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MINERALIZATION AND STRUCTURE IN THE REPUBLIC OF YEMEN: AN OVERVIEW AND NEW CONTRIBUTION

Mohamed T. S. Heikal*, Ahmed M. AL-Kotbah** and Boshra M. AL-Awadhi.**

*Geology Dept., Fac Sci., Tanta Univ., Egyptr.

**Earth and Environmental Sci. Dept, Fac. Sci. Sana'a Univ. Republic of Yemen

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ABSTRACT

Yemen has a longstanding reputation as a source of precious metal as well as non-metallic minerals from different geologic environments. Modified Distribution maps of mineralization in combination with fault system in the Republic of Yemen were prepared for the first time with reference to geologic map supplement with available data account, whenever possible.

Metallic mineral occurrences include gold, base metals (Zinc, silver, copper and nickel). The main occurrences of gold are Mukalla area, central and northern shield as well as western Highland. There is potential for gold mineralization along the line of shear zones (NW & NE trends). The gold mineralization is hosted by Proterozoic mafic-intermediate metavolcanics and calc-alkaline granitic stocks. There are several occurrences of base metals in Yemen; zinc-lead-silver that are mostly hosted by upper portion of the Jurassic Amran Group (mainly dolomitized limestone) of Jabali locality (main occurrence), they are structurally controlled providing strong evidence between major faults (mainly NW trend) and its mineralization. Copper and nickel metals are widespread in the Precambrian rocks of Yemen (Hammourh, Al-Baydah, Fadahah, Sadah and Hajjah areas). The mineralization is hosted by different lithologies vary in composition from schist, gneiss, amphibolite, felsic metavolcanics to volcano-sedimentary assemblages. Almost mineralized occurences were emplaced during the Precambrian along NW fractures associated with major fault system of NW trend.

Iron and iron-titanium mineralization occur in Sadah, Al-Baydah and Mukayras areas. They are hosted by metamorphosed volcano-sedimentary assemblages. Mineralized zones of magnetite, hematite, siderite, limonite, ilmenite and titanomagnetite are mostly connected with the faulting. Tin-Tungsten mineralization forms hydrothermal veins hosting in volcano-sedimentary assemblages and post-orogenic granites locating in the northwestern and southern parts of Yemen. These mineralized veins are commonly with tectonically controlled preferred orientation.

Uranium and thorium mineralization has been found in the Cretaceous sandstone and Precambrian alkaline granites in the northwestern and southeastern parts of Yemen. On the other hand REEs mineralization is reported in the southern and southeastern parts of Yemen. It is hosted by linear and veinlets of carbonatites trending NE which are consistent with major trend of southern fault system.

The most potential resource of non-metallic minerals are rock salt, gypsum, natural zeolite, feldspar, fluorite, black sand and talc. They are widely distributed in all over Yemen, in particular, both Mesozoic and Cenozoic rocks. Fluorite and talc occur within hydrothermal veins and shear zones respectively associated with NW and ENE fault system.

INTRODUCTION

Data concerning the mineral resources in the Republic of Yemen have been conducted primarily since the early 1970's and have been carried out almost exclusively by the Government of Yemen.

In 1970 strojexport, on behalf of the Government of the Algeria, carried out exploration of several small areas of Precambrian rocks in the Taiz area, in particular Al-Hammurah area, in which copper and nickel ore deposits have been discovered. The initial BGR programs concentrated on the sampling and evaluation of the limonite-hematite gossan in Sadah area during 1974 to 1978 (Thiele 1979). The people's Republic of China conducted mineral exploration in the Al-Baydah area and investigated a number of occurrences of metallic and nonmetallic mineralization in 1977-1978. In the late 1970's and more recently the status of the knowledge of

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mineralization in Yemen was summarized by few workers (e.g. Gaber, 1977, El-Shatoury and Al-Eryani, 1979; Christmann *et al.*,1989 and Reportson Group,1992)

In recent Years, the Government of Yemen has developed a new and modern mining lode reflecting data base of mineral resources information. A geological study and tectonic framework of mineralization, were carried out through several field trips in combination with detailed studies of space images to develop our knowledge about the economically important areas in the Republic of Yemen. However, the main target is to record the geology of mineralization, their mode of occurrences and their possible availability in future.

In fact mineral exploration in the Republic of Yemen has not yet reached a development stage but a promising mineralization in some localities may warrant detailed exploration and investigation.

Geology

The geology of Yemen is very diverse ranging from Late Archean to Pleistocene in the age. The main outcrops of lithostratigraphic units are shown in Fig. 1. Precambrian rocks (PC) include late Archean to Proterozoic gneissic terranes (Fig. 2) and Pan-African island arc terranes and suture zones; those provide the link between the arc collage of the Arabian shield and the gneissic Mozambique belt of east Africa (e.g. Heikal, 1987; Sakran , 1993 and Baydoun *et al.*,1998).

Paleozoic Wajid sandstone (unmappable with the present scale) occurs north of Saddah town in the western NW Yemen. The age of the Wajid sandstone is matter of debate (Combrian-Ordovician-Permain) as defined by Geukens (1966), and Grolier and Overstreet (1978) .

Mesozoic sediments are represented by the Lower-Middle Jurassic Kholan Formation(mainly sandstone) and Jurassic Amran Group (mainly limestone) (Fig.3b)as well as Cretaceous - Early Tertiary Tawilah Group (mainly sandstone) and Al-Maharah Group (mainly shallow marine and calcareous sediments) as mentioned by (Beydoun, 1982; Al-Thour 1992).

Tertiary granites cropout sporadically along the marginal Red sea escarpment for over 200km (e.g. Al-Kadasi, 1988; Mohr, 1991). The granitoids was emplaced between 21-23 Ma (e.g. Civetta *et al*, 1978; Capaldi *et al*, 1987) which are consistent with similar ages of large amounts of silicic volcanics erupted in the upper part of the volcanic pile.

Tertiary volcanics (Yemen volcanic Group); this group covers some 50,000km2 in the western Yemen(Fig.I) and may be over 2050 m thick comprising basalt-rhyolite suite (e.g. Ghiesa *et al*, 1989; Menzies *et al*, 1990).

Tertiary pre-rift sediments are represented by the Hadhramout Group (Paleocene-Middle-Eocene) which consist of carbonates bedded gypsum and sandstones (Beydoun *et al*, 1998).

Oligocene-Miocene syn-rift: entrusive and extrusive flood basalt outpourings(Robertson Group, 1992) and a series of ring complexes of synitic composition (Gameil *and Heikal*, 2005) in combination with thick clastics of turbiditic nature.

Quaternery volcanics are exposed in the form of discrete volcanic fields; Sana'a-Amran (Fig. 3a), Sirwah- Marib, Dhamar-Rad'a and Balhaf Bir Ali (Grolier and Overstreet, 1978). These volcanic fields comprise basaltic composition.

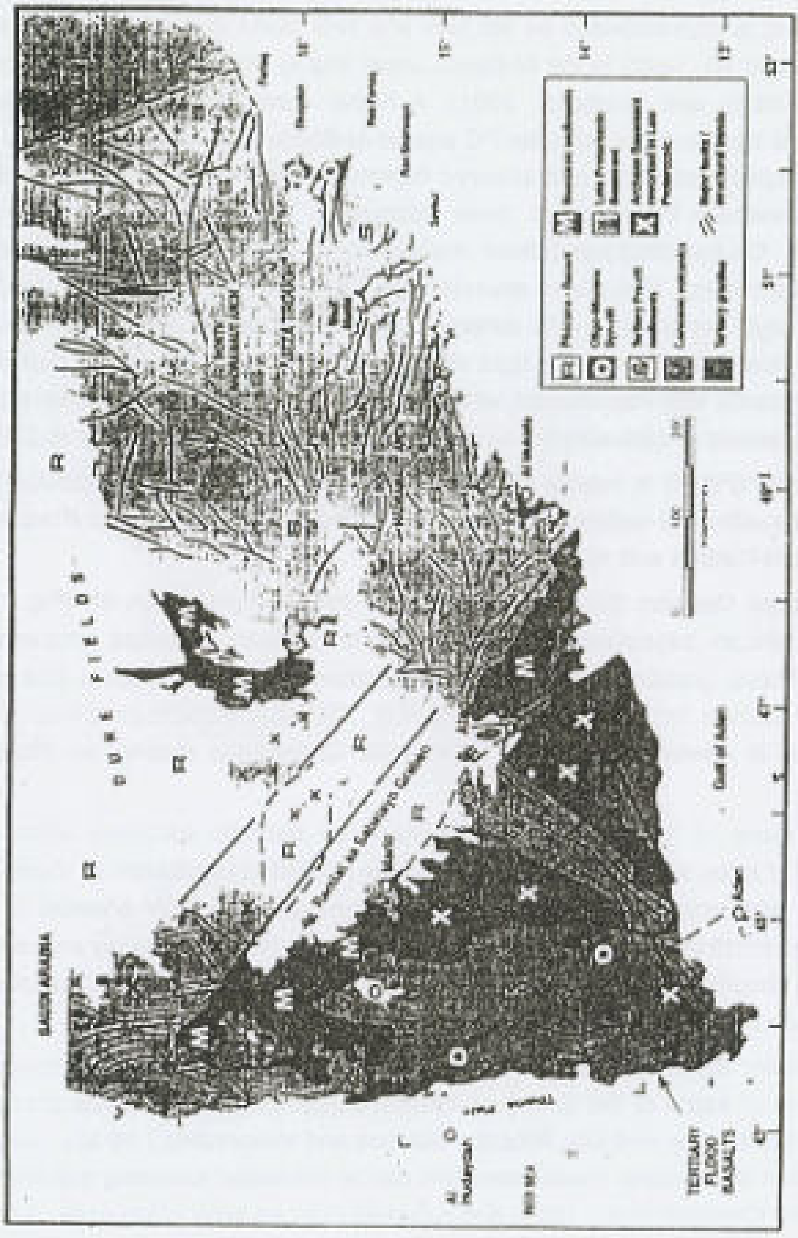

Fig. 1 Geological map of Yemen (slightly modified after Ropertson Group 1992).

Structure and Tectonic Framework of Yemen

The structural implications and tectonic framework of Yemen are characterized by large Archean-Proterozoic basement fault block transected by the northwest southeast trending Jurassic-Cretaceous intracratonic rift system of the Ramlat Syabtan graben, bounded to the south and to the west by Tertiary to present day,the Gulf of Aden and Red sea rift system (Figs. 1,4,5). The structural implications of Yemen based on the subdivision of Robertson (1992) and the present authors are as follows:

1. **Central block**: This block comprises PC terrians bounded by the Red Sea faults, the northern and southern edges of the Ramalt As Sabatayn graben fault (Fig. 1). The Precambrian basement is characterized by NE,NW and N-S faults in the Hajjah and Sadah areas (Heikal, 1987) and NE faults in the Al-Bayda areas (Fig.4) (Al-Kotbah, 1992, Al-Khribash *et al.*, 2000 and Al-Kotbah and Al-Ubaidi, 2001). A highly compressed fold structure with recumbent and isoclinal folds is common in the PC around Al-Bayda (Fig. 4), Hajjah and Al-Jawf. On the other hand, highly tectonized and sheared basement rocks trending NE and ENE may have undergone reactivation in Phenerozoic time producing the bounding fault (Fig. 2, author's observation). On the other hand,three main tectonic phases are well identified in Al Bayda area (Fig.4) as follows : first phase reveals regional schistosity and NE plunging folds (1) of tight isoclinal style associated with different types of lineation; second phase of the tectonic zones (2) indicates NNE plunging tight overturned folding and strike-slip faulting and the third phase represents late Pan-African which is accompanied by major strike-slip fault leading to the emplacement of calc-alkaline to alkaline magmatism (Al-Khirbash *et al.*,2000).

NW Block: this zone (Fig. 1) is outside the areas of Mesozoic and Tertairy extension and is characterized by rocks with an ill-defined fracture system related to reactivation of Precambrian and Jurassic trends (Al-Kotbah and Al-Ubaidi , 2001).

Ramlat As **Sabatayn Graben:** the northwest trending Jurassic-Cretaceous rift (Fig. 1) that intersect the Pan African basement form district tension faults bounded grabens. The northwest trend in these grabens may reflect reactivation of PC lineaments that extend southeastwards into Yemen from Saudi Arabia (Heikal, 1987 and Robertson Group, 1992). The Al-Mukalla high is devoid of Jurassic rocks with Cretaceous resting on Proterozoic basement (Fig. 1).

Gulf of Aden: parts of Yemen are characterized by tectonic fractures affect areas marginal to the Gulf of Aden with N-S extensional regime related to separation of Yemen from Somalia (Fig. 5). A wide zone of crustal extension developed with E-W oriented in some instances down to the north tilted fault blocks. True sea-floor spreading probably only began in the Miocene and rift shoulder uplift began at about 16 Ma and resulted in significant erosion of the flanks with Cretaceous strata (Huchon and Kanbari, 2003).

Red Sea Rift Basin: the main extensional episode related to Red Sea rifting took place, soon after, deposition of some of the youngest Yemen volcanics on the Tihama plain, these are unconformable overlain by mid-late Miocene elastics and evaporates (10 Ma, Huchon *et al.*, 1991). The amount of the upper crustal extension can be estimated assuming a domino style of rotated fault blocks (Davison *et al.*, 1994) and strecting over an area 75km wide. Simply, in brief words,the Proterozoic rocks of Yemen were deformed into a series of NW, NE, ENE fault blocks and N-S trending fold belts. The sedimentary rocks are relatively undeformed except for block faulting. These structures are likely related to reactivation of the Late Proterozoic Najid fault system of NW faults (e.g. Moore and Al-Shanti, 1979 and Al-Shanti and Roobal, 1979).

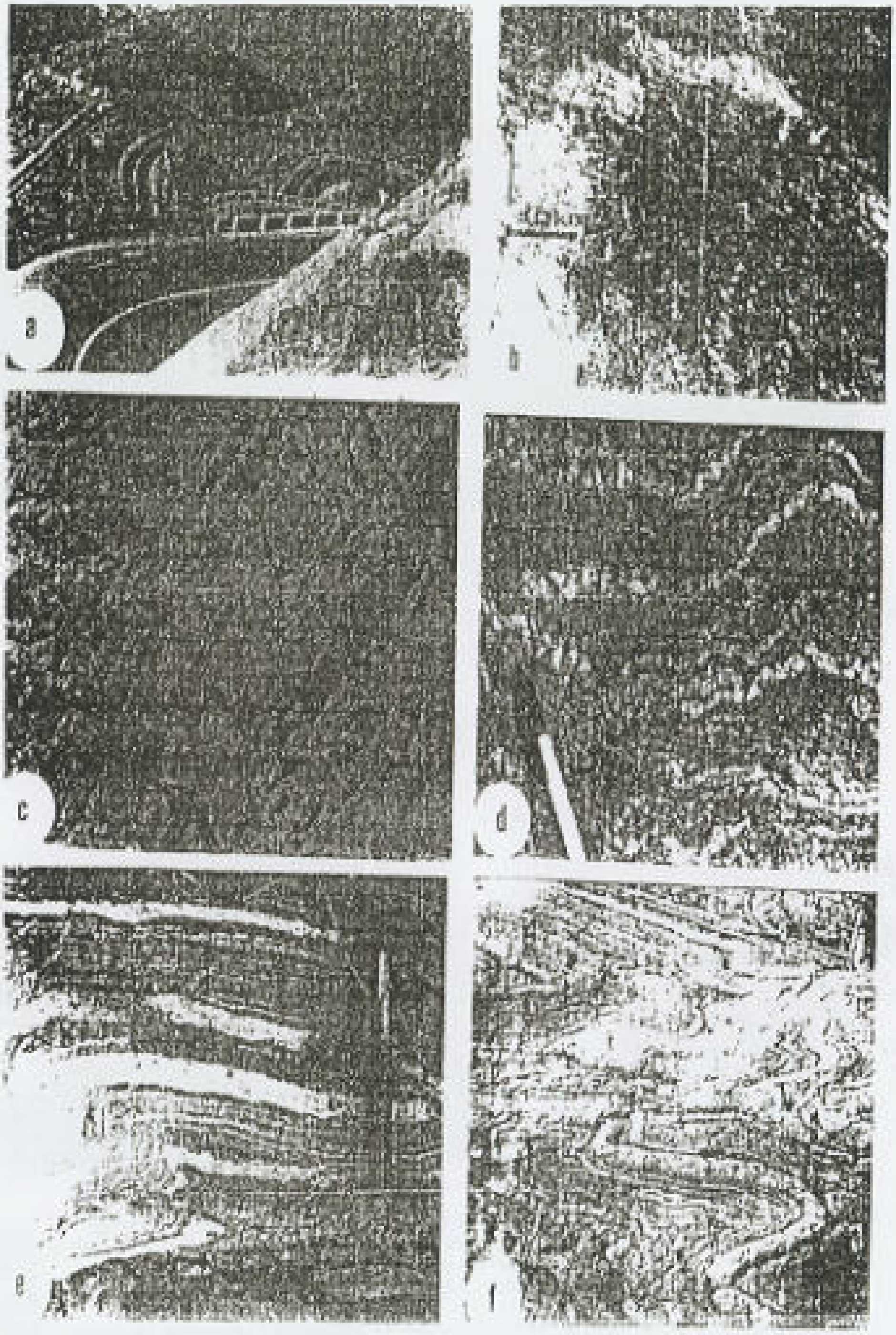

Fig. 2 Field photographs showing structural implications in southern parts of Yemen.

a) Switchback of Therah area and consists of Precambrian rocks.

b) Space- image showing reverse fault (arrow) within high-grade gneiss in Al-Bayda belt (southern part of Yemen).

c) Shear zones trend NE in gneissic rocks, AL-Bayda area.

d-f) Stromatic migmatites banding and a complex system of minor folds, Al- Bayda area,

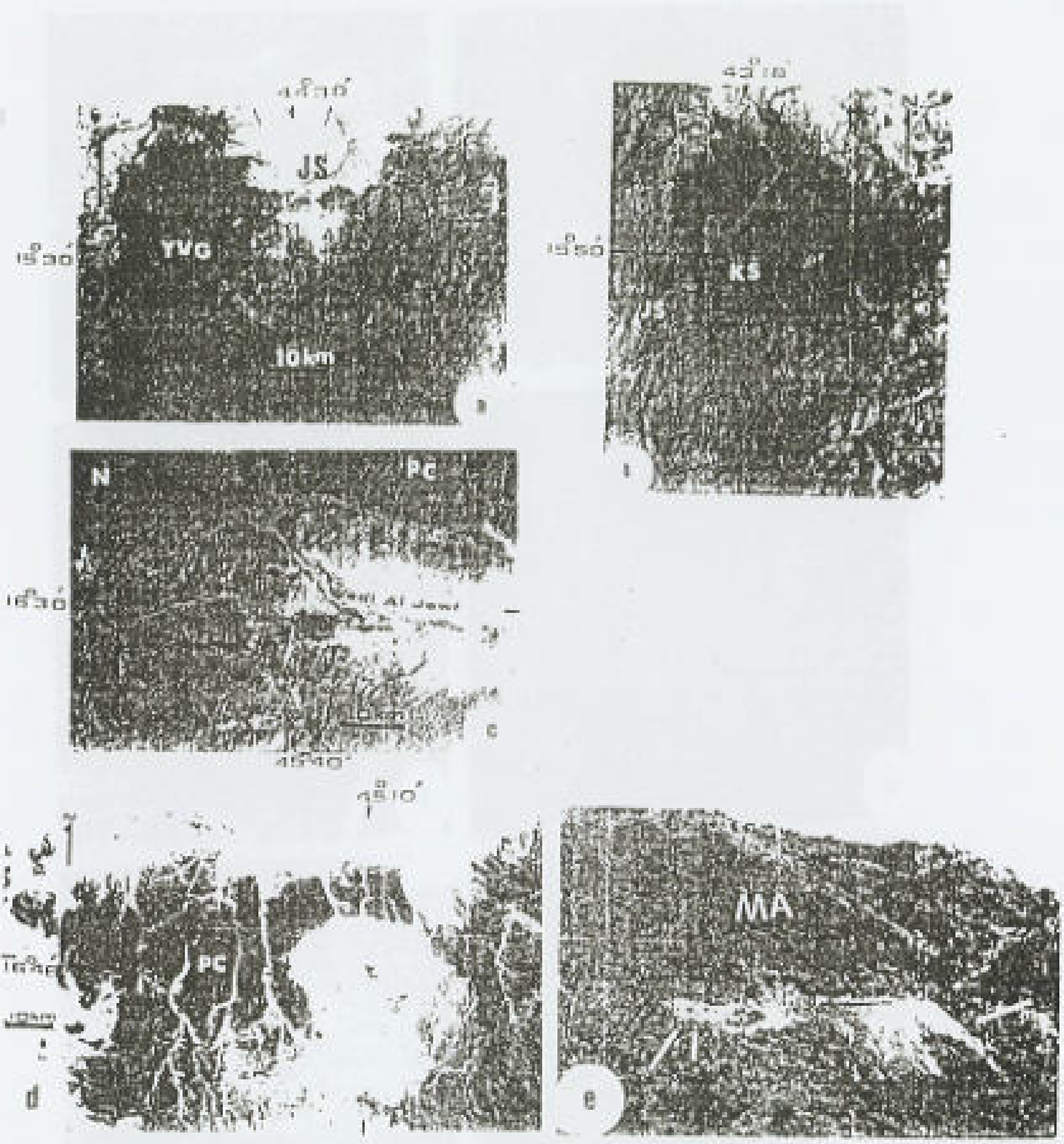

Fig.3 satellite images showing main rock units and their promising areas of mineralization in Yemen.

a) Sana'a area surrounded by Yemen volcanic Group (YVG) and Jurassic sediments (JS) in which Pb-Zn-Ag mineralization and gypsum deposits are well notified.
b) Sedimentary sequence of Kholan Group (KS) and Amran GP(JS) located near Hajjah area (NW Sana'a) in which metallic deposits have been found.
c) Wadi Al-Jawf (northern part of Yemen) bounded by sedimentary sequences (S) in which goldmineralization has been notified.
d) Precambrian outcrops (PC) in Al- Lawdh area (NE Sadh) where gold mineralization has been recorded.
e) Gold mineralization (arrows) hosting by meta-andesite (MA) at Wadi Medden, Mukalla belt (southern part of Yemen).
f) Gold nugget of crudely spherical shaped as result of slow precipitation of gold from stream waters,wadi Medden.

Fig.4. Satellite image of Al-Bayda area showing three main tectonic zones (arrows).

Mineralization

The present authors reviewed and contributed to the available data on the several mineral deposits in Yemen. This study was meant to prepare a modified distribution maps for metallic and non metallic deposits (Fig. 6A&B) known to occur in the different geologic environments as well as to throw some light on the mode of occurence of these deposits.

Metallic Mineralization

Figure 6A shows the modified distribution map of the various metallic mineralization known in the Republic of Yemen. They include gold, base metals (Zn, Pb, Ag, Cu or Ni)., iron , titanium , tin- tungsten mineralizations as well as uranium, thorium and REE's showings. A brief account on these commodities is reported.

Gold Mineralization

The gold is one of the most important and promising minerals that occur in Yemen; over 40 known occurrences, mostly are hosted by Precambrian rocks which have been the focus of the most mineral exploration to date. The most common occurrences of the gold mineralization (Fig. 6A) are as follows:

Wadi Madden Area

The Madden gold mineralization is considered to be the largest known occurrence in Yemen (ACMR, 2003).

It is located some 50km northwest of Al-Mukalla city (Fig. 6A) and 780 km SE Sana'a. The deposit was discovered in 1976 by Hunting company, where the gold bearing shear zones have been found within meta-andesites (Fig. 3e). Almost shear zones trend NW and NE extending tens of meters (author's observation). Also, such gold nuggets has been found at Wadi Madden as an indication of placer deposits (Fig. 3f). In 1985, Soviet geological team estimated the resources as 679,000 tons at average grade of 14.8g Au/t and I I g Ag/t (ACMR, 2003). On the other hand, the hosting rocks bearing gold mineralization have been deformed by multi-phases of folding, faulting and shearing and later are intruded by alkaline stocks (author's observations).

Al-Harigah Area (Hajjah District)

The area is located some 270 km NW Sana'a .Shallan and Heikal (1989) pointed out that a gold showings within such calc-alkaline to alkaline plutons in Hajjah district. In 1997, the Canadian Mountain company delineated the gold are dimensions by 3.2 km length, 600 m width and 200 m thick indicating 31 million tons as possible reserve at grade 11.04g Au/t.

Waragah and Utmah areas

are located around Dhamar city, SE Sana'a (Fig. 6A) in which gold mineralization is hosted by Tertiary Volcanics of felsic composition (rhyolites and ignimrites) in the form of a complex veinlets oriented NE, NW and ENE. Field occurrences of the gold mineralization indicates that these deposits as a result of hydrothermal veins . There are several mineralization associated with gold such as mercury and Arsenic and silver. Many feroign companies in 1990's showed the highest accommodation of Au are being 120 ppb and 293 ppb for Waragah and Utmah respectively (ACMR, 2003).

Sadah-Al-Jawf Area (Northern shield area)

Many of ancient mines occur in Sadah and Al-Jawf areas (Figs.6A,3c) , where the gold-bearing quartz veins oriented NE and NW directions) in a mafic metavolcanics and such alkaline granite plutons was mined by the ancient Yemenis. Al-Lawdh area (Fig. 3c-d) is located northeast of Sadah, considered to be the most significant quartz-veins bearing gold, in which most veins strike NE and dip steeply west.

Lead, Zinc and silver Mineralization

Several Pb-Zn-Ag occurrences were hosted by carbonate rocks of the platform of Yemen (Fig. 6A). The Jabali deposit represents the most promising lead-zinc-silver mineralization of this country.

Jabali Area is located some 110 km northeast of Sana'a (Fig. 6A). This site is considered to be the ancient silver mine last operated in the tenth century. This deposit was discovered in 1980 by Yemeni Team of the geological survey in cooperation with the French company (BRGM).

The zinc mineralization at Jabali is hosted by dolmitized and recrystallized bioclastic and reefal limestones of Jurassic Amran Group (Figs.7a&b) apparently by replacement a porous beds and solution cavities (Al Ganad *et al.*, 1994). In addition they suggest that Pb-Zn-Ag mineralization propably originated from the early Proterozoic basement along major faults trending NW (Fig.6A). The probable reserve is estimated to be 9.28 million tons with an average grade of 10.8% Zn , 1.2% Pb and 779 g/t for Ag .

Tabaq Area is located about 360 km northeast of Aden (Fig.6A) . The zinc-lead mineralization is hosted by carbonate sequence from Jurassic to Paleocene. The results of some analyzed samples revealed that an average grade of zinc is 12% and lead is 3.8% (Arab Conference Mineral, 2003). The zinc-lead mineralization at Tabaq area is distributed along major faults oriented ENE which is consistent with the Gulf of Aden trend (Fig.6A).

In general, most known Zn-Pb-Ag occurrences in Yemen are genetically related to Jurassic-Paleocene ages and the high potential of this mineralization occurs along the edges of the Ramlat As Sabatyen graben (Fig.6A).

Copper-Nickel Mineralization

Numerous gassons are distributed in many areas of Yemen that were investigated by many workers (e.g. Stroj export, 1970 ; Geomine,1984 ; Michel,1989; Shallan and Heikal,1989) . They considered that Cu-Ni mineralization is mostly hosted by Precambrian rocks and Tertiary volcanics (in part). The main significant occurrences are as follows:

Al-Hamurah Area

Is located some 50 km southeast of Taiz (Fig.6A). The Cu-Ni mineralization occurs as a sets of veins and mafic lamprophyre dykes within gneisses and amphibolites. These veins and assiociated dykes (up to 4.5 m thick) dip 60-80 SW exhibiting variable degrees of deformation. Massive copper sulphides mainly chalcopyrite associated with pentalandite are mostly common in the form of anastomosing stringers. Minor pyrite and pyrrhotite are also notified. Geomine (1984) estimated the mineralization contained 13.7 mt with an average grade of 0.55% Cu and 0.31 % Ni .

Maswar Area

Is located 80 km northwest of Sana'a (Fig.6A) .The Cu-Ni-Pt mineralization showings are reported by Shallan and Heikal (1989) which are hosted by Precambrian gabbroid and ultramafic rocks located near Wadi Laah (Hajjah district). Recently, Guntix company (1998) estimated the possible reserve about 40 mt with an average grade of 2% Cu and 2% Ni as well as minor amounts of Co, Pt and Pd.

Al-Bayda Area

Is located some 270 km southeast of Sana'a (Grolier and Overstreet, 1978). The present authors observed a polymetallic sulphides hosting by metamorphosed volcano-sedimentary assemblages in which a wide zone of disseminated sulphide mineralizations have been notified along shear zones and/or faults trending NE and ENE .Many testing wells were drilled along shear zones exhibiting a promising mineralization showings.

Sadah Area

Numerous gassons are found at the northwest of Sadah city. The present gassons of sulphides are hosted by upper Proterozoic metamorphosed volcano-sedimentary assemblages (Pouit, 1984) A wide zone of disseminated copper, gold and silver have been notified along shear zones and/or faults trending NE and ENE (author's observation).

Ghaber Area

Is located some 50 km southwest of Al Mukalla city (Hadrameut Governorate)(Fig.6A). The copper mineralization is hosted by metamorphosed volcano-sedimentary assemblages (Schramm et al., 1986) in which a wide zone of veins and veinlets oriented NE and ENE .

Iron and Fe-Ti oxides Mineralizations

Magnetite and Fe-Ti oxides mineralizations are widespread throughout Yemen .Almost mineralizations are hosted by Precambrian gabbroid rocks and metamorphosed volcano-sedimentary assemblages . Furthermore, lateritic soil enriched with iron oxides are widely distributed in many areas, in particular, across Sana'a-Taiz road(Fig.Vc).

Sadah Area

Meinhold (1982) considered that Al Masna iron prospect one of the most important iron occurrences of Yemen (Fig.6A), in which 940,000 tons of hematite-pyrrhotite-siderite association with an avergae grade of 34% Fe content are mentioned as a proved ore. He considered that these ores are similar to those found at Wadis Wassat and Qatan in Saudi Arabi (Greenwood, 1980). On the basis of the field aspect, the present iron prospect is hosted by graphite schist intercalated with marble and mafic metavolcanics.

Al-Bayda Area

Sabah iron prospect is considered to be the most promosing iron mineralization in Yemen (author's observation). The present prospect is located

some 16 km NW Al-Bayda town (Figs.6A,7d-e) . Multi discontineous irregular lenses and pockets are hosted by metamorphosed volcano-sedimentary assemblages cosscutting by shear zones trending NE and ENE. Mineralogy of the iron prospect includes magnetite, hematite, titanomagnetite and pyrrhotite with an average grade of 74% Fe (Geological Survey of China, 1978 and the present authors).

Mukeyras Titanomagnetite

Is located 210 km northeast of Aden (Fig.6A), where disseminated ilmenite-titanomagnetite , apatite and vandium mineralizations have been hosted by gabbroid rocks of Precambrian age. Estimated resources of 130 mt Fe, 46 mt of P and 0.15% V2O5 (ACMR, 2003).

Al-Majil Abyan Area

Is located some 116 km NW Abyan town (Fig.6A) in which hematite-magnetite lenses have been hosted by quartzite leading to 46,000 tons of 56-76% Fe(ACMR, 1994) .

On the other hand, there are many occurrences of placer deposits containing ilmenite-magnetite, titanomagnetite and polymetallic sulphides are well notified along coastal lines of Gulf of Aden and Red Sea.

Tin-Tungston Mineralization

Tin-tungston mineralization occurs in several geological environments in Yemen, in particular, Precambrian granitoid rocks (Shallan and Heikal,1989). The most important occurrence of these deposits is located along Marib-Ataq structural line (NW trend) (Fig.6A) in which sheelite, molybdenite and cassiterite mineralized veins have hosted within Precambrian meta-andesites and granodiorites (Veselov, 1990). On the other hand,cassiterite mineralization is widely distributed in pegamatitic phases across Rada'a-Al Bayda road and Marib-Sadah road.

Radioactive and REE's Mineralization

Uranium showings are reported for the first time in Hajjah district (NW Sana'a) by Heikal (1987) in which Precambrian late-tectonic granitoids at Suq Al Aman village (Fig.6A) contain uranophane and curite wise.On the other hand, a good anomalies of Uranium and Thorium values have been reported in Wajid Sandstones (NW sadah, Fig.6A) as mentioned by Meinhold (1982). Furthermore, a good anomalies of Uranium are reported by Eobunate *et al.* (1988) within iron-rich sandstones of Cretaceous age .

Rare earth elements mineralizations is reported in SE Lawder area (Fig.6A) in the form of parallel veins of carbonatites with an average 3m thick (Ba-Battat, 1991). These carbonatite veins are confined to fault zone trending NE (Fig.6A).

Non-Metallic and Industrial Mineralizations

The most potential resources of the non-metallic and industrial minerals in Yemen are rock salt, gypsum, feldspar, fluorite, celestite, zeolite, talc and black sands (Fig.6B)

Rock Salt

Rock salt has been represented by two geological environments namely : salt domes in Sabatayn Formation (Amran Group ; Upper Jurassic) located at the area between Marib and Shabwah that is consistent with the major fault trending NW (Fig. 6B), and the Salif Formation (Miocene) which is found on the Red Sea Coast (Fig. 6B) to the north of Al-Hudaydah. It is associated with gypsum and anhydrite . Total reserves of rock salt in Yemen are estimated to be more than 300 million tons (Arab Conf. Mineral Resources 2003).

Gypsum

The geological environments of gypsum deposits are identical to rock salt as mentioned before. In addition two formations namely Rus Formation (Lower Eocene) in Abyan - Shabwah and Ambakhoh Formation (Oligocene) in Al-Mukallah area (Fig. 6B) are well reported.

About 70000 tones of gypsum per year mined at Al Salif locality (Red Sea Coast) (Arab Conf. Mineral Resources 2003) The total reserves of thin qualified gypsum are more than 300 million tons. On the other hand, there are two major faults trend ENE and NW are consistent with the distribution of gypsum deposits in Yemen (Fig. 6B).

Feldspar

Nine major locations of feldspar (Fig. 6B) (mainly potash feldspar) are found in the form of large crystals in pegmatites hosted by alkali feldspar granite . Earge crystals of feldspars up to 30 cm long occur within the intermediate zones of complex pegmatites located in NW Hajjah, the area between Al-Baydah - Abyan - Mukaeras where many swarms of pegmatites are found. Total reserve of feldspar in Yemen estimated to be around 21 million m^3.

The distribution of feldspar is compatible with the major fault oriented ENE direction (Fig. 6B).

Fluorite

Many occurrences of fluorite veins are represented in Yemen, in particular, the area between Abyan and Al-Baydah at Wadi Irqah, in which several veins of hydrothermal origin (author's observation) bearing megacrystals of fluorite and quartz are associated with the Ataq - Irqah fault system (NW trend, Fig. 6B) . Resources of fluorite as estimated to be around 900.000 tons (Strojetpant, 1988).

Celestite

Strontium deposits of Celestite are mainly found at Wadi Hadramout (Fig. 6B) in the form of either interbedded laminae and layers between sedimentary sequence enriched in magnesian and clay or associated with alluvial sediments along the coastal belt of Gulf of Aden (author's observation). The Celestite forms prismatic crystals with 25 cm long, 20 - 25 cm thick, locally arranged in rosettes. The authors suggest that the origin of celesite is epigenetic and related to Karstification processes.

Zeolite

Zeolites are hydrated silicates of aluminums, sodium and calcium . The zeolites when pure are colourless or white (Fig. 7d), but many specimens are reported to be yellow, green and orange due to the presence of some impurities.

The natural zeolites contain more than 40 minerals, the commercial ones being clinoptilolite, chapazite, mandinite and phillispite. These minerals are commonly hosted by basaltic tuff (Fig. 7d), acid volcanic tuffs associated with volcanic glass of Tertiary and Quaternary volcanics. Zeolite minerals occur within Ibb - Taiz -Dhamar zone of Yemen Volcanic Group (Fig. 6B) along major fault trending NK. The types of zeolite in Yemen include clinoptilolite, heulandite, mordinite, stilbite, laumonotite and natrolite (detected by XR D by the present authors). Zeolite reserves about 80 million m^3 (Arab Conf. Mineral, 2003).

Talc

Talc deposits are found in several regions in Yemen (Fig. 6B) where ultramafic -metavolcanic rocks of Precambrian age have been occurred. Two main occurrences of talc deposits have been reported; South Taiz - Abyan - Al-Bayda Zone along shear zone within ultramafics trending NE and to the west of Sadah area (Fig. 6B) hosting by mafic metavolcanics in the form of separated lenses up to 500 m long and 50 m thick. Almost zones trending ENE and NW (Fig. 6B).

Black Sands

There are many documented occurrences of beach black sands and a placer deposits containing ilmenite, titan-magnetite, rutile, magnetite, zircon, monazite, in Yemen (Fig. 6B). These placer deposits are found on the beaches coast of Al Mukalla and along the Red Sea coastline (Fig. 6B). Total resources of black sands in Yemen are estimated to be 500 million tones (Arab Conf. Mineral, 2003).

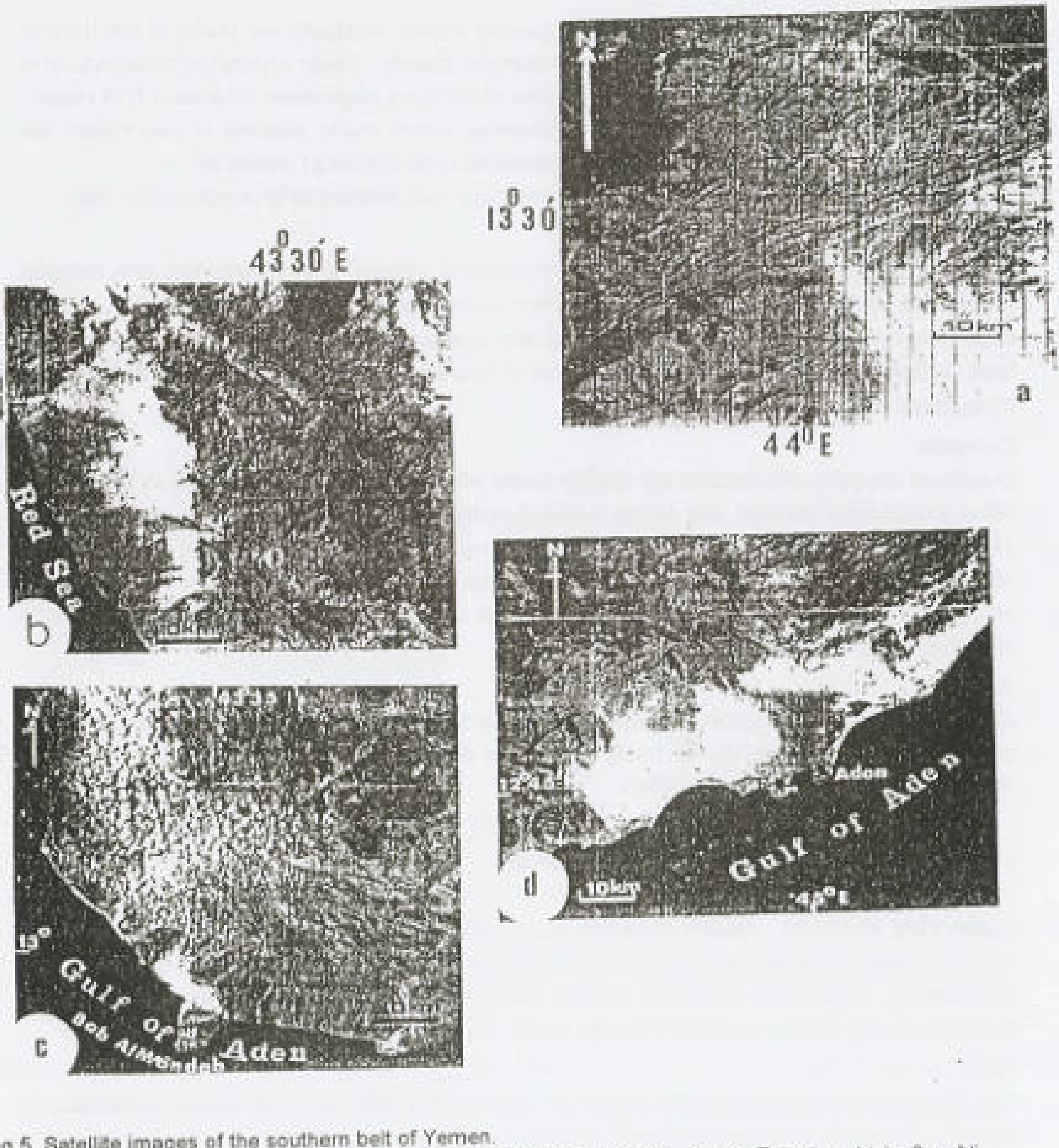

Fig.5. Satellite images of the southern belt of Yemen.
a) Shear zones within metamorphgosed rocks trending NE, south Taiz in which Cu- Ni mineralization is well recognized.
b-d) Gulf of Aden area in which such tectonic zones trend ENE(arrows).

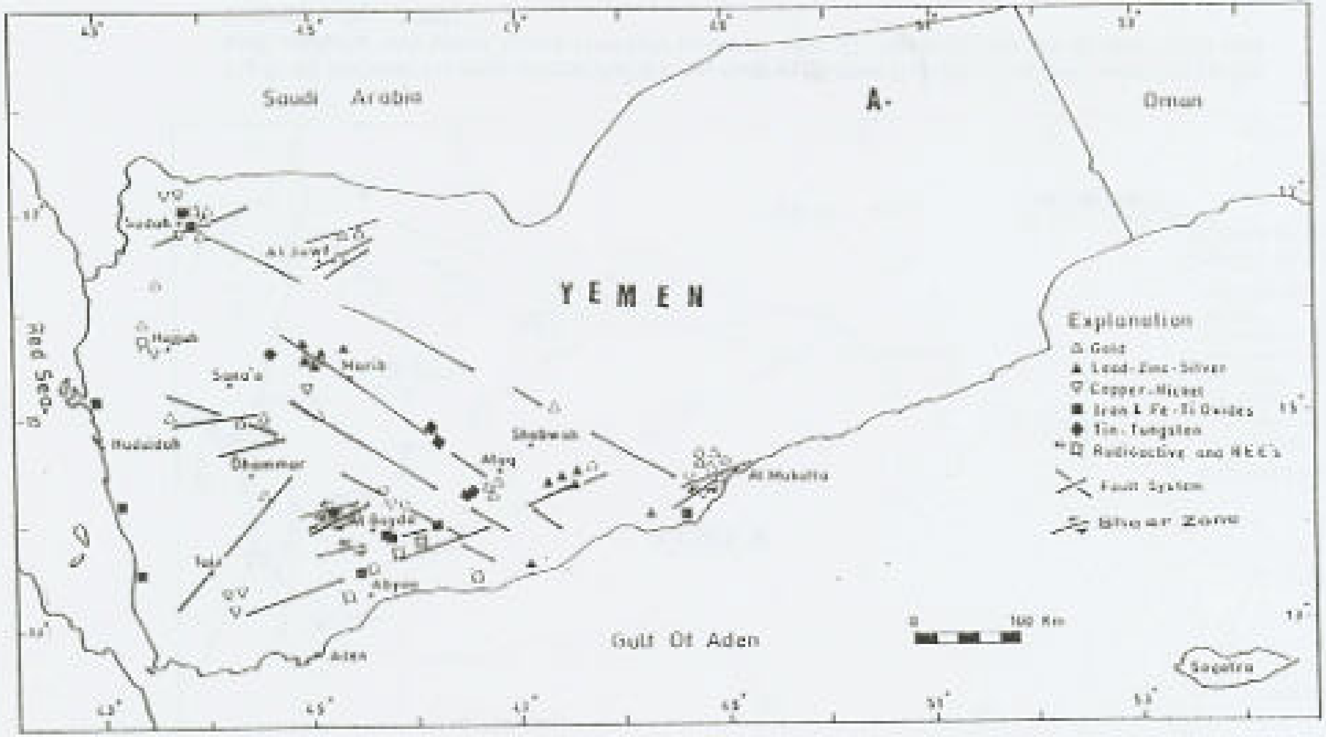

Fig.6. A) Distribution map of metallic ore deposits in Yeman Republic and their relations to the fault systems and shear zones. Strongly modified after El- Shatoury and Al- Eryani (1978) and Robertson Group (1992).

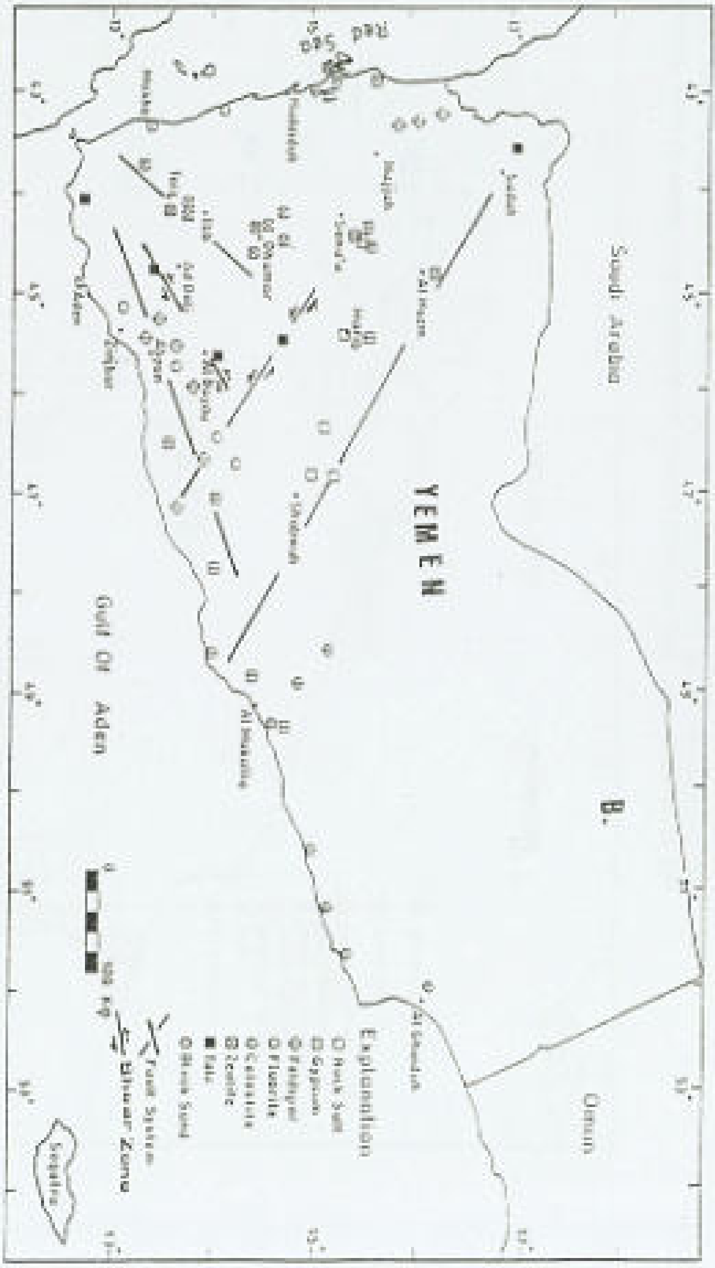

Fig.6 B) Distribution map of metallic ore deposits in Yemen Republic and their relations to the fault systems and shear zones (strongly modified after El- Shatoury and Al- Eryani, 1978 and Robertson Gp., 1992).

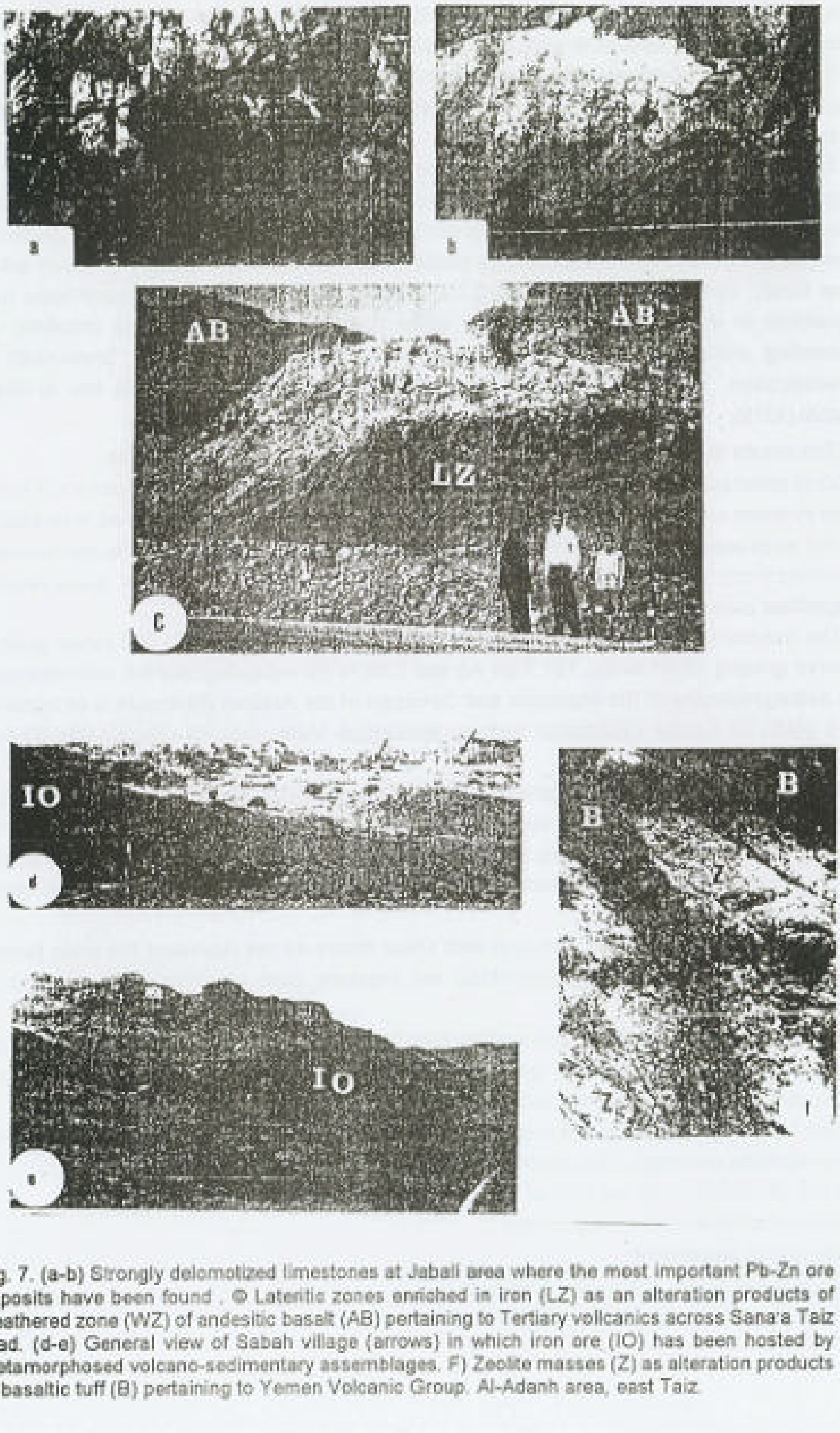

Fig. 7. (a-b) Strongly dolomotized limestones at Jaball area where the most important Pb-Zn ore deposits have been found . © Lateritic zones enriched in iron (LZ) as an alteration products of weathered zone (WZ) of andesitic basalt (AB) pertaining to Tertiary vollcanics across Sana'a Taiz road. (d-e) General view of Sabah village (arrows) in which iron ore (IO) has been hosted by metamorphosed volcano-sedimentary assemblages. F) Zeolite masses (Z) as alteration products of basaltic tuff (B) pertaining to Yemen Volcanic Group. Al-Adanh area, east Taiz.

SUMMARY AND CONCLUSIONS

Since 2002 the present authors reviewed and compiled the available data concerning with the mineral deposits in Yemen. Also, they contributed to the mineral potential of Yemen by discovering new occurrences of uranium and celestite deposits.

In fact the northwestern and southern parts of Yemen are considered to be the metallogenic province, where their geologic environments and tectonic framework are reasonable for mineralization.

On the structural point of view in Yemen, the relationship between fault system and / or shear zones reported and mineral potential provides excellent and interesting evidences of its distribution and occurrences. Bearing in mind the relationship between PC fault system and mineralization in overlying sedimentary strata (e. g. Pb - Zn - Ag deposits) of Jabali area . In most cases, vertical movements on PC faults could have provided a structural traps for ore deposition in the cover strata. On the other hand, the Najd fault zone provides some interesting evidence concerning the relationship between major fault 'lineaments' and mineralization. This is in good agreement with Moore and Al-Shanti (1979) and Al-Shanti & Roobal (1979).

The results obtained in the present work give the following concluding remarks :

1. Most mineralization reported in Yemen are concentrated along fault systems and / or shear zone in which are easy channelways for the mineralizing solutions and acted as favorable Locii for ore emplacement . Therefore the distribution of gold, lead, zinc, copper, tin and radioactive mineralizations are closely related to the main trends (NW, NE, ENE) of major faults and megashear zones.

2. The mineral potential of Jabali Zn - Ag - Pb deposits with over 3.800.000 tonne geological reserve grading 16.11 % Zn, 131.7 g/t Ag and 2.09 % Pb indicating that the understanding of the paleogeography of the Mesozoic and Cenozoic of the Arabian Peninsula is of importance as a guide for further exploration such as Mississippi- Valley type Pb - Zn deposits (Al Shanti, 1979)

3. The gold potential of the Precambrian basement especially in Sadah - Al Jowf and Al-Mukalla areas should be assessed. The distribution of gold mineralization is controlled by three major faults and / or shear zones trending ENE, NE and NW. This provides some interesting evidence of the role of faulting as a factor in the genesis and structural control of hydrothermal mineralization.

4. The major fault system in common with shear zones do not represent the main factors in the metallogenesis of some non metallic ore deposits, such as celestite, zeolite and black sands .

5. Reactivation of NW Najd fault system has been observed in the Red Sea coastal areas affected by Tertiary rift tectonic, leading to the development of such mineralization in Yemen (e. g. tin-tungsten, fluorite, rock salt and gypsum)

6. The field of mining for mineral exploration in Yemen is still unsatisfactory in relation to the mineralization showings. This shortfall is attributed to a number of factors :

a) Lack of research into the field of mining and the process as of finding minerals.

b) Old and outdated mining regulations.

c) Shortfall in investment.

d) Shortage of skilled and experienced persons.

e) Lack of sufficient Pan-Arab trading.

7. Yemen has a vast wealth of important minerals as yet mostly untouched such as gold, copper, nickel, zinc, lead in a addition to industrial minerals such as zeolites, talc, gypsum and rock salt.

8. Further geological studied on a mineralization in particular gold, uranium, copper, nickel and iron are strongly recommended by the present authors, where mineralization showings are well recognized.

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التمعدنات والتراكيب في الجمهورية اليمنية استعراض عام واضافات جديدة

محمد ثروت صلاح هيكل*- أحمد محمد القطبه** - بشرى العواضي**

*قسم الجيولوجيا - كلية العلوم - جامعة طنطا - مصر

**قسم علوم الأرض والبيئة - كلية العلوم - جامعة صنعاء - اليمن

تعتبر اليمن من الدول الواعدة في الثروة المعدنية المتنوعة حيث تتواجد البيئات الجيولوجية المناسبة لعمليات التعدين وقد تم في هذا العمل اضافات جديدة ومبتكرة لخرائط توزيع الثروة المعدنية الفلزية واللافلزية في اليمن حيث تتواجد خامات الذهب والزنك والرصاص والنحاس والزنك والحديد والقصدير والتسجتين بكميات واعدة في بيئات جيولوجية ملائمة لتواجد تلك الخامات في أماكن عديدة في الجمهورية اليمنية وتم أكتشاف شواهد ممتازة لتمعدنات اليورانيوم والثوريوم وتمعدنات العناصر النادره في الأجزاء الجنوبية والجنوبية الشرقية لليمن. هذا بالأضافة الي تمعدنات الجبس والملح والزولايت والفلورايت والرمال السوداء في بيئات جيولوجية متعددة. ارتبطت تلك التمعدنات في الغالب من حيث التوزيع والنشأة في بعض الأحيان بصدوع وأنطقة قص ذات اتجاهات عديدة أهمها شمال غرب وشرق - شمال- شرق ويعتبر نطاقي مأرب حجة صنفيرة ،شبوه- المكلا البيضا من أهم المناطق الواعدة في التعدين في اليمن حيث البيئات الجيولوجيه والتراكيب الصدعيه ذات التأثير الواضح في التوزيع والنشأة لتلك التمعدنات. أرتبطت تلك التمعدنات في الغالب من حيث توزيعها بصدوع وأنطقة قص ذات إتجاهات معينة أهمها شمال غرب ، شرق - شمال شرق- ويعتبر نطاقي مأرب - حجة - صعده ، شبوه - البيضا - المكلة من أهم المناطق الواعده للتعدين فى اليمن حيث ترتبط البيئات الجيولوجية مع التراكيب الجيولوجية معطية نموزجا فريدا في توزيع ونشأة تلك التمعدنات.