KUSHK ZINC-LEAD DEPOSIT A TYPICAL BLACK-SHALE-HOSTED DEPOSIT IN YAZD STATE, IRAN

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Abstract

Kushk zinc- lead deposit is located about 167 km east of the city of Yazd, Iran. The geographical location of the mine is 31°, 40' N and 55°, 40' E. Different rock types including volcanics and subvolcanics (rhyolites, rhyodacites, dacites, and rhyolitic tuffs) and sedimentary rocks (shale, limestones and dolomites) crop out in the area. Mineralization of the deposit occurs in black shale of the late Precambrian time. The paragenetic sequence of the minerals indicates two stages of mineralization for lead minerals (galena) and one stage for zinc minerals (sphalerite). The Kushk deposit bears several similarities to the base metal deposits related to submarine volcanisms and sedimentation. The deposit is hosted by black shale and is proposed to be similar to the Rammelsberg (Germany) and Sullivan (British Colombia, Canada) deposits. The Kushk deposit is believed to be associated with the evolution of Protrozoic continental rifting in Iran and the mineralization in this deposit passes gradually outward into an iron rich sulfide zone which is the case in Sullivan-type deposits.

Introduction

Kushk zinc-lead deposit is located 42 km northeast of Bafq and about 167 km east of the city of Yazd in central Iran. Geographically it is located at 31°, 40' N and 55°, 40' E (Fig. 1). Mining at Kushk deposit has been documented as early as the 13th century [20,22].

The most recent discoveries were made at the site in 1939 when the Iranian Ministry of the Economy began mining this typical black-shale-hosted deposit. Subsequently, several detailed and semi-detailed studies have been carried out on the Kushk deposit [2,8] and in the neighbouring areas [4,5,10,12].

Reserve grades, based on the list of active mines of Iran published by the Iranian Ministry of Mines and Metals in 1985, are 15 percent zinc and about 3 percent lead, and the total reserve of the deposit is estimated to be 1.5 million tons of Zn-Pb ores.

Keywords: Base metal deposits; Black-shale-hosted deposits'; Kushk mine; Zinc-lead deposits

Field work was done in this study along with detailed laboratory examinations. More than 200 thin sections, polished sections and polished-thin sections, along with several chemical analyses, X-rays, electron microscopic and electron microprobe analyses were used to obtain detailed petrography and mineralogy in order to get to the genesis of the deposit and compare the Kushk deposit with the classical type black-shale-hosted zinc-lead deposits in other parts of the world.

Geology

The rock units, ranging in age from Precambrian to Quaternary, along with several disconformities, crop out in the Kushk area. Based on radiometric age determination, the black shale which hosts the deposit is upper Protrozoic in age [7,11,12], and based on lithologic characteristics two sequences of rock units have been identified in the

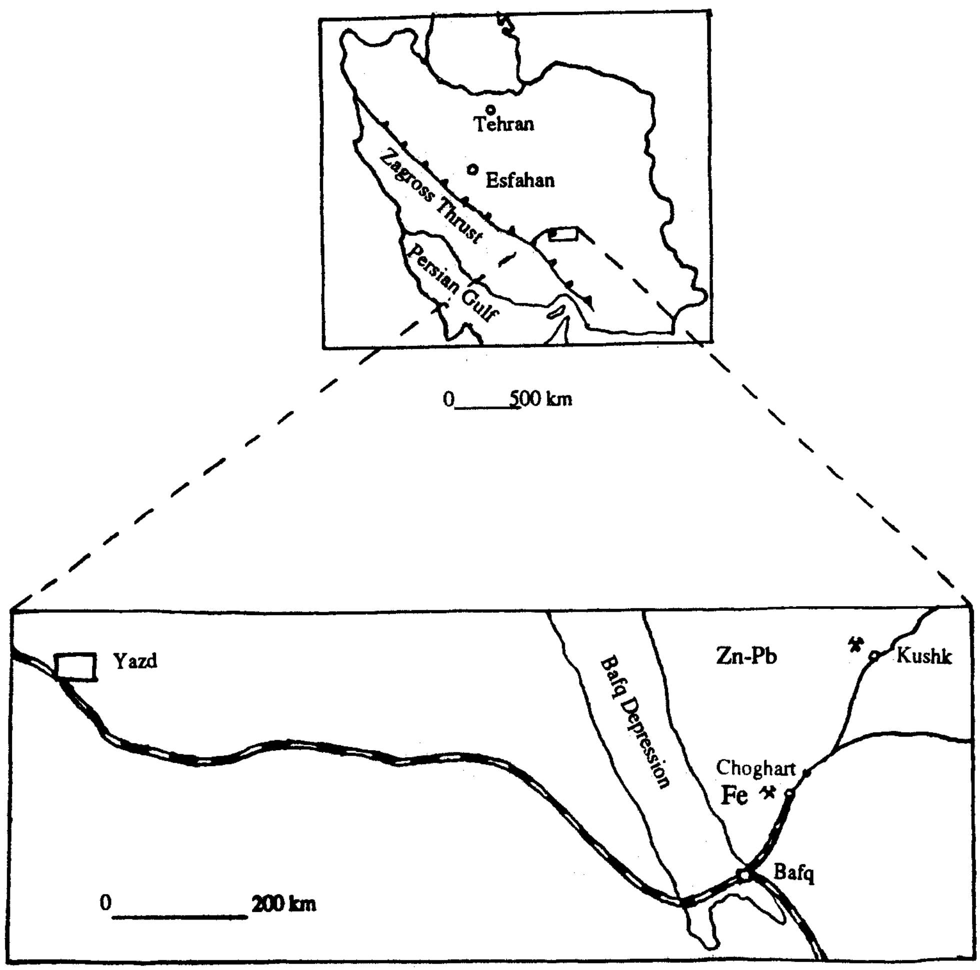

Figure 1. Location map of the Kushk area

mine area: mine sequence and volcano-sedimentary sequence. The mine sequence includes rhyolites, calcareous sandstone, silt, barren and mineralized black shale, limestone and dolomite (Fig. 2). The volcano-sedimentary sequence includes volcanic tuffs, limestone, dolomite, microconglomerate and two hematite horizons. These two sequences are separated by a NW-SE trending fault which is known as the Kushk fault.

The age of the black shale, which is the main rock unit in the area and is host to the ore minerals, is determined to be 595±120 million years, which makes it an upper Protrozoic age sediment [12]. This unit has very fine laminations and, in addition to quartz grains and clay minerals, organic materials are also generally observed in the rock.

Mineralogy

The ore minerals recognized in the Kushk mine include sphalerite, galena, melnicovite and the gangue minerals include pyrite, quartz, calcite, dolomite, gypsum, anhydrate and clay minerals. Variscite (Fig. 3), which is a hydrated phosphate mineral, was also found in the mine and was first reported in the Kushk area by the authors [23].

Mineralization in the Kushk mine is very simple but the minerals are seen in a great variety of structures and textures. The more common features are the laminated, disseminated, massive type, brecciated, frameboidal and botryoidal forms of the minerals.

Pyrite and galena, among other minerals in the Kushk area, appear to be crystallized in more than one stage of crystallization. Pyrite, which can be seen in a variety of forms, is the most common mineral mined in the area. It ranges in size from a few microns to a few millimeters and in shape from xenomorphic to euhedral crystals. In many places in the mine area, pyrite has replaced the rock or fossil fragments of the rock (Fig. 4). The replacements are seen to occur in live organisms or following the death and burial of the organisms as stated by Tufar [19].

Three stages of pyrite mineralization are recognized in the Kushk area. The first stage of crystallization of pyrite resulted in euhedral shaped pyrite more common in the shale, but less common in the mineralized zones. The second stage of pyrite crystallization produced xenomorphic pyrites which are generally seen as spherical in shape and the third type of pyrite is skeletal in texture (Fig. 5).

Galena is also seen in two different shapes which are euhedral and xenomorphic. It appears that euhedral galena is crystallized in the first stage of galena mineralization (Fig. 6) and the xenomorphic textured galena was formed later in the sequence of crystallization; its mineralization followed the sphalerite mineralization. The sequence of mineralization is shown in Figure 7. Detailed chemical analyses on the samples also indicated traces of copper, silver, and cadmium in the Kushk mine.

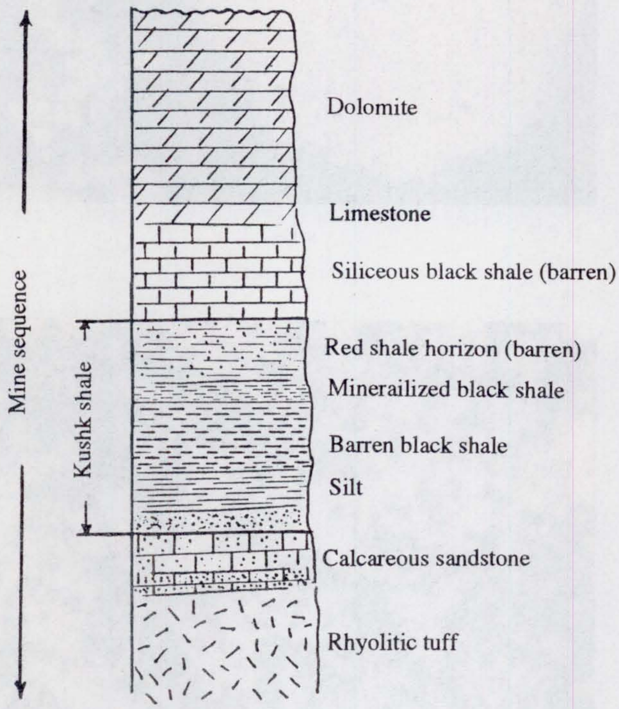

Figure 2. Lithostratigraphic column of mine sequence in the Kushk mine

Petrogenesis

More than 50 detailed chemical analyses (Table 1) and 11 analyses were carried out on the trace and rare elements (Table 2) of igneous rocks from the Kushk area to study the petrogenesis of the igneous magma. The petrographic and petrochemical characteristics of the igneous rocks are very similar. The intrusive rocks of the late Precambrian time range in composition from gabbroic, including pyroxenites, diabase, and gabbro to acidic rocks including granite and syenite, while the extrusives are mainly rhyolitic in composition along with some rhyodacite, dacite, and quartz bearing lathite. The pyrroclastic rocks of the area include tuffaceous rhyolites and ignimberites.

Based on Na_2O + K_2O/SiO_2 diagrams [13,14], the intrusive rocks of the study area turned out to be alkaline and calc-alkaline in composition. The basic and intermediate rocks are mainly located on the alkaline part of the diagrams while the acidic rocks are found on the calc-alkaline part (Fig. 8).

Comparing the alkaline and calc-alkaline rocks of the area with the models presented by Barberi *et al.* [3], the igneous rocks of the Kushk area are more likely to be part of an old rift with high volcanic activity, and based on Na_2O+K_2O/SiO_2 ratio using the diagram presented by Cox *et al.* [6], it seems that although the age of the feature is

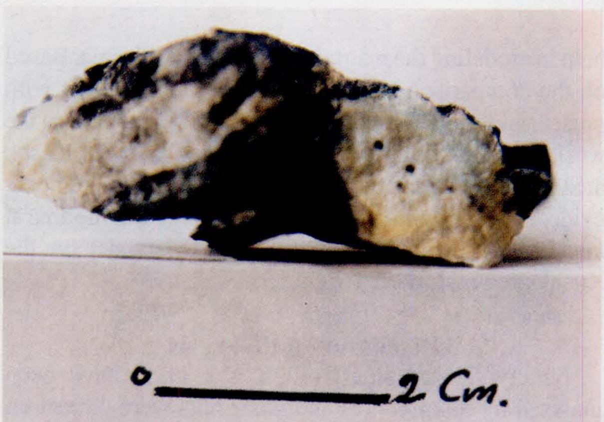

Figure 3. The mineral variscite found in the Kushk shale

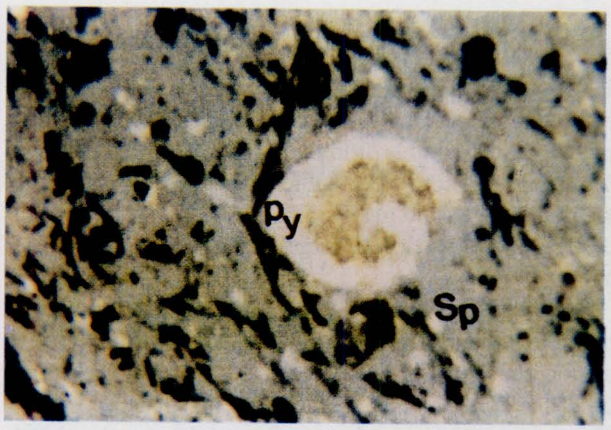

Figure 4. Replacement of fossil fragments by pyrite. 400x
Py: Pyrite Sp: Sphalerite

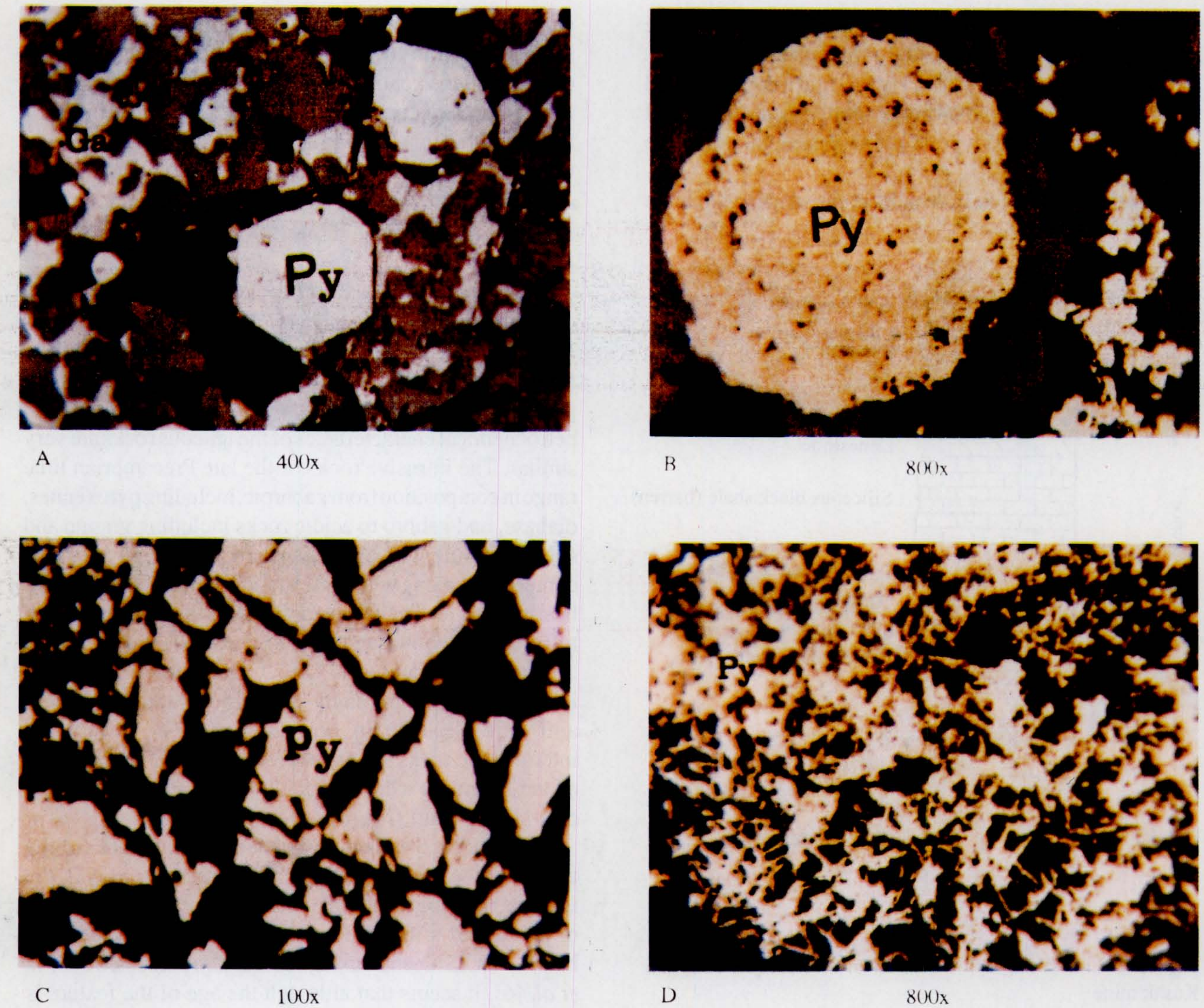

Figure 5. Different forms of pyrite in the Kushk shale A. Euhedral grains B. Spherical C. Brecciated D. Skeletal

quite different, the rock types of the Kushk area (Bafq) and East African Rift are quite comparable. This is good enough reason for the study area to be assumed to be part of an old continental rift in the Proterozoic time (Fig. 8). This idea is more acceptable when we compare the magmatic rocks and magmatisms of the Kushk area with the Rio Grand Rift of Mexico which is almost the same age.

According to Ankeny *et al.* [1], the temperature and pressure of the basic intrusive body at about 15 km depth caused the partial melting of the overlying crust and produced volcanic rocks which are acidic in composition. This model, and the fact that continental rifts are associated with alkaline magmatism and are bimodal in composition, help in modeling the magmatism of the Kushk area. Based on the comparison between the Kushk magmatism with present and ancient continental rifts in different parts of the world, it is inferred that the igneous rocks of the Kushk area belong to an active rift with high volcancity. Tectonic evidence has also indicated a tensional phase in the area at late Proterozoic time, and the proposed model for the Kushk area is shown in Figure 9.

Discussion on Genesis

Ninety-six samples from Kushk mine have been analysed by Stanton [18] and the results were plotted on the system SiO_2-Al_2O_3-CO_2. Basically, no differences were observed in the minerals due to the increase in sulfur percentage and so it was inferred that this deposit is syngenetic in origin.

In 1976, Gibbs proposed the Kushk deposit to be a paleo-Kuroko-type deposit and he had the idea that the ore solution of the deposit resulted from a calc-alkaline magma and was directly connected to convergent plate margins in an island arc system. In the present study, several dissimilarities were found between Kushk deposit and Kuroke type deposits, amongst them: In the Kuroko type deposits there is usually a feeder pipe known as stringer ore

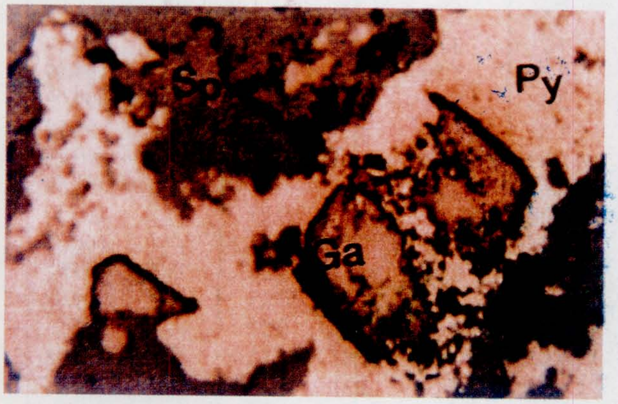

Figure 6. Galena grain which is broken and replaced by pyrite of a later stage in the sequence of mineralization. 400x
Ga: Galena Sp: Sphalerite Py: Pyrite

which is not recognized in the Kushk mine. There is also an iron bearing black chert known as Tetsusekeie usually located on the top part of the Kuroko type deposits which is absent in the Kushk deposit. The absence of siliceous alteration in the foot wall of the mine, montmorillonite and zeolite mineralization on the top of the ore body, and the lack of barite is all evidence against the proposed Kuroko type deposit. Simple mineralogy, iron poor sphalerites, abundance of pyrite in different forms, connection with continental rifts are also evidence against the Kushk deposit being proposed as a Kuroko type deposit.

Black shale hosted massive sulfide deposits, on the other hand, are classified as distal deposits [9], and are also classified as Sullivan type deposits [16]. These deposits, which vary in scale, may be stratabound or stratiform in structure. Layering and laminations on the scale of millimeters to centimeters are common in these deposits. The sulfide minerals are usually found as interlayers with thin layers of tuffs, volcano-clastic rocks or shale. They are mostly sheetlike deposits and sharp contacts are seen between rich zones and gangue minerals. The main sulfide minerals in these deposits are sphalerite, and galena along with pyrite, and the main gangue minerals are usually quartz, calcite, and sometimes barite. These deposits are mainly found in the Paleozoic and earlier age sediments (Table 3). According to Sawkins [17], the Sullivan type deposits are also associated with continental riftings.

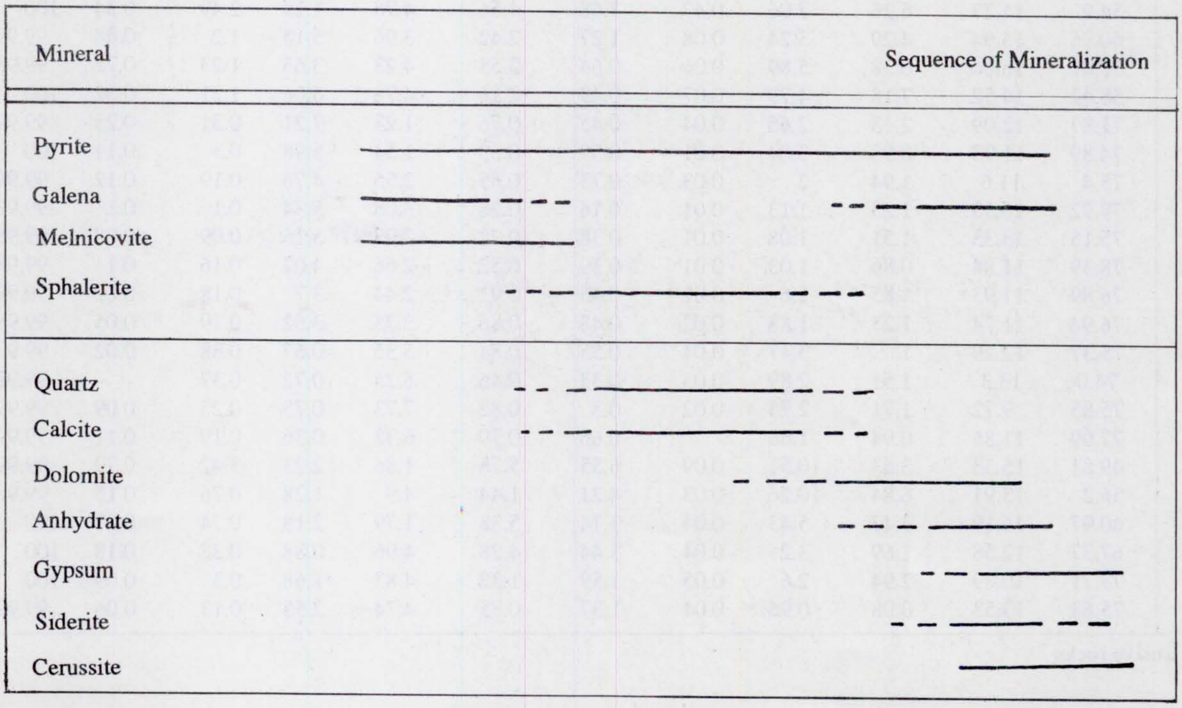

Figure 7. Paragenetic sequence of mineralization in the Kushk mine

Table 1. Chemical analyses of intrusive bodies and extrusive rocks from Bafq area, (after Mehrabi, [15])

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	Total
1*	68.42	14.73	0.21	4.2	0.06	2.94	0.68	4.33	3.77	0.46	0.1	100
2	51.57	15.96	1.46	9.28	0.5	6.61	5.55	5.12	1.71	1.9	0.33	100
3*	62.64	14.62	1.26	5.74	0.15	3.9	4.05	4.15	2.66	0.65	0.15	99.97
4*	65.88	17.24	1.9	1.16	0.01	2.33	0.5	3.04	7.56	0.39	0.07	99.98
5*	71.68	14.07	0.89	1.77	0.02	2.04	0.34	2.4	5.48	0.3	0.05	99.98
6	45.45	13.1	4.79	8.56	0.21	5.59	8.9	3.38	2.55	4.62	1.17	100
7*	72.82	12.15	0.93	1.97	0.03	1.58	0.34	4.32	4.6	0.25	0.06	100
8*	74.09	11.81	1.5	1.57	0.01	1	0.44	1.74	7.17	0.26	0.06	99.99
9	44.21	9.07	4.92	10.78	0.24	11.21	7.4	2.6	2.29	3.75	0.78	99.99
10	43.49	12.05	3.72	9.7	0.24	23.68	6.56	0.79	0.74	1.68	0.33	100
11*	62.43	15.15	2.46	7.15	0.13	0.86	5.2	3.68	1.83	0.85	0.26	100
12*	71.09	15.22	1.43	1.05	-	1.28	2.39	3.59	3.53	0.41	-	99.99
13*	74.72	12.38	1.11	0.77	-	1.05	2.33	0.24	7.15	0.23	-	99.98
14*	75.53	13.26	1.37	0.94	-	0.56	1.81	3.11	3.12	0.29	-	99.99
15	58.95	19.06	3.29	2.2	-	2.29	2.39	3.99	6.84	0.27	-	99.98
16*	75.53	13.52	0.42	0.28	-	0.64	0.81	0.25	8.29	0.26	-	99.99
17*	75.08	13.82	1.14	0.78	-	0.45	0.56	1.29	6.65	0.23	-	100
18*	69.9	13.84	2	1.48	-	3.08	3.14	4.35	1.69	0.53	-	100.01
19	59.39	1.1	3.27	7.62	0.11	10.14	16.92	0.33	0.76	0.26	0.07	99.97
20	58.62	8.89	3.51	5.27	0.06	13.31	7.4	1.88	0.79	0.25	-	99.98
21	52.57	1.99	4.84	11.29	0.22	8.93	19.51	0.18	0.19	0.27	-	100
22	51.31	16.44	4.14	9.24	0.12	5.53	5.63	1.91	2.02	3.12	0.52	99.98
23	49.29	14.85	6	8.99	0.13	5.03	6.95	1.79	3.31	3.26	0.4	100
24	53.12	15.92	4.88	8.1	0.1	4.73	6.41	1.51	3.39	3.13	0.38	99.98
25	49.88	14.74	6.19	7.56	0.11	5.41	5.58	3.13	2.46	3.31	0.44	99.99
26	48.78	14.74	5.94	8.07	0.11	2.96	5.96	2.81	4.72	3.44	0.47	100
27	55.96	14.7	3.34	8.49	0.09	2.42	4.52	3.65	3.24	2.59	0.87	99.98
28	53.14	16.29	6.14	7.92	0.11	2.79	3.59	4.27	2.48	2.48	0.76	99.97
29	54.49	16.68	4.87	8.07	0.11	2.67	3.1	3.99	3.73	1.52	0.76	99.99
30	54.9	14.27	6.26	7.06	0.47	3.68	4.56	4.78	1.19	2.49	0.34	100
31	60.96	16.94	4.29	3.24	0.08	1.27	2.42	3.96	5.15	1.2	0.48	99.99
32	58.01	16.64	6.38	5.89	0.06	0.64	2.53	4.23	3.65	1.23	0.72	99.98
33	58.42	14.52	7.18	4.79	0.07	0.49	2.16	4.78	6.06	1.21	0.32	100
34	71.87	12.09	2.13	2.65	0.04	0.45	0.76	1.23	7.21	0.31	0.25	99.99
35	74.89	11.93	0.98	3.04	0.01	0.59	0.63	1.54	5.98	0.3	0.11	100
36	75.4	11.6	1.94	2	0.03	0.73	0.65	2.55	4.78	0.19	0.12	99.99
37	77.92	10.53	1.23	1.13	0.01	0.16	0.28	3.08	5.34	0.1	0.1	99.98
38	75.15	13.33	1.51	1.08	0.01	0.38	0.22	2.97	5.16	0.09	0.08	99.98
39	78.39	11.84	0.86	1.03	0.01	0.39	0.52	2.66	4.02	0.16	0.1	99.98
40	76.89	11.93	1.85	1.6	0.02	0.45	0.91	2.44	3.7	0.18	0.02	99.99
41	76.94	11.74	1.23	1.88	0.02	0.48	0.86	2.75	3.82	0.19	0.05	99.98
42	75.37	12.29	1	3.47	0.04	0.55	0.84	5.36	0.67	0.38	0.02	99.99
43	74.06	13.3	1.51	2.89	0.03	0.33	0.46	6.25	0.72	0.37	-	99.92
44	75.85	9.72	1.71	2.75	0.02	0.3	0.82	7.73	0.75	0.25	0.09	99.99
45	77.09	11.86	0.94	1.66	-	0.66	0.79	6.32	0.36	0.19	0.11	99.99
46	49.81	15.33	3.63	10.51	0.09	6.55	5.78	1.86	2.23	3.42	0.79	99.99
47	56.2	13.91	6.84	10.26	0.03	4.21	1.44	4.9	1.28	0.76	0.15	99.98
48	60.97	16.19	3.47	5.43	0.04	3.74	5.38	1.79	2.18	0.74	0.07	100
49	67.37	12.58	1.69	3.2	0.04	3.44	4.28	4.96	0.88	0.38	0.18	100
50	73.71	10.89	2.94	2.6	0.05	1.59	1.32	4.83	1.68	0.3	0.09	100
51	75.68	13.53	0.08	0.96	0.04	1.37	0.85	4.74	2.55	0.13	0.06	99.99

* Extrusive rocks

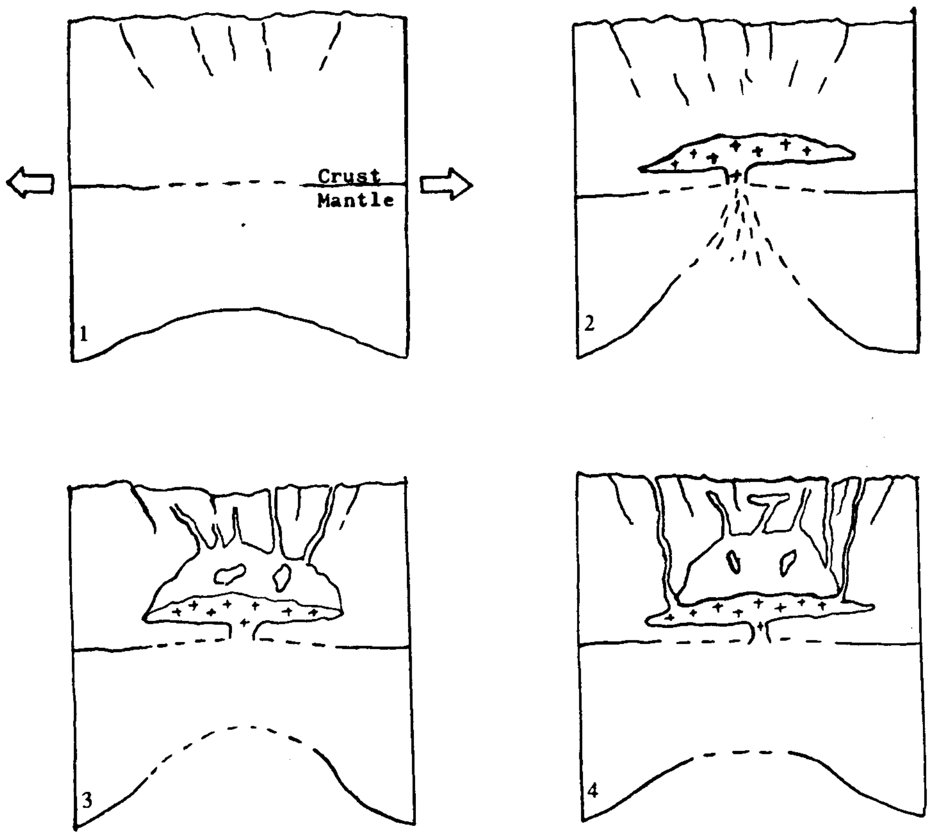

Figure 9. Proposed model for tectono-magmatic activity in Kushk area at late Proterozoic time (based on the model presented by Ankeny *et al.* [1]

Table 3. Some examples of the base metal deposits hosted by sedimentary rocks comparable to the Kushk deposit, (Sawkins, [17])

Deposit or district	Age	Metal composition	Tonnage (10^4)	Host rocks	Reference
Lik, NW Alaska	Miss.	Zn, Pb	25+	Carb. shale, short	Forrest and Sawkins (1983)
Red Dog	Miss.	Zn, Pb	85+	Carb. shale	D. M. Moore *et al.* (1986)
Rammelsburg, Germany	Devonian	Zn, Pb, Cu	22	Carb. slates	Hannak (1981)
Meggen, Germany	Devonian	Zn, Pb	50	Carb. slates	Krebs (1981)
Macmillan Pass	Devonian	Zn, Pb	20	Carb. siliceous shale	Carne and Cathro (1982)
Gataga	Devonian	Zn, Pb	30	Siliceous pyrite shale	MacIntyre (1982)
Howards Pass	Silurian	Zn, Pb	?	Carb. sandstone, chert	Carne and Cathro (1982)
Anvil	Cambrian	Zn, Pb	140	Graphitic phyllite	Carne and Cathro (1982)
Sullivan, B.C.	Prot. (1.4)	Zn, Pb	155	Argillite	Ethier *et al.* (1976)
Mt. Isa, Aust. (Zn, Pb)	Prot. (1.65)	Zn, Pb	88.6	Carb. shale, dotomite	Mathias and Clark (1975)
Hilton, Aust.	Proterozoic	Zn, Pb	35.6	Carb. shale	Mathias *et al.* (1973)
Lady Loretta, Aust	Proterozoic	Zn, Pb	8.6	Carb. shale	Loudon *et al.* (1975)
McArthur River, Aust.	Prot. (1.65)	Zn, Pb	190	Dolomite, shale	R. N. Walker *et al.* (1977)
Metamorphosed Equivalents					
Broken Hill, NSW	Prot. (1.7-2.0)	Pb,Zn	180	Fesic gneiss	Johnson and Klingner (1975)
Gamsberg, S. Africa	Prot.	Zn, Pb	93	Meta-pelites	Rozendaal (1980)
Big Syn, S.Africa	Prot.	Zn, Pb	101		
Black Mountain, S. Africa	Prot.	Cu, Pb	82	Micaschist	Ryan *et al.* (1982)
Broken Hill, S. Africa	Prot.	Pb, Zn	85	Iron formation	

Table 2. Chemical analyses on 11 samples of the igneous rocks for trace and rare elements from Bafq area, using spectrometric method. All values are in ppm, (after Mehrabi, [15])

	(1)	(2)	(3)*	(4)*	(5)*	(6)	(7)*	(8)*	(9)	(10)	(11)*
B	10	31	11	50	58	7	16	30	10	22	14
Ba	1000	422	774	414	381	282	420	608	285	119	108
Ce	243	117	225	160	240	121	248	295	143	228	280
Co	10	28	17	7	14	26	11	8	48	94	9
Cr	457	275	655	475	700	159	950	778	346	530	438
Cu	14	17	33	13	14	23	19	18	44	12	12
Ga	18	13	15	50	26	11	22	16	9	6	14
La	5	12	14	5	5	23	5	5	32	27	22
Ni	122	110	317	115	230	62	400	290	214	644	165
Pb	24	950	28	5	5	7	5	5	15	955	9
Sc	9	12	15	8	5	9	5	5	14	16	15
Sr	196	164	331	80	55	287	50	55	293	115	85
V	75	117	100	37	20	90	18	15	114	119	13
Y	28	28	34	38	41	31	27	33	33	36	75
Zn	141	440	175	95	108	176	116	126	239	800	177
Zr	80	54	102	91	137	111	151	177	153	209	320

* Extrusive rocks

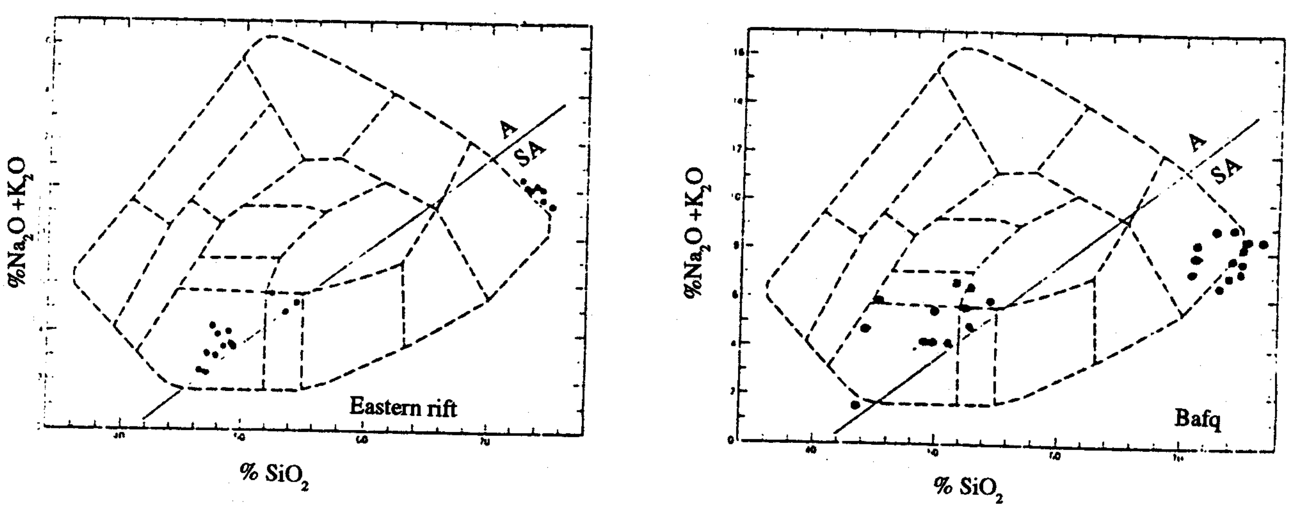

Figure 8. Comparison of $Na_2O + K_2O/ SiO_2$ ratio between East- African Rift and Bafq Area

Several similarities exist between the Kushk deposit and Sullivan type deposits, among which the more important ones are: being stratiform; hosting by black shale; being simple in mineralogy; having sphalerite as the main economic minerals; sheetlike deposits; having calcite and quartz as gangue minerals: sedimentary textures as the main texture in the deposit; and belonging to continental rifting. All of these similarities, which are also seen mainly in the Rammelsberg deposit in Germany, help in classifying the Kushk zinc-lead deposit of Iran as an example of Sullivan type deposits [24].

Based on paragenetic sequence of minerals and mineral relationships, it is also inferred that the mineralization of the Kushk mine, like Kupferschiefer in Europe, [21], occurred in several stages which could be outlined as synsedimentary deposition, syndiagenetic deposition, and post diagenetic deposition. Evidence for different stages of mineralization could be seen in most of the thin sections, and the mode for the first stage of deposition considering the proposed tectono-magmatic model (Fig. 9) is inferred as in Figure 10.

Conclusion

Field studies, along with detailed laboratory

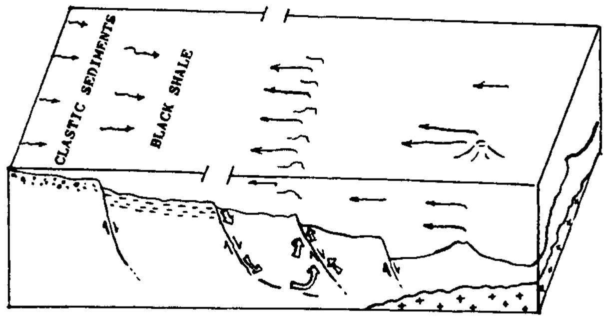

Figure 10. Proposed model for the first stage of ore deposition

examinations, were done on the Kushk zinc-lead deposit in order to interpret the mode of formation of the deposit and compare it with other black shale hosted base metal deposits in the world. Several similarities were recognized between the Kushk deposit and deposits such as the Rammelsberg deposit in Germany and the Sullivan deposit in British Colombia, Canada, and based on these similarities the Kushk deposit is proposed to be an example of the Sullivan type deposit.

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Correction

Regretfully, the following error occured at the final process of printing of the previous issue (Vol. 8 No. 1, Winter 1997, Zemestan 1375, *J. Sci. I.R. Iran*) beyond the journal management's control, which is hereby corrected:

P. 47: A duplicate copy of Figure 3 (on page 48) was wrongly placed on page 47, which should be replaced by the following correct Figure:

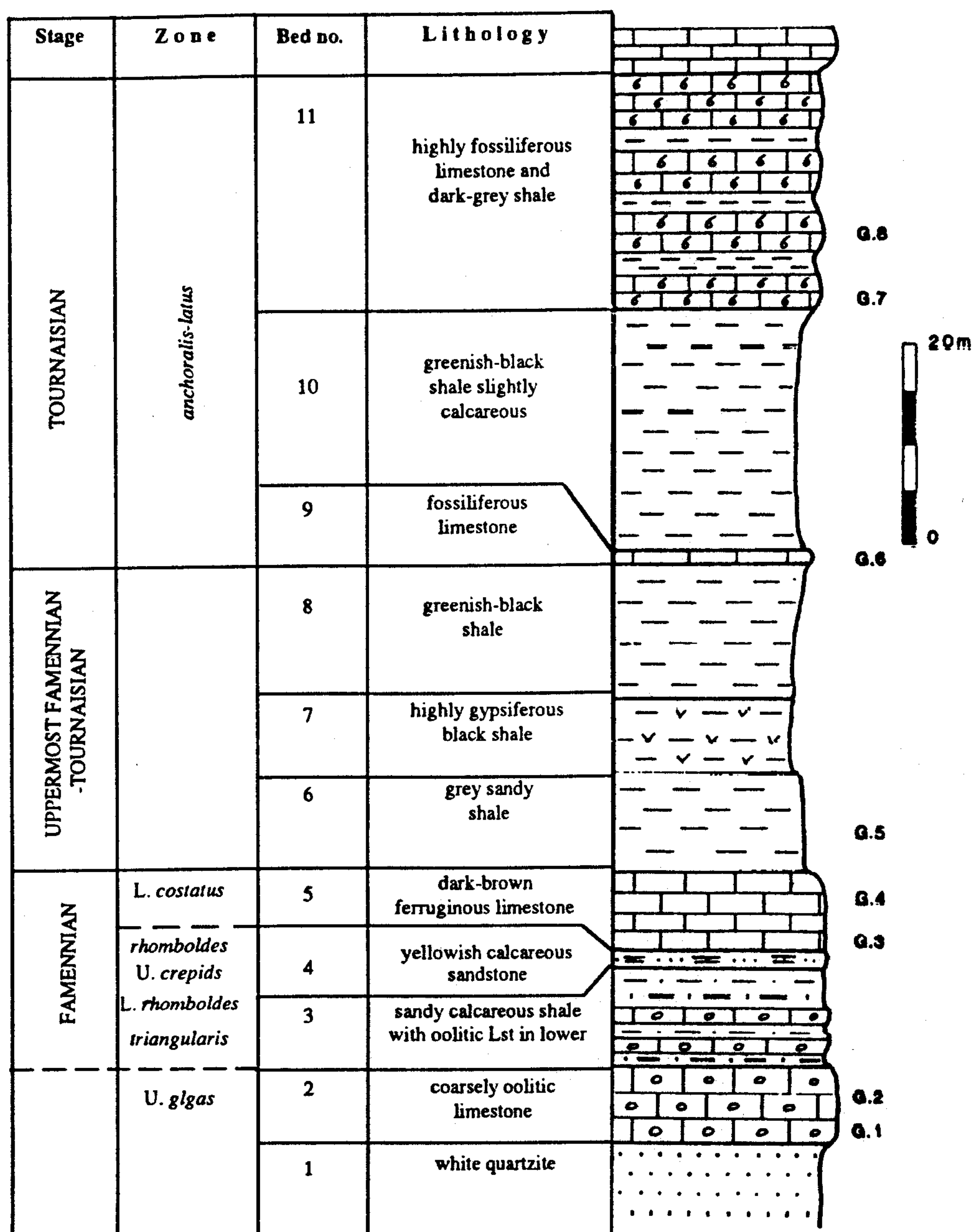

Figure 2. Reference section of part of the Cephalopod Bed and overlying strata in the Howz-e-Dorah area (Section A).