .
- FIG. 12F. Photomicrograph of sphalerite with chalcopyrite emulsion texture in mutual contact with magnetite. The magnetite is partly martitized and is replaced by sphalerite. Umm Ash Shalahib area. Incident polarized light,  $\times 85$ .

The host rocks are predominantly rhyolitic volcanoclastics with some andesitic associations. Carbonates and/or chert or jasper are usually intercalated in the vicinity of the mineralized zones, thus reflecting periods of volcanic quiescence during which these chemical sediments and the mineralization were emplaced by submarine volcanic exhalations.

The host rocks and the mineralizations were regionally metamorphosed to greenschist-grade with the development of characteristic mineral assemblages with only relics of the primary minerals. However, primary textures are commonly preserved, except where the rocks were sheared and developed foliation. The ore minerals were remobilized, segregated and eventually recrystallized to coarser assemblages.

Proper massive sulfide lenses were not encountered in any of the five localities; instead, stockwork and disseminated ore types represent the dominant mineralization in all five occurrences. In all cases, mineralization is stratabound and restricted to a particular lithostratigraphic unit, but locally remobilized along pre-existing fractures to the overlying or underlying units. Mineral assemblages represent primary ores that have been coarsened and deformed to variable degree giving the ores their characteristic brecciated nature reflected in the associated pyrite and other metamorphic textures present. Later hydrothermal activity within zones of mineralization caused alteration of the host rocks with the development of quartz, calcite, chlorite and epidote veinlets.

The intensity of deformation and metamorphism varies from one locality to the other. Both Umm Ad Damar and As Safra exhibit rather intense effects, while the other three occurrences could be considered generally as moderately affected, but with localized intense shearing and brecciation. The ore mineral assemblages which are essentially sulfides with rather small amounts of sulfosalts and tellurides contain in all areas a variable amount of associated primary iron oxides, mainly magnetite and hematite. This could be interpreted as due to low sulfur fugacity in the system for short periods during the formation of the ores.

Wall rock alteration is ubiquitous in all areas investigated, yet the intensity and type of alteration varies from one locality to the other, e.g. chloritization is present in all five occurrences, yet it is very strong at Ash Shizm to the extent that some rocks are completely altered to chlorite in the immediate vicinity of the ore zones. On the other hand, potash feldspar metasomatism is rather intense in Al Musayna'ah where the plagioclase phenocrysts of the andesite prophyry and that of the groundmass are replaced by potash feldspar adjacent to the rhyolite dike swarms. This K-metasomatism is extremely developed in zones of mineralization and fades gradually away from the dikes. Alkali metasomatism is well demonstrated in Al Musayna'ah andesite and As Safra rhyolite.

Geotectonically, all five areas occur within a short distance from paleoplate margins marked by the occurrence of ophiolitic rock sequences. The time span of emplacement of the host rocks ranges from 650 to 800 Ma (Jackson and Ramsay

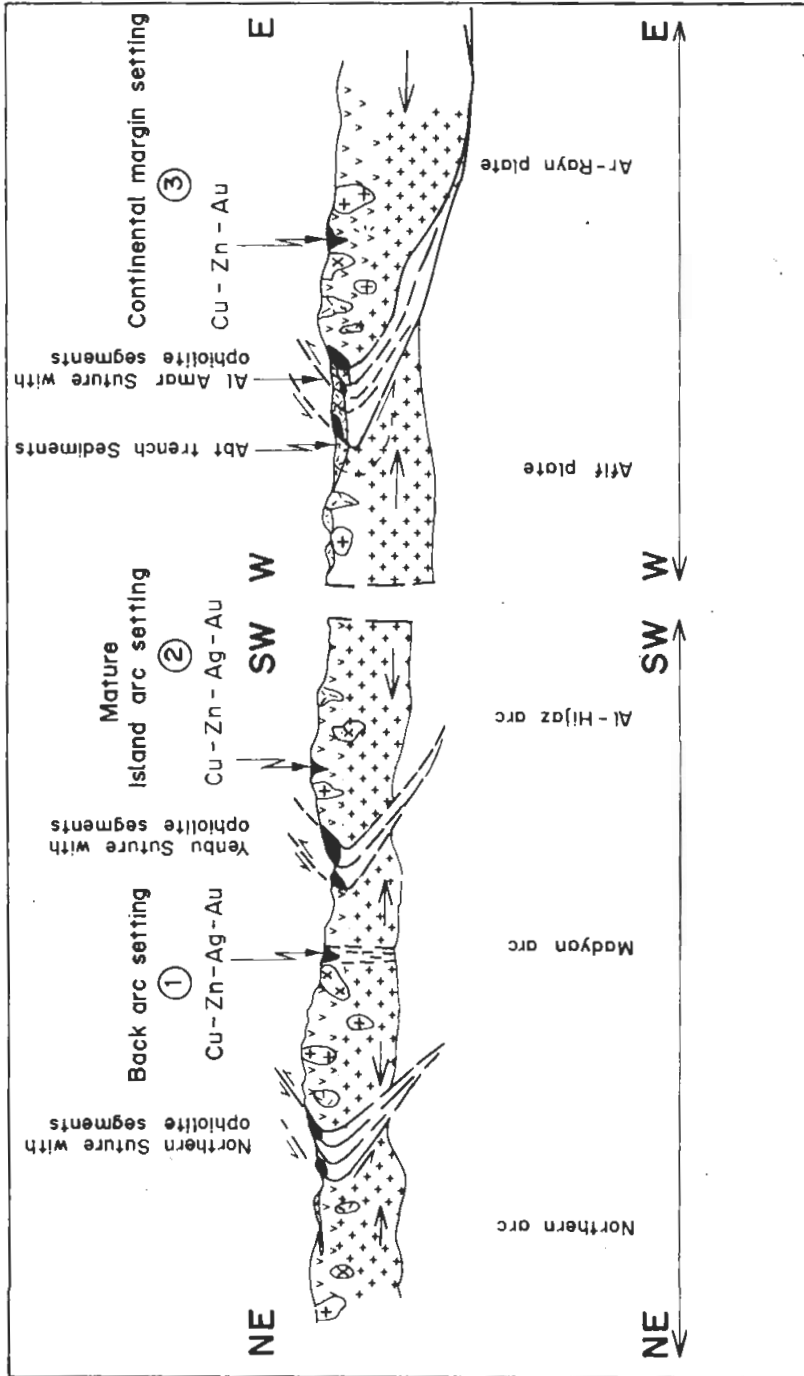


FIG. 13. Schematic sections to demonstrate geotectonic setting of the five mineral deposits.  
 ① Ash Shizm ② Umm Ad Damar, As Safra, Al Musayna'ah ③ Umm Ash Shalahib.

TABLE 1. Comparison of the characteristic features of the five studied occurrences.

Occurrence Property	Ash Shizm	Umm Ad Damar	As Safra	Al Musayna 'ah	Umm Ash Shalahib
Commodity	Cu (Zn, Ag)	Cu-Zn	Cu (Zn, Au)	Cu	Zn-Cu (Ag-Au)
Country Rocks Volcanic-dominant	Yes	Yes	Yes	Yes	No
Country Rocks Sediment dominant	No	No	No	No	Yes
Types of Volcanic Rocks	Bimodal: Rhyolite flow and pyroclastics. Basalt, usually pillowed.	Rhyolitic to dacitic tuffs. Minor andesite pyroclastics.	Rhyolitic and andesitic tuffs, schistose.	Andesitic flow and pyro- clastics traversed by swarms of rhyolite dikes.	Rhyolitic tuffs and flows.
Types of Sedimentary Rocks	Chert and minor carbonates.	Chert and carbonates.	Carbonates.	Carbonates and sandstones.	Alterations of carbo- nates, conglomerates, sandstones, and chert.
Grade of Metamorphism	Greenschist.	Greenschist, locally intensive schistosity.	Greenschist, locally intensive schistosity.	Greenschist, local pyrometasmatism.	Greenschist, local pyrometasmatism.
Deformation of Country Rocks	Extensional fractures.	Intensive shearing.	Intensive shearing.	Extensional fractures.	Extensional fractures.
Form of Ore	Stringers and disseminations				
Ore controls	Ore restricted to the rhyolitic unit, remobi- lized along secondary fractures.	Ore restricted to rhyolitic to dacitic unit, remobilized along intensely sheared zone.	Ore restricted to rhyolitic unit, remobi- lized along NNE fault zone.	Ore restricted to andesitic pyroclastics, remobilized along se- condary Najd fractures.	Ore restricted to rhyolite unit, remobi- lized along secondary fractures.
Essential Primary minerals	Pyrite, chalcopyrite, sphalerite in variable proportions				

TABLE I. (continued)

Occurrence		Ash Shizm	Umm Ad Damar	As Safra	Al Musayna'ah	Umm Ash Shalahib
Property						
Accessory Primary Minerals	Sulfides	Bornite, galena, pyrrhotite, mackinawite	Galena, pyrrhotite.	Pyrrhotite, galena, marcasite.	Galena.	Galena, mackinawite, hessingerite.
	Oxides	Titanomagnetite, magnetite.	Titanomagnetite, magnetite, hematite.	Titanomagnetite, magnetite.	Titanomagnetite, magnetite, hematite.	Titanomagnetite, magnetite, hematite.
	Tellurides	Altaite, hessite, tellurobismuthite, tetradymite.	Hessite, altaite, coloradoite, tellurobismuthite, fronbergite.	Hessite, altaite, tetradymite, bismuthinite, emplectite, wittichinite.	-	-
	Sulfosalts	Tetrahedrite.	Tetrahedrite, fahlor.	Tetrahedrite, fahlor.	-	Tetrahedrite.
	Others	Cobaltite, native silver.	-	Cubanite, bismuth.	-	-
Secondary Minerals						
	Cu	Covellite, chalcocite, neodiginite, malachite, chrysocholla, bronchianite, tenorite.				
	Fe	Gochite, lepidocrosite, hydrated ferric oxides.				
Gangue		Chlorite, quartz, chalcedony, sericite, calcite, epidote in varying proportions + barite in Umm Ash Shalahib.				
Wall Rock Alterations	Products	Epidotization, chloritization, silicification, argillization	Sericitization, chloritization, silicification, kaolinization, development of talc later ferrugination	Sericitization, propylitization, silicification, albittization	K-metasomatism, chloritization, sericitization, propylitization, silicification, albittization, secondary ferrugination	Chloritization, silicification, propylitization
	Degree	moderate	intense	intense	low to moderate	low to moderate
Tectonic setting		Extensional regime probably back-arc or inter-arc basin.	Island-arc environment.	Island-arc environment.	Mature island-arc environment.	Active continental margin or mature island arc environment.

1980) which places all five occurrences within cycle "B" of the lithostratigraphic classification of the volcanosedimentary sequences of the Arabian Shield. The tectonic models thus suggested for these mineralizations would be related to maturing volcanic activity at waning stages of accretion and collision of adjacent converging plates. The setting thus could be either in a back arc basin setting as suggested for Ash Shizm, or mature island arc environments for the other occurrences. Some authors consider Umm Ash Shalahib as a continental margin setting (Figure 13).

Despite the extensive exploration program carried out in all five mineralized localities by DGMR and affiliated geologic missions, which included geological, geochemical and geophysical work as well as drilling, no economically worthwhile deposit has been recommended for exploitation. The quantity and grade of these deposits, besides their occurrence in remote areas without the infrastructures to support mining operations, classifies them as non-economic at present or in the near future. Several other deposits of this type occur in similar situations all over the Arabian Shield, but they are of no greater economic interest than those studied in the present work, except perhaps those at Jabal Sayid. Further exploration could locate more deposits within the Hulayfah Group type rocks and its equivalents, but we believe that this should not be encouraged for the time being. Table 1 gives a summary of the characteristic features of the studied occurrences.

### Acknowledgement

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## دراسة مقارنة لخمسة مواقع تمعدن كبريتيدية في الصخور البركانية بالدرع العربي

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المستخلص . من دراسة خمسة مواقع لتمعدنات كبريتيدات الفلزات القاعدية البركانية الانتشاء في الدرع العربي في مناطق : الشزم ، أم الدمار ، الصفرة ، المصينة و أم الشلاهب وجد أنها تحتوي جميعا على صخور بركانية كلسقلوية من مجموعة الحليفة أو المتطبقات المكافئة ، وقد اشتمل البحث على دراسات حقلية وبتروجرافية ومعدينية وكيميائية .

ومن مختلف الدراسات العملية تبين أن الصخور الحاوية للتمعدن هي أساساً صخوراً بركانية يغلب عليها التركيب الحمضي الكلسقلوي ومعظمها من الريوليت وبعض الأنديزيت . أما البازلت فموجود فقط بالقرب من تمعدن الشزم . هذا وقد تعرضت جميع هذه الصخور في مختلف مناطق التمعدن لتحول إقليمى للدرجة المنخفضة من سحنة الشست الأخضر وبعض التشوه الذي يصل أحياناً إلى التورق ، بالإضافة إلى تأثيرها في نطاقات التمعدن بالمحاليل الحرمائية ، وتختلف شدة التحول والتشوه من منطقة إلى أخرى . وقد تأثرت نطاقات التمعدن بدورات لنشاطات حرمائية لاحقة مما نتج عنها عمليات تغير سريسي و كلوريتي وسيليسي .

أما من ناحية الوضع الجيوتكتوني لهذه المواقع فقد نشأت في بيئات مختلفة . فتمعدن الشزم قد ترسب في صحبة صخرية ثنائية التركيب في قوس جزيري خلفي . أما تمعدنات أم الدمار والصفرة والمصينة فقد ترسبت في بيئة أقواس جزيرية في مرحلة النضج . وتختلف بيئة ترسيب تمعدن أم الشلاهب عن غيره حيث يحتمل أن يكون من نوع تمعدنات جبال الأنديز على حافة قارية .

وتدل الدراسات المجهرية لتلجمعات المعدنية في المواقع الخمسة أن حجم حبيبات معادن الخامات الأولية قد كبر وتشوه بدرجات مختلفة عما كانت عليه عند ترسيبها ، معطية طبيعة بريشية مميزة وأنسجة تحول أخرى ظاهرة بوضوح في معدن البيرت المصاحب لمعادن الفلزات القاعدية .

وقد تبين من مجمل هذه الدراسات التفصيلية أن كل هذه التمعدنات توجد على هيئة كبريتيدات منبثة و/أو في أجسام من العريقات الشبكية فقط دون وجود أي تمعدن كتلي في أي منها . ويرى الباحثون أن ذلك يعزى إما إلى عدم تكونها أصلاً أو بسبب إزالتها بعوامل



التعرية التي تعرضت لها بعد تكونها . ونظراً إلى أن احتياطي الخام ورتبته متواضعة فتعتبر هذه التمعينات ذات أهمية اقتصادية محدودة في الوقت الحاضر .

ويرى الباحثون أن تركز الأبحاث والدراسات المستقبلية للتمعدن البركاني في صخور مجموعة الحليفة أو على المتكونات المكافئة خاصة الجزء العلوي منها ، حيث إنها تتميز عن باقي متكونات ومجموعات الصخور في الدرع العربي باحتوائها على أعلى نسبة من مواقع تمعدن الكبريتيدات القاعدية بركانية الأصل .