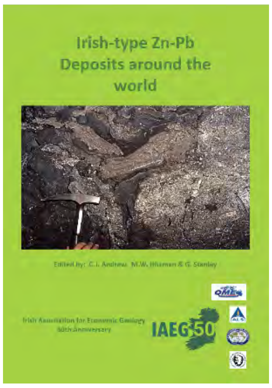

Irish Association for Economic Geology

(founded 1973)

Home Page: https://www.iaeg.ie

Carbonate-hosted Zn-Pb-Cu-Ba (-Ag) mineralization in the Mehdiabad deposit, Iran: new insights, new discoveries

Ghazaleh Khan Mohammadi[1], Abdorrahman Rajabi[1], Shojaedin Niroomand[1], Pouria Mahmoodi[2], Carles Canet[3] & Pura Alfonso[4]

[1] *School of Geology, College of Science, University of Tehran, Tehran 1417614411, Iran.*
[2] *Department of Geology, Faculty of Sciences, Tarbiat Modares University, Tehran 14115111, Iran.*
[3] *Escuela Nacional de Ciencias de la Tierra, Universidad Nacional Autónoma de México, Coyoacán, Mexico City 04150, Mexico;*
[4] *Departament d'Enginyeria Minera, Industrial i TIC, Universitat Politècnica de Catalunya, Av. de les Bases de Manresa 61–73, 08242, Manresa, Spain*

Corresponding Author: Ghazaleh Khan Mohammadi ghazaleh.khanmohammmadi@gmail.com

To cite this article: Khan Mohammadi, G., Rajabi, A., Niroomand, S., Mahmoodi, P., Canet, C. & Alfonso, P. (2023) Carbonate-hosted Zn-Pb-Cu-Ba (-Ag) mineralization in the Mehdiabad deposit, Iran: new insights, new discoveries. *In:* Andrew, C.J., Hitzman, M.W. & Stanley, G. '*Irish-type Deposits around the world*', Irish Association for Economic Geology, Dublin. 545-556.
DOI: https://doi.org/10.61153/ZZWJ5211

To link to this article: https://doi.org/10.61153/ZZWJ5211

Carbonate-hosted Zn-Pb-Cu-Ba (-Ag) mineralization in the Mehdiabad deposit, Iran: new insights, new discoveries

Ghazaleh Khan Mohammadi[1], Abdorrahman Rajabi[1], Shojaedin Niroomand[1], Pouria Mahmoodi[2], Carles Canet[3] & Pura Alfonso[4]

[1] *School of Geology, College of Science, University of Tehran, Tehran 1417614411, Iran.*
[2] *Department of Geology, Faculty of Sciences, Tarbiat Modares University, Tehran 14115111, Iran.*
[3] *Escuela Nacional de Ciencias de la Tierra, Universidad Nacional Autónoma de México, Coyoacán, Mexico City 04150, Mexico;*
[4] *Departament d'Enginyeria Minera, Industrial i TIC, Universitat Politècnica de Catalunya, Av. de les Bases de Manresa 61–73, 08242, Manresa, Spain*

Abstract The Mehdiabad deposit in the Yazd-Anarak metallogenic belt (YAMB), central Iran, is the largest carbonate-hosted Zn-Pb-Ba-Cu (-Ag) deposit in the world, with a reserve of 630 Mt sulphide and non-sulphide ore. It was formed during the Early Cretaceous by the replacement of barite and hydrothermally dolomitized breccia bodies of the Taft and Abkuh formations. This deposit consists of different ore zones, including the feeder zone, massive ore (including sulphide-oxide parts), massive barite ore, and copper-rich sulphide-barite ore, formed in an extensional environment related to the Naein-Baft back-arc basin. The deposit is stratabound and comprises a wedge-shaped sulphide-barite orebody with complex replacement textures of sulphides and barite. The primary sulphide ore, including a copper-rich core (with a reserve of more than 50 Mt of copper ore), developed in a barite sheath and characterized by the replacement of barite and pyrite by an assemblage of chalcopyrite, bornite, sphalerite and galena. Several stages of barite and sulphide deposition in the Mehdiabad deposit are similar to those reported in other Irish-type and barite-replacement sediment-hosted Zn-Pb deposits worldwide (e.g., Red Dog deposit, Alaska, USA).

Keywords: Barite replacement, Zebra texture, Metallogeny, back-arc basin

Introduction

More than 350 sediment-hosted Zn–Pb±Ag±Ba deposits have been reported in Iran (Rajabi *et al*., 2012a, 2019a; Rajabi, 2022) occuring in a wide variety of siliciclastic and carbonate rocks from early Cambrian to Tertiary age (Fig. 1A). The Yazd-Anarak metallogenic belt ('YAMB') in Central Iran hosts several carbonate-hosted Zn–Pb deposits, including a number believed to be Irish-type (e.g., Mehdiabad, Mansourabad, and Farahabad) and structurally controlled MVT-type (e.g., Nakhlak and Darreh-Zanjir) mineralizations. Most deposits (e.g., Mehdiabad, Darreh-Zanjir, Farahabad, and Mansourabad) occur within the early Cretaceous Taft Formation in the southern portion of the YAMB (Rajabi *et al.*, 2012a), but a few of the MVT deposits are hosted by Late Cretaceous carbonate rocks (e.g., Nakhlak deposit). Amongst all of these deposits, Mehdiabad is by far the largest Zn–Pb-Ba-Cu (±Fe±Mn) deposit in the world, and us located in the southern Yazd-Anarak metallogenic belt (YAMB) of Central Iran (Leach *et al.,* 2005; 2010; Rajabi *et al*., 2012a; Fig. 1). Ghasemi (2006) and Rajabi *et al.* (2012a) have reported oxide reserves of 45.2 Mt at 7.15% Zn and 2.47% Pb and sulphide reserves of 116.5 Mt at 7.3% Zn and 2.3% Pb in this deposit. However, recent exploration revealed the total geological resource of this deposit to total about 630 Mt at 4.2% Zn, 1.2% Pb, 0.5% Cu and 51 g/t Ag, along with > 42 Mt of barite (Rajabi, 2022; Rajabi *et al.*, 2023).

The origin of the Mehdiabad deposit has been a subject of prolonged discussion since its discovery, and despite several studies (e.g., Ghasemi, 2006; Reichert, 2007; Rajabi *et al*., 2012; Maghfouri *et al*., 2019; Liu *et al.*, 2023; Rajabi *et al.*, 2023), there is still considerable uncertainty regarding its genesis. Ghasemi (2006) investigated the geology and mineralogy of the deposit, and Reichert (2007) provided some geochemical data on the oxide ores and weathering conditions. Rajabi *et al*. (2012a) suggested an Irish-type model for forming the Mehdiabad deposit. Based on geochemistry and geological evidence, Maghfouri *et al.* (2019) suggested the sedimentary exhalative

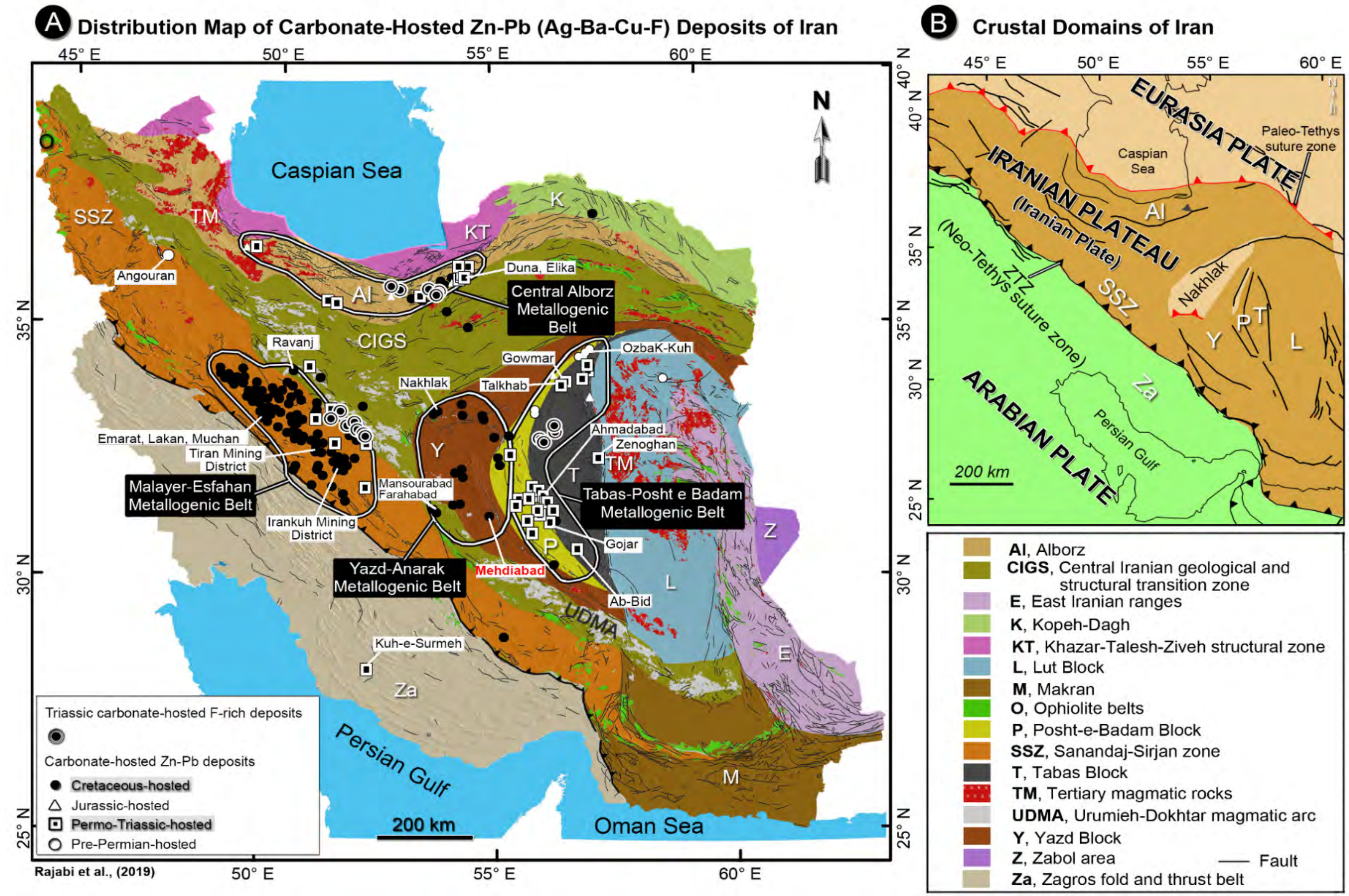

Figure 1: A) *Simplified tectonic map of Iran (Aghanabati, 1998) and distribution map of carbonate-hosted (MVT and Irish-type) Zn-Pb and F-rich deposits according to the age of host rocks in the Central Alborz, Tabas-Posht e Badam, Malayer-Esfahan, and Yazd-Anarak metallogenic belts (Rajabi et al., 2012a; 2019a; 2022).* ***B)*** *Simplified terrane map of the western Tethysides, and crustal domains of Iran (Rajabi et al., 2019a).*

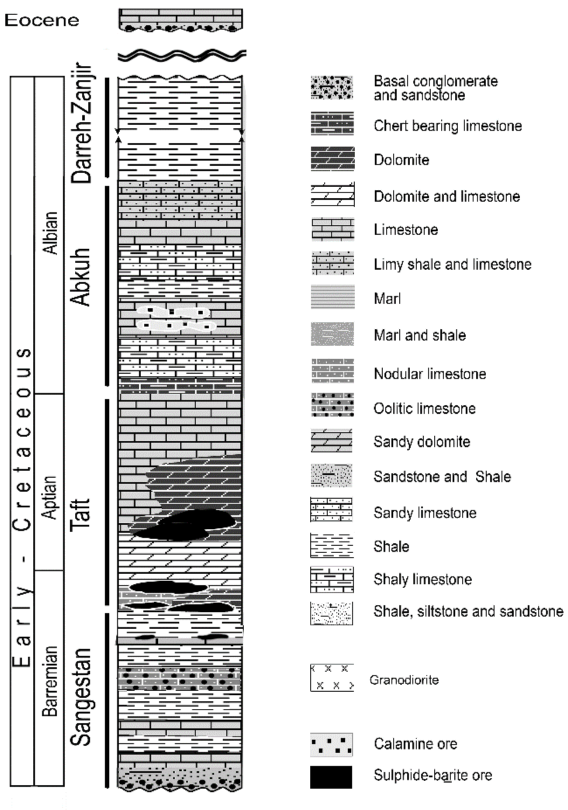

Figure 2: *Generalized lithostratigraphic columnar sections of Mehdiabad deposit (Modified after Rajabi et al., 2012).*

(SedEx) model for forming the Mehdiabad deposit. However, unlike the SedEx deposits, the primary host rock of this deposit is dolomitized limestone and ultimately represents replacement textures. Liu *et al.* (2023) proposed that the barite provided a host and a sulphur source for the later Zn-Pb mineralization in Mehdiabad as an MVT deposit. Here, we review data on the geologic setting, nature and main geological and structural controls of the mineralization; and propose a deposit model.

Tectonic Setting

The Mehdiabad deposit is located in the southeastern part of the YAMB, within the Yazd block of the Central Iranian Microcontinent in the Iranian plateau which coincides with the Cimmerian terranes of Iran. This microcontinent consists of three structural units - from east to west, the Lut, the Tabas, and the Yazd blocks (Berberian & King, 1981; 1982, Alavi, 1994). The Iranian plateau is located along the Tethyan suture between Eurasia (Variscan domain) and the Arabian plate. It records the closure of at least two oceans, the Palaeo-Tethys in the Mesozoic, and the Neo-Tethys in the Cenozoic (Fig. 1B). Recent evidence collected from the ophiolite belts around the Central Iranian Microcontinent shows that they represent sutures that, are in fact, rather complex structures formed as a succession of back-arc basins in the early Cretaceous (Shahabpour, 2005; Bagheri & Stampfli, 2008; Moghadam *et al.*, 2009).

Following the subduction of Neo-Tethyan oceanic crust beneath the southern margin of the Iran Plateau in the early Cretaceous, the Nain-Baft back-arc basin began opening, thus separating the Sanandaj-Sirjan Zone from the Central Iranian Microcontinent (Ghasemi & Talbot, 2005; Moghadam *et al.*, 2009). In addition, the north of Central Iran (e.g., Sabzevar) was affected by a series of back-arc extensional events (Bagheri & Stampfli, 2008). With the opening of these back-arc basins, the Cretaceous is defined on the Iran plateau by a marine transgression, whilst deep water sediments, basaltic pillow lavas, and continental slope deposits accumulated in a number of multi-branched back arcs (Berberian & King, 1981). Rajabi *et al.* (2012, 2023) suggested that the extensional back-arc environment between the Sanandaj-Sirjan Zone and Central Iran in early Cretaceous time created favourable conditions for the formation of VHMS ore deposits within the riftogenic sequence and Irish-type deposits in the passive marginal carbonate platforms on both edges of the basin.

Geologic Setting

In the YAMB, the early Cretaceous sequence comprises (base to top) the Sangestan, Taft, and Darreh-Zanjir Formations. The Sangestan Formation unconformably overlies the Shirkuh granite and metamorphic rocks of the Shemshak Group (Fig. 2). The Sangestan consists of shales and siltstones with intercalated layers of calcarenites and fine-grained to coarse-grained quartz-feldspathic sandstones and sandy shales, and, to the top, changes to limestones with coral fragments (Ghasemi, 2006; Reichert, 2007). This formation is conformably overlain by the Taft Formation (Barremian to probably Aptian in age) and consists mainly of dolomite and dolomitic to ankeritic limestones, with minor organic matter-rich shales, with silty shales at the bottom. This formation is the primary host rock to the Mehdiabad deposits, and its thickness reaches up to 400m in the early Cretaceous carbonate platform of the Yazd Block (Wilmsen *et al.*, 2013). The upper part of the Taft Formation, known in the Mehdiabad area as the Abkuh Formation (informal name; Babakhani *et al.*, 1988), consists of cherty or clayey limestones alternating with massive reef facies and lenses of calcareous shales (Aghanabati, 2004). Shales of the Darreh-Zanjir Formation conformably overlie these sediments (Fig. 2).

A series of N-S and NE-SW fault systems control the structural geology of the Mehdiabad deposit. The Black Hill Fault is the major structural control of the orebodies and defines the western boundary to the mineralization. It is a normal dip-slip fault with an NNW-SSE strike and dips 65º to 70º to NE, on which the hangingwall is the Abkhu and Taft Formations, and the footwall is the Sangestan Formation (Fig. 3). The Black Hill is a syn-sedimentary fault, according to the occurence of sedimentary breccias and debris flows on the west side of the deposit (Ghasemi, 2006; Rajabi *et al*., 2012a; Maghfouri *et al.*, 2019). The geologic map of the Mehdiabad deposit shows the position of the primary faults in this area.

Mineralization

The sulphide and barite mineralization of the giant Mehdiabad deposit occur in the upper part of the Sangestan (minor non-economic ore) and Taft (principal ore) Formations (Ghasemi,

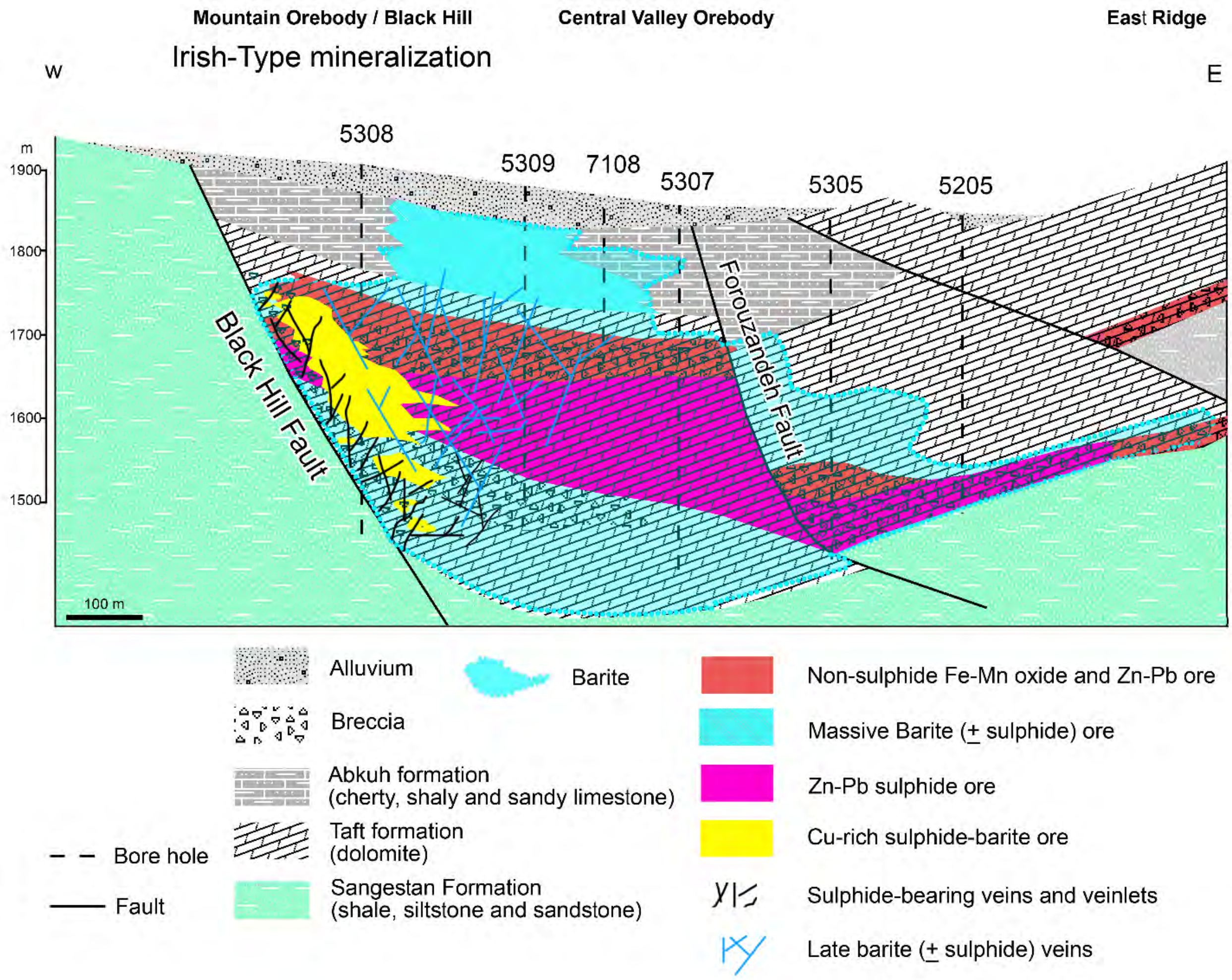

Figure 3: *Schematic cross-section of the Mehdiabad deposit (modified after Reichert, 2007; Rajabi et al., 2012; Lui et al., 2023).*

2006). The main orebody of Mehdiabad occurs within a half-graben within a large N–S synform (Ghasemi, 2006; Reichert, 2007; Rajabi *et al*., 2012a) and is laterally delimited by faults (Fig. 3). The Zn–Pb-Ba-Cu (±Fe±Mn) mineralization occurs along two horizons that extend over a strike length of at least 3.4 km (Reichert *et al.*, 2013; Maghfouri *et al*., 2019). The lower and main horizon of the mineralization is comprising three parts: the Mountain/Black Hill orebody and the Central Valley orebody, with the East Ridge orebody (Fig. 4), hosted in Taft Formation and located in a topographic depression. The second ore horizon is only observed at the Calamine Mine and is hosted in Abkuh Formation. Most parts of mineralization at the Black Hill and East Ridge are oxidized and consist of smithsonite, cerussite, hydrozincite, and hemimorphite, along with haematite and goethite, whereas the Central Valley orebody is mainly formed by sulphide mineralization (sphalerite, galena, pyrite, chalcopyrite, covellite, and chalcocite). The deposit also includes barite, dolomite, siderite, Fe-dolomite, calcite, and quartz as gangue minerals. Bulk barite in the upper part of the deposit is economical, but it is considered a gangue mineral in other parts. The Mountain orebody is limited to the west by the Black Hill Fault and to the east by the Forouzandeh Fault (Fig. 3). The sulphide ores of both Valley and Mountain/Black Hill orebodies are hosted by dolomitic limestones (Rajabi *et al*., 2023).

Based on the orebody geology, mineralogy, ore textures and fabrics, the orebodies in the Mehdiabad deposits can be divided into different ore types, including feeder zone, massive ores (including sulphide-oxide parts), massive barite ores, and copper-rich sulphide-barite ores (Fig. 3). The feeder zone consists of irregular veins and veinlets of dolomite, chalcopyrite, pyrite, galena, barite, quartz, sphalerite, and cut altered and brecciated host rocks adjacent to the Black Hill Fault (Fig. 5). The massive ore includes sulphide in the basal parts, sulphide-oxide in the middle part, and massive Fe-Mn oxides with minor barite at the top. The massive barite ore at the top of the orebodies (Fig. 3A) includes massive replacement and zebra textured barite (Fig. 6) along with minor sulphides that occur above the zone of the later barite stockwork veins (Fig. 3B). These irregular barite veins are widespread in the Mountain/Black Hill and the Central Valley orebodies and cut the whole sulphide and Fe-Mn oxide massive ores (Fig. 3C). Besides the Zn-Pb sulphide mineralization, the copper-rich sulphide-barite zone (Fig. 7) is one of the most economically important orebodies and contains more than 50 Mt of copper ore and is developed

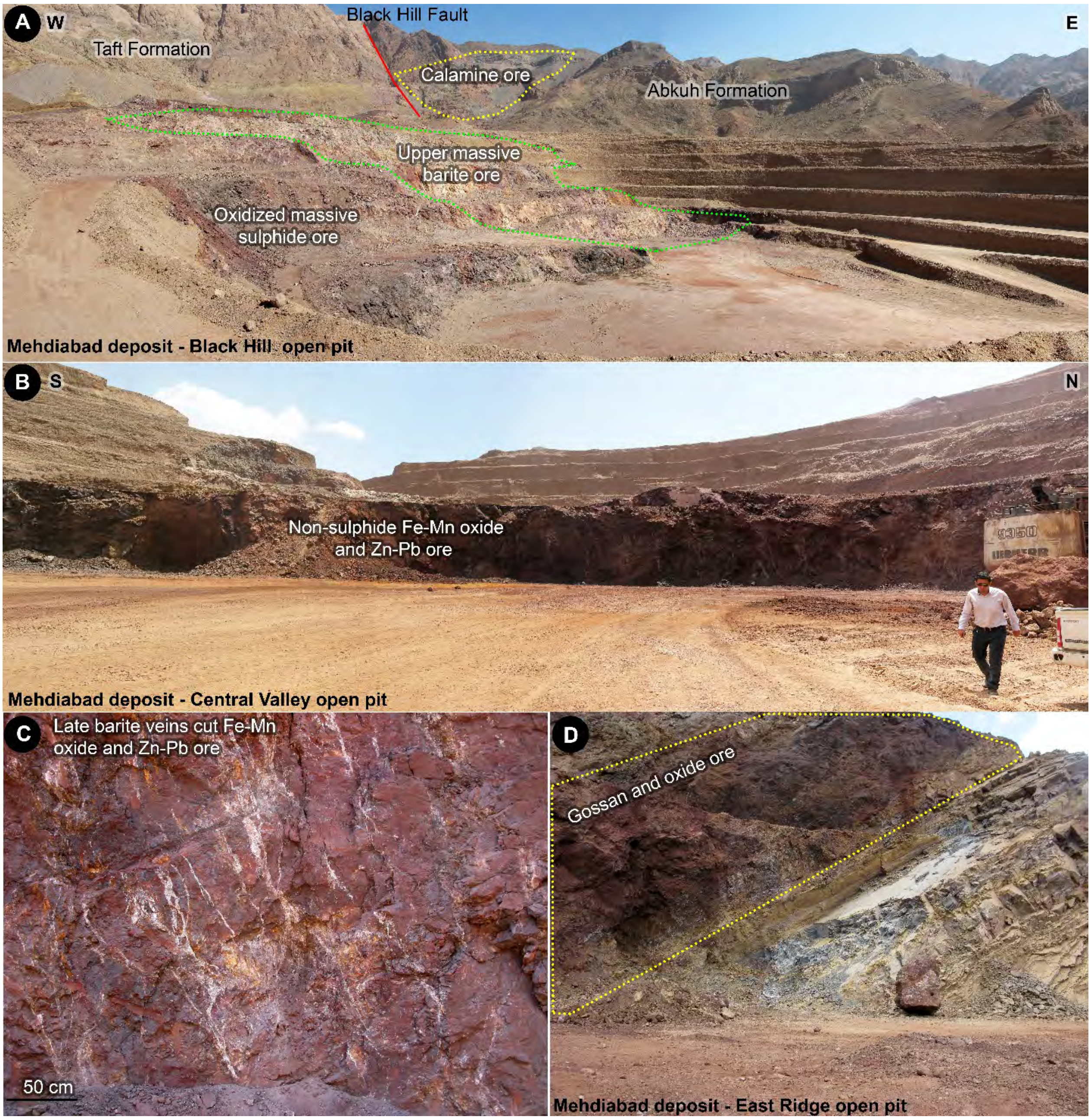

Figure 4: *Outcrop views from Black Hill open pit and Calamine ore (A), Central Valley (B) and East Ridge (D) open pits in Mehdiabad giant deposit, representing oxidized massive ore, upper massive barite, non-sulphide Fe-Mn oxide and Zn-Pb ore, and late barite veins (C).*

proximally to the Black Hill Fault. This cupriferous ore zone contains chalcopyrite, bornite, chalcocite, covellite, minor sphalerite, and galena, replacing earlier coarse-grained pyrite and barite (Fig. 7).

Mineralogy and textural variations

The mineralogy and paragenesis of the sulphide and non-sulphide minerals of the Mehdiabad deposit have been studied by many authors (Reichert *et al.*, 2003; Reichert, 2007; Maghfouri *et al.*, 2019; Liu *et al.*, 2023). Minor laminated sulphides are emphasized by Maghfouri *et al.* (2019). They divided the mineralization into three stages, including fine-grained sulphide lamina and bands (Stage 1) with a syn-sedimentary origin; the coarse-grained base metal sulphides (Stage 2), as breccias and veins to textures that formed by post-sedimentation sub-seafloor replacement; and late stage of mineralization characterized by massive to laminated barite and minor sulphides that formed predominantly on the seafloor.

Lui *et al.* (2023) proposed five stages of mineralization in Mehdiabad, including fine- to coarse-grained barite with lesser siderite formed in Stages 1, 2 and 3; quartz-sulphide mineralization (Stage S_3) deposited in early Cretaceous; and the primary Zn-Pb sulphide mineralization (Stage 5) with massive sphalerite and galena that formed after the early Cretaceous. Never-

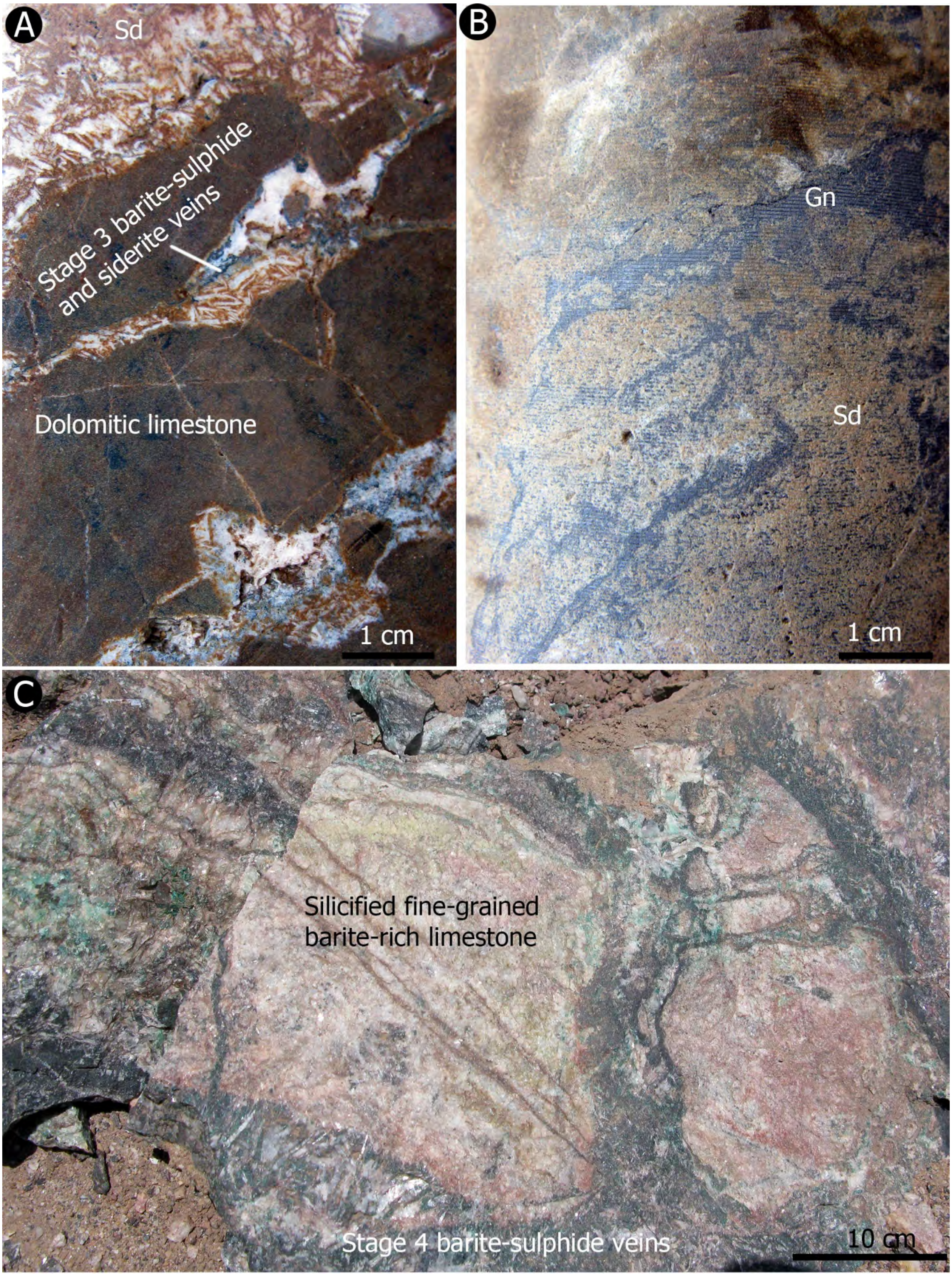

Figure 5: *Complex veins and veinlets of sulphides and barite in the feeder zone of the Mehdiabad deposit. Gn: galena, Sd: siderite.*

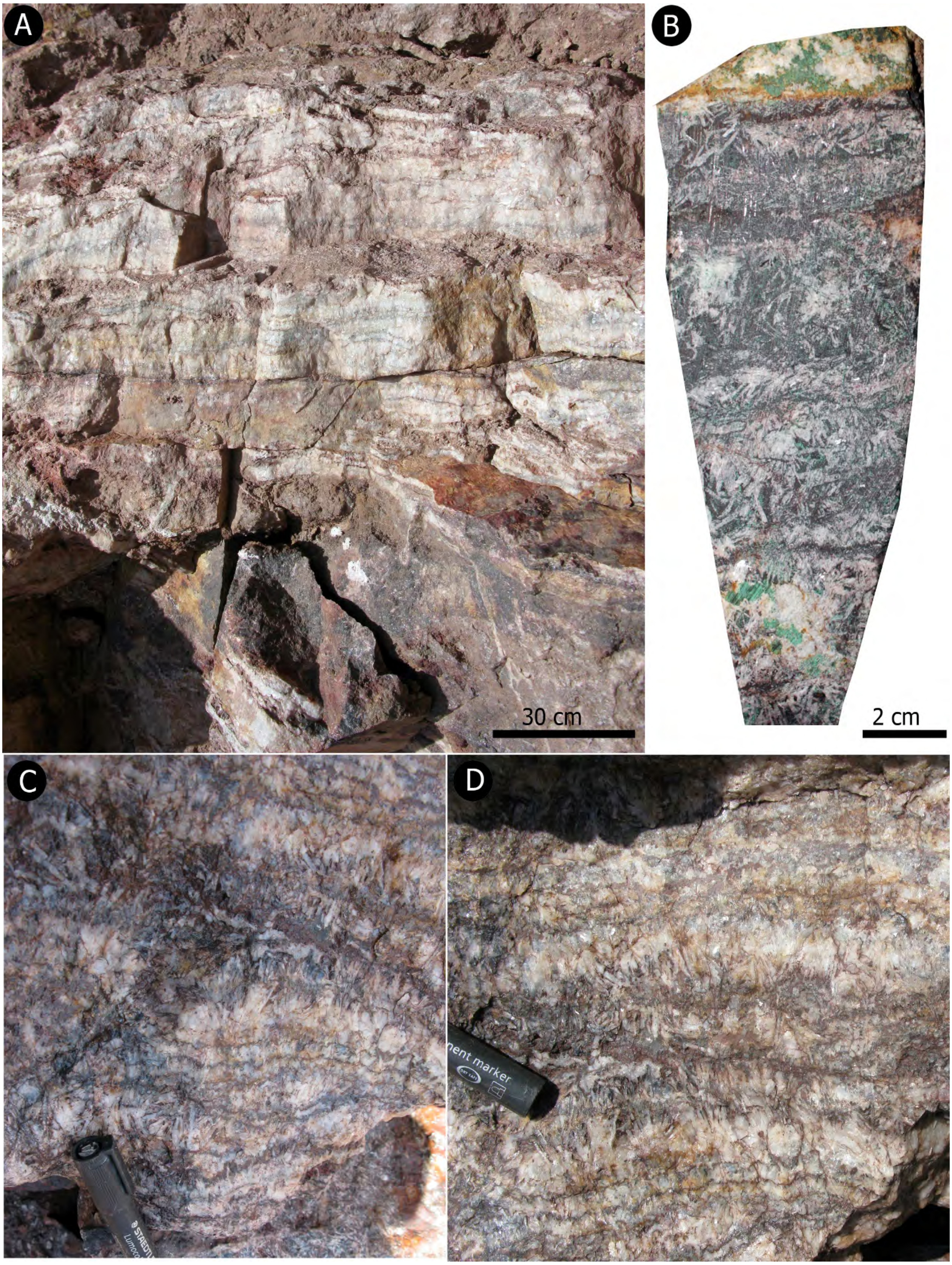

Figure 6: *Crustiform banded barite (A) and zebra texture (B-D) from the Mehdiabad deposit consisting of interlayered barite and altered sulphides.*

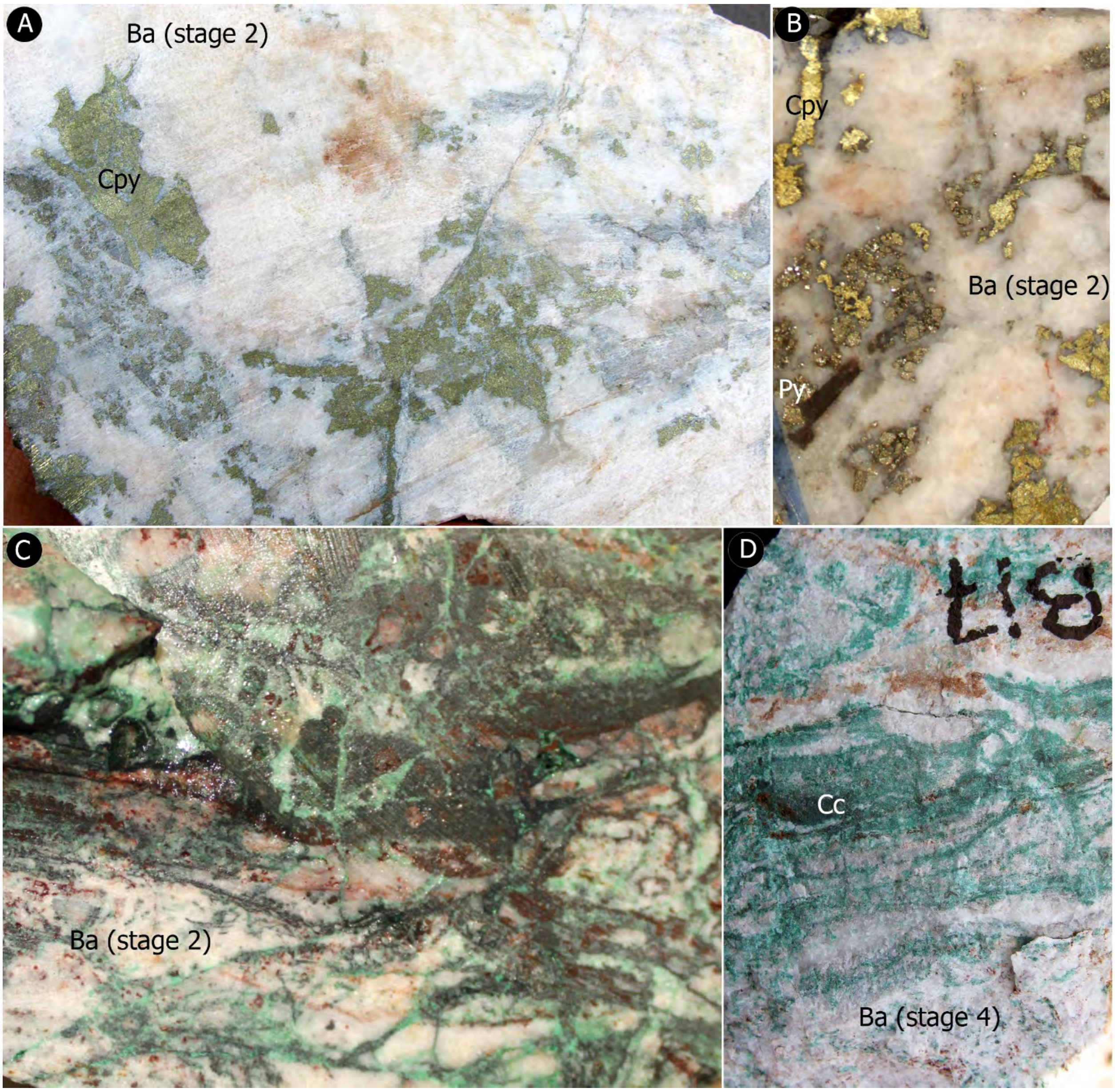

Figure 7: *Hand specimen samples of copper mineralization in copper-rich sulphide-barite ore of the Mehdiabad deposit illustrate the replacement of barite with sulphides. Cpy: chalcopyrite, Py: pyrite, Gn: galena, Cc: Chalcocite, Ba: barite.*

theless, our detailed mineralogical and textural investigation of the ore outcrops in new mining activities and boreholes reveals different ore stages for depositing the sulphide and barite orebodies in this deposit.

The earliest e mineralization is characterized by volumetrically minor sulphides, including framboidal pyrite and fine-grained barite, and minor sphalerite and galena.

Stage 2 includes the pre-sulphide, massive fine-grained barite (up to 1 mm) developed as irregularly distributed tabular crystals in the host carbonate rock (Fig. 5C).

Stage 3 consists of siderite with coarse-grained barite crystals (Fig. 5A, B) up to 3 cm long. These minerals occur mainly as veins, which crosscut and replace earlier mineralization and the carbonate host rocks. When exposed to the outcrop, the Mn-rich siderite makes a brown to black halo of secondary Fe-Mn oxide mineral. In some parts of the mine, this barite is associated with galena, sphalerite, chalcopyrite, colloform pyrite, and siderite, which developed as zebra texture.

Stage 4 of mineralization includes stockwork veins and veinlets composed mainly of quartz, sphalerite, galena, chalcopyrite, bornite, and pyrite. These veins crosscut the previous barite, sulphides and carbonates. Chalcopyrite is observed as a replacement in barite and pyrite (Fig. 5C), in the feeder zone and the massive ore. Galena and sphalerite also replace barite, siderite, and previous sulphides in all veins, especially near the Black Hill fault.

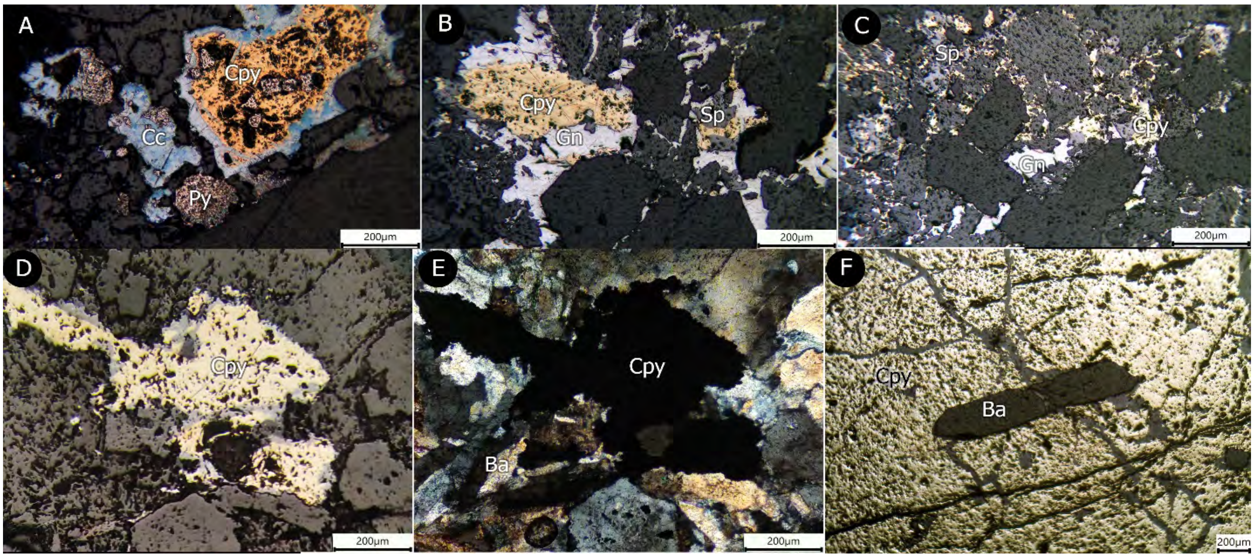

Figure 8: *Photomicrographs of sulphides and barite replacement textures in Mehdiabad deposit.* ***A-C****) Replacement of pyrite (Py) with chalcopyrite (Cpy), galena (Gn) and sphalerite (Sp). Galena and sphalerite also replace chalcopyrite.* ***D-F****) Replacement of barite with chalcopyrite.*

Stage 5 is characterized by white barites, followed by the massive sulphide replacement, with abundant sphalerite and galena. These sulphides replace the former barite crystals and other sulphides. The last stage of mineralization includes the formation of late massive barite at the upper part of the deposit, which is characterized by the widespread zebra texture (barite, sulphides and Fe oxides) at the upper part, and a barite vein network, interrupting the orebodies at the bottom.

Discussion

Some studies have suggested that the giant Mehdiabad deposit is an MVT deposit (e.g., Leach *et al.*, 2005; Song *et al.*, 2019; Lui *et al*., 2023), and others (e.g., Maghfouri *et al.*, 2019) suggests that it is a sedimentary exhalative (SedEx) deposit. Although the simple mineralogy of Stage 1 is similar to that of some shale-hosted massive sulphide Zn-Pb deposits worldwide (Goodfellow & Lydon., 2007; Rajabi *et al.*, 2020), the textures are unlike those believed to have formed by an exhalative process. Laminated monomineralic bands of sulphides are rare at Mehdiabad, and the most laminae and banded ore described by previous authors are, in fact, finely banded replacement barite-sulphides and zebra texture of barite and sulphides at the top of the orebodies.

There were several stages of barite deposition and hydrothermal events in the Mehdiabad deposit. The abundance of barite might be compared with barite forming at cold seeps along modern continental margins. Lui *et al.* (2023) suggested that migrating methane-rich fluids from the Sangestan Formation to the Taft Formation transported Ba^{2+} from marine organic matter dissolved biogenic barites and formed a diagenetic barite front at the sulphate-methane transition zone in the early Cretaceous. In addition, colloform pyrite and dendritic textures and the temporal association with fine-grained barite are common at modern sea-floor vents and also have been described in Irish-type ore deposits (Kelley *et al*., 2004; Wilkinson *et al*., 2005). The banding and crustification of Stages 3 and 5 of barite and sulphides in the vein ores in the Mehdiabad deposit reflect deposition in open space. The occurrence of multiple veins sets primarily near the Black Hill syn-sedimentary fault (south-southwestern margins of the deposit) can represent evidence that these veins may represent feeder zones to the massive barite and sulphide mineralization.

One of the most critical mineralization phenomena at Mehdiabad is the development of copper mineralization in the vicinity of the Black Hill Fault (Fig. 3), which, with a reserve of more than 50 million tonnes, forms an important part of the mineralization. Most of this Cu mineralization is formed within barite-sulphide stockwork veins and includes the replacement by chalcopyrite and bornite of barite and pyrite (Figs. 7, 8). These minerals are often subsequently replaced by later galena and sphalerite. The concentration of copper mineralization in the vicinity of the Black Hill Fault is further evidence of its role in developing mineralization as a pathway for ore-forming fluids. The main stage of sulphide mineralization developed as replacement within diagenetic barite and played a crucial role in forming the later giant Zn-Pb sulphide orebodies (Lui *et al*., 2023).

The fluid inclusion studies (Maghfouri, 2017; Lui *et al.*, 2023; Rajabi *et al*., 2023) completed to date on the Mehdiabad Zn–Pb-Ba-Cu deposit show that the bulk of the homogenization temperature data from hydrothermal calcite, barite, dolomite, and quartz all fall in the range of 80° to 250° C, with the majority falling between 120° and 230° C, and their salinity varies from 1 to 20 wt% NaCl equivalent (Fig. 9). This data represents extensive overlap with other sediment-hosted Zn-Pb deposits (including SedEx, Irish, and MVT types), and even volcanogenic massive sulphide (VHMS) deposits, but the majority of the results are most similar to Irish-type ore deposits and represent higher temperatures than MVT deposits (Fig. 9). Investigation of data on the chemistry of fluid inclusions, resembles

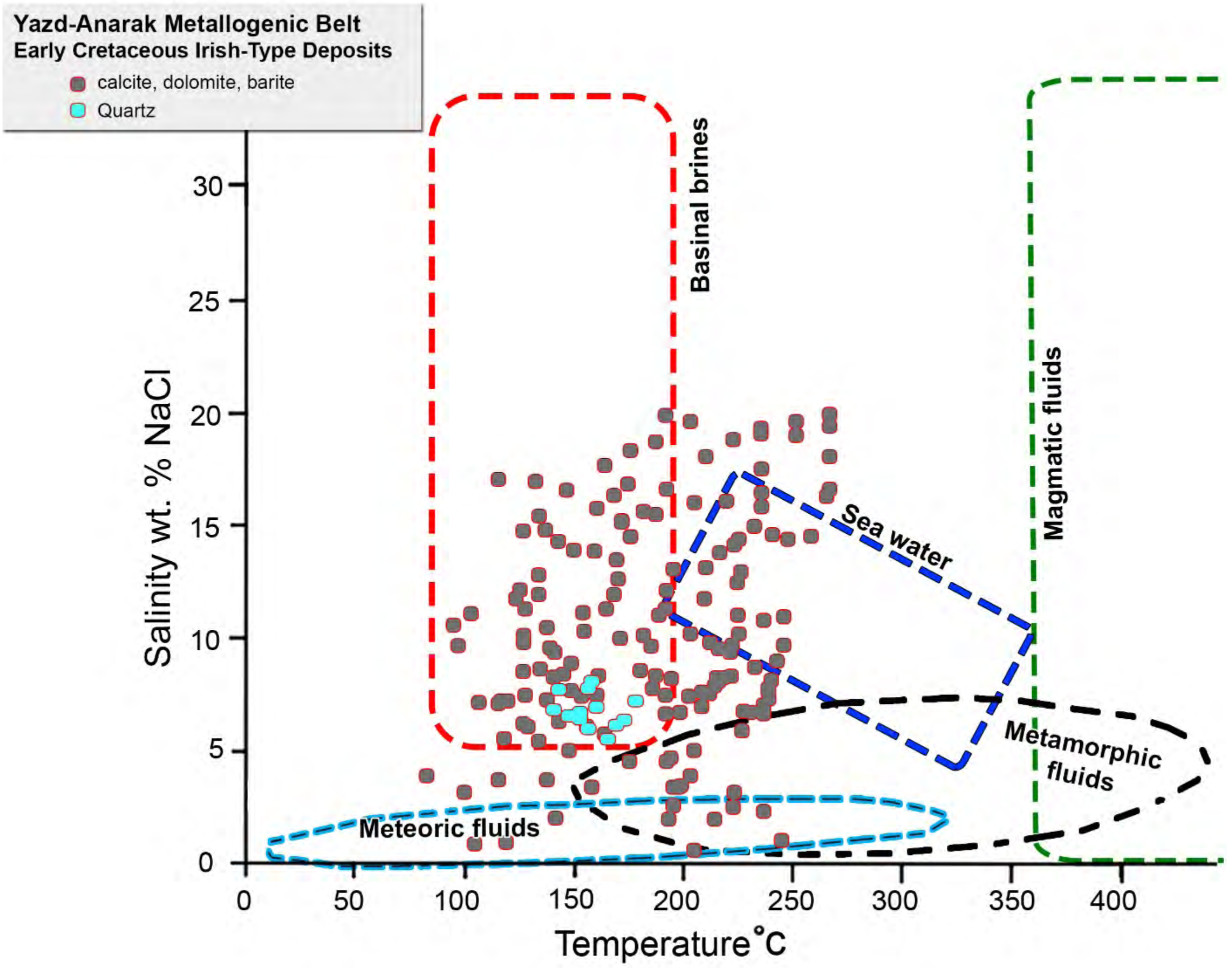

Figure 9: *Summary of published fluid inclusion homogenization temperature–salinity pairs from Mehdiabad deposit (modified after Rajabi et al., 2019b, 2023; Data from Maghfouri, 2007; Lui et al., 2023).*

a series of basinal brines and seawater for the ore-forming fluid (Rajabi *et al*., 2023). According to the geologic, mineralogy and textural features, the Mehdiabad deposit can be classified as Irish-type mineralization that occurred relative to a syn-sedimentary normal fault, in a half-graben structure and shows a significant difference from the orogenic MVT deposits.

Summary and Conclusions

Mehdiabad is the largest carbonate-hosted barite and Zn-Pb-Cu deposit in the world and consists of different ore zones, including the feeder zone, massive ore (including sulphide-oxide parts), massive barite ore, and copper-rich sulphide-barite ore. Consideration of the geologic characteristics of this deposit leads to a recognition of the following features:

(1) The Mehdiabad deposit formed in an extensional environment related to the Naein-Baft back-arc basin undergoing active extensional faulting and subsidence.

(2) The sulphide and barite mineralization is controlled by the syn-sedimentary active Black Hill (normal) Fault that may have acted as the feeder zone and conduit for ore fluids and also generated debris flow breccias.

(3) The deposit is stratabound and comprises a wedge-shaped sulphide-barite orebody.

(4) Orebodies reveal complex textures of sulphides and barite, such as brecciated, replacement, colloform, zebra, banded replacement, and very minor laminated.

(5) Alteration consists mainly of dolomitization and silicification and Fe-dolomite and siderite are also common.

(6) Barite is an important gangue mineral, replaced by coarse-grained pyrite, chalcopyrite, galena and sphalerite. Laminated sulphides are minor, and there is no evidence of exhalation in the formation of orebodies.

(7) Temperatures of ore deposition are typically 80°C to about 250°C (majority 120°-230°C), and salinities range from 1 to 20 wt% NaCl equiv., with the majority falling between 5 and 17 wt%.

These features are similar to those in other Irish-type and some barite-replacement sediment-hosted Zn-Pb deposits worldwide, suggesting that diagenetic and replacement processes in carbonate rocks formed the Mehdiabad deposit.

Acknowledgements

We would like to express our gratitude to Colin Andrew for his support, guidance, and assistance throughout the paper process. This research was made possible through funding from the Society of Economic Geology (SEG) and the Irish Association for Economic Geology (IAEG), to whom we extend our sincerest thanks.

References

Aghanabati, A., (2004). Geology of Iran: Geological Survey of Iran, 600 p.

Alavi, M., (1994). Tectonics of the Zagros orogenic belt of Iran: New data and interpretations: *Tectonophysics*, v. 229, p. 211–238.

Babakhani, A., Samimi, M.N., & Molaali, A.H. (1988). Geological studies on the Mehdiabad lead and zinc project: Geological Survey of Iran, unpublished internal report.

Bagheri, S., & Stampfli, G. M. (2008). The Anarak, Jandaq and Posht-e-Badam metamorphic complexes in central Iran: new geological data, relationships and tectonic implications. *Tectonophysics*, v.451(1-4), 123-155.

Berberian, M., & King, G. C. P. (1981). Towards a palaeogeography and tectonic evolution of Iran. *Canadian Journal of earth sciences*, v.18(2), 210-265.

Ghasemi, M. (2006). Formation mechanism of the Mehdiabad Zn–Pb deposit and its comparison with other near lead and zinc deposits [Unpublished M.Sc. thesis]: Research Institute of Earth Sciences, Geological Survey of Iran, 238 p.

Ghasemi, A., & Talbot, C. J. (2006). A new tectonic scenario for the Sanandaj–Sirjan Zone (Iran). *Journal of Asian Earth Sciences*, v.*26*(6), 683–693.

Goodfellow, W.D., & Lydon, J.W., (2007). Sedimentary exhalative (Sedex) deposits. In: Goodfellow, W.D. (Ed.), Mineral Deposits of Canada: A Synthesis of Major Deposit Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods. *Geological Association of Canada, Mineral Deposits Division, Special Publication*, pp. 163–183.

Kelley, K.D., Dumoulin, J.A., & Jennings, S., (2004a). The Anarraaq Zn-Pb- Ag and barite deposit, northern Alaska: evidence for replacement of carbonate by barite and sulphides. *Economic Geol*ogy v.99, 1577–1591.

Leach, D. L., Bradley, D. C., Huston, D., Pisarevsky, S. A., Taylor, R. D., & Gardoll, S. J. (2010). Sediment-hosted lead-zinc deposits in Earth's history. *Economic Geology*, v.*105*(3), 593–625.

Leach, D. L., Sangster, D. F., Kelley, K. D., Large, R. R., Garven, G., Allen, C. R., & Walters, S. (2005). Sediment-hosted lead-zinc deposits: A global perspective.

Liu, Y., Song, Y., Fard, M., Hou, Z., Ma, W., & Yue, L. (2023). The Characteristics and Origin of Barite in the Giant Mehdiabad Zn-Pb-Ba Deposit, Iran. *Economic Geology*.

Maghfouri, S., Hosseinzadeh, M. R., Choulet, F., Alfonso, P., Zadeh, A. M. A., & Rajabi, A. (2019). Vent-proximal sub-seafloor replacement clastic-carbonate hosted SEDEX-type mineralization in the Mehdiabad world-class Zn-Pb-Ba-(Cu-Ag) deposit, southern Yazd Basin, Iran: *Ore Geology Reviews*, v.113, 103047.

Maghfouri, S. (2017). Geology, Geochemistry, Ore Controlling Parameters and Genesis of Early Cretaceous Carbonate-clastic Hosted Zn-Pb Deposits in Southern Yazd Basin, with Emphasis on Mehdiabad Deposit. Unpublished Ph.D. Thesis. Tabriz University, Iran, pp. 475.

Moghadam, H. S., Whitechurch, H., Rahgoshay, M., & Monsef, I. (2009). Significance of Nain-Baft ophiolitic belt (Iran): Short-lived, transtensional Cretaceous back-arc oceanic basins over the Tethyan subduction zone. *Comptes Rendus Geoscience*, v.*341*(12), 1016–1028.

Rajabi, A., Mahmoodi, P., Rastad, E, Canet, C., Alfonso, P., Niroomand, S., Yarmohammadi, A., Peernajmodin, H., Akbari, Z., (2023). An Introduction to The Early Cretaceous Irish-Type Deposits of Iran. *Irish Association for Economic Geology* (This Violume), 2023.

Rajabi, A. (2022). *Metallogeny and geology of sediment-hosted Zn-Pb deposits of Iran*. The University of Tehran Press. 470 pp.

Rajabi, A., Alfonso, P., Canet, C., Rastad, E., Niroomand, S., Modabberi, S., & Mahmoodi, P. (2020). The world-class Koushk Zn-Pb deposit, Central Iran: A genetic model for vent-proximal shale-hosted massive sulphide (SHMS) deposits–Based on paragenesis and stable isotope geochemistry. *Ore Geology Reviews,* v.124, 103654.

Rajabi, A., Mahmoodi, P., Rastad, E., Niroomand, S., Canet, C., Alfonso, P., Tabakh Shabani, A., & Yarmohammadi, A. (2019a). Comments on "Dehydration of hot oceanic slab at depth 30–50 km: Key to the formation of Irankuh-Emarat Pb-Zn MVT belt, Central Iran" by Mohammad Hassan Karimpour and Martiya Sadeghi. *Journal of Geochemical Exploration*, v.205, 106346.

Rajabi, A., Rastad, E., & Canet, C. (2012a). Metallogeny of Cretaceous carbonate-hosted Zn–Pb deposits of Iran: geotectonic setting and data integration for future mineral exploration. *International Geology Review*, v. 54(14), 1649-1672.

Reichert, J., Borg, G., & Rashidi, B., (2003). Mineralogy of calamine ore from the MehdiAbad zinc-lead deposit, Central Iran. In: Eliopoulos, D.G. (Ed.), *Mineral Exploration and Sustainable Development*. Millpress, Rotterdam, pp. 97–100.

Reichert, J. (2007). A metallogenetic model for carbonate-hosted non-sulphide zinc deposits based on observations of Mehdi Abad and Irankuh, Central and Southwestern Iran.

Shahbpour, J. (2005). Tectonic evolution of the orogenic belt in the region located between Kerman and Neyrize. J*ournal of Asian Earth Science*s, v. *24*, 405–417.

Song, Y.C., Liu, Y.C., Hou, Z.Q., Fard, M., Zhang, H.R., & Zhuang, L.L. (2019). Sediment-hosted Pb-Zn deposits in the Tethyan domain from China to Iran: Characteristics, tectonic setting, and ore controls: *Gondwana Research*, v. 75, p. 249–281.

Wilkinson, J.J., Eyre, S.L., & Boyce, A.J., (2005). Ore-forming processes in Irish-type carbonate-hosted Zn-Pb deposits: evidence from mineralogy, chemistry and isotopic composition of sulphides at the Lisheen Mine. *Economic Geology* v.100, 63–86.

Wilmsen, M., Fürsich, F.T., & Majidifard, J., (2013). The Shah Kuh Formation, the latest Barremian – early Aptian carbonate platform of Central Iran (Khur area, Yazd Block). *Cretaceous Res*. v. 39, 183–194.