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ORIGINAL PAPER

Upper Cretaceous carbonate hosted zinc–lead–barite deposits in Northern Thrust Zone, northern Iraq: petrography and geochemistry

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Abstract Zinc–lead–barite deposits located in Lefan and Lower Banik localities of about 25 km northeast of Zakho City, Northern Iraq consist of a group of strata-bound sulfides hosted in Upper Cretaceous (Upper Campanian–Maastrichtian) dolomitic limestone. Carbonate-hosted ores contain 3.77% Zn, 2% Pb, and 5% Fe, while in lower Banik, they contain 1.5% Zn, 0.37% Pb, and 1.4% Fe. Diagenetic processes, such as dolomitization and recrystalization in addition to the type of microfacies, provided appropriate physical and chemical conditions that permitted the passage of ore-bearing fluids and participated in precipitation and ore localization. These deposits are precipitated in a platform and developed within the Foreland Thrust Belt. Ore precipitated as infill of intergranular dolomite porosity with replaced dolomite and rudist shells forming disseminated crystals that occupy intergranular pore spaces around dolomite and calcite and as infill of dissolution spaces and fractures.

Keywords Petrography · Geochemistry · Carbonate · Dolomitization · Sulfide minerals

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Introduction

Upper Cretaceous carbonate-hosted zinc–lead–barite deposits represent the Aqra–Bekhme Formation and Shiranish Formation. Mineralization in these formations was recorded at Lefan and Lower Banik localities. The global positioning system measurements of latitudes, longitudes, and elevations are fixed in Table 1. Lefan locality is situated of about 4.5 km east of Shiranish Islam village and 25 km north Zakho City, while Lower Banik is located of about 11 km east of Lefan (Fig. 1). Previously, the Aqra–Bekhme Formation was described as two independent units, but Bellen et al. (1959) considered that these two formations are often not well distinguishable in area where they are superimposed upon each other, for such cases the application of the name Aqra–Bekhme Formation is recommended. The name Aqra–Bekhme has been suggested by Buday (1980) where these intervening formations are absent (Jassim and Goff 2006). Bellen et al. (1959) described Bekhme Formation as a reef limestone complex with massive rudist, shoal reefs. Al-Rawi and Al-Hamadani (1984) also concluded that the Aqra Formation is composed of recrystallized reefal limestone deposited in shallow water. Jassim and Buday in Jassim and Goff (2006) mentioned that the Aqra and Bekhme Formations were deposited mostly in a reef/fore-reef environment. These formations have been studied by many authors from paleontologic, stratigraphic, petrographic, and geochemical points of view.

The researchers Bellen et al. (1950), Kassab (1972, 1973, 1977), Al-Shaibani (1973), Buday (1980), Hadad (1980), Youkhana and Sassakian (1986), Al-Qaim et al. (1986), and Dhannoun and Hadad (1989) are pioneer authors. Unfortunately, no author discussed the Aqra–Bekhme Formation and Shiranish Formation as host rocks

Table 1 Longitudinal, latitudinal, and elevation global positioning system (GPS) values of localities of zinc–lead–barite deposits in the Upper Cretaceous carbonate, Northern Iraq

Locality	Longitude	Latitude	Elevation (m)
Lefan	42°53′24″	37°13′40″	1,332
Lower Banik	42°59′6″	37°13′20″	1,023

for mineralization. This paper provides the first study of petrography and geochemistry of the mineralized localities in the Aqra–Bekhme Formation and Shiranish Formation. Furthermore, it expresses a further contribution to the previous studies that have been carried out on petrology and geochemistry of these formations.

Geology

Carbonate sedimentary rocks of the Aqra–Bekhme Formation and Shiranish Formation are country rocks of zinc–lead–barite deposits in Lefan and Lower Banik localities. In the Lefan locality, zone of mineralization extends of about 80 m parallel to the bedding plane and exposes on the southern limb of anticline, striking E–W, dipping of about 50° S (Fig. 1). In Lower Banik, mineralization exposes within shear zone outcrops on a steep ridge of dolomitic limestone bed striking E–W and dipping 65° S (Fig. 1). The terrain of the studied areas is generally rugged. Outcrop of mineralization is indicated by weak impregnation of smithsonite that often associates gossan and limonite.

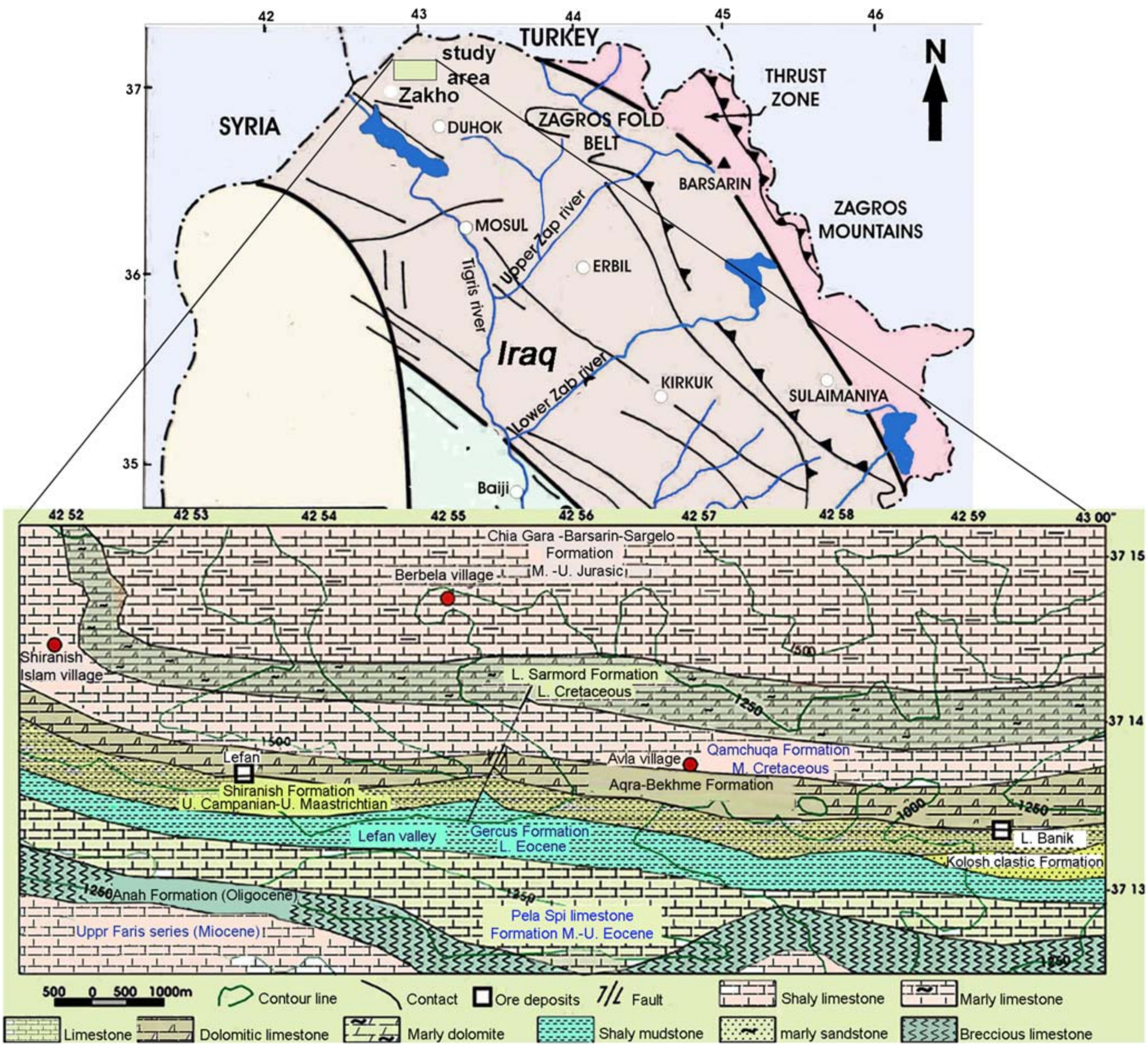

Fig. 1 Location and geological map of the Zn–Pb–barite deposits are showing mineralized zones in Lefan and Lower Banik

Table 2 Mineralogical composition of the Upper Cretaceous carbonate-hosted zinc–lead–barite, Northern Iraq

Formation	Locality	n	Calcite%			Dolomite%			Sd%	Qtz%	Sph%	Ga%	Ba%
			Min.	Av.	Max.	Min.	Av.	Max.	Av.				
Aqra–Bekhme	Lefan	15	32	68	92	4	20	51	2	2	4.9	1.2	1
	L. B.	20	16	48	73	16	41	83	3	2	2	0.6	2
Shiranish	Lefan	9	36	71	90	1	23	62	2	1	2	0.4	2

Sd siderite; *Qtz* quartz; *Sph* sphalerite; *Ga* galena; *Ba* barite; *L. B.* Lower Banik

Sulfides replaced carbonate rocks and generally occur as disseminated ore. Barites sometimes associate with sulfide ore, but often occur as independent mineral in veins. The Aqra–Bekhme Formation (Upper Cammpanian–Maastrichtian) mainly consists of dolomitic limestone and represents a reef facies deposited in shallow water (Buday 1980), which is conformably emplaced over Qamchuqa Formation (Albian–Barremian; Bellen et al. 1959). The deep basinal facies of Shiranish Formation (Upper Cammpanian–Maastrichtian), which generally consists of limestone, appear to be emplaced conformably over shoal facies of the Aqra–Bekhme Formation (Fig. 1). Sediments of the Latest Maastrichtian age are absent (Kassab 1972 and 1973). Shiranish Formation is the youngest formation in the Mesozoic (Buday and Jassim 1987) and emplaces on the top of the stratigraphic sequence. The upper surface of the Shiranish Formation seems erosional and unconformably separate between Upper Cretaceous and Tertiary.

Material and methods

Two mineralized areas were studied, one of them, in Lefan locality and, the other, in Lower Banik locality. In Lefan locality, hundred samples were collected systematically along traverse extends perpendicular to the bed strike with sampling interval of about 3-m across the Aqra–Bekhme Formation and Shiranish Formation. These samples have been studied petrographically, and 24 of them were chosen for chemical analyses. In Lower Banik locality, 50 samples were collected from accessible parts on the steep ridge with different sampling interval that increases or decreases where it was necessary. Samples were taken across veins and fractures to follow the mineralogical and chemical changes. Twenty samples of them were chosen for chemical analyses. Major and trace elements except calcium and magnesium are determined by atomic absorption spectrophotometry technique, which was carried out at the Department of Chemistry, College of Science, University of Baghdad. Calcium and magnesium were determined by titration against ethylenediaminetetraacetic acid. Duplicate of 300 polished and thin sections were prepared in the workshop of Earth Science Department, College of Science, University of Baghdad. X-ray powder diffraction was also applied on some samples to determine the mineral composition. This technique was carried out at the Earth Sciences Department, College of Science, University of Baghdad and at State Company of Geological Survey and Mining. Dunham (1962) classification was used for describing carbonate microfacies.

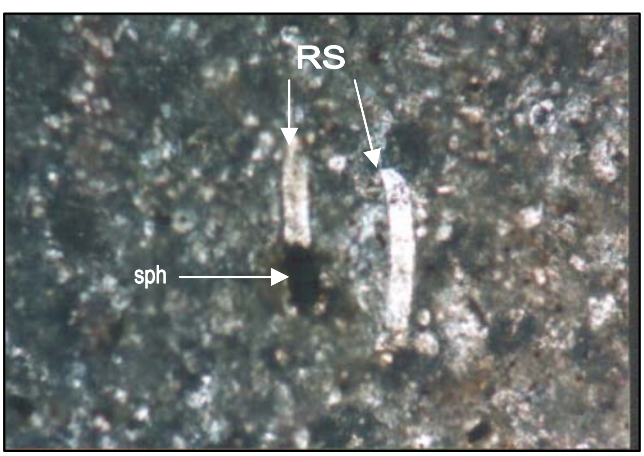

Fig. 2 Rudistid packstone microfacies shows sphalerite (*sph*) replacing rudist shells (*RS*)

Petrography of carbonate hosted ore

1. In Lefan locality

In this area, carbonate-hosted ores are included both in the Aqra–Bekhme Formation and Shiranish Formation. The studied section is petrographically described as follows:

(a) Aqra–Bekhme Formation

Dolomitic limestone of the Aqra–Bekhme Formation includes calcite ranges from 32% to 92% and 68% in average, while dolomite ranges from 4% to 51% and 20% in average (Table 2). Calcite and dolomite are the most abundant carbonate minerals, less so is siderite. Skeletal grains of rudist shells are the most abundant fossils that were replaced by sulfide especially sphalerite (Fig. 2). The

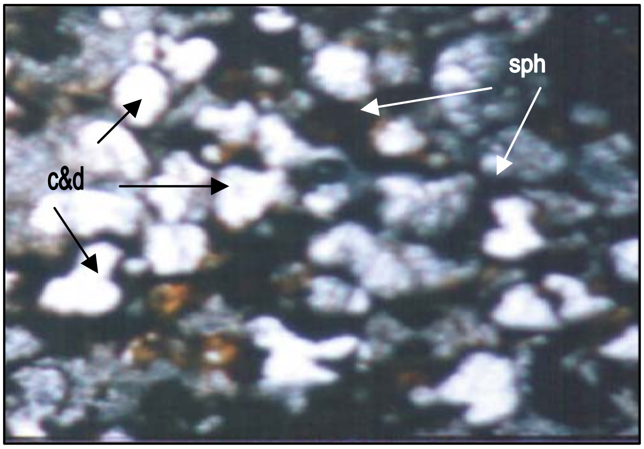

Fig. 3 Sphalerite (*sph*), cemented dolomite (*d*), and calcite (*c*)

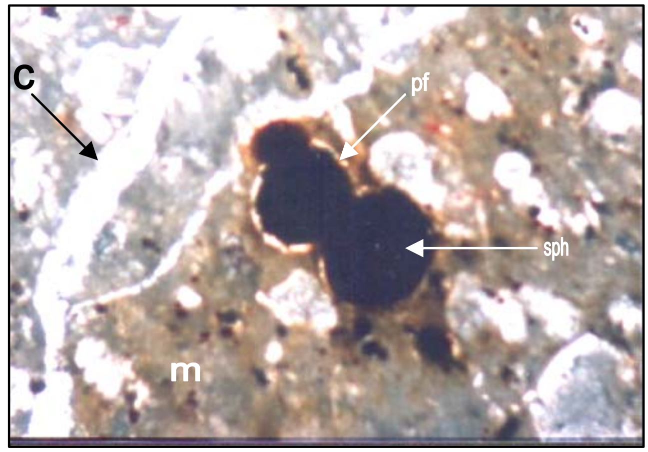

Fig. 5 *Foraminifera* lime wackstone microfacies displays a local micro-depositional environment of sphalerite (*sph*). *pf* planktonic *Foraminifera*; *m* micrite, *C* calcite

scarcity of micrite either reflects the converting of micrite to spary calcite or high mechanical energy (Friedman 1985). Dolomite occurs as small rhombic grains, and their content increases toward mineralized zone, while micrite decreases, consequently, the permeability appears to be increased with dolomite. The skeletal shape of fossils appears to be dislocated, deformed, brecciated, and recrystallized. Obviously, ore minerals seem to have epigenetically deposited cementing dolomite and calcite grains (Fig. 3), filling interstitial spaces, voids, and microfractures (Fig. 4). Dolomite and rudist shells are preferable media for replacement than calcite. The microfacies of the upper part of the Aqra–Bekhme in the Lefan locality is rudistid packstone (Fig. 2), which is considered a back reef facies that gradually changes into rudistid wackestone toward the formation bottom where grains become mud-supported fabric. The rudistid packstone microfacies was interpreted as back-reef facies (Aqrawi et al. 1998).

(b) Shiranish Formation

Calcite ranges from 36% to 90% and, in average, 71%, while dolomite ranges from 1% to 62% and, in average, 23%. There is a negative relationship between calcite and dolomite that clearly refers to dolomitization that also occurred in Shiranish Formation. Skeletal grains represented by planktonic *Foraminifera* are common, and they appear to be scattered within micrite. Carbonates of the Shiranish Formation are generally composed of mud-supported fabric. The microfacies of the studied part of Shiranish is foraminiferal lime wackestone (Fig. 5). The pelagic lime wackestone microfacies are usually interpreted as basinal deposits (Wilson 1975).

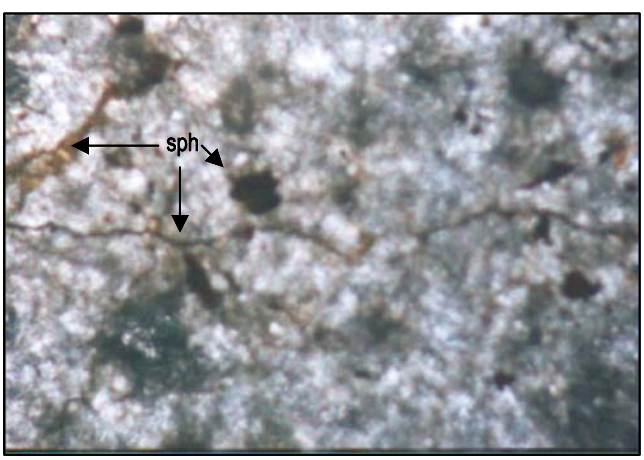

Fig. 4 Sphalerite (*sph*) fill voids and microfractures in carbonate host rocks

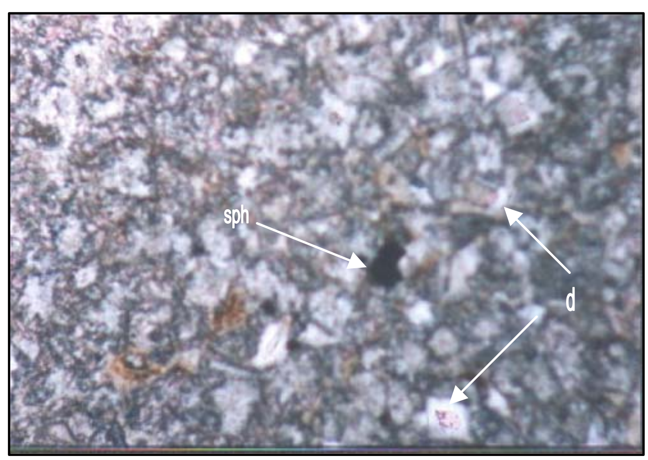

Fig. 6 Clear-rim, cloudy-center dolomite (*d*)-hosted sphalerite (*sph*) in microcrystalline carbonate of the Aqra–Bekhme Formation at the Lower Banik locality

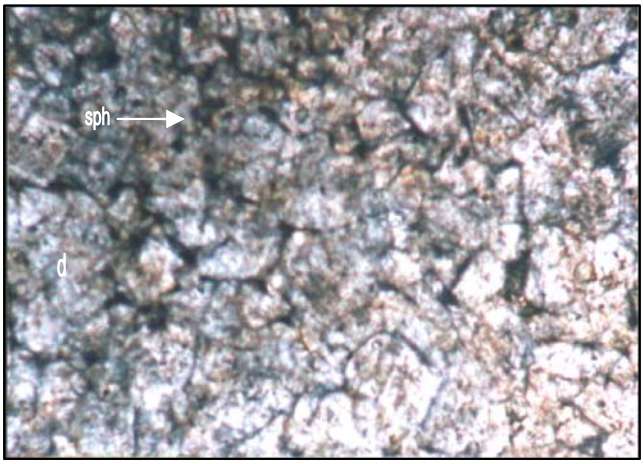

Fig. 7 Ore deposited around grain boundary of dolomite (*d*) in microcrystalline carbonate of the Aqra–Bekhme Formation at the Lower Banik locality

2. In Lower Banik

In this area, the formation generally consists of highly dolomitic limestones that mostly belong to the Aqra–Bekhme Formation. Calcite ranges from 16% to 73% and 48% in average, while dolomite ranges from 16% to 83% and 41% in average (Table 2). The rhombs of dolomite conjugate together with subhedral and euhedral grains of calcite-forming submosaic texture and displaying polysynthetic twining. Dolomitization and recrystalization deformed fossil shape and mainly deleted the original sedimentary texture. Some of the dolomitic rhombs exhibit zonation, which may reflect Mg/Ca in each zone (Folk and Land 1975) and iron content variation (Pun et al. 2001). Interstitial spaces have been formed among dolomite rhombs and seem to resemble mud cracks in shape referring to the increase of porosity, consequently, dolomitization.

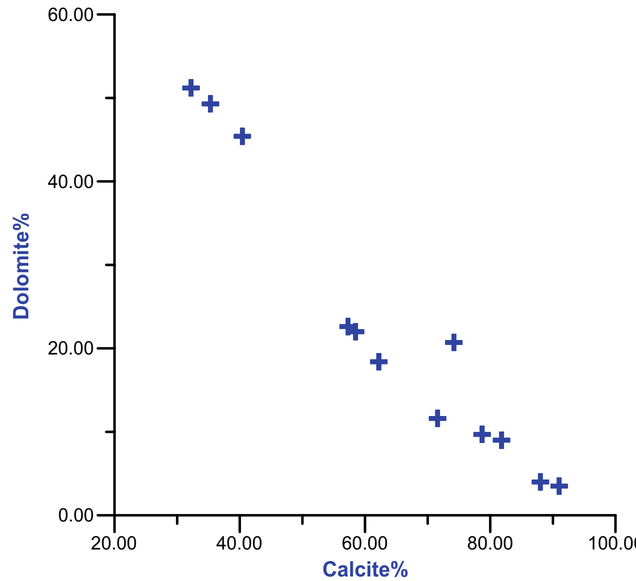

Fig. 8 Negative relationship between dolomite and calcite in the Aqra–Bekhme Formation at the Lefan locality (r=−0.93)

Other dolomites exhibit clear-rim, cloudy-center (Fig. 6). Siderite amount is higher than that present in Lefan locality. It is characterized by high relief, euhedral crystal shape, perfect cleavage, and wavy extinction. The rudistid packstone microfacies of the Aqra–Bekhme in the Lefan locality (Fig. 2) appears to have changed to microcrystalline carbonate microfacies (Figs. 6 and 7) at the lower Banik locality. Dolomitization and recrystalization are the common diagenetic processes. Dolomite content in lower Banik is higher than that of the Lefan locality (Table 2).

Primary and secondary ores

Primary ore is characterized by simple mineralogy, which mainly consists of sulfide minerals such as sphalerite,

Table 3 Geochemical results of Upper Cretaceous carbonate-hosted ore of the Aqra–Bekhme Formation in the Lefan locality

Samples no.	Fe_2O_3 (%)	CaO	MgO	ZnO	PbO	L.O.I	I.R	Total (%)	Ag (ppm)	Cd	Ni	Cr	Cu	Mn	Co
1L-AB	4.07	34.9	10.7	6.25	1.5	39.9	1.3	98.6	30	160	40	26	116	42	35
2L-AB	2.66	36.5	9.88	4.45	1.33	40	2.8	98.0	25	135	35	30	100	44	35
3L-AB	2.11	33.7	11.1	4.33	1.49	41.7	1.4	96.0	97	33	45	120	120	86	30
4L-AB	5.73	40.0	3.99	9.76	1.78	36	2.5	99.9	20	175	35	36	156	30	40
5L-AB	5.59	39.5	4.77	9.92	1.57	36.3	2.1	99.8	20	165	28	50	112	54	20
6L-AB	3.16	39.0	4.92	11.0	1.0	36.5	3.2	99.4	<10	265	25	160	80	336	25
7L-AB	4.11	43.8	2.51	5.63	1.05	38.6	3.6	99.6	<10	110	30	95	82	48	20
8L-AB	1.19	46.9	2.33	2.11	1.2	39.9	3.7	97.6	<10	66	15	70	158	46	22
9L-AB	0.81	50.6	0.85	0.93	0.3	40.8	2.6	97.3	15	40	44	35	120	36	45
10L-AB	2.09	48.7	1.95	1.23	1.75	40.5	2.0	98.3	35	55	19	40	86	56	25
11L-AB	1.15	25.2	0.75	0.09	0.02	42.0	3.2	99.9	<10	35	14	73	55	67	30
12L-AB	2.3	48.0	4.5	1.11	0.02	42.1	0.8	98.9	<10	45	<10	66	95	120	15
Average	14.3	40.5	4.9	4.7	2.2	39.5	2.4	97		107	28	67	106	80	27

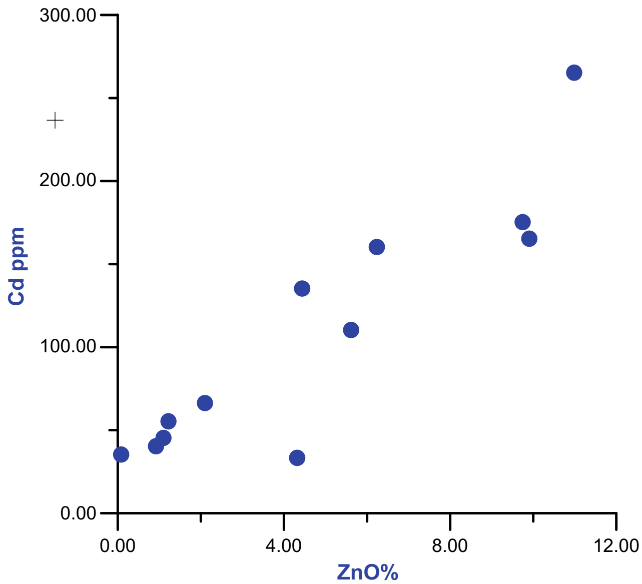

Fig. 9 Positive relationship between ZnO and Cd in the carbonate-hosted ore of the Aqra–Bekhme Formation at the Lefan locality (r= 0.89)

galena, and very little quantity of pyrite. Features of ore emplacement range from replacement to open space filling. Ore appears to be as small veins and veinlets. Disseminated clusters of crystals that occupy intergranular pore spaces around dolomite are the common microfeature. Primary ore has been precipitated from hypogene solutions (oilfield brine connate waters that partially mixed with hydrothermal fluids of magmatic origin; Awadh et al. 2006).

Most of the primary sulfide ores were altered to secondary ores by influence of supergene solutions. Sphalerite was altered to smithsonite, galena altered to cerussite and anglesite, and pyrite altered to goethite. Gossan consists essentially of a mass of hydrated iron oxides (limonite), which are also formed in some parts on the surface. They represent the leached and oxidized near-surface part of vein-containing sulfides. Iron minerals mainly occur as siderite and, in less quantity, as subordinate pyrite. Barite is the dominant translucent mineral that mostly associates ore and sometimes occurs as an independent mineral in veins and veinlets. Fluorite is very rare;

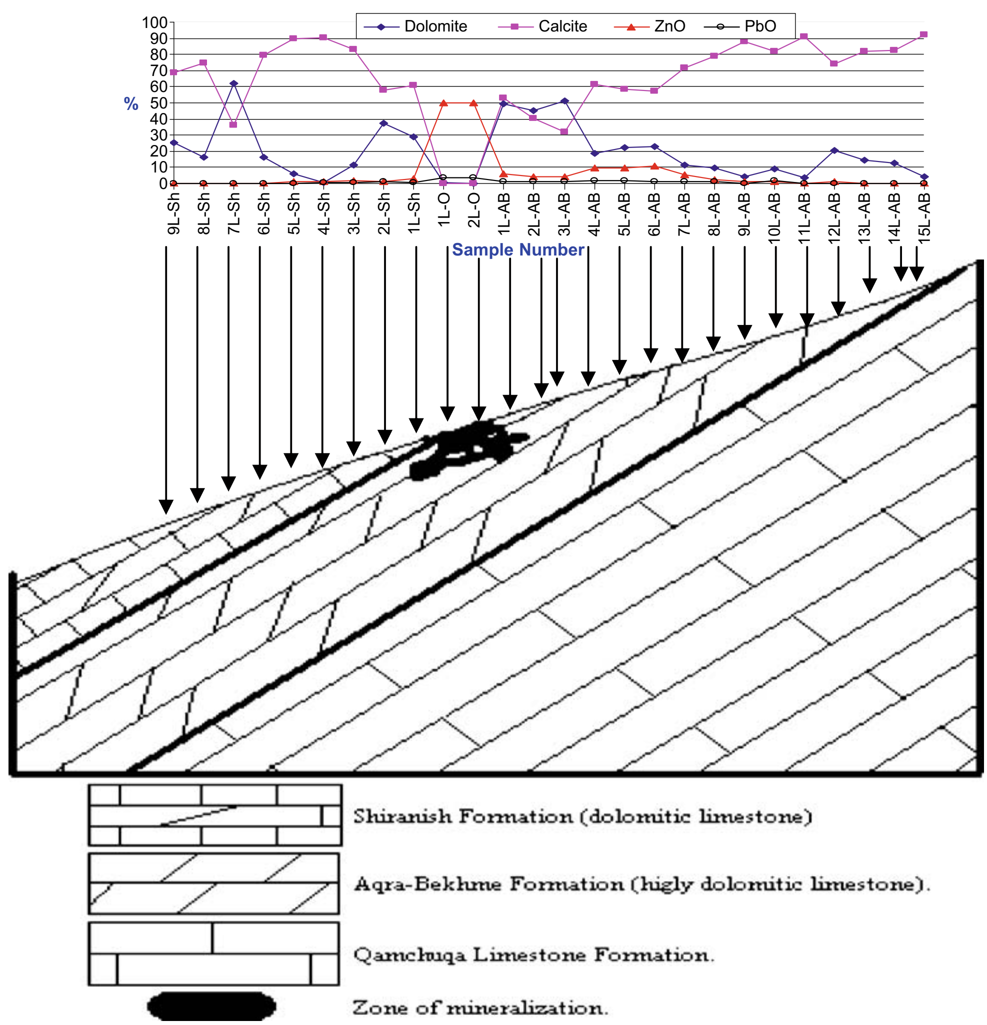

Fig. 10 Ore main emplacement within the Aqra–Bekhme Formation, ZnO an PbO concentration increase with dolomite content. The results of bulk ore samples that were directly collected from zone of mineralization are neglected

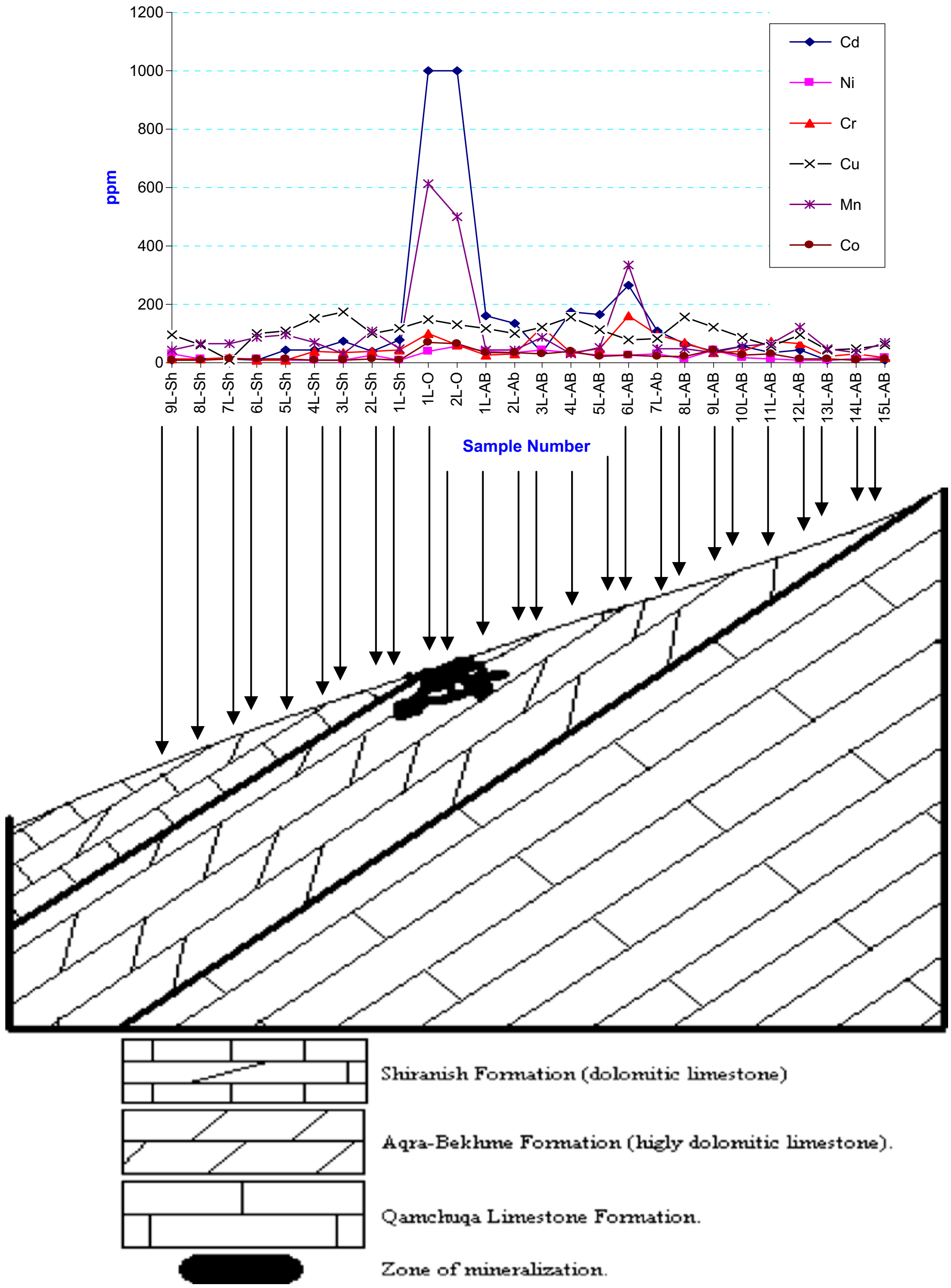

Fig. 11 Trace element distribution pattern along traverse cross-cuts of the Aqra–Bekhme Formation and Shiranish Formation shows element dispersion from ore-bearing fluids on both sides of the mineralized zone especially within the Aqra–Bekhme Formation. Sampling interval equal 10 m approximately

therefore, only several grains could be seen within carbonate rocks at the lower Banik locality.

Host rock alteration

Early diagenetic dolomitization appears to be an essential control factor of ore deposition as well as recrystalization and restricted silicification. All these diagenetic processes that took place before mineralization made carbonate rocks more receptive to mineralized fluids; therefore, they were considered as important factors of ground preparation. Dissolution, recrystalization, and silicification of carbonate host rocks are common types of alteration and considered as synmineralization changes. These effects may have developed after pre-mineralization changes (dolomitization, recrystalization, and silicification) at the same time of mineralization. Dolomitic grains that form as vein wall and lie in contact with the invading fluids appear to be coarser than that of those lying far away. Alteration effect may extend 1-cm beyond a vein wall, or they may extend a kilometer around a network of veins (Guilbert and Park 1986).

Table 4 Geochemical results of non-mineralized Upper Cretaceous carbonate of the Aqra–Bekhme Formation in the Lefan locality

Sample no.	Fe_2O_3 (%)	CaO	MgO	L.O.I	I.R	Total (%)	Zn (ppm)	Pb	Ag	Cd	Ni	Cr	Cu	Mn	Co
13L-AB	0.56	50.43	3.11	42.66	2.0	99.	35	18	10	10	10	22	45	50	13
14L-AB	1.12	50.11	2.75	42.37	.62	100.1	27	10	<10	11	12	30	50	33	10
15L-AB	1.03	53.01	0.95	41.86	2.4	99.6	25	13	<10	10	17	18	61	68	11

Geochemistry of carbonate hosted ore

1. In Lefan locality

(a) Aqra–Bekhme Formation

Carbonate-hosted ores are mainly composed of calcite and dolomite. The averages of CaO% and MgO% are 40.5% and 5%, respectively, and also, they include 4.7% ZnO and 2.2% PbO as averages (Table 3). Zinc and lead contents mainly came from sphalerite and galena, respectively, and their alteration products, such as smithsonite, cerussite, and anglesite. The negative correlation coefficient between calcite and dolomite (Fig. 8) refers to dolomitization and also supports the formation a high permeable zone, which was participated by ore reception as well as that of reef permeable strata of the Aqra–Bekhme Formation. Cadmium perfectly correlates with Zn (Fig. 9), while Ag correlates with Pb (Awadh et al. 2006). Obviously, these positive correlations support that the Cd is present within sphalerite, but the Ag is present within galena. Zinc and lead concentrations are systematically changed with the increase of dolomite content toward the upper part of the Aqra–Bekhme Formation and near the contact surface with Shiranish (Fig. 10). The higher concentrations of ore are found within the Aqra–Bekhme Formation at the Lefan locality. Mineralization is represented by samples 1L-AB to 9L-AB and extends of about 90 m up dip, while 10L-AB, 11L-AB, and 12L-AB samples represent the non-mineralized samples (Figs. 10 and 11) (Tables 3 and 4). Distribution of trace elements (Cd, Ni, Cr, Cu, Mn, and Co) shows that the dispersion process happened within the Aqra–Bekhme Formation on both sides of the mineralized zone with less extent through the Shiranish Formation (Fig. 11). Dolomite content within the Aqra–Bekhme in Lower Banik Formation is higher than that of its content in the Lefan locality; this fact led to suggest that there are other control factors besides dolomitization. These factors are interpreted as lithological and structural controls; the lithological factor was represented by Rudistid Packstone microfacies, but the fractures and contact surface between the Aqra–Bekhme Formation and Shiranish Formation are considered as structural controls.

(b) Shiranish Formation

The averages of CaO% and MgO% are 52% and 4%, respectively (Table 5). These values relatively show the decrease of dolomite content towards the Shiranish Formation in comparison with the Aqra–Bekhme Formation. Mineralization was represented by samples 1L-Sh to 6L-Sh (Table 5) and extends of about 60 m down dip (Figs. 10 and 11), while samples 7L-Sh, 8L-Sh, and 9L-Sh are not mineralized (Table 6). The negative relationship between calcite and dolomite (Fig. 12) also supports dolomitization that took place in this formation. Mineralization appears to have less localized in this part than the Aqra–Bekhme Formation and increases with dolomite content. Cadmium clearly associates with sphalerite (Fig. 13). Carbonate-hosted ores contain 1.32% ZnO and 0.55% PbO (Table 5). Trace element distribution values in this formation are less than that of the Aqra–Bekhme Formation. Dispersion processes were also limited and did not exceed 30 m.

Table 5 Geochemical results of Upper Cretaceous carbonate-hosted ore of the Shiranish Formation in the Lefan locality

Samples no.	Fe_2O_3 (%)	CaO	MgO	ZnO	PbO	L.O.I	I.R	Total (%)	Ag (ppm)	Cd	Ni	Cr	Cu	Mn	Co
1L-Sh	1.13	43.0	6.33	2.75	0.87	43.0	1.1	98.53	<10	80	10	44	118	46	10
2L-Sh	1.33	43.9	8.13	1.10	1.22	42.0	1.4	99.15	15	40	25	40	102	108	11
3L-Sh	0.45	50.3	2.54	1.95	0.67	43.0	0.9	99.92	12	75	<10	33	174	30	10
4L-Sh	2.13	75.0	0.16	0.91	0.55	40.8	2.0	97.4	16	45	<10	38	152	69	<10
5L-Sh	1.99	52.0	1.28	0.94	0.01	41.0	1.3	98.56	<10	45	<10	<10	110	95	11
6L-Sh	2.06	49.7	3.55	0.27	0.03	43.3	0.9	99.83	<10	10	12	<10	98	88	15
Average	1.5	52.	4	1.32	0.55	42.2	1.3	99		38		29	125	89	11

Table 6 Geochemical results of non-mineralized Upper Cretaceous carbonate of the Shiranish Formation in the Lefan locality

Sample no.	Fe_2O_3 (%)	CaO	MgO	L.O.I	I.R	Total (%)	Zn (ppm)	Pb	Ag	Cd	Ni	Cr	Cu	Mn	Co
7L-Sh	1.30	39.4	13.5	43.3	2.0	99.8	30	10	<10	15	11	18	10	65	11
8L-Sh	2.50	46.7	3.45	41.4	3.7	98.2	15	<10	<10	12	15	15	62	65	<10
9L-Sh	1.07	46.2	5.55	43.4	3.1	99.9	15	11	<10	10	30	11	95	42	<10

2. In Lower Banik locality

The studied area in the lower Banik locality was described as a highly dolomitic limestone. It belongs to the Aqra–Bekhme Formation, which composes 39% CaO and 9% MgO (Table 7). Correlation coefficient between calcite and dolomite (−0.97) clearly refers to dolomitization (Fig. 14). Carbonate-hosted ores include of 2% ZnO and 0.4% PbO (Table 7). Zinc and lead seem to have a less concentration than of Lefan. Cadmium also appears to have included within sphalerite; this case seems obvious by a positive trend between ZnO and Cd (Fig. 15). Silver was associated with Pb and included within galena (Awadh et al. 2006).

Discussion and conclusions

The Aqra–Bekhme Formation consists of a shallow water carbonate that was deposited mostly in reef/back-reef environment. Two depositional microfacies have been identified. The first one is rudistid packstone microfacies in the Lefan locality, and the second is the microcrystalline carbonate microfacies in the Lower Banik locality. The Shiranish Formation consists of a deep water carbonate, and the foraminiferal lime wackestone microfacies is a distinctive characteristic of the lower and middle parts of the Shiranish Formation. Emplacement of deep basinal facies of the Shiranish Formation over shoal water facies of the Aqra–Bekhme Formation indicates rapid subsidence. This subsidence has been interpreted by Awadh et al. (2006) as a crustal extension and rifting.

Reef structure of the Aqra–Bekhme Formation provided suitable physical and chemical conditions for localizing ore. The high porosity of the rudistid packstone microfacies provided spaces where ores were deposited. Rudist shells appear to be easily replaced by ores, so that they were considered as preference environment for ore deposition. Planktonic foraminiferal wacke limestone microfacies of the Shiranish Formation appear to have less content of ore than of the rudistid packstone microfacies of the Aqra–Bekhme Formation. In addition to microfacies type, early dolomitization and recrystalization are provided permeable strata that also participated in ore emplacement. Dolomitization requires an overall reduction in volume in the ratio of 100 to 88, with consequent increase in porosity (Pettijohn 1975). Dolomite is extremely brittle fractured; thus, it has provided excellent

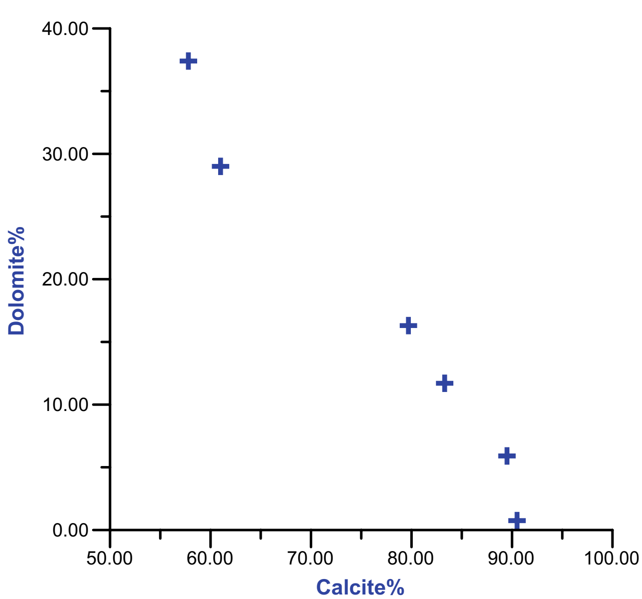

Fig. 12 Negative correlation coefficient (r=−0.92) between calcite and dolomite of the Shiranish Formation at the Lefan locality

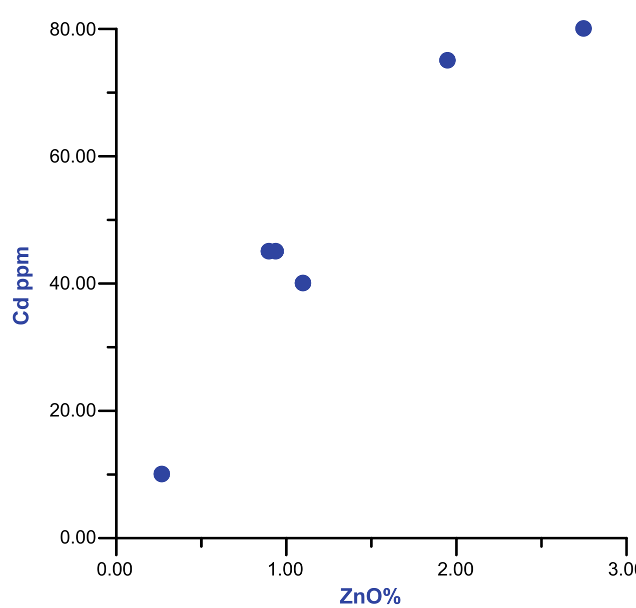

Fig. 13 Positive correlation (r=0.89) between ZnO and Cd in the carbonate-hosted ore of the Shiranish Formation at Lefan

Table 7 Geochemical results of Upper Cretaceous carbonate-hosted ore of the Aqra–Bekhme Formation in the Lower Banik locality

Samples no.	Fe_2O_3 (%)	CaO	MgO	ZnO	PbO	BaO	L.O.I	I.R	Total (%)	Ag (ppm)	Cd	Ni	Cr	Cu	Mn	Co
1BS-AB	1.78	45.3	5.92	1.02	0.65	0.001	40.11	3.11	98.0	10	95	20	19	88	105	15
2BS-AB	5.61	41.	7.33	2.10	0.44	0.002	40.60	1.300	98.5	<10	110	<10	50	45	320	10
3BS-AB	4.41	38.1	9.12	2.85	0.28	0.9	40.75	3.22	99.8	<10	185	15	33	79	250	12
4BS-AB	3.35	45.1	4.95	0.91	0.27	1.85	40.48	1.95	98.9	<10	79	<10	74	65	255	15
5BS-AB	3.73	36.8	12.2	2.90	0.44	0.001	42.00	1.81	99.9	<10	115	12	93	132	205	25
6BS-AB	2.45	45.8	3.50	2.31	0.33	1.10	40.20	3.20	99.0	<10	155	12	93	132	205	25
7BS-AB	3.99	45.0	3.75	0.75	0.12	0.001	44.0	1.90	99.9	<10	79	19	65	110	230	13
8BS-AB	2.45	35.7	19.0	0.93	0.25	0.002	40.90	1.11	100.	<10	50	<10	60	65	113	19
9BS-AB	1.83	35.6	17.4	2.10	0.62	1.77	37.55	2.95	99.8	11	215	11	<10	78	200	30
10BS-AB	3.18	39.3	8.99	2.00	0.33	2.79	40.79	2.03	99.5	<10	160	25	75	60	140	12
11BS-AB	3.20	42.9	7.61	1.33	0.29	0.001	43.11	2.00	100.	<10	100	13	75	45	98	10
12BS-AB	6.63	36.7	9.81	1.95	0.11	2.83	39.45	2.13	99.8	<10	144	29	120	105	275	20
13BS-AB	8.15	41.0	5.11	1.75	0.56	0.001	40.10	2.20	99.4	12	135	35	110	95	350	<10
14BS-AB	2.25	39.7	8.18	2.48	0.67	4.12	39.33	2.75	99.6	21	180	13	85	132	275	19
15BS-AB	3.54	34.8	10.3	2.80	0.95	0.001	39.51	3.65	97.7	15	110	44	90	83	155	16
16BS-AB	6.76	36.8	8.98	2.16	0.75	0.001	40.31	3.22	99.1	11	165	25	125	96	313	19
17BS-AB	7.11	36.9	8.11	2.35	0.12	0.001	40.00	4.39	99.2	<10	120	21	140	75	290	11
18BS-AB	3.55	39.4	7.93	0.75	0.3	3.75	39.43	4.44	99.7	<10	90	15	80	130	130	10
19BS-AB	4.01	41.4	7.10	2.00	1.02	0.001	41.00	2.56	99.3	14	150	10	75	118	114	10
20BS-AB	1.66	35.4	14.9	2.50	0.47	0.002	43.00	1.95	99.9	12	170	12	25	100	98	10
Average	4.0	39.1	9.0	2.0	0.4	1.0	41.0	2.6	99.4		130	18	71	89	201	15

geochemically reactive fluid conduits and traps for epigenetic ore fluids.

In the Lefan locality, ore appears to be precipitated within the pronounced porous zone in the Aqra–Bekhme Formation parallel to bed strikes near contact surface with the Shiranish Formation. Ore minerals are formed predominantly by the impregnation and selective dolomitized strata. The high dolomite content of the host rocks caused the markedly high proportion of zinc, lead, and iron. Because there is no information of vertical depth and we do not have core samples, the increase of ZnO and PbO systematically toward the contact surface between the Aqra–Bekhme Formation and Shiranish Formation led to suggest that the ore body may be localized in high

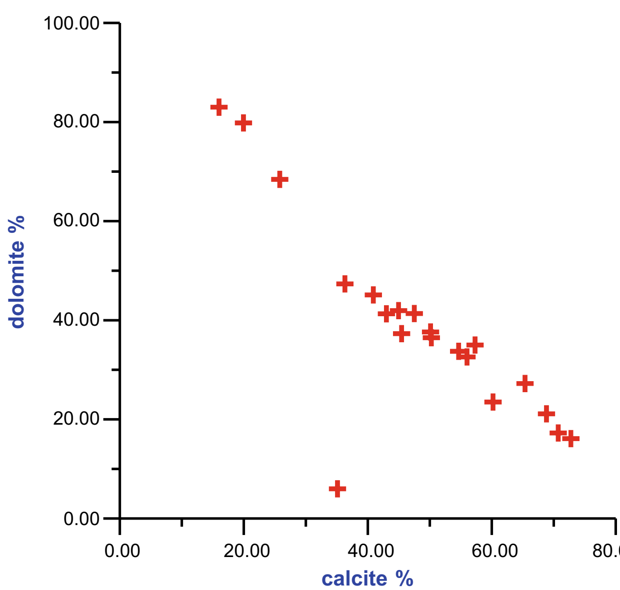

Fig. 14 Negative relationship between dolomite and calcite of the Aqra–Bekhme carbonate-hosted ore at the Lower Banik locality (r=−0.97)

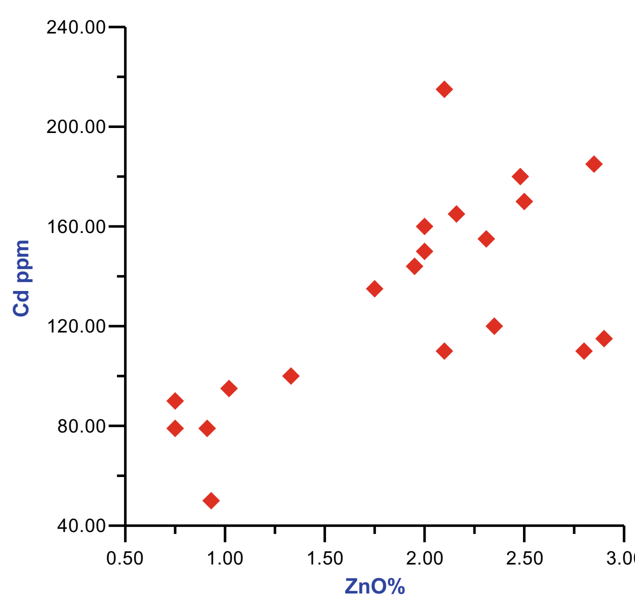

Fig. 15 Positive correlation between ZnO and Cd in the Aqra–Bekhme carbonate-hosted ore at the Lower Banik locality r=0.8

permeable zone within the Aqra–Bekhme under structural and lithological controls. Early and late dolomitization took place. The clear-rim, cloudy-center dolomite type probably formed during late diagenesis (Sibley 1982). Mineralization in the Shiranish Formation does not extend or disperse at long distance. Mineralization has been localized within permeable strata of dolomitic limestone that belongs to reef facies of the Aqra–Bekhme Formation as a strata-bound type with limited extent toward the Shiranish Formation.

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