J.K.A.U.: Earth Sci., vol. 3, Special Issue: 1st Saudi Symp. on Earth Sci., Jeddah, 1989, pp. 145-155 (1410 A.H. / 1990 A.D.)

The Metallogeny of Gold Deposits in Saudi Arabia and Its Significance in Gold Exploration and Exploitation

HUSSEIN SABIR
Saudi Arabian Directorate General of Mineral Resources - BRGM Geological Mission, Jeddah, Saudi Arabia.

ABSTRACT. Metallogenic studies relating to gold deposits in the Saudi Arabian Shield show that gold is hosted mainly by two broadly-recognized geologic environments, namely volcanosedimentary successions and plutonic complexes, within which four principal types of gold mineralization have been recognized on the basis of rock-facies association, morphological setting and mineral assemblages.

1. Gold mineralization associated with oxidized sulfide zones, as at Al Hajar and Shaib at Tair prospects (Wadi Shwas-Wadi Bidah areas), comprising brecciated, silicified, ferruginous and sandy-textured facies, in which free gold is finely disseminated in supergene alteration minerals and associated siliceous gangue.

2. Gold mineralization in zones of massive sulfides, in close association with volcanosedimentary facies (cherts, carbonates, graphitic tuffs), as at Al Masani and Nuqrah, forming a concordant mineralized interval commonly at the top of the sulfide body. This mineralization, which is also locally enriched in silver, displays a complex gold-silver-telluride-sulfide and silver sulfosalt mineral assemblage.

3. Gold mineralization occurring in vein-like bodies and/or stockworks hosted by chloritized and siliceous volcanic facies and subvolcanic intrusions, as at Mahd adh Dhahab and Al Amar, where the mineralization is characterized by relatively high gold content, expressed both by the notable concentration of free gold in sulfides, chlorite and quartz, and by the relative abundance of gold and gold-silver tellurides.

4. Gold mineralization related to plutonic complexes as at Sukhaybarat, Zalim, Bari and Jabal Ghadarah that is typically characterized by close association of gold with arsenopyrite and pyrite, general scarcity of base-metal sulfides and a marked depletion in gold tellurides.

These metallogenic studies in conjunction with detailed geological and geochemical investigations led to the redefinition of exploration targets for gold mineralization in the Saudi Arabian Shield, and the re-examination of known gold occurrences and ancient mines of small dimensions, following the recent improvements in gold extraction by heap leaching and cyanidation techniques.

Introduction

Gold mineralization in Saudi Arabia has been the subject of many geological studies (Boyle *et al.* 1984, Smith *et al.* 1985, Viland *et al.* 1987) and economic investigations (Viland 1986, Sauzay 1987).

The rising interest in gold is manifested by the increase in gold prospecting programs by various geological teams working on behalf of the Ministry of Petroleum and Mineral Resources (Directorate General of Mineral Resources, Bureau de Recherches Géologiques et Miniéres, and United States Geological Survey), by the opening of ancient gold mines (Mahd adh Dhahab and Sukhaybarat), and by the application of newly improved methods of gold extraction (heap leaching and cyanidation).

This report comprises a study of the metallogenic and geological characteristics of gold mineralization in various geological settings represented by typical examples at Sukhaybarat, Mahd adh Dhahab, Al Amar, Ash Shakhtaliyah, Jabal Ghadarah, Zalim, Ad

Duwayah, Shaib at Tair, Al Hajar, Nuqrah and Al Masani (Fig. 1), with implications for regional exploration and exploitation.

The report forms part of the work of the Bureau de Recherches Géologiques et Minières (BRGM), entirely supported by the Ministry of Petroleum and

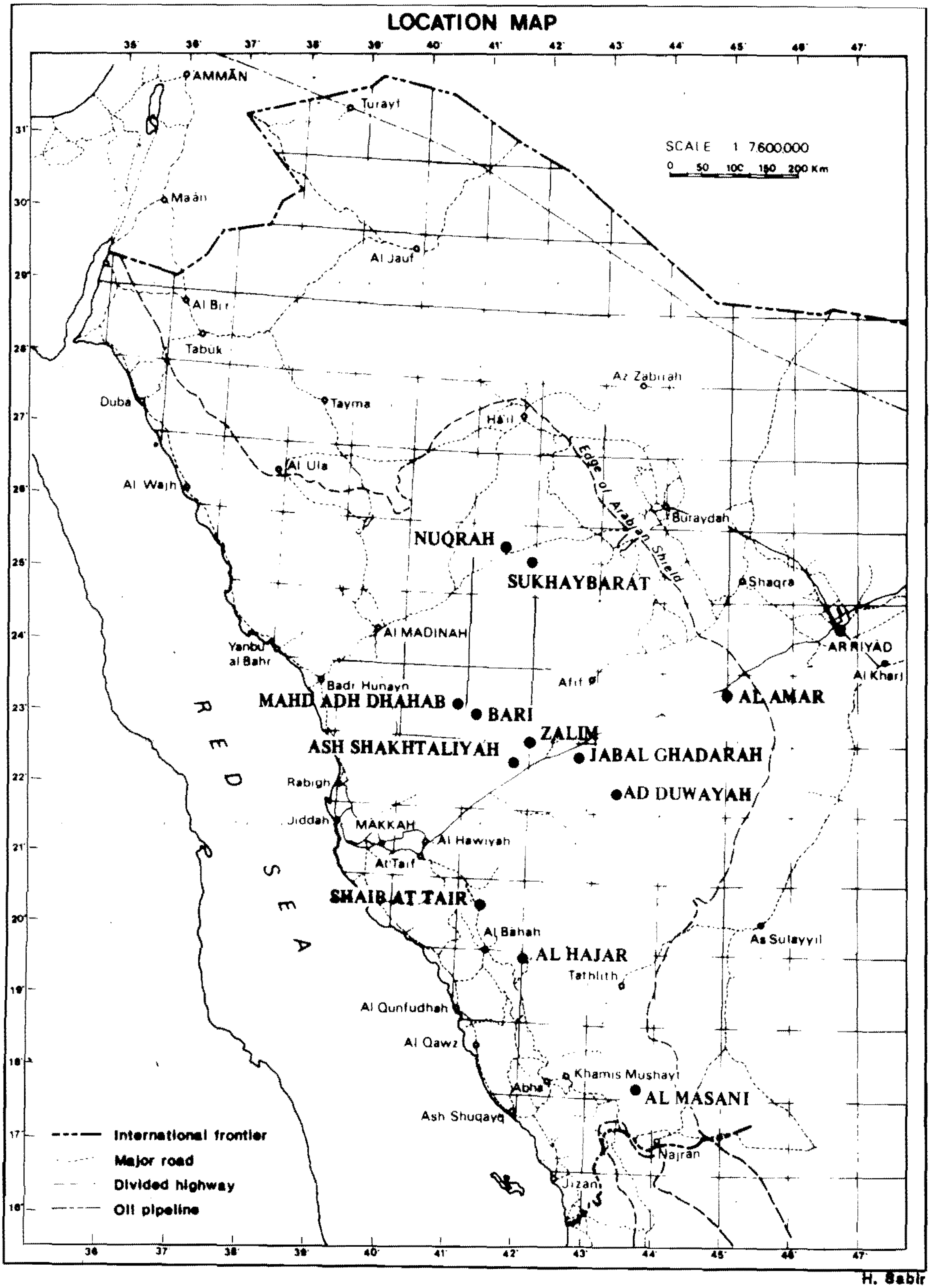

FIG 1. Location map of gold-bearing deposits in Saudi Arabia.

Mineral Resources, and is presented to the First Saudi Symposium on Earth Sciences, King Abdulaziz University, Jeddah, 1989.

Geological Environments Hosting Gold Mineralization

Gold mineralization shows a wide distribution throughout the Saudi Arabian Shield, as indicated by the presence of numerous ancient workings (pits, dumps and stopes) along gold-bearing quartz veins. Recent studies suggest that the geographical distribution and localization of these gold workings were probably governed by the proximity to ancient water wells and the easy access to old routes, factors that were essential for the development of ancient mining sites (Sabir 1983).

Geologically, the distribution of gold mineralization (excluding placer deposits) coincides with two of the most widely recognized geological environments in the Arabian Shield, namely, volcanosedimentary successions and plutonic complexes.

1. Volcanosedimentary Successions

These correspond to a differentiated volcanic episode representing mafic to intermediate and felsic evolutionary phases that tend to be aligned along north- to northeast-trending orogenic belts (Fig. 2) belonging to the Hulayfah group or its probable equivalents of the Farri, Jeddah, Bahah and Baish groups of upper Proterozoic age (Delfour 1983). Base and precious metal (gold and silver) mineralization is closely associated with the felsic portion of these orogenic belts, locally accompanied by zones of chloritization and silicification.

At the present state of knowledge, the most important gold-bearing volcanic belts are the Sayid, Al Amar, Wadi Shwas, and Wadi Bidah belts. The Sayid belt contains the Mahd adh Dhahab gold deposit (Fig. 2, No. 26) and the Al Amar belt, the Al Amar deposit (Fig. 2, No. 34); these being the largest known gold deposits in Saudi Arabia. The Wadi Shwas and Wadi Bidah belts contain, among others, the newly discovered Al Hajar (Fig. 2, No. 11) and Shaib at Tair (Fig. 2, No. 19) gold prospects, respectively, with potentially significant gold mineralization (Cottard *et al.* 1989).

2. Plutonic Complexes

Plutonic complexes hosting gold mineralization occur in various parts of the Saudi Arabian Shield, and show a compositional variation ranging from diorite and quartz-diorite to granodiorite (Jackson 1985). Plutonic-related gold mineralization, however, is mostly developed in the central and northern parts of the Shield, where numerous occurrences and prospects have been discovered, such as those of Sukhaybarat, Bari, Zalim, and Jabal Ghadarah (Fig. 2). The mineralization is closely associated with variable visible vein structures and in places diffused into the wall of the intrusion with manifestations of hydrothermal alteration.

Principal Types of Gold Mineralization and Their Characteristic Metallogenic Features

The detailed metallogenic and geological investigations of gold mineralization have led to the delineation of four principal types or models of occurrences of gold mineralization on the basis of rock facies association, morphological setting and mineral assemblages. As such, 12 gold prospects and deposits, among the most significant known gold localities in the Saudi Arabian Shield, have been selected as typical examples illustrating the metallogenic and geologic character of three recognized types of gold mineralization associated with volcanosedimentary facies (Fig. 3), the fourth type (Fig. 4) being in close relation to plutonic complexes.

Type 1. Gold in Oxidized Sulfide Zones

A newly discovered type of gold mineralization where the gold, commonly accompanied by silver, occurs in brecciated, silicified, ferruginous and sandy-textured friable facies forming the oxidation zone in the upper part of the sulfide body. This mineralization has been found in several occurrences and prospects in the Wadi Bidah and Wadi Shwas districts (Cottard *et al.* 1989), such as Shaib at Tair and Al Hajar prospects (Fig. 2). The mineralization displays a very fine-grained and disseminated texture with free gold being observed as fine lamellar to subrounded inclusions (10-12 microns in size) in quartz and supergene alteration minerals (Fig. 5). The paragenetic assemblage is relatively simple, comprising essentially gold, goethite, hematite, rutile and some pyrite (Fig. 3). The silver content of this mineralization is expressed by the presence of tetrahedrite, and argentiferous gold (electrum) being the only silver-bearing minerals observed in the ore assemblage.

Type 2. Gold in Massive Sulfide Zones

Massive sulfide zones containing variable proportions of gold and silver have been discovered in several localities in the Saudi Arabian Shield (Al Masani, Nuqrah, Jadmah, Ar Rjum, Shaib at Tair and Al Hajar), the most important of which being Al Masani and Nuqrah (Pouit *et al.* 1984). These sulfide zones occur as stratabound mineralized intervals associated with volcanosedimentary facies such as chert, carbo-

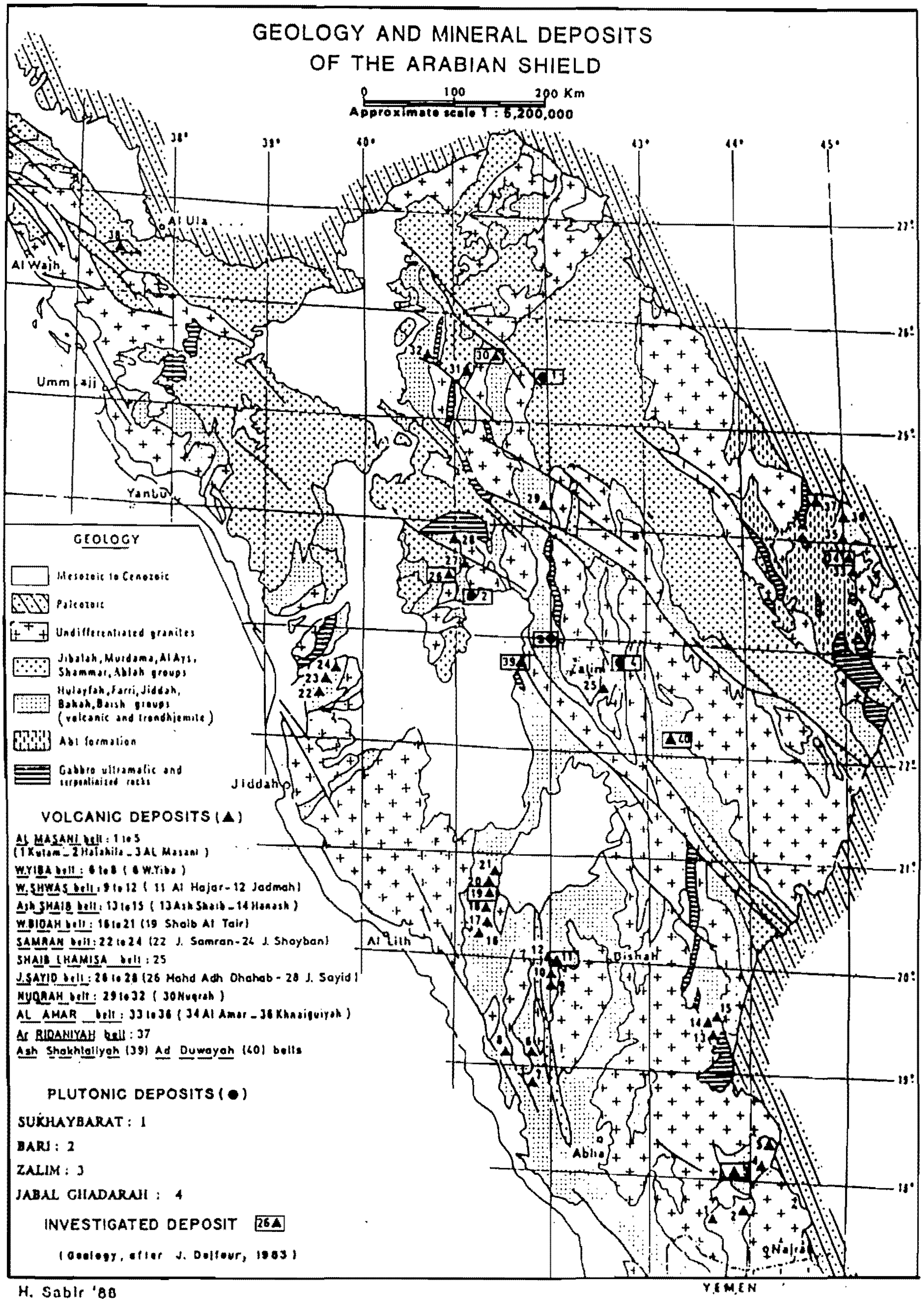

FIG. 2. Geology and mineral deposits of the Arabian Shield.

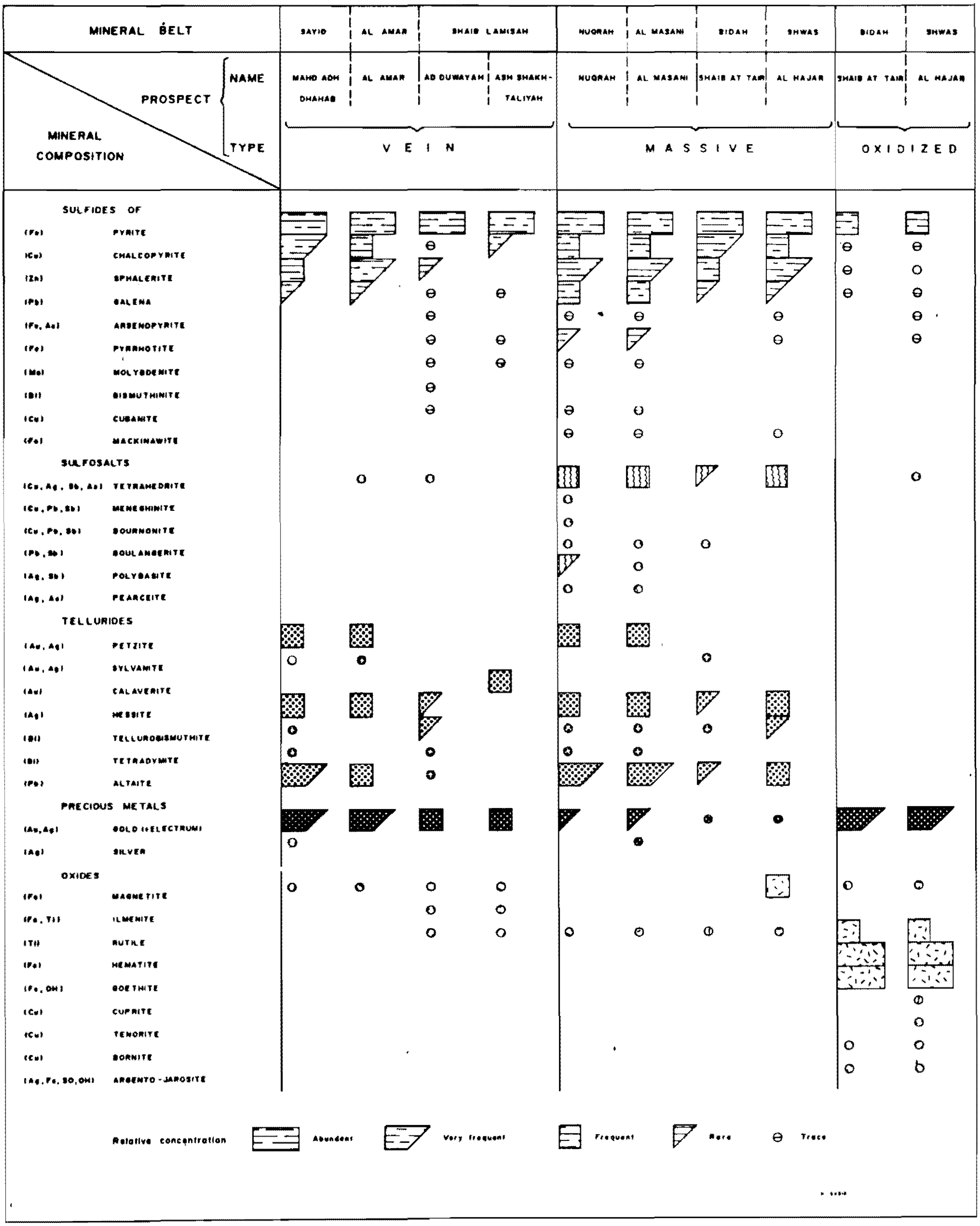

FIG. 3. Volcanogenic gold-bearing sulfide deposits in Saudi Arabia.

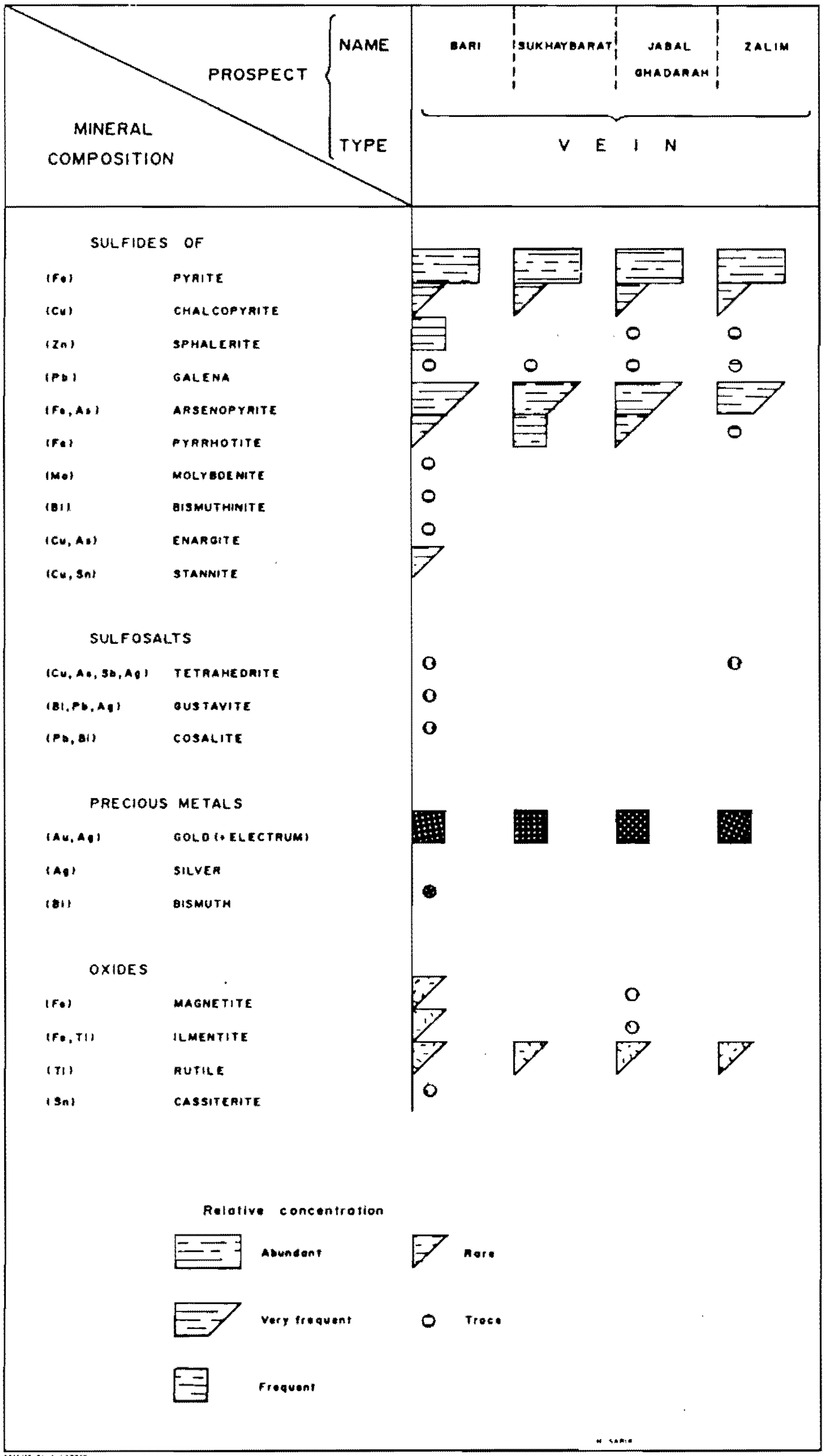

FIG. 4. Plutonic-related gold deposits in Saudi Arabia.

FIG. 5. Gold (g) fine disseminations in hematite (m). Al Hajar, core sample 778, × 500, oxidized zone gold mineralization type 1.

FIG. 6. Gold (g) with petzite (p) in chalcopyrite (c) containing hessite (h). Al Masani, core sample 38153, × 200, massive-sulfide gold-bearing mineralization type 2.

nates, and graphitic tuffite, commonly at the top of the sulfide body, and containing distinctly banded and massive sulfides predominantly of zinc and copper with minor lead, silver and gold. The mineralization is characterized by a complex mineral association (Fig. 3) comprising sulfides of iron, copper, zinc, lead and arsenic (pyrite, chalcopyrite, sphalerite, galena, arsenopyrite, pyrrhotite, cubanite and mackinawite), sulfosalts of copper, lead, antimony, arsenic and silver (tetrahedrite, meneghinite, bournonite, boulangerite, polybasite and pearceite), tellurides of gold and silver, bismuth and lead (petzite, sylvanite, calaverite, hessite, tellurosbismuthite, tetradymite and altaite), precious metals (gold and silver), together with iron and titanium oxides (magnetite and rutile).

The gold displays two principal forms of occurrence :

- Fine included grains in the sulfides, with a characteristic white-yellowish hue suggestive of the mixed gold-silver "electrum" variety as confirmed by electron microprobe analysis.
- Discrete intergrowths of the gold-silver telluride petzitė, which is commonly associated with gold (Fig. 6)

This mineralization is also marked by the local enrichment in silver which can be explained by:

- The relative abundance of silver-bearing sulfosalts (tetrahedrite, polybasite and pearceite).
- The widespread occurrence of silver and gold-silver tellurides (hessite and petzite).
- The occurrence of gold as the mixed gold-silver "electrum" variety.

Type 3. Gold in Vein and/or Stockwork Sulfide Zones

This includes such deposits as Mahd adh Dhahab, Al Amar, Ad Duwayah and Ash Shakhtaliyah, where the mineralization is linked to a system of quartz veins forming interconnected vein-like bodies hosted by chloritized and silicified volcanic facies and subvolcanic intrusions. This mineralization is marked by relatively high gold content with variable quantities of silver, copper, zinc and lead.

The mineral assemblage comprises a sulfide-telluride-precious metal-oxide association that is distinctly depleted in sulfosalt minerals (Fig. 3). The gold is present as the free metal (Fig. 7) and in the form of tellurides (Fig. 8) which show both a notable concentration and a variety of species in this mineralization (petzite and sylvanite at Mahd adh Dhahab and Al Amar and calaverite at Ash Shakhtaliyah). These tellurides are also the principal silver carriers in this mineralization.

Type 4. Gold in Vein Structures Related to Plutonic Complexes

This mineralization, represented by the Bari, Sukhaybarat, Jabal Ghadarah, and Zalim prospects,

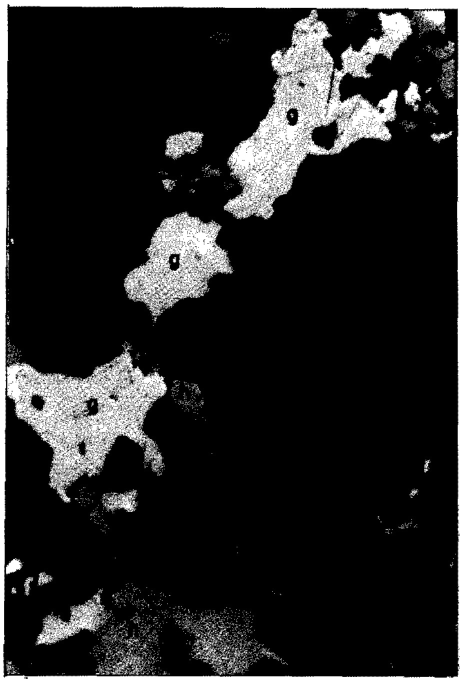

FIG. 7. Gold (g) with hessite (h). Mahd adh Dhahab, core sample 38685, × 100, vein-sulfide gold-bearing mineralization type 3.

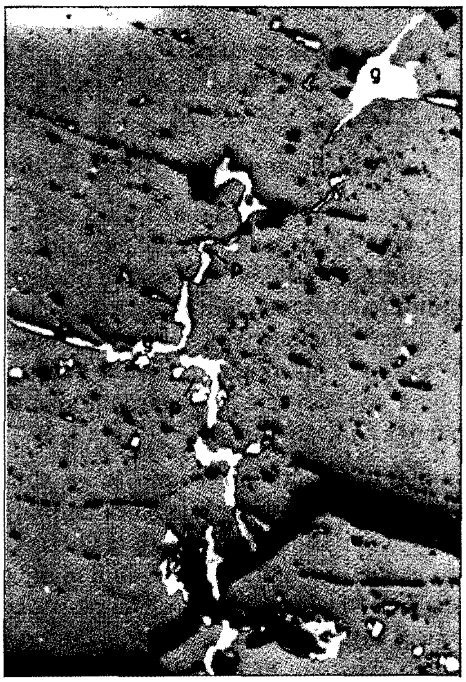

FIG. 8. Gold (g) fine veinlets with petzite (p) in sphalerite (s). Al Amar, core sample 29335, × 200, vein-sulfide gold-bearing mineralization type 3.

displays a coarsely crystalline, fractured and sheared texture. Unlike volcanogenic gold-bearing mineralization, plutonic-related gold mineralization (Fig. 4) is characterized by :

1. The intimate association of gold with pyrite and arsenopyrite. The detailed investigation of this relationship shows that gold appears only in the presence of arsenopyrite (Fig. 9). However, notable concentrations of arsenopyrite have been observed that do not contain gold.

FIG. 9. Gold (g) included in fractured arsenopyrite (a). Sukhaybarat, core sample 45952, × 500 plutonic-related gold mineralization type 4.

2. The general scarcity of base-metal sulfides and sulfosalts.
3. The marked depletion of gold and silver tellurides.
4. The occurrence of appreciable quantities of pyrrhotite together with trace amounts of bismuth (bismuthinite, native bismuth, cosalite and gustavite), tin (stannite and cassiterite) and molybdenum (molybdenite) minerals, suggesting a pluton-derived mineralization.

Applications to Gold Exploration and Exploitation

Oxidized Gold Mineralization

Exploration efforts have been recently concentrated on the newly discovered oxidized gold mineralization, which can be an important source of gold, as demonstrated by the production of the first gold ingot in December 1988 from the Al Hajar prospect, Wadi Shwas area. This type of mineralization is potentially an important exploration target, the discovery of which has led to the re-examination of gossans and siliceous hydrothermal occurrences in the various recognized volcanosedimentary belts of the Saudi Arabian Shield (Fig. 2). Although some zones of these belts are well explored (Nuqrah, Al Amar and Wadi Bidah), others are still under study (Wadi Shwas and Jabal Sayid). Still, others (Ash Shaib and Wadi Yiba) have not yet been systematically investigated to record all gossans and hydrothermal products.

In addition, the recent improvement in gold extraction by heaping leaching and cyanidation techniques has given a new impetus for exploring this type of gold mineralization in bodies of small dimensions, thereby leading to the re-investigation of known mineral occurrences and ancient mines for possible exploitation by different cost-effective methods than has been considered in the past.

Volcanogenic Massive-Sulfide Gold-Bearing Mineralization

This type can be an important source of zinc and copper but remains a minor gold exploration target, in view of its low gold content, except where gold is locally enriched in certain deposits, such as Al Masani and Nuqrah, where the metal can be mined together with silver as a by-product in the course of exploitation of base metals.

Volcanogenic Vein-Sulfide Gold-Bearing Mineralization

Exploration for vein and/or stockwork gold-bearing mineralization, such as Mahd adh Dhahab and Al Amar, involves relatively deep drilling, underground development work, bulk sampling and detailed ore studies to improve gold recoveries. This type of mineralization, however, remains a promising target in which gold grades are generally high enough to support underground mining.

Plutonic-related Gold Mineralization

Comprising variable mineralized plutonic-related vein structures, this type of mineralization could be a viable exploration target, as at Sukhaybarat, where such vein structures are closely spaced enough to make open-pit mining profitable. In this respect, the Sukhaybarat deposit serves as a typical model of this type of mineralization, which demonstrates that small, low-grade deposits, amenable to open-pit mining could be exploited commercially, thereby favoring the search for similar deposits in plutonic environments.

Conclusion

The various outlined geological and metallogenic features of gold mineralization in Saudi Arabia provide important implications for both regional gold exploration and profitable exploitation.

Of specific relevance to gold exploration is the recognition of principal types of mineralization that serve as guidelines to exploration programs in favorable geological environments. This approach has eventually led to the redefinition of exploration targets, with the volcanosedimentary types of gold mineralization (oxidized and vein types) being of first priority.

The gold-bearing oxidized mineralization as at Al Hajar, Jadmah, and Shaib at Tair prospects (Wadi Shwas-Wadi Bidah areas) is closely associated with brecciated, silicified, ferruginous and sandy-textured facies, resulting from supergene alteration and acidic leaching of underlying sulfides and their host volcanic facies. The mineralogy of the ore is simple, with gold being disseminated as fine inclusions in oxide and hydroxide minerals (hematite and goethite) and associated siliceous gangue.

The recent discovery of gold in the oxidized zones of these sulfide prospects in the Wadi Bidah and Wadi Shwas belts has on the one hand sparked the search for this type of gold mineralization in other volcanosedimentary belts in the Saudi Arabian Shield through the re-examination of known gossans and siliceous hydrothermal products, in the hope of finding similar potential gold-bearing prospects. On the other hand, the recent improvement in gold extraction techniques by heap leaching and cyanidation has given new impetus to re-investigate known gold occurrences, or groups of occurrences and ancient mines of small dimensions, for possible exploitation by different cost-effective methods than has been considered in the past.

Volcanogenic type gold-bearing mineralization, as at Mahd adh Dhahab and Al Amar, forms stockwork and interconnected vein-like bodies in close association with chloritized and silicified acidic facies and subvolcanic intrusions. This type of mineralization involves relatively deep drilling, underground development work, and bulk sampling, and is marked by a complex gold-telluride-sulfide mineral assemblage, but remains a promising exploration target as it contains gold grades high enough to support underground mining.

Plutonic-related gold mineralization, as at Sukhaybarat, Bari, Zalim and Jabal Ghadarah, is linked to a variety of vein structures and displays a characteristic gold-arsenopyrite-pyrite association with a marked depletion in gold tellurides. This type of mineralization can be a viable exploration target in plutonic environments, as exemplified by the Sukhaybarat model which demonstrates that small low-grade deposits are amenable to profitable exploitation by open-pit mining.

References

Boyle, D. McK., **Badahdah, S.S.** and **Saleh, Y.T.** (1984) Review and ranking of the mineral potential of auriferous quartz vein occurrences, *Saudi Arabian Deputy Ministry for Mineral Resources Open-File RF-OF-04-7:* 79 p.

Cottard F., **Abdulhay, G.**, **Artignan, D.**, **Coumoul, A.**, **Gélot, J.L.**, **Roubichou, Ph.**, **Sabir, H.**, **Trinquard, R.** and **Vadala, P.** (1989) A new type of auriferous mineralization in the southern Shield of Saudi Arabia *in, Abstracts of the First Saudi Symposium on Earth Sciences, King Abuldulaziz University, Jeddah, 1989,* p. 42.

Delfour, J. (1983) Geology and mineral resources of the northern Arabian Shield; a synopsis of BRGM investigations, 1965-1975: *Saudi Arabian Deputy Ministry for Mineral Resources, Jeddah, Technical Record BRGM-TR-03-1:* 217 p.

Jackson, J.N. (1985) Mineralization associated with felsic plutonic rocks in the Arabian Shield, *Saudi Arabian Deputy Ministry for Mineral Resources Bulletin* **29:** 213-227.

Pouit, G., **Elsass, P.**, **Ferrand, A.**, **Milesi, J.P.**, **Prévôt, J.P.** and **Sabir, H.** (1984) Metallogenic base metal studies: review of activity during 1980-1983 A.D. (1400-1403 A.H.), *Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report BRGM-OF-04-11:* 74 p.

Sabir, H. (1983) Ancient mining activity and its relationship to modern mineral exploration in Saudi Arabia (in Arabic): Saudi Arabian Deputy Ministry for Mineral Resources, *Symposium on ancient exploitation of Arab mines, 1403, Jeddah, Arab Organization for Mineral Resources:* 16 p.

Sabir, H. and **Pouit, G.** (1984) An overview of volcanogenic massive sulfide mineralization in Saudi Arabia, *Faculty of Earth Sciences, King Abdulaziz University, Jeddah, Kingdom of Saudi Arabia, Bulletin* **6:** 501-509.

Sauzay, C. (1987) Economic outlook for gold deposits in the Zalim area (May, 1985), *Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report BRGM-OF-06-35:* 44 p.

Smith, E.A., **Barnes, D.P.**, **Johnson, P.R.**, **Bognar, B.**, **Garfield, L.** and **Scheibner, E.** (1985) A review of the geology, mineralization and mineral-resource potential of the Kingdom of Saudi Arabia, *Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report RF-OF-05-1* (3 volumes): 596 p.

Viland, J.C. (1986) Assessment for gold in the Zalim area, central Arabian Shield; review of BRGM work, *Saudi Arabian Deputy Ministry for Mineral Resources, Jeddah, Open-File Report BRGM-OF-06-11:* 110 p.

Viland, J.C., **Billa, M.**, **Couturier, P.**, **Paupy, A.**, **Kleiber, J.** and **Sonnendrücker, P.** (1987) Review of gold mineralization in the Arabian Shield, *Saudi Arabian Directorate General of Mineral Resources Open-File Report BRGM-OF-07-6:* 22 p.

نشـأة رواسب الـذهب في المملكـة العربية السعودية وأهميتها في استكشاف الذهب واستغلالـه

حســين صــابر
المديرية العامة للثروة المعدنية ، البعثة الجيولوجية الفرنسية
جـــدة ، المملكة العربية السعوديـــة

المستخلص . أظهرت الدراسات المتعلقة بنشأة رواسب الذهب في المملكة العربية السعودية أن تمعدن الذهب يكمن في بيئتين جيولوجيتين مميزتين على نطاق واسع ، هما السلسلة المتعاقبة للصخور البركانية الرسوبية والصخور البلوتونية المعقدة . وقد تم التعرف فيهما على أربعة أنواع رئيسة من تمعدن الذهب على أساس سمات الصخور المصاحبة ، والشكل التوضيحي للتمعدن ، والمجاميع المعدنية المكونة :

١ - تمعدن الذهب المصاحب لمناطق الكبريتيد المؤكسد كما في مكمن الحجار وشعيب الطير (منطقة وادي شواص ، وادي بيدة) والتي تشكل صخورًا تفتتية سيليسية حديدية ورملية الململس ، ويكون الذهب فيها على شكل حبيبات دقيقة منثورة في المعادن السطحية المتحولة والشوائب السيليسية المصاحبة .

٢ - تمعدن الذهب في مناطق الكبريتيد الكتلي الوثيق الصلة بالصخور البركانية الرسوبية (صخور صَوَّانية ، كربونات ، مواد جرافيتية) كما في المصانع والنقرة والتي تكوِّن أفقًا معدنيًا متطابقًا في قمة الجسم الكبريتيدي . هذا التمعـدن ، الغني بالفضـة محليًا ، يظهـر تركيبًـا معقدًا لمجموعة المعادن المكونة من الذهب والفضة والتلوريد والكبريتيد الحامل للمعادن الأخرى .

٣ - تمعدن الذهب الموجود في عروق المرو التي تُشكل أجسامًا متشابكة أو مبعثرةً تحتضنها صخور واقتحامات بركـانية متحولة (سيليسية وكلوريتية) كما في مهد الدهب والأمار حيث يمتاز التمعدن بالنسبة العالية لمكونات الذهب تتضح في التركيز الملحوظ لحبيبات الذهب الحر في معادن الكبريتيد والكلوريت والمرو ، وكذلك في الوفرة النسبية لمعادن التلوريد الحاملة للذهب والفضة .

٤ - تمعـدن الذهب المصاحب للصخور البلوتونية المعقدة كما في الصُّخيبرات وظلم وبعاري وجبل غدارة والـذي يمتـاز بالصلة الـوثيقـة بين الـذهب ومعادن البيريت والأرسينوبيريت ، وبنُدرةٍ عامةٍ لكبريتيد المعادن الأساسية ، وكذلك بالنضوب الواضح لمعادن التلوريد الحاملة للذهب .

وقـد أدت هذه الـدراسـات التمعـدنية مع التحـريات الجيولوجية والجيوكيميائية إلى إعادة تعريف أهداف الاستكشـاف لتمعـدن الـذهب في منطقة الدرع العربي السعودي ، وإلى إعادة دراسة مواقع الذهب المعروفة والمناجم القديمة الصغيرة الحجم تبعًا للتحسينات الحديثة في تقنية استخلاص الذهب عن طريق الغسل الرذاذي لأكوام الخام بمحلول السيانيد .