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Geology of the Ishmas Gold Prospect, Kingdom of Saudi Arabia

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ABSTRACT. The area of the Ishmas gold prospect is underlain by the Upper Proterozoic rocks of the Arabian Shield. These are here interpreted, in part, to represent an ophiolitic assemblage and include serpentinized websterite and other altered ultramafics, cumulate and massive gabbros, metabasalts, metarhyolites and related rocks, quartzites, metadolomitic limestone and skarn, all intruded by granite bodies and dykes. The contacts between the different rock units are generally tectonic. The volcanic rocks are bimodal in nature, and were formed from a low K-tholeiitic magma in a spreading ocean floor environment. The gabbros are of an oceanic type and the ultramafic rocks are ophiolitic cumulates, characterized by low contents of lithophile elements. So, on the basis of this, and other field observations, it is believed that these rocks represent an ophiolite sequence, autochthonous in nature, formed as a result of rifting and subsequent closure of an ocean.

Rocks of the area are cut by faults striking in a number of directions, namely: N-S, 45-60, 140-160 and 155.

Quartz veins in the area are believed to represent three stages of vein formation; an early stage (striking N-S), an intermediate stage (striking 140-160 and 45-60) and a late stage (striking 115). The intermediate stage of vein formation was the most important gold-forming episode.

The gold deposits are probably related spatially to the Najd fault system. They are hydrothermal, epigenetic precious metal vein-type (bonanza) deposits. The source of gold and associated chalcophile elements is most probably the altered ultramafic rocks.

Introduction

The Ishmas area, in which a number of ancient gold mines are known to occur, is part of the Jabal Ishmas-Wadi Tathlith gold belt (Worl 1979). It is bounded by latitudes 20 51 N and 21 N and longitudes 43 13 E and 43 22 E, and is included in the Nabitah orogenic belt (Stoeser and Camp 1984) of the Arabian Shield. The shield is built up dominantly of layered rocks (metavolcanics and metasediments) that have been intruded by different suites of plutonic rocks. Most parts of the shield have been affected by multiple episodes of deformation and low grade regional metamorphism (greenschist facies), but locally amphibolite facies conditions were attained. Mafic-ultramafic belts, lenses, and slivers are encountered in the shield (Schmidt *et al.*

1973, Greenwood *et al.* 1976, 1980, Delfour 1980, and Jackson and Ramsay 1980). Different hypotheses on the crustal evolution of the shield have been postulated. Most authors favour an island arc accretion-microcontinent collision model (Greenwood *et al.* 1976, 1980, Frisch and Al Shanti 1977, Gass, 1977(a&b), Shackelton 1979, Delfour 1980, Fleck *et al.* 1980, Roobol *et al.* 1983, and Al Shanti and Gass 1983). However, Kemp *et al.* (1982) postulated that the crustal evolution of the northwestern Arabian Shield took place through repeated tectonomagmatic events that represent the first stages of a chelogenic cycle. Recently, Stoeser and Camp (1984) suggested that the Late Proterozoic Arabian Shield is composed of at least five geologically distinct terranes separated by four ophiolite-bearing suture zones. Three ensimatic island-arc terranes occur in the western parts of the shield, whereas the two terranes in the eastern part of it have continental affinities. The Ishmas area falls within the ensimatic island-arc terranes in this configuration.

The area dealt with here is underlain by Precambrian metavolcanic and metasedimentary rocks of the Hali and Halaban groups that have been intruded by some bodies of gabbro and granite. Serpentinite, marble, and talc-actinolite schists are encountered, mainly developed in association with the Nabitah, Ishmas East, and Ishmas West faults (Gonzalez 1974).

Geology of the Area

Serpentinites, gabbros, metabasalts, metarhyolite and related rocks, quartzite, metadolomitic limestone, skarn, granite, and dykes are exposed in the area (Plate 1). Quartz veins of different sizes and attitudes cut across all these units.

The ultramafic rocks form lenses and slivers scattered along the central parts of the area and are interpreted to be the oldest units present in the area. They include serpentinite with relicts of their parent rock, and quartz-carbonate-serpentine rock (birbirite).

The serpentinites form slivers trending N-S or 150° and dipping westerly, and are usually surrounded or overlain by gabbros. The contact between the two units is tectonic as indicated by the intensive shearing. The serpentinites are cut by serpophite and quartz veinlets of the same strike as their host rocks. The serpentinites are mainly composed of antigorite and chrysotile, together with some serpophite, talc, relicts of enstatite and augite, and opaque minerals. Relicts of enstatite are more abundant than those of augite. The mineral grains show signs of shearing and alignment.

The quart-carbonate-serpentine rock (birbirite of Augustithis 1965) occurs as small isolated hills associated with the main fault planes, or at the base of the gabbro. These masses of birbirite are intensely sheared and cut by some quartz, serpophite, and magnesite veinlets. Their colours are variable, and they are usually spongy and soft due to the leaching of carbonates from the weathered surface. They are composed mainly of anhedral to subhedral quartz, carbonate (siderite and magnesite), talc, chrysotile, serpophite, antigorite, relicts of enstatite and opaques. Sometimes,

Plate I

these mineral grains show a preferred orientation. These birbirite bodies were probably produced by the effect of hydrothermal solutions rich in CO_2 on the ultramafic parent rocks at the termination of the serpentinization process.

Two different varieties of gabbros were recognized in the field, namely, cumulate and massive gabbros.

Cumulate gabbros extend from south to north in the central part of the area bound by the Ishmas East and Ishmas West faults. Igneous lamination, and cumulate structures are common features and they generally strike 150-180° and dip steeply to the southwest-west. Mafic-rich and leucocratic bands alternate, and each ranges in thickness from 1 to 10 cm. The gabbros are traversed by a number of mafic and felsic dykes, as well as by quartz veins. These gabbros are composed mainly of distorted plagioclase (labradorite), partly altered to epidote, carbonate, and albite, probably due to saussuritization. The most common mafic mineral is clinopyroxene (augite), altered in some instances to tremolite (uralitization). In turn, the tremolite is, in some cases, altered to prochlorite and penninite. Some of the cumulate gabbro outcrops are characterized by intense shearing. In addition, these are also jointed parallel to and at right angle to zones of shearing. In these gabbros, the plagioclase (labradorite) grains are twisted and sheared, and their twin planes have been observed in some sections.

Massive gabbros are encountered in the southwest-central and western parts of the area. In contrast to cumulate gabbros, the massive gabbros are characterized by the absence of any cumulate texture, and the related layering due to alternate leucocratic and mafic-rich layers. They are dominantly melagabbro and are poorly foliated. Also, iddingsite (probably after olivine) and orthopyroxene (hypersthene) were seen in some sections of this massive gabbro.

Metavolcanics include both metabasalt and metarhyolite. The metabasalts are more frequent in the west-central part of the area. Their contacts with the gabbros are generally tectonic. They are medium to fine grained and show porphyritic texture. These rocks are highly altered, and when possible to identify, the phenocrysts are labradoritic in composition. Epidote, clinozoisite, and carbonate (products of saussuritization of labradorite), prochlorite, and actinolite (after the earlier clinopyroxene) are the main constituents.

On the other hand, metarhyolite, dacite and rhyolitic tuffs are intercalated with metasediments and form a belt extending parallel to the mafic-ultramafic units in a fault contact to their east. They are foliated mainly in either N-S or in 30-60° directions and have vertical or steep dips. The rocks are fine-grained, porphyritic, and composed mainly of quartz, sericitized K-feldspars (sanidine and perthite), plagioclase (albite and oligoclase), and biotite (usually altered to chlorite and iron oxides). The metarhyolitic tuffs are always rich in carbonate (calcite). Iron oxides, sphene, and apatite are accessories.

Regionally metamorphosed sediments are represented in the area by quartzite and metadolomitic limestone. In addition, skarns produced by contact metamorphism are also encountered.

Quartzites in the southern parts of the area are well foliated in E-W and 60° directions. Their foliations have vertical or very steep dips to the south. Bedding appears to be completely masked by metamorphism. They are fine to medium-grained, and composed mainly of euhedral to subhedral quartz with minor amounts of K-feldspar (perthite) and sericite.

Metadolomitic limestones are widespread, mainly in the eastern parts of the area. They are well foliated, with foliations striking in many directions in the different outcrops. The main foliation directions are N-S, E-W, 20-30, and 140-160° and all are steeply dipping. Bedding is evident, and is concordant with the foliation. The rocks are sugary, fine to medium-grained, and composed mainly of dolomite and fine aggregates of quartz. The accessory minerals are epidote and opaque minerals (iron oxides and/or graphite).

In areas where these limestones are in contact with gabbros, and to a lesser extent with granites, skarns are developed. These are dense, massive and coarse-grained with granoblastic and poikiloblastic textures. They are composed mainly of grossularite and andradite garnets, vesuvianite, diopside, hypersthene, wollastonite, calcite, tremolite, labradorite, quartz, and scapolite, as identified microscopically and by the XRD method.

Low relief isolated outcrops of granite occur in the wide plain formed by the erosion of the batholiths. The granite is highly weathered and poorly foliated in the 20-30° and the 45-60° directions with vertical or steep dips to the southeast. It is cut by a number of dykes of different compositions and by quartz veins and veinlets trending 60 or 115°. The rock is coarse-grained, and is composed mainly of quartz, K-feldspar (perthite) which shows perthitic string and zonation textures, plagioclase (albite and oligoclase), and brown biotite which is slightly altered to chlorite and iron oxides. The accessory minerals are opaques (iron oxides), sphene and zircon.

The rocks of the area are cut by a number of dykes, most of which are diabasic in composition. They generally trend in N-S, 40-60°, and 120-140° directions and are intermittently exposed for many hundreds of meters along strike. Their rocks are medium-grained and are composed mainly of partly altered labradorite, amphibole (tremolite-actinolite), and chlorite (prochlorite) with some relicts of orthopyroxene (hypersthene) and clinopyroxene (augite). The accessories are opaque minerals and iddingsite. In addition, some felsic dykes have intruded both granite and the gabbro bodies near their contacts with the metarhyolites. They extend for some 60 meters. Those that have intruded gabbro bodies trend mainly in the 40-60° direction while those that have intruded granite trend 130-140°. These dykes are fine to medium-grained, and composed mainly of quartz, K-feldspar, plagioclase (albite), and biotite that has been slightly altered to chlorite. It is believed that the felsic dykes in the gabbro bodies are genetically related to the metarhyolites.

Petrochemical Investigation

Nineteen samples, representing the different rock units were selected and analysed for their major element contents. Results are given in Table 1. In spite of the limited number of samples analysed, it is possible to observe the following trends:

TABLE 1. Major and minor oxides and CIPW classification of the ultramafic, gabbroic, felsic volcanic and metasedimentary rocks.

	Ultra-mafic	Gabbros							
Major and minor oxides	M_{241}	M_{203}	M_{206}	M_{220}	M_{224}	M_{229}	M_{230}	M_{243}	M_{244}
SiO_2	42.0	53.1	47.0	51.0	51.7	51.6	51.2	49.6	50.7
Al_2O_3	3.3	11.3	14.0	17.0	15.1	17.7	15.1	14.7	15.1
Fe_2O_3	12.3	3.0	5.7	3.2	4.2	3.2	4.6	7.0	6.0
FeO	1.4	4.2	4.9	1.9	2.7	4.3	5.5	3.7	5.2
MgO	18.2	6.3	9.3	7.8	4.0	6.0	8.0	6.0	4.1
CaO	10.9	19.1	14.4	13.5	17.7	12.1	11.2	11.5	10.5
Na_2O	0.5	0.7	1.0	1.8	2.4	2.2	1.6	2.5	3.0
K_2O	0.1	0.1	0.1	0.4	0.4	0.4	0.1	0.4	0.2
TiO_2	0.3	0.8	0.4	0.3	0.9	0.8	0.8	1.5	1.6
MnO	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.2
P_2O_5	n.d	n.d	n.d	n.d.	n.d	n.d	n.d	n.d	n.d
L.O.I.*	10.9	1.1	3.8	3.8	1.4	2.4	1.9	2.8	1.8
Total	100.1	99.9	101.1	100.8	100.6	100.9	100.2	99.9	99.5
Normative minerals									
Quartz	–	11.1	2.2	4.8	4.9	5.4	8.0	6.5	7.7
Orthoclase	0.7	0.6	0.6	2.4	2.4	2.4	0.5	2.4	1.2
Albite	4.4	6.0	8.7	15.7	20.5	18.9	13.8	21.8	26.0
Anorthite	7.2	27.7	34.3	38.3	29.5	37.8	34.3	28.5	30.6
Wollastonite	22.3	28.5	17.0	12.8	24.5	9.7	9.3	12.6	9.7
Enstatite	45.2	15.9	23.8	20.0	10.0	15.2	20.3	15.4	10.5
Ferrosilite	–	4.3	4.1	0.6	0.2	4.4	5.4	–	2.4
Forsterite	3.9	–	–	–	–	–	–	–	–
Fayalite	–	–	–	–	–	–	–	–	–
Magnetite	4.8	4.4	8.5	4.8	6.1	4.7	6.8	8.5	8.9
Hematite	10.5	–	–	–	–	–	–	1.4	–
Ilmenite	0.6	1.5	0.8	0.6	1.7	1.5	1.5	2.9	3.1
Femic**	87.4	54.6	54.1	38.8	42.7	35.5	43.3	40.8	34.5
Earth's cations									
Si	43.5	50.9	45.2	48.4	48.9	48.7	48.9	48.1	49.0
Al	4.0	12.8	15.9	19.0	16.8	19.7	17.0	16.8	18.3
Fe^{+2}	1.2	3.4	3.9	1.5	2.1	3.4	4.4	3.0	4.2
Mg	28.1	9.0	13.3	11.0	5.6	8.4	11.4	8.7	5.9
Differentiation index	5.4	17.6	11.5	22.9	27.8	26.7	22.4	30.7	34.9

* L.O.I. = Loss on ignition (CO_2, H_2O^+, and H_2O^-)

** Femic = Normative color index (olivine + orthopyroxene + clinopyroxene + magnetite + ilmenite + hematite.

Differentiation index = Sum of normative quartz + orthoclase, albite, leucite nepheline + Kalsilite.

n.d. = not detected.

M_{241} Serpentine with relicts of pyroxene.

M_{203} Sheared cumulate gabbro.

M_{206} Cumulate gabbro, dark band.

M_{220} Cumulate gabbro, light band.

M_{224}, M_{229}, M_{230}, M_{243} and M_{244} Massive gabbro

Basalts			Felsic volcanic rocks						Meta-sedimentary rock
M_{104}	M_{116}	M_{490}	M_{226}	M_{208}	M_{212}	M_{222}	M_{333}	M_{238}	M_{236}
49.2	49.0	48.0	50.9	75.5	69.8	67.6	62.7	75.4	19.5
15.9	13.1	14.3	13.2	11.7	14.1	15.1	15.2	11.3	3.8
2.4	4.1	2.8	5.3	2.3	2.1	3.1	3.0	0.4	3.4
10.1	9.8	7.0	11.6	1.7	1.4	1.1	3.8	0.7	1.1
7.8	7.6	8.8	5.0	1.3	1.3	1.4	2.7	0.5	5.0
9.9	9.1	13.7	7.8	0.1	1.8	6.2	2.7	2.0	34.3
1.9	3.5	2.7	2.6	5.1	4.8	0.8	5.3	5.7	0.3
0.4	0.4	0.8	0.1	0.1	1.9	2.1	0.5	1.3	0.5
0.6	1.5	0.6	2.5	0.4	0.8	0.7	1.4	0.5	0.2
0.2	0.3	0.1	0.3	0.1	0.1	0.1	0.2	0.2	0.7
n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
1.7	1.5	1.4	0.9	0.9	1.2	1.6	3.3	2.6	31.5
100.1	99.9	100.2	100.2	99.4	99.3	99.8	100.8	100.4	100.3
–	–	–	8.4	43.9	29.4	40.3	19.5	34.8	
2.4	2.4	4.8	0.6	0.6	11.4	12.6	3.0	7.9	
16.3	30.1	13.8	22.2	43.8	41.4	6.9	46.0	49.3	
34.2	19.2	24.8	24.2	0.5	9.1	31.3	13.7	1.4	
6.5	11.2	18.4	6.2	–	–	–	–	3.6	
19.5	10.7	11.9	12.5	3.2	3.3	3.6	6.9	1.3	
16.0	7.1	5.3	13.4	0.8	–	–	2.6	0.2	
0.2	6.0	7.2	–	–	–	–	–	–	
0.2	4.4	3.5	–	–	–	–	–	–	
3.5	6.0	4.1	7.7	3.4	2.6	1.9	4.5	0.6	
–	–	–	–	–	0.4	1.9	–	–	
1.2	2.9	1.2	4.8	0.8	1.5	1.4	2.7	1.0	
47.0	48.3	51.5	44.7	8.2	7.8	8.6	16.7	6.6	
46.8	46.5	44.7	49.3	72.0	66.2	66.1	59.7	71.4	
17.8	14.6	15.69	15.1	13.1	15.8	17.4	17.0	12.6	
8.0	7.8	5.5	9.4	1.4	1.1	0.9	3.0	0.6	
11.1	10.7	12.2	7.2	1.8	1.8	2.0	3.8	0.7	
18.7	32.5	26.6	31.1	88.2	82.2	59.8	68.5	91.9	

M_{226} Slightly altered metabasalt.

M_{104} and M_{116} Moderately altered metabasalt

M_{490} Highly altered metabasalt.

M_{208}, M_{212} and M_{238} Metarhyolite.

M_{222} and M_{333} Metarhyolitic tuff.

M_{236} Metadolomitic limestone.

1. For the ultramafic rock sample, silica and alumina, as well as the minor element contents are comparable with the contents expected from a parent pyroxenite (websterite). On Fig. 1, it plots in the mafic-ultramafic cumulate ophiolite field (Coleman 1977, and Warden *et al.* 1982).

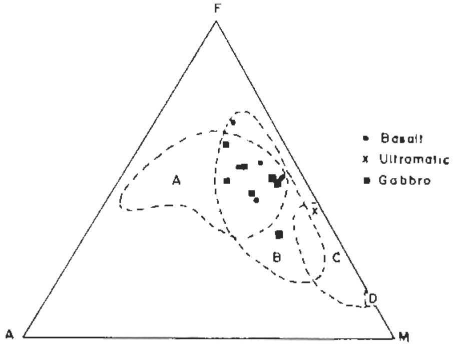

FIG. 1. AFM plot for the mafic and ultramafic rocks using CIPW norm classification. A = $K_2O + Na_2O$, F = $FeO + Fe_2O_3$, M = MgO, A – approximate field for ophiolitic pillow lava (Coleman 1977), B – Oceanic gabbro (Bakor *et al.* 1976), C – mafic and ultramafic cumulate ophiolitic rocks (Coleman 1977), D – metamorphic periodite (Coleman 1977). After Warden *et al.* 1982.

2. All the gabbros (cumulate, sheared cumulate, and massive gabbros) are characterized by relatively high calcium contents, probably due to alteration, and high Fe_2O_3 contents, attributed to oxidation of the opaque minerals. On Fig. 1 all the gabbros plot in the oceanic gabbro field (Bakor *et al.* 1976).

3. The metabasalts have relatively high Fe_2O_3 contents, attributed to oxidation of the opaque minerals. The low potassium contents reflect the nature of the parent magma. On Fig. 1 the basalts plot in the oceanic gabbro field, and this indicates their oceanic origin. Figures 2, 3 and 4 show that the metabasalts plot in subalkalic and tholeiitic fields.

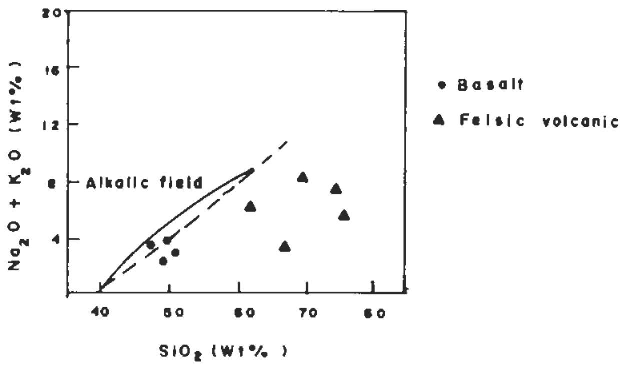

FIG. 2. Alkalies versus silica (wt %) variation diagram to differentiate alkalic and subalkalic volcanic rocks. The dashed line after MacDonald (1968) and the solid curve line after Irvine and Baragar (1971).

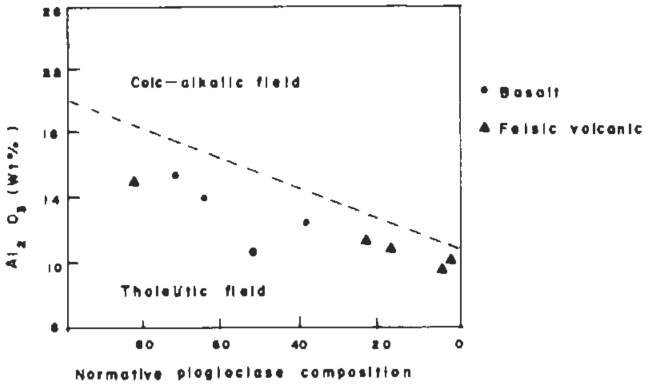

FIG. 3. Al_2O_3 (wt %) versus normative plagioclase composition diagram to differentiate tholeiitic and calc-alkalic volcanic rocks (after Irvine and Baragar 1971).

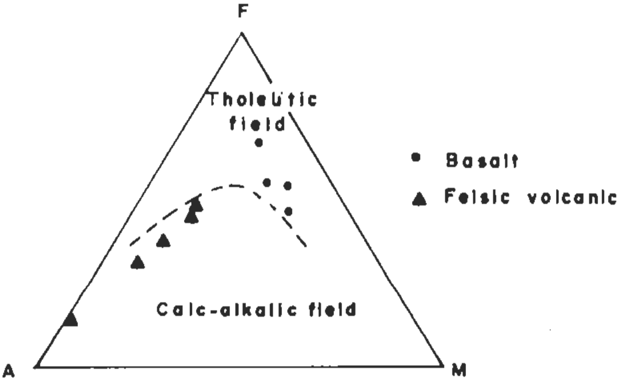

FIG. 4. AFM diagram to discriminate tholeiitic and calc-alkalic composition volcanic rocks, using CIPW norm classification. A = $Na_2O + K_2O$, F = $FeO + Fe_2O_3$, M = MgO. The dashed line separates tholeiitic and calc-alkalic composition fields (after Irvine and Baragar 1971).

4. The metarhyolite and related rocks are relatively high in CaO, MgO, Fe_2O_3, and loss on ignition. This may be due to alteration and the richness of the parent tuffs in carbonate minerals. They are characterized by their low sodium and potassium, and high titanium contents, possibly reflecting the composition of their parent magma. Figures 2, 3 and 4 show that the metarhyolite and related rocks plot in the subalkalic and tholeiitic fields, and hence may represent the end products of differentiation of a tholeiitic basalt series (Irvine and Baragar 1971 and Miyashiro 1974).

Mineralization

A number of ancient workings are known, all of which are restricted to quartz veins that occupy dilatant zones (fault planes and related fractures). Among these veins three generations may be identified, namely:

1. Barren quartz veins trending N-S, and restricted to the ultramafic and gabbroic rocks. These may be the oldest generation, formed subsequent to the low grade regional metamorphism in small dilatant zones related to Bishah (700 Ma B.P.) or earlier orogenies (Greenwood *et al.* 1980).
2. Quartz veins trending either 140-160° or in the almost perpendicular direction (45-60°). They are encountered in almost all rock units, and are most probably related to the Najd fault system (500-600 Ma B.P.). These veins are relatively rich in Au and other chalcophile elements (Ag, Cu, Pb and Zn). Moreover, veins striking 45-60° are richer in Au than the 140-160° veins. This may be attributed to the fact that the 45-60° fractures (second order and tensional fractures) were more favourable for the deposition of the vein materials than the 140-160° fractures, which are first order, wider and larger fractures.
3. Veins trending 115°. These are the youngest set of the veins since they cut others trending 60°. They are the best developed veins in the area and are composed of brecciated country rocks, two generations of quartz and carbonate minerals. They are relatively poor in Au but rich in other chalcophile elements such as Ag, Cu, and Zn (El-Medani 1984).

The presence of the ore minerals in the form of very minute grains in the quartz veins made it useless to do any ore microscopic investigations. Instead identification of mineralization depended on the chemical analyses of the collected samples (El-Medani 1984).

With regard to the genesis of the mineralization, it is believed that the gold-bearing quartz veins are epigenetic and were formed during the stage of metamorphism and regional tectonism. This is indicated by the fact that they fill dilatant fracture zones. These zones are related to regional tectonism, specifically the Najd fault system, since the gold-bearing veins are those trending 140-160° and 45-60°, *i.e.* the same trends of the Najd primary and secondary faults. The lack of isotopic and fluid inclusion data renders it impossible to determine exactly the nature of the mineralizing solutions, whether metamorphic, meteoric or magmatic. They could have been of metamorphic origin generated at deeper levels where heat enough to expel water and chalcophile elements from the host rocks could have been generated (Moore 1975). Thus, it seems possible to relate the gold-bearing hydrothermal solutions to the low grade regional metamorphism. In fact, many gold deposits have been formed within the temperature interval 50-150°C (Boyle 1979, Smirnov *et al.* 1983). The source of gold and associated chalcophile elements is most probably the hydrothermally altered ultramafic rocks cropping out in the area and extending eastwards along the Nabitah fault zone which includes the area mapped here. Solutions percolating through these rocks might have leached the metals and carried them into the overlying rocks to be deposited in the already open fractures and fault zones. This suggested model of formation is similar to that proposed by Sillitoe (1977), for the epithermal precious and base metal deposits (the vein or bonanza type), spatially related to regional tectonism and genetically to calc-alkaline subaerial volcanism at convergent plate boundaries. However, bimodal basalt-rhyolite volcanic rocks related to extensional tectonic regimes, as in the case of the San Juan Mountains, Colorado, and the Great Basin, Nevada in the Western United States may also host precious and subordinate base-metal deposits of epithermal type (Sillitoe 1977).

Discussion

Rocks encountered in the area include ultramafics, gabbros, and metavolcanic-metasedimentary rocks. They are metamorphosed to the epidote-amphibolite and greenschist facies. These rocks are foliated, with their foliations striking in the 150-180° direction and dipping to the west in the area west of the Ishmas East fault but to the east on the other side of the fault. The most prominent structural feature of the area is that it is intensely faulted. The major faults in the area trend in a N-S direction and dip to the west. They are probably related to pre-Najd faulting episodes. In addition, two other sets are encountered, striking at 140-170° and at right angles to this direction, namely 45-60°. These two sets are contemporaneous and filled with the same generation of gold-bearing quartz veins. These faults may be related to the Najd fault system as defined by Greenwood *et al.* (1980) and Delfour (1980). A fourth set is represented by minor faults striking 115° and are frequently seen to cut faults of the 60° set.

The nature and distribution of the rock units in the area suggest that they may pertain to an ophiolite sequence as defined by the Geological Penrose Conference on ophiolites (Anonymous 1972). The contacts between these units are generally tectonic. Moreover, just outside of the area mapped, what could be a sheeted dyke complex and pillowed basalt of limited extensions was observed.

Petrochemical data, in spite of the limited number of samples analysed, suggest that the volcanic rocks are bimodal in nature and probably formed from a low K-tholeiitic parent magma. On the different discrimination diagrams used (Fig. 1 to 4), the volcanic rocks plot in the field characteristic of low K-tholeiitic magma of oceanic floor tectonic setting and thus presumably formed at a divergent plate margin (Irvine and Baragar 1971). Gabbros also plot in the field for oceanic bodies (Bakor *et al.* 1976), and the ultramafics (Coleman 1977 and Warden *et al.* 1982). The mafic-ultramafic units are also characterized by low lithophile element (Ti, V, Y, and Zr) contents. However, the oceanic floor field for the volcanics in many diagrams may also include some tholeiitic basalts formed under continental rifting environment (Floyd and Winchester 1975). Therefore, it is possible that the basalts of the area have been formed at a divergent ocean-floor ridge or in a continental rifting environment prior to actual spreading (El-Medani 1984).

All the field, petrographic and petrochemical data reviewed above are consistent with one another, and suggest strongly that the rocks in the area represent an ophiolite sequence.

In support, it is pointed out here that Frisch and Al-Shanti (1977) considered the area under investigation as a part of the N-S Hulayfah-Hamdah ophiolite belt, which represents a suture zone. Moreover, Gettings (1983) noted that the Nabitah fault zone, which includes the area under consideration, is a suture zone with different crustal thicknesses, rock densities and seismic velocities on the two sides of the zone. Stoeser and Camp (1984) interpreted the suture zone as an orogenic belt associated with the collision of the Afif terrane with the western arc terrane.

With regard to the emplacement of this ophiolite sequence, most workers (Frisch and Al-Shanti 1977, Shackleton 1979, Delfour 1980 and Stoeser and Camp 1984) have related it to an obduction process taking place above an easterly dipping subduction zone. Nevertheless, Kemp *et al.* (1982) suggested that the ophiolites in the northwestern Arabian Shield are autochthonous masses formed *in situ* by continental rifting followed by oceanization related to ultramafic diapirs. A third model, which represents a compromise between the two, is that suggested by Garson and Shalaby (1976), who related the emplacement of the ophiolite belts in the Nubian-Arabian Shield to obduction during continental collision following rifting of a once continuous continental mass.

In the present study, the authors would like to state that if an emplacement through subduction is entertained, then the model must be modified so that the subduction zone dips to the west to be compatible with the structural field observations. Moreover, extensive erosion of the island arc/microcontinents involved in the collision must be assumed to account for the lack of certain features characteristic of subduction, particularly of andesites which would be expected to be extensive as well as of metamorphic rocks in the blue schist, eclogite or high grade facies.

On the other hand, they feel more inclined to accept the model involving continental rifting then the formation of autochthonous ophiolite sequences through oceanization related to ultramafic diapirs, and subsequent closure. This accounts better for observations such as:

1. The area is characterized by low grade regional metamorphism and generally slight deformations. The complex folding and high pressure regional metamorphism commonly associated with subduction related to continent-continent or continent-arc collision and suturing are absent.
2. The volcanic rocks in the area and in many other places in the shield belong to a bimodal basalt-rhyolite suite (Kemp *et al.* 1982, Roobol *et al.* 1983), a characteristic feature that distinguishes tensional intra-plate environments, *i.e.* rifting (Martin and Piwinskii 1972).
3. The basalts in the area, and in the shield in general, are dominantly massive. Sheeted dyke complexes and pillowed lavas are scarce. The massive diabase and scarce dykes could be related to the opening of marginal seas or to oceanization (Karamata 1980).
4. The presence of associated skarn indicates the intrusive nature of at least some of the massive gabbros.
5. The ultramafic unit (websterite) is rich in magnesian orthopyroxene, and the mafic-ultramafic units are poor in titania. If the rocks of the complex crystallized simultaneously in a single magma chamber, then olivine was the dominant cumulate silicate phase, otherwise orthopyroxene rich in magnesia and poor in titania would be the dominant phase due to the effect of low pressure on the melting products of their source (Brown *et al.* 1980).

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جيولوجية تمعدن الذهب بمنطقة إشماس بالمملكة العربية السعودية

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تتبع صخور منطقة تمعدن الذهب بإشماس الحقب البروتيروزوي الأعلى بالدرع العربي . ويمثل بعض تلك الصخور تتابعاً أوفيوليتياً وتشمل صخور الوبستريت المتحول إلى سربنتينيت وصخوراً فوق مافية أخرى متحولة ، وصخور الجابرو التراكمي والكتلي ، والبازلت المتحول ، والريوليت المتحول ، والكوارتزيت ، والحجر الجيري والدولوميتي المتحول وصخور التحول بالتلامس (سكارن) وكلها تقطعها أجسام وسدود جرانيتية . والتلامس بين الوحدات الصخرية المختلفة بنائي بصفة عامة . وقد وجد أن الصخور البركانية ثنائية الطور ، وأنها قد تكونت من صهير ثولييتي شحيح البوتاسيوم موجود في وسط قشرة محيطة متباعدة . وأن الجابرو من النوع المحيطي ، والصخور فوق المافية هي تراكمات أفيوليتية وعلى أساس هذه الحقائق فإنه يعتقد أن هذه الصخور تمثل تتابعا أفيوليتيا تكوَّن في مكانه نتيجة تصدع ثم انغلاق محيطي .

تقطع صخور المنطقة صدوع ممتدة في عدة اتجاهات ، وبالذات شمال جنوب ، ٤٠ – ٦٠ ، ١٤٠ – ١٦٠ ، ١١٥ .

يعتقد أن عروق الكوارتز في المنطقة تمثل ثلاث مراحل تكوُّن هي : مرحلة أولية (ممتدة شمال – جنوب) ، مرحلة متوسطة (ممتدة ١٤٠ – ١٦٠ ، ٤٥ – ٤٦) ومرحلة نهائية (ممتدة ١١٥) ، المرحلة المتوسطة لتكوُّن العروق هي أهم مرحلة لتكون الذهب .

من المحتمل أن تمعدن الذهب في المنطقة له علاقة قوية بنظام صدوع نجد . ويعتقد أن تمعدن الذهب تكوَّن من محاليل حرورية بنفس الطريقة الموصوفة لتكوُّن عروق الفلزات الثمينة التالية أو مايعرف باسم نوع بونانزا . يحتمل أن مصدر الذهب وبقية العناصر الكبريتيدية هو الصخور فوق المافية .