J KAU: Earth Sci., vol. 4, pp. 31-44 (1411 A.H./1991 A.D.)

Pb and Sr Isotopic Study of Mineralization at Mahd Adh Dhahab and Nuqrah, Arabian Shield

S.O. BAQABAS, H.D. HAKIM and A.H. HASHAD
Faculty of Earth Sciences, King Abdulaziz University
Jeddah, Saudi Arabia

ABSTRACT. Lead extracted from 5 samples of galena from the Au-Ag-base metal vein deposit of Mahd adh Dhahab shows a tightly clustered isotopic composition with an average two-stage Pb-Pb model age of 685 Ma. Use of the Tatsumoto group of constants yields an average age of 766 Ma. A minimum age of 769 ± 5 had previously been established by U-Pb dating of zircon separated from the Ramram granite intruding the Mahd Group, which hosts the mineralization. The obtained Pb-Pb dates are, however, older than a Rb-Sr isochron date of 645 ± 19 Ma obtained on a porphyritic rhyolite plug which also intrudes the Mahd Group. This relationship ascertains the noninvolvement of the rhyolite in the ore formation. With the exception of the Mahd adh Dhahab deposit, all dated vein-type deposits in the Shield have Pb-Pb dates that range between 550 and 450 Ma.

Lead extracted from 3 samples of the stratiform massive sulfide deposit of An Nuqrah prospect also has a uniform isotopic composition similar to that of Mahd adh Dhahab. It yields an average Pb-Pb model date of 685 Ma, with a possibility of being too young by 30-50 Ma. A Rb/Sr isochron age on Asfar granite batholith emplaced into Hulayfah Group rocks hosting the mineralization also gave a 685 Ma date. The deformation effects of the batholith on the ore minerals implies that the granite intrusion occurred shortly after the deposition of the Hulayfah Group volcanosedimentary rocks, and their contemporaneous massive sulfides. Common lead ages obtained are similar to ages obtained previously on other massive sulfide deposits of the Arabian Shield.

Application of the plumbotectonics model indicates evolution of mineralization in both areas within an island arc environment. However, the similarity of Pb isotope compositions between An-Nuqrah and Mahd adh Dhahab does suggest that the source regions of lead in the two areas have remarkably similar isotopic composition.

Introduction

The objectives of this paper are (1) to report Pb isotopic measurements and calculate model ages for sulfide deposits in the Mahd Adh Dhahab mine and the An Nuqrah prospect in Saudi Arabia, and compare the results with previous data (Delevaux *et al.* 1967, Stacey *et al.* 1980, Bokhari and Kramers 1982), (2) to establish age relations between mineralization and enclosing country rocks as determined by the Rb-Sr whole rock method, and (3) to define the probable source material of lead in the two deposits. Detailed microscopic studies of the dated sulfides and country rocks have also been undertaken.

The common Pb dating method depends on certain assumptions concerning the age of the Earth, the heterogeneity of the mantle and the stages through which the mineral deposit has been evolved. The combination of certain assumptions constitutes a model used for age dating. In this study, lead isotopic dates were calculated according to the two-stage model of Stacey and Kramers (1975). Details of assumptions upon which this model is founded are discussed in Franklin *et al.* (1983), Faure (1986) and Baqabas (1989). The values used as constants for the age of the Earth, the time of formation of the proto-crust material, and the U and Pb isotopic ratios at that time are shown in Table 1.

TABLE 1. Ratios and constants used in Pb isotopic age dating method.

Ratio and constants	Definition	Value	Ref.
$a_o = {}^{206}Pb/{}^{204}Pb$	Primeval lead as obtained from Canyon Diablo Troilite	9.307	5
$b_o = {}^{207}Pb/{}^{204}Pb$		10.294	5
$c_o = {}^{208}Pb/{}^{204}Pb$		29.475	5
$\lambda 1$	decay constant of ${}^{238}U$	0.155125×10^{-9}	1
$\lambda 2$	decay constant of ${}^{235}U$	0.98485×10^{-9}	1
$\lambda 3$	decay constant of ${}^{232}Th$	0.049475×10^{-9}	2
T	age of Earth	4.570×10^9	3
		4.509×10^9	4
μ	present day ${}^{238}U/{}^{204}Pb$		

References: 1. Jaffey *et al.* 1971; 2. LeRoux and Glendenin 1963; 3. Stacey and Kramers 1975; 4. Cumming and Richards 1975; 5. Tatsumoto *et al.* 1973.

Previous works by Stacey *et al.* (1980) show significant differences in Pb isotopic abundances among sulfide deposits of the Arabian Shield. These differences are more dependent on geographic location than on mode of occurrence (massive or vein type) as might be expected. Sulfides of the central and western part of the Shield yield Pb isotopes that are on the average less radiogenic by about 0.8% in the ${}^{208}Pb/{}^{204}Pb$ ratios and about 0.3% in the ${}^{207}Pb/{}^{204}Pb$ ratios at a given ${}^{206}Pb/{}^{204}Pb$ value than corresponding types in the eastern part of the Shield. This finding was among the earliest factual notations that the eastern part of the Shield has a different geotectonic setting from that in the central and western parts being underlain by Precambrian basement rocks as old as about 2100 Ma. This study is oriented towards finding any significant difference in age or Pb isotopic composition among sulfides of different origin.

Analytical Techniques

This paper reports the first Pb isotopic measurements obtained from the Faculty of Earth Sciences (FES) geochronology laboratory. Details of the Pb extraction and purification technique are given by Baqabas (1989) and are slightly modified from Barnes *et al.* (1973). Pb is extracted by dissolving the sulfide sample in concentrated nitric acid, filtering, adding thioacetamite to the filtrate, precipitating PbS by heating, and finally purifying this sulfide from coprecipitated CuS by passing the solution in an anion exchange resin stacked in a 7 cm long-0.25 cm radius column. Details of Sr extraction and purification technique in this laboratory have been described in Radain *et al.* (1984).

The mass spectrometric measurements were made on a VG Isomass-54E and replicate analyses of NBS-981 gave the data presented in Table 2. The determined values are only slightly lower than the recommended values (Catanzaro *et al.* 1968) of the order of 0.2-0.3 percent. The conversion factors to normalize our values to the absolute values generally used are given in the same Table.

TABLE 2. Analyses for NBS-981 Pb-isotopic standard.

Number of run	$\frac{^{208}Pb}{^{206}Pb}$	standard error	$\frac{^{207}Pb}{^{206}Pb}$	standard error	$\frac{^{206}Pb}{^{204}Pb}$	standard error	$\frac{^{207}Pb}{^{204}Pb}$	standard error	$\frac{^{208}Pb}{^{204}Pb}$	standard error
1	2.16010	.187	0.91286	.081	16.96286	0.201	15.44098	0.106	36.57319	.155
2	2.17128	.217	0.91584	.135	16.91249	0.087	15.50464	0.190	36.79718	.214
3	2.16594	.239	0.91218	.088	17.08246	2.10	15.60472	2.20	37.10288	2.326
Average	2.16582		0.9136		16.9859		15.5168		36.8244	
Standard deviation	0.0056		0.0019		0.0873		0.0825		0.2659	
% Precision	0.516		0.425		1.028		1.063		1.44	
Recommended value	2.1689		0.9149		16.931		15.491		36.721	
Conversion factor	1.0014		1.0014		0.9968		0.9983		0.9972	

Replicate measurements on the NBS-987 Sr standard are shown in Table 3 from which precision estimates were calculated. A correction for mass spectrometric fractionation was made to $^{87}Sr / ^{86}Sr$ ratios based on $^{86}Sr/^{88}Sr = 0.1194$. The accuracy of our results can be judged from comparison of the mean of our $^{87}Sr/^{86}Sr$ ratios with the recommended value of 0.7102 given by NBS.

Mahd Adh Dhahab Mining District

Geology and Mineralization

The Mahd Adh Dhahab area hosts epithermal Au-Ag base metal veins in a sequence of bimodal volcanic and volcanoclastic rocks. Details on the geology of this area are given by Hakim (1978), Hilpert *et al.* (1984), Huckerby *et al.* (1983), Kemp *et al.*

TABLE 3. Analyses for NBS-987 Sr-isotopic standard.

Number of run	$^{86}Sr/^{88}Sr$	standard error	$^{87}Sr/^{86}Sr$	standard error	$^{84}Sr/^{88}Sr$	standard error
1	0.120417	0.202	0.710150	0.138	0.006755	0.370
2	0.119561	0.228	0.710111	0.104	0.006759	0.273
3	0.119544	0.357	0.710249	0.020	0.006759	0.125
4	0.120597	0.151	0.710241	0.126	0.006756	0.331
5	0.120569	0.051	0.710202	0.023	0.006769	0.153
6	0.120332	0.081	0.710194	0.021	0.006767	0.123
7	0.119740	0.291	0.710190	0.023	0.006767	0.115
Average	0.12011		0.71019		0.006761	
Standard deviation	4.73×10^{-4}		4.84×10^{-5}		5.79×10^{-6}	
% Precision	0.788		0.0136		0.001713	
Recommended value	0.1194		0.71023		0.00675	

(1982), and Afifi (1989). This sequence, from old to young, includes a succession of andesite, lower agglomerate, lower tuff, upper agglomerate and upper rhyolitic tuff. The sequence is intruded by a porphyritic rhyolite plug and intersected by several sets of faults. Details about mineralization are given by Doebrich and Leanderson (1984), Hakim (1978), Luce *et al.* (1975, 1979), Rye *et al.* (1982), Worl (1979) and Afifi (1989, 1990). The mineralization occurs in chloritic quartz veins that fill several generations of fractures.

Polished sections revealed pyrite, sphalerite, chalcopyrite, chalcocite, neodiginite, covellite, bornite, and galena together with some tellurides such as hessite, petzite, altaite and tellurobismuth, in addition to electrum. Some silver sulfosalts are also present. Inclusions of hematite were observed, and interpreted as indicators of an oxidizing environment in the early stage of ore deposition. However, Sabir (1980) and Afifi (1990) also reported magnetite, and the latter inferred periodic reducing conditions. The minerals have been subjected to deformation and metamorphism both during formation and after deposition. Among the features suggesting these events are: elongation of chalcopyrite and sphalerite crystals, fracturing and brecciation of pyrite, anomalous anisotropism in pyrite, development of deformation twins in sphalerite and chalcopyrite, development of emulsion texture of chalcopyrite in sphalerite (chalcopyrite disease). Under the effect of heat fine-grained chalcopyrite inclusions clustered together forming blebs of different sizes and shapes randomly distributed within the sphalerite. Recrystallization of pyrite and development of pyrite porphyroblasts is also common. Details of these features are given by Hakim and El Mahdy (in preparation).

Geochronology

Because of the mobility of Rb and Sr during diagenesis and low grade metamorphism, all rocks comprising the Mahd Group are unsuitable for Rb-Sr age dating (Calvez and Kemp 1982). A possible exception is the porphyritic rhyolite intrusion, the age of which will be a minimum limit for the age of the Mahd Group. A four-point isochron age of 645 ± 19 Ma with an initial $^{87}Sr/^{86}Sr$ of 0.7048 ± 0.0003 was obtained for least altered samples of this rhyolite (Fig. 1) based on the data presented in Table

4. This date is lower than a U-Pb zircon age of 769 ± 5 Ma obtained on the Ramram complex (Calvez and Kemp 1982) which also intrudes the Mahd Group. The anomalously young Rb-Sr age is attributed to the possible effects of Rb addition during K metasomatism (Hakim 1978) and/or Sr loss during hydrothermal alteration (Afifi 1989). Most of the plug is altered and samples excluded from dating after petrographic examination show variable degrees of chloritization and silicification. It is thus appropriate to consider the 645 ± 19 Ma Rb-Sr date a minimum age for the plug while the 769 Ma age of Ramram complex retains its significance as a minimum age for the Mahd Group.

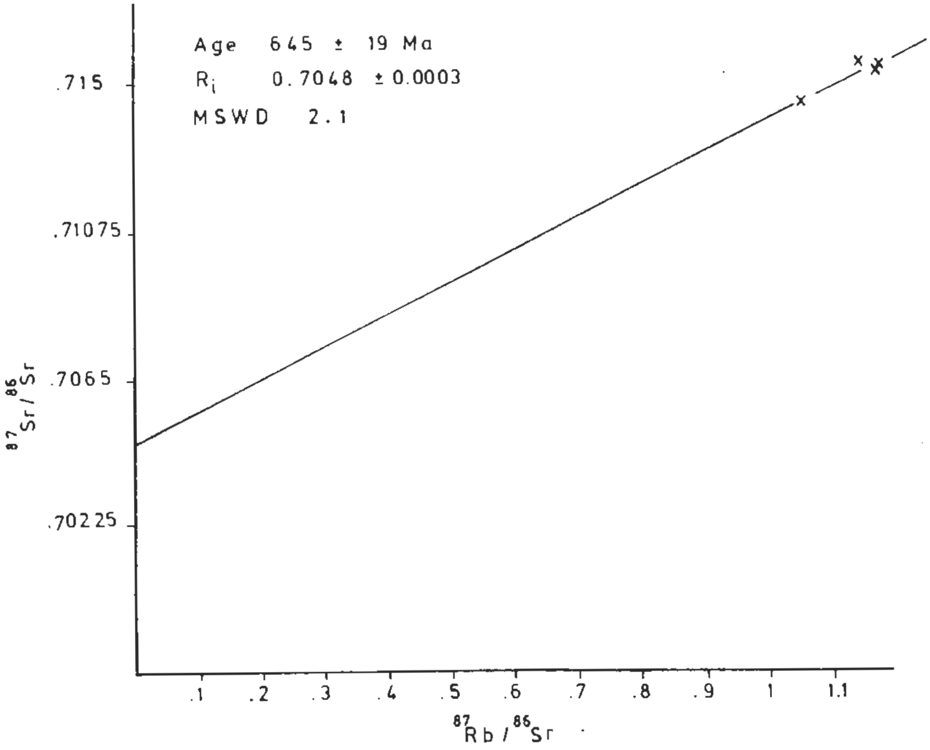

Fig. 1. Isochron plot for Mahd adh Dhahab porphyritic rhyolite.

Table 4. Rb and Sr concentrations and Sr isotopic composition of Mahd adh Dhahab porphyritic rhyolite.

Sample	Rb	Sr	Rb/Sr	$^{87}Sr/^{86}Sr$
1	13.9	34.4	0.40448 ± 0.003	0.71550 ± 0.029
2	13.51	34.2	0.39453 ± 0.012	0.71571 ± 0.112
3	12.6	34.7	0.36396 ± 0.0046	0.71450 ± 0.017
4	13.2	32.6	0.40540 ± 0.0025	0.71561 ± 0.280

Most previous workers (Luce *et al.* 1979, Huckerby 1984, Hilpert *et al.* 1984, and Doebrich and Leanderson 1984) had concluded that rhyolite intrusion caused the mineralization. However, the presence of mineralized quartz veins in the porphyritic rhyolite suggests that the latter predated the mineralization as previously inferred by Worl (1979) and Afifi (1989, 1990).

Isotopic data on lead extracted from galena separated from five sulfide samples, all collected from the southern ore zone (SOZ) of the Mahd Adh Dhahab mine, are presented in Table 5. The data show a simple and uniform lead isotopic composition. They also agree, to a great extent with the data of Stacey *et al.* (1980) shown for comparison. Such comparison is important in checking the accuracy achieved in the FES geochronology laboratory in its first Pb isotopic study.

TABLE 5. Isotopic composition of lead extracted from Mahd adh Dhahab sulfides.

Sample	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	ages by Ma		Reference
				a	b	
V 1	17.398	15.487	36.995	691	750	1
V 2	17.421	15.503	37.081	704	757	1
V 3	17.376	15.453	36.903	678	733	1
V 6	17.403	15.462	36.950	694	725	1
M 3	17.374	15.453	36.887	677	733	1
87520	17.402	15.477	36.957	681		2
87223	17.405	15.474	36.978	673		2
DDB-11	17.406	15.477	36.959	688		2
69115	17.407	15.485	36.975	693		2
64026	17.408	15.471	36.917	665		2
R-81-A	17.381	15.423	36.953	692		3

a – ages according to Stacey and Kramers model (1975) b – ages according to Tatsumoto Table (1973)
Ref. (1) This study; (2) Stacey *et al.* 1980; (3) Rye *et al.* 1982.

Applying Stacey and Kramers (1975) common lead model, the ages obtained range between 677 and 704 Ma with an average of 689 Ma. This model has been selected on the basis of a calibration study made by Stacey *et al.* (1980) on the applicability of different common lead dating models in Arabian Shield settings. It has also been selected to conform with the increasing evidence on the role of plate tectonics in the evolution of the Shield. The mine falls in the Hijaz terrane which is underlain by rocks of an island arc setting (Calvez *et al.* 1984, Stoeser 1986). In such a setting, recycling of crustal material during subduction is likely and it is inappropriate to assume a single stage model for the sulfide mineralization under such complex conditions. Stacey *et al.* (1980) concluded from their calibration study that "the Stacey and Kramers model apparently gives reasonable age estimates in the Saudi Arabian setting, yielding ages for effectively single stage leads that may be too young by no more than 30-50 m.y.". The reason for this conclusion is obviously the relatively short period which must have elapsed between the formation of the later subducted oceanic crust and the mineralization. This time may be too short to generate sufficient radiogenic lead to significantly contaminate the mineralizing fluids. The extremely uniform lead isotopic composition of the Mahd Adh Dhahab galenas supports the validity of using the Stacey and Kramers (1975) model. According to the plumbotectonic model of Doe and Zartman (1979), all the studied samples fall near the mantle average growth curve (Fig. 2a) which is consistant with the suggested island arc setting, and homogeneity of the source.

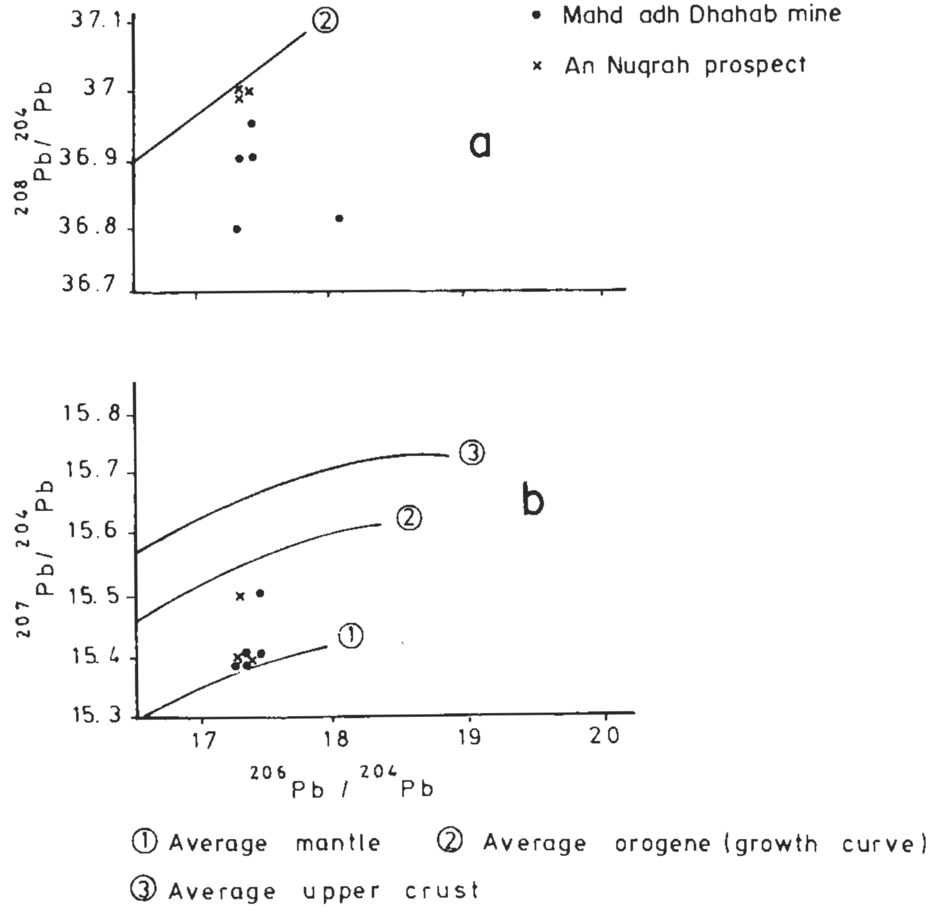

FIG. 2. Application of plumbotectonic model diagrams of Doe and Zartman 1979, to Mahd adh Dhahab mine and An Nuqrah prospect.

Applying the constants estimated by Tatsumoto (1973) to calculate lead model ages using the interpolation provided in Doe and Stacey (1974), the data in Table 5 provide ages that range between 725 and 757 Ma with an average of 740 Ma. These ages are older by about 50 Ma than those calculated by the Stacey and Kramers model and may account for the 30-50 Ma discrepancies found by Stacey *et al.* (1980).

All the model lead ages estimated in this study for the Mahd mineralization (681-740 Ma) point to a younger age compared to the minimum age of the Mahd Group (769 ± 5 Ma). The discrepancy is at least 25 Ma, and may reach some 80 Ma which indicates that mineralization occurred long after deposition of the volcanic volcanoclastic sequence. In fact, Afifi (1990) provides evidence that the mineralization occurred after the initial folding and metamorphism of the Mahd Group.

An Nuqrah Prospect

Geology and Mineralization

An Nuqrah area hosts massive sulfide mineralization in a sequence of intermediate to acidic volcanic and volcanoclastic rocks which alternate with thick beds of dolostone. The whole sequence belongs to the Hulayfah Group which rests with unconformity over an ophiolitic complex (Delfour 1977). The rocks were folded during Ar Ruqabah orogeny and were subsequently intruded by the Asfar granitoid batholith. The Hulayfah group is divided into the lower Afna formation and upper Nuqrah formation, which hosts the mineralization. Details about the geology and petrographic description of different members of the two formations are given by Baqabas (1989) and Delfour (1977).

Mineralization at An Nuqrah occur in the form of lenses of different shapes, sizes and thickness. In the prospect area, mineralization is hosted by the Nuqrah formation, divided into units of chloritic felsic tuff, felsic tuff, chloritite, dolomitic chloritite and dolostone. The mineralized lenses are mostly along the contact between mafic volcanics in the hanging wall and chloritized rhyolitic volcanics in the footwall. The mineralized lenses are separated laterally by barren beds of dolostone and tuffs. Deformation appears to have affected all the sulfide lenses.

Ore minerals identified at An-Nuqrah include sphalerite, galena, chalcopyrite and pyrite, with minor altaite, hessite, calaverite, polybasite, acanthite, covellite, arsenopyrite, marcasite, pyrrhotite, bournonite and gold. The presence of framboidal pyrite indicates a low temperature, stagnant, submarine, biologically influenced environments during the formation of the deposit (Guilbert and Park, 1986). The mineralization appears to have been affected by several stages of metamorphism and deformation during and after its formation. This is suggested by sinuous, tightly folded and deformed bands of sphalerite, chalcopyrite and galena; and by emulsion texture of chalcopyrite in sphalerite rather than the regular pattern of exsolution. Due to annealing, the chalcopyrite lamellea clustered together forming droplets or irregular blebs randomly distributed within sphalerite. The ductile sulfide are strongly elongated into parallel bands of chalcopyrite, galena and sphalerite. In few cases pyrite shows brecciation and pullapart texture in galena is common. More details on the ore microscopy of the mineralization is given by Baqabas (1989).

Geochronology

Delfour (1977) estimated an average K-Ar age of 740 Ma based on seven K-Ar whole rock determinations on samples of dacite and andesite collected from Jabal at Tin, the southern extension of Jabal 'Afinah. This date was inferred as the time of eruption of intermediate lava in the lower Afna formation. He also dated five samples from quartz keratophyre flows which occur stratigraphically above the sulfide mineralization using K-Ar whole rock method. These samples gave dates in the range 507-564 Ma, with an isochron at 567 Ma, which dates the last important thermal event.

No previous Rb-Sr isotopic dating has been carried in An-Nuqrah area. In this study, six samples from Asfar granitic pluton define a whole rock isochron age of 685 ± 46 Ma, with an initial ^{86}Sr/^{87}Sr ratio of 0.7033 ± 0.0006 and MSWD value of 1.60 (Fig. 3) based on data of Table 6. This age is much older than the K-Ar whole rock dates and sets a minimum age for the Nuqrah formation. The large uncertainty in the age is possibly related to remobilization of Rb and/or Sr during the greenschist metamorphism, to which all rocks in the area were subjected. The age agrees, however, within the reported limits of error, with the Rb-Sr age of the Mine Hill rhyolite at Mahd Adh Dhahab and suggests a possible regional metamorphic event that caused a regional resetting of the Rb-Sr clocks in this part of the Shield.

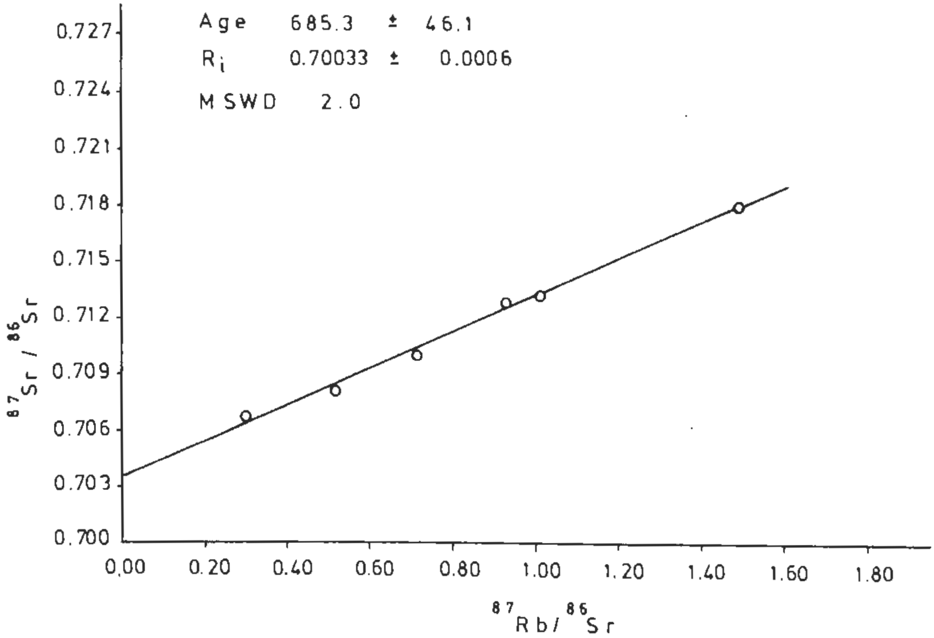

FIG. 3. Isochron plot for Asfar granite.

TABLE 6. Rb and Sr concentrations and Sr isotopic composition of post-Hulayfah Asfar granite.

Sample	Rb	Sr	Rb / Sr	^{87}Sr / ^{86}Sr
1	30.3	168.6	0.1799 ± 0.0004	0.7076 ± 0.0001
2	27.4	110.6	0.2481 ± 0.0029	0.7098 ± 0.0011
3	20.2	63.0	0.3214 ± 0.0067	0.7128 ± 0.0016
4	15.3	164.6	0.1046 ± 0.0036	0.7068 ± 0.0010
5	21.2	60.6	0.3497 ± 0.0056	0.7128 ± 0.0007
6	101.1	195.7	0.5167 ± 0.0012	0.7175 ± 0.0008

The age of the Asfar granite falls within an episode of widespread arc magmatism. Stoeser (1986) assigned an age range of 770-640 Ma for this event based on a considerable number of isotopic dates from essentially intermediate plutonic rocks. The limited number of these dates put some constraints on the origin of these rocks and their place in the early evolutionary history of the Shield.

Three sulfide samples were selected from a drill-core provided by Petromine-Grangs Mining Company. Due to difficulty of separating galena, lead extraction from the whole sulfide was performed according to a technique described in Baqabas (1989). The Pb isotopic compositions of the three samples are listed in Table 7 together with model ages calculated according to the model of Stacey and Kramers (1975) and Tatsumoto (1973). The Stacey and Kramers model ages range between 678 and 689 Ma averaging 685 Ma and Tatsumoto model ages range between 761 and 773 Ma, averaging 766 Ma. The discrepancy between the two model ages is somewhat higher than the 30-50 Ma anticipated from the calibration study of Stacey *et al.* (1980). The average ages are however remarkably similar to ages obtained on Mahd Adh Dhahab mineralization.

TABLE 7. Lead isotopic analysis of An-Nuqrah deposit.

Sample	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	age by Ma		Ref.
				a	b	
N 2	17.394	15.500	37.087	689	773	1
N 3	17.392	15.486	37.090	688	761	1
N 4	17.375	15.480	37.067	678	765	1
Average				685	766	1
	17.406	15.476	37.039	680		2

a, b as in Table 5. References 1 and 2 as in Table 5.

The similarity of lead isotopic data from Mahd Adh Dhahab and Nuqrah (Fig. 2a) indicates that original sources of the lead in the arc terranes of western Arabian Shield hosting both prospects had similar lead isotopic composition but no genetic relationship is clear. The uniformity of lead isotopic composition in An-Nuqrah prospect supports the validity of applying Stacey and Kramers (1975) model.

Since the mineralization in this area is strata-bound, its estimated model ages of (685-766 Ma) should be very close to the age of the Nuqrah formation which accords with the Rb-Sr age of the intruding Asfar granitic batholith (685 ± 46 Ma). The deformational features observed in the sulfide polished sections may have been caused by the granitic intrusion.

Discussion and Conclusion

The lead model 689 Ma average age for Mahd Adh Dhahab mineralization is the oldest and perhaps the only vein type deposit age that is older than 600 Ma. All other vein deposits in the Arabian Sheild, regardless of their geographic locations, fall mostly between 550 and 450 Ma (Stacey *et al.* 1980). Much of these vein mineralizations coincide with the northwesterly trending Najd fault system which is estimated to have occurred in the waning stages of the Pan African "orogeny", approximately 550 Ma ago.

The age difference between Mahd Adh Dhahab mineralization and all other vein-type mineralization in the Shield is supplemented by another important difference: it is uniform in its Pb isotopic composition, contrary to most vein type deposits that show wider ranges in their Pb isotopic ratios.

Table 8 illustrates the narrow range of ages obtained on Nuqrah compared to some ages previously obtained on massive sulfide deposits in the Arabian Shield such as Jabal Sayid and Wadi Shwas (Stacey *et al.* 1980) and Al Khunnaigiyah (Bokhari and Kramers 1982). All these deposits are hosted by volcanic and volcanoclastic rocks which belong to Halaban or the equivalent Hulayfah Group, estimated to have been formed between 800 and 650 Ma ago (Calvez *et al.* 1984) i.e. same age range of mineralization. This confirms their syngenetic origin.

TABLE 8. Model lead ages of massive deposits in the Arabian Shield.

Area	Age Ma		
	1	2	3
An Nuqrah	685	680	
Al Khunaigiyah			728 810
Jabal Sayid		720	718 746
Wadi Shwas		695	670 720

1) This work. 2) Stacey *et al.* (1980) 3) Bokhari and Kramers (1982).

The Pb isotope data of An Nuqrah and Mahd Adh Dhahab as well as previous data from the western Shield plot above mantle growth curve, and below orogene growth cruve of Doe and Zartman (1979) plumbotectonic model (Fig. 2b). This pattern is similar to sulfide deposits in other parts of the world that are thought to have evolved in ensimatic or primitive island arc environments. On the other hand, data on massive sulfides and vein deposits in the eastern Shield fall on or slightly above ^{208}Pb/^{204}Pb orogene growth curve (Stacey *et al.* 1980) indicating the presence of a continental basement in this region.

It is concluded that precision and accuracy achieved in this work is quite satisfactory to continue applying this method in the FES geochronology laboratory for dating of sulfide mineralization in the Shield. These studies are necessary to check the apparent disconcordance between ages of massive-type volcanogenic deposits (750-650 Ma), and vein-type deposits (550-450 Ma), with the possible exception of Mahd Adh Dhahab deposit which, though vein-type, formed 685 Ma ago. The low radiogenic Pb content of sulfides from the western part of the Shield supports Bokhary and Kramers (1981) Sr and Nd isotopic studies in suggesting an ensimatic island arc model for the evolution of this part of the Shield.

Acknowledgement

We are grateful to O. El Mahdy for his assistance and advice on ore microscopy. Prof. B. Leake read the manuscript and made valuable suggestions. Two anonymous reviewers provided critical and constructive comments which greatly improved the final manuscript. We also appreciate the enthusiastic assistance of S. Ali on Pb isotopic analysis.

References

Afifi, A.M. (1990) *Environments of gold telluride mineralization in the Mahd Adh Dhahab district, Arabian Shield,* PhD dissertation, Ann Arbor, Univ. of Michigan, 280 p.

Afifi, A.M. (1989) Geology of the Mahd Adh Dhahab district, Kingdom of Saudi Arabia: *Saudi Arabia DGMR Open-File Report USGS-OF-***09**-2, 49 p.

Baqabas, S.O. (1989) *Lead isotope study of some sulfide mineralization in the Arabian Shield,* M.Sc. thesis, Faculty of Eath Sciences, King Abdulaziz University, Jeddah, 134 p.

Barnes, I.L., Murphy, T.J., Gramlich, J.W. and **Shields, W.R.** (1973) Lead separation by anodic deposition and isotopic ratio mass spectrometry of microgramme and smaller samples, *Analytical Chemistry* **45** (11): 1881-1884.

Bokhari, F.Y. and **Kramers J.D.** (1981) Island arc charater and late Precambrian age of volcanics at Wadi Shwas, Hijaz, Saudi Arabia: geochemical and Sr and Nd isotopic evidence, *Earth and Planetary Science Letters* **54:** 409-422.

Bokhari, F.Y. and **Kramers, J.D.** (1982) Lead isotope data from massive sulfide deposits in the Saudi Arabian Shield, *Econ. Geol.* **77:** 1766-1769.

Calvez, J.Y. and **Kemp, J.** (1982) Geochronological investigations in the Mahd adh Dhahab quadrangle: *BRGM-TR-***02**-*5,* 41 p.

Calvez, J.Y., Alsac, C., Delfour, J., Kemp, J. and **Pellaton, C.** (1984) Geological evolution of the western central and eastern parts of the northern Precambrian Shield, Kingdom of Saudi Arabia, *Bull. Fac. Earth Sci., King Abdulaziz University* **6:** 23-48.

Catanzaro, E.J., Murphy, T.J., Shields, W.R. and **Garner, E.J.** (1968) Absolute isotopic abundance ratios of common, equal-atom and radiogenic lead isotope standards: *U.S. NBS, Jour. Res., Sec. A, Phys. Chemistry* **72A:** 261-267.

Cumming, G.L. and **Richards, J.R.** (1975) Ore lead isotope ratios in a continuously changing earth: *Earth Planet. Sci. Lett.* **28:** 155-171.

Delevaux, M.H., Doe, B.R. and **Brown, G.G.** (1967) Preliminary lead isotope investigations of brine from the Red Sea, galena from the Kingdom of Saudi Arabia and galena from United Arab Republic (Egypt), *Earth Planet. Sci. Lett.* **3:** 139-144.

Delfour, J. (1977) *Geologic map of Nuqrah quadrangle, sheet 25E,* Kingdom of Saudi Arabia, DGMR map **GM-28.**

Doe, B.R. and **Stacey, J.S.** (1974) The application of lead isotope to the problem of ore genesis and ore prospect evaluation: a review, *Eco. Geol.* **69:** 757-776.

Doe, B.R. and **Zartman, R.E.** (1979) Plumbotectonics I, the Phanerozoic, *in:* **Barnes, H. (ed.)** *Geochemistry of Hydrothermal Ore Deposits,* 2nd ed. John Wiley and Sons, New York, pp. 22-70.

Doebrich, J.L. and **Leanderson, J.P.** (1984) Geology and hydrothermal alteration of the Mahd adh Dhahab epithermal precious metal deposits, Kingdom of Saudi Arabia, *USGS-OF-***04**-32.

Faure, G. (1986) *Principles of Isotope Geology,* 2nd ed. John Wiley and Sons, New York.

Franklin, J.M., Roscoe, S.M., Loveridge, W.D. and **Sangster, D.F.** (1983) Lead isotope studies in superior and southern provinces, *Geol. Surv. Canada Bull.* **No. 351:** 3-12.

Guilbert, J.M. and **Park, C.F.** (1986) *The geology of ore deposits,* Freeman and Company, p. 985.

Hakim, H. (1978) *Geology and the genesis of gold-silver veins at Mahd adh Dhahab,* Ph.D. thesis faculty of graduate studies, the University of Western Ontario.

Hilpert, L.S., Robert, R.J. and **Dirom, G.A.** **(1984)** Geology of Mine Hill and the underground working Mahd adh Dhahab Mine, Kingdom of Saudi Arabia, *USGS-TR-***03**-2, 36 p.

Huckerby, J.A., Moore, J., McM, and **Davis, G.R.** (1983) Tectonic control of mineralization at Mahd adh Dhahab gold mine, western Saudi Arabia. *Tran. Inst. Min. Metall* (sect. B: Appl. Earth Sci.) p. 92.

Jaffey, A.H., Flynn, K.F., Glendenin, L.E., Bentley, W.E. and **Essling, A.M.** (1971) Precision measurement of half-lives and specific activities of ^{235}U and ^{238}U, *Physics Review,* **4:** 1988.

Kemp, J., Gros, Y. and **Prian, J.P.** (1982) *Geologic map of Mahd adh Dhahab quadrangle, sheet 23E,* Kingdom of Saudi Arabia, map **GM-64 A,** 1:250000, 39 p.

LeRoux, L.J. and **Glendenin, L.E.** (1963) Half-life of thorium 232, *Proc. Nat. Con. Nucl. Energy,* Pretoria, South Africa.

Luce, R.W., Bagdady, A.Y. and **Roberts, R.J.** (1975) Geology and ore deposits of the Mahd adh Dhahab district, Kingdom of Saudi Arabia, *USGS-OF-***76**-865.

Luce, R.W., O'Nell, J.R. and **Rye, R.O.** (1979) Mahd adh Dhahab, Precambrian epithermal gold deposit, Kingdom of Saudi Arabia, *USGS-OF*-**79**-1190.

Radain, A.A., Abdel-Monem, A.A. and **Gazzaz, M.A.** (1984) Rb-Sr dating and geochemistry of Jabal Bitran Granite, Idsas area, Saudi Arabia, *Bull. Fac. Earth Sci., King Abdulaziz University* **6**: 211-221.

Rye, R.O., Hall, W.E., Cunningham, C.G., Czamanske, G.K., Afifi, A.M. and **Stacey, J.S.** (1982) Preliminary mineralogic, fluid inclusion, and stable isotope study of the Mahd adh Dhahab gold mine: *USGS-OF*-**03**-4, 26 p.

Sabir, H. (1980) Precambrian polymetallic sulfide deposits in Saudi Araiba and their metallogenic significance, *Inst. Appl. Geol. Bull.* **3** (2): 83-92.

Stacey, J.S., Doe, B.R., Roberts, R.J., Delvaux, M.H. and **Gramlich, J.W.** (1980) A lead isotope study of mineralization in the Saudi Arabian Shield, *Contrib. mineral. Petr.* **74**: 175-188.

Stacey, J.S. and **Kramers, J.D.** (1975) Approximation of terrestrial lead isotope evolution by a two stage model, *Earth and Plan. Sci. Lett.* **26**: 207-221.

Stoeser, D.B. (1986) Distribution and tectonic setting of plutonic rocks of the Arabian Shield, *J. Afr. Earth Sci.* **4**: 21-46.

Tatsumoto, M. (1973) Time differences in the formation of meteorites as determined from the ratio of lead-207 to lead-206, *Science* **180**: 1279-1283.

Worl, R.G. (1979) Ore controls at the Mahd adh Dhahab gold mine, Kingdom of Saudi Arabia, in Evolution and mineralization of the Arabian Shield, *King Abdulaziz Univ. Inst. Appl. Geol. Bull.* **3** (2): 93-106.

دراسة نظائرية للرصاص والإسترنشيوم في تمعدنات مهد الذهب والنقرة بالدرع العربي

سالم عمر باقبص ، هاشم حكيم و أحمد حسنين حشاد
كلية علوم الأرض ، جامعة الملك عبد العزيز ، جدة ، المملكة العربية السعودية

المستخلص . يظهر الرصاص المستخلص من خمس عينات جالينا من رواسب العروق بمنطقة مهد الذهب تركيبا نظائريا شديد التشابه بمتوسط عمر ٦٨٥ مليون سنة طبقا لنموذج رصاص - رصاص ذي المرحلتين (في النشأة) . كما تعطى عمرًا متوسطا قدره ٧٦٦ مليون سنة باستخدام قيم ثوابت طاتسموتو . هذه الأعمار أقدم من عمر محقون ريوليت بورفيري يُعطي بطريقة الرابيديوم - إسترنشيوم بحوالي ٦٤٥ ± ١٩ مليون سنة . يتداخل هذا الريوليت في مجموعة المهد والتي يتداخل فيها أيضا جرانيت رمرم الذي أعطى بطريقة اليورانيوم - رصاص على زيركون مفصول منه عمرا قدره ٧٦٩ ± ٥ مليون سنة . بهذا تؤكد هذه الأعمار عدم اشتراك محقون الريوليت في عملية التمعدن ، كما تبرز نتيجة هامة وهى اختلاف عمر التمعدن بمهد الذهب (٦٨٥ مليون سنة) عن باقي أعمار رواسب العروق بالدرع العربي والتي تتراوح أعمارها بين ٤٥٠ و ٥٥٠ مليون سنة .

ويُظهر الرصاص المستخلص من ٣ عينات من الرواسب الكبريتيدية الكتلية ذات الطبيعة الطباقية في منطقة النقرة أيضا تجانسا نظائريا مماثلا للرصاص المستخلص من مهد الذهب ، ويعطى عمرا قدره ٦٨٥ مليون سنة باستخدام نموذج رصاص - رصاص ذي المرحلتين مع احتمال أن يكون هذا العمر منخفضا بمقدار ٣٠-٥٠ مليون سنة . كما يعطى جرانيت عصفر المتداخل في صخور مجموعة حليفة الحاوية للتمعدن عمرا قدره ٦٨٥ مليون سنة باستخدام طريقة الروبيديوم - إسترنشيوم . وتشير أثار التشوه الذي سببه الجرانيت على معادن الخام إلى أن التداخل حدث في أعقاب ترسب مجموعة حليفة وما تحوية من تمعدنات كبريتيدية متزامنة . وتماثل أعمار الرصاص أعمارا سبق الحصول عليها على رواسب كبريتيدية كتلية في الدرع العربي . ويتضح من تطبيق نموذج علاقة الرصاص بالبنيات الحركية أن الرصاص نشأ في المنطقتين في بيئة أقواس جزر ، كما أن تماثل التركيب النظائري بين النقرة ومهد الذهب يشير إلى أن مصدر الرصاص في المنطقتين متماثل في التركيب النظائري .