Eksplorium *p*-ISSN 0854-1418
Volume 46 No. 2, June 2025: 1095–1106 *e*-ISSN 2503-426X

Studies of Geology, Mineralisation and Fluid Involved in Lead and Zinc Indice of the Dareh Qileh (Northeast of Aligudarz)

Mahdieh Safizadeh

Department of Geology, Payame Noor Universtiy, PO BOX 19395-3697 Tehran, Iran
m.safizadeh@pnu.ac.ir

Article Received: 05 May 2025, **Revised:** 15 June 2025, **Accepted:** 27 June 2025

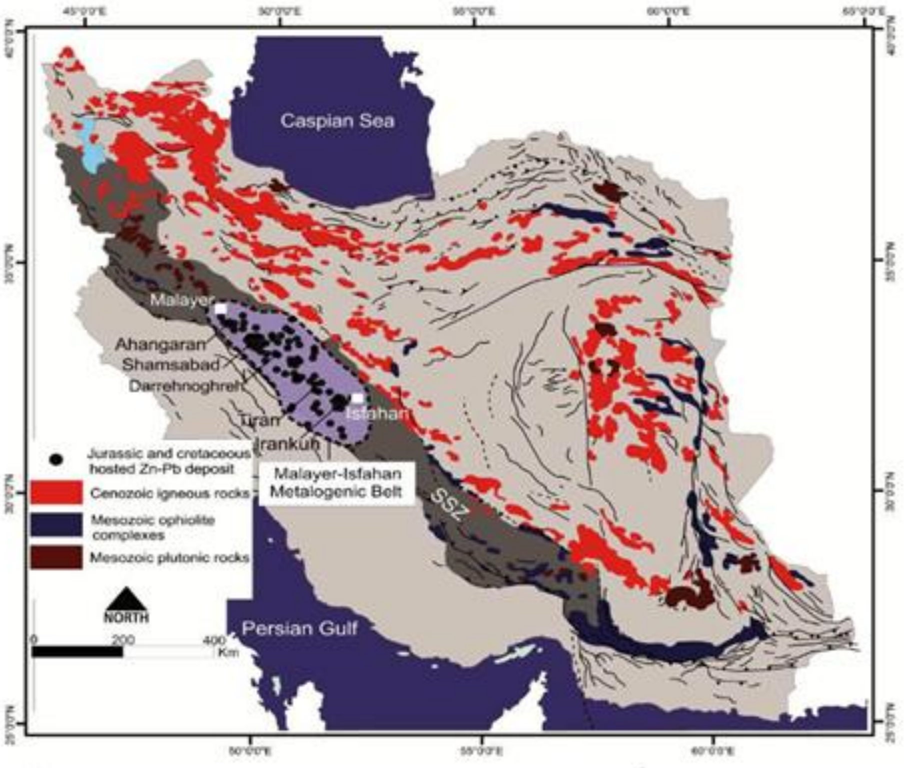
ABSTRACT

The tectono-magmatic evolution of NW Iran records the Paleozoic–early Mesozoic formation and consumption of the Neo-Tethys Ocean. Debate focus on how the regionally-distributed basement exposures and their diverse evolution setting are connected in the division of Iranian tectonic basins. The oldest sediments that are exposed in the study area are the Upper Triassic-Jurassic sediments and sandstones of the region have been altered by the Late Cimmerian phase to the level of the greenschist facies (biotite zone). The structural elements present in the area include faults, folds, joints, and plates. The Upper Triassic-Jurassic sediments and sandstones of the region have been altered by the Late Cimmerian phase to the level of the greenschist facies (biotite zone). The degree of alteration of the rocks in question, based on microscopic studies, is at the level of the albite, epidote-hornfels facies. The mineralization in this deposit has formed in the form of veins and lenses with layering and along the quartz veins. The mineralogy of the mineral includes sphalerite, galena, pyrite and to a very small extent chalcopyrite. In studies of the fluids involved, the homogenization temperature of the fluid inclusions varied in the temperature range between 115-215 degrees Celsius, and based on studies conducted on the samples, the salinity of the fluids involved is equal to 10 to 22 percent by weight equivalent to common salt. The density of the fluids also varies from 0.8 to more than 0.9. According to microthermometry studies, the evolution of the mineralizing fluid was due to mixing with surface waters in the mineralizing fluid, which led to the deposition of the mineral. It can be said that the mineralizing fluid shows a range of characteristics of basin brines and atmospheric fluids. In general, studies show that the deposition of metallic minerals occurred simultaneously from the hydrothermal fluid transported to the region and deposition along the vein quartz left by these fluids. According to the results of the studies and based on the tectonic environment, the type of host rock, the homogenization temperature and the salinity of the fluid interlayers, the deposit can be considered similar to the Irish-type zinc-lead deposits. Our study provides an evolution model that integrates the various complexes of NW Iran into a common Late Cambrian to Late Triassic evolution of the neo-Tethys.

Keywords: Sanandaj-Sirjan, lead and zinc, fluid inclusions , microthermometry, Irish-type deposits

Introduction

Iran has high potential in terms of lead and zinc mineralization, more than 600 mines, deposits and mineral occurrences of lead and zinc are known in the Iranian zone. (Qurbani, 2002; Mehrabi et al., 2024; Nejadhadad et al., 2023). Due to the location of the largest lead and zinc reserves in Iran in the Sanandaj-Sirjan zone, this zone is considered the most important host for lead and zinc mineralization in Iran. In general, sedimentary lead and zinc deposits are divided into two main groups. The first group is deposits with host rocks of shale, sandstone, siltstone or a combination of clastic rocks (SEDEX) and the second group includes deposits in carbonates, which are known by the general name Mississippi Valley Type (MVT).These two groups are considered the most important types of sedimentary lead and zinc deposits. These deposits are not directly related to igneous activities (Leach et al., 2010; Lawley et al., 2022; Salvioli-Mariani et al., 2024). The Dareh Qileh lead and zinc deposit is located 10 km northeast of Aligudarz and northeast of Lorestan province, at the contact of the Cretaceous and Jurassic faults and in the Jurassic metamorphosed sandstones. It is located in the middle part of the Sanandaj-Sirjan zone in the Malayer-Isfahan mineralization region in the division of tectonic basins. The Malayer-Isfahan metallogenic belt, as the most important zone containing lead and zinc deposits in Iran, hosts numerous mineralizations in clastic host rocks of Middle to Upper Jurassic age and carbonate-volcanic units in Lower Cretaceous rock sequences. Considering the type of host rock, which is mainly clastic (shale and sandstone) and carbonate (limestone and dolomitic limestone) belonging to the Late Jurassic and Early Cretaceous, mineralization has mainly formed in the form of veins or veinlets of calcite and quartz as void fillers, in fractures and rarely as dense grains in the host rock. Silicic, dolomitic and calcite alteration are their prominent features. In the studied area, the main minerals include galena, sphalerite, rarely barite and fluorine, and the minor minerals include pyrite, chalcopyrite, marcasite, calamine, rarely iron oxides and lead and zinc carbonates including cerussite and smithzonite. Jurassic clastic units in this metallogenic belt host important lead and zinc deposits and indices. In general, the characteristic of this zone is the widespread presence of Triassic-Jurassic slates and the replacement of granitoid masses (Liu et al., 2023; Ruban, 2024; Soheili et al., 1993). Lead and zinc deposits in the Sanandaj-Sirjan structural zone were formed mainly during the Triassic, in carbonate sequences and next to deep faults (Li et al., 2024; Shahabpour, 2006; Zhou et al., 2024). This study was conducted to investigate the petrography of ore deposits and also to study the fluids involved to investigate the characteristics of the mineralization fluid. The results of this research offer enhanced discrimination for deposits around the world.



Map of Iran's structural zones taken from Agha Nabati 2005 and the location of the Malayer-Isfahan metallogenic belt taken from Rajabi et al.,2012 and Momenzadeh , 1976.

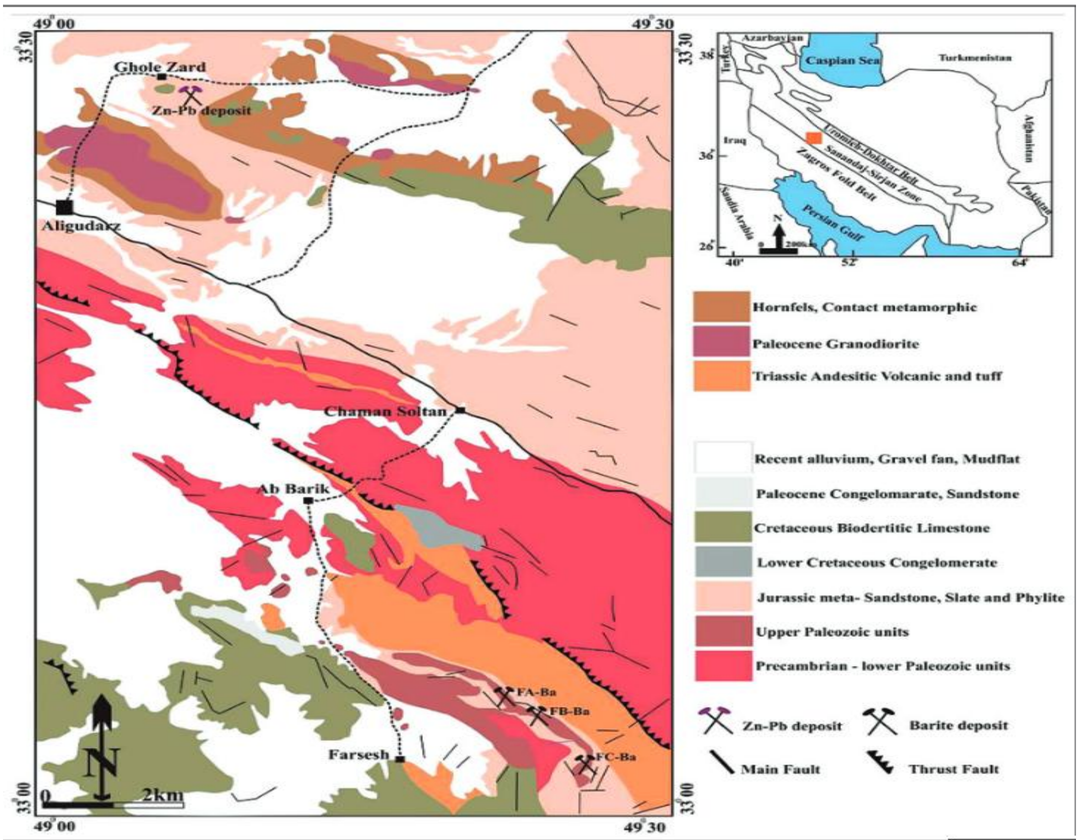
Geology

The Malayer-Isfahan belt, which has been introduced as one of the lead and zinc mineralization areas of Iran, is part of the Sanandaj-Sirjan zone. According to Rastad et al. (2017), the tectonic phase in the Lower Cretaceous was extensional, which led to the formation of subsurface and transsurface basins in the Isfahan-Malayer metallogenic belt, and resulted in the abundance of lead and zinc deposits with sedimentary host rocks. In this belt, in addition to the extensive lead and zinc mineralization, in the Early Cretaceous, iron, manganese, and barite mineralization, etc. can also be noted. This metallogenic belt with a northwest-southeast trend is considered the largest and most important MVT type lead and zinc mineralization belt in Iran, where more than 170 deposits with very high mineral potential have been identified (Bigdeli et al., 2024; Rajabi et al., 2024; Yousefi and Kreuzer, 2024; Yousefi et al., 2024) . Geodynamically, the formation environment of Jurassic lead and zinc deposits includes rift basins within the volcanic arc to the back-arc associated with the subduction of the Neotethys Ocean. Jurassic mineralizations have vein-veinlet, shear, and layered mineralization facies, and the main mineralization process occurred as a succession under the sea floor.

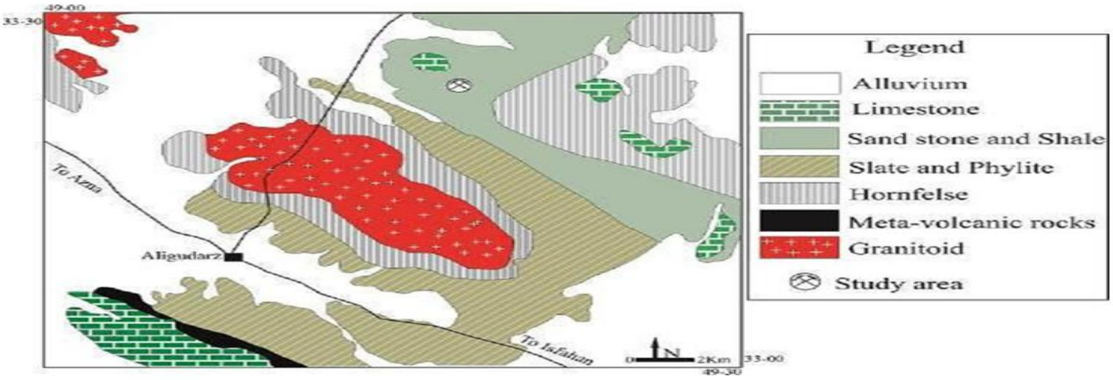
The oldest sediments that are exposed in the study area are the Upper Triassic-Jurassic sediments, which are widely distributed. These sediments consist of a uniform sequence of phyllite, quartzophyllite, and slate alternating with grayish-greenish metamorphic impurity sandstones (Farhadinejad, 1998; Silwal et al., 2024; Sindhuja et al., 2022). Cretaceous sediments are also placed on the Upper Triassic-Jurassic sediments by a fault boundary, and the Triassic-Jurassic sediments have formed as metamorphic sandstones, phyllites, and siltstones several hundred meters thick under the influence of various folding phases. The advance of the Cretaceous sea in the Aptian-Albian caused the deposition of carbonate sediments, which later, under the influence of the Laramide thermodynamic phase, caused folding and schist formation (Lamont et al., 2024; Mehrabi, 2023; Mohajal, 1993). In terms of tectonic and metamorphic characteristics of the Sanandaj-Sirjan zone, the Malayer-Isfahan region is located in the central part of this zone, which includes numerous overthrust, so that the carbonate rocks related to the Cretaceous have been overthrust onto the equivalent formations of Shemshak (Hamedan phyllites). Due to this action, severe deformations have occurred in the region (Alavi, 1994; Kilias, 2024; Vukovski et al., 2024). As a result of the action of tensile phases in the region, the resulting deformations are seen as siliceous boudinages in the limestone. The compressional phases in the region, which are the result of the Cimmerian and Alpine orogeny, have caused the formation of structures with a northwest-southeast extension, which can be called plunge folds, reverse folds and reverse faults. The transformation of Jurassic rocks has caused these rocks to become slate or schist, while the transformation of Cretaceous rocks has caused the formation of crystallized limestones and marble, and this transformation is considered an important factor in the migration of materials (Lefeuvre et al., 2024; Pourbanab, 1991; Zulauf et al., 2024).

The structural elements in the region include faults, folds, joints and plates. The Upper Triassic-Jurassic sediments and sandstones of the region have been altered under the influence of the Late Cimmerian phase to the level of the green schist facies (biotite zone) (Karimi et al., 2025; Mork et al., 2024; Soheili et al. 1931). The thermal effect of the intrusive masses on the rocks of the region (Upper Triassic-Jurassic metamorphosed sediments) is not significant and has only caused the recrystallization of quartz, sericite, muscovite and a small amount of biotite minerals, so that barely any traces of newly formed biotites are observed in them, and the amount of biotites increases as you approach the intrusive mass. The degree of alteration of the aforementioned rocks, based on microscopic studies, is at the level of the albite, epidote-hornfels facies . Lead and zinc mineralization in this region is associated with northwest-southeast trending normal and thrust faults. In addition, mineralization has also occurred in northeast-southwest trending normal faults (Mahdavi-Rahimi, 2010; Sun et al., 2023; Zhang et al., 2024).

The detailed work in the various complexes, as summarized in this chapter, also highlights the problems with the present piecemeal reconstructions. Obvious are the need for more geochronologic data to constrain the duration of specific evolution stages, and more geochemistry for deciphering the tectonic setting of the complexes. Perhaps foremost, we need a testable model that integrates the diverse evolution settings of the complexes, rifting, oceanic-plateau formation, plume activity, arc magmatism, collision and thus promotes future verifications/falsifications of its distinct aspects.



Simplified geological map of the Aligudarz region (with modifications from Soheili et al., 1992).



Geological map of the Dareh Qileh lead and zinc deposit in the Aligudarz region (modified after Soheili et al., 1999).

Research Method

The study includes detailed desert studies and laboratory studies. Accordingly, field studies include a complete survey of the mineral area of the deposit and host rock, rock exposures in the area, and sampling from different parts of the mineralization and selecting 25 hand samples of host rocks and minerals in order to investigate the nature of the mineralized horizons and study the types of minerals. Fifteen samples of quartz related to the mineralization of the area were selected for studies of the fluids involved. Thin and polished sections and double-polished sections were prepared from the aforementioned samples for geological studies and investigations.

Mineralography

One of the important aspects of ore formation is the study of mineralogy and the sequence of mineral formation in the ores. In terms of mineralogy, the Dareh Qileh lead and zinc ore deposit mainly consists of sphalerite and galena with pyrite and very small amounts of very fine-grained chalcopyrite dispersed or included in other minerals. Sphalerite is the most abundant sulfide mineral that is uniformly dispersed in a matrix rich in pyrite and galena. Sphalerite is present as a filler of empty spaces without being associated with any joints, cracks or faults, which indicates that the formation of this mineral is not secondary. Galena is second in abundance after sphalerite, and most of the mineralization of galena has occurred along quartz veins with a replacement texture. Galena is also found in various forms filling voids, which proves its initial presence and coeval with sedimentation in the deposit. Galena is sometimes found in cataclastic form. Pyrites, which often show a dispersed texture, are amorphous. Amorphous pyrite, along with sphalerite, galena, chalcopyrite, are formed in fractures and cracks. The minerals forming the host rock are carbonate minerals, including calcite, which can be seen as coarse-grained in thin sections. Calcite is seen in many cases with a replacement texture in the rock. Quartz veins are abundantly visible. Quartz veins have a replacement texture (Crespo et al., 2024; Gonzalez-Esvertit et al., 2023; Shahabpour, 2006). Scattered quartz grains are also visible in the host rock. This type of quartz is aligned with the layers of the host rock due to the tolerance of the metamorphic phase.The minerals also have a fissure-filling texture, which in this case is located next to the quartz that has been replaced in the host rock. Metal minerals (especially sphalerite) and quartz usually have inclusions of the host rock, which indicates the replacement of the host rock by the mentioned minerals (Frenzel et al., 2025; Ehya, 2008; Tale-Fazel et al., 2023). Quartz is also considered the most abundant waste mineral in the study area, which clearly shows shear, space-filling, fissure-filling, comb, grain, replacement and vein textures, and in some cases it is also present in coarse-grained form (Ge et al., 2023; Lak et al., 2018; Xia et al., 2024;).

Studies of the Involved Fluid

The study of involved fluids helps us to reveal facts about the stages of mineral formation (Goudarzi et al., 2024; Roedder, 1984). The study of early involved fluids has proven to be the best means of determining the temperature of the deposit. The lack of cleavage, transparency of the mineral, and ability to easily recrystallize make quartz a suitable host for involved fluids (Dolnicek et al., 2024; Pe-Piper et al., 2024; Walshe and Hobbs, 1999). The study of involved fluids in the Zn-Pb mineral indice of Dareh Qileh was carried out to investigate the characteristics of the mineralizing fluid on the vein quartz replaced in the host rock.

Investigation of the characteristics of involved fluids in the study area

In the studied samples, the size of the involved fluids varies between about 5 and 10 microns and often has a regular and elliptical shape. The largest involved fluids are two-phase involved fluids (High liquid). Single-phase inclusions that are composed of liquid at room temperature are rare and are not used in thermobarometric studies because it is not possible to observe the gas phase in them. Most of them have a regular elliptical shape and are rarely found in amorphous form. In this type of two-phase involved fluids, including a liquid containing H_2O - CO_2, CO_2 dissolved in water is seen in the form of clathrate during the solidification process. The initial involved fluids of quartz veins appear complete, well-formed and also coarse in microscopic observations. From the study of quartz crystals in veins in the studied area, three types of involved fluids have been identified:

1- L+V type involved fluids: Two-phase involved fluids (High liquid)

In this type of involved fluid, there is a liquid phase along with a gas bubble phase. The liquid phase occupies the largest volume of the involved fluid. The most studied type of involved fluid in the samples is this type of involved fluid.

2- L+V type involved fluids include liquids containing H_2O – CO_2, two-phase involved fluids

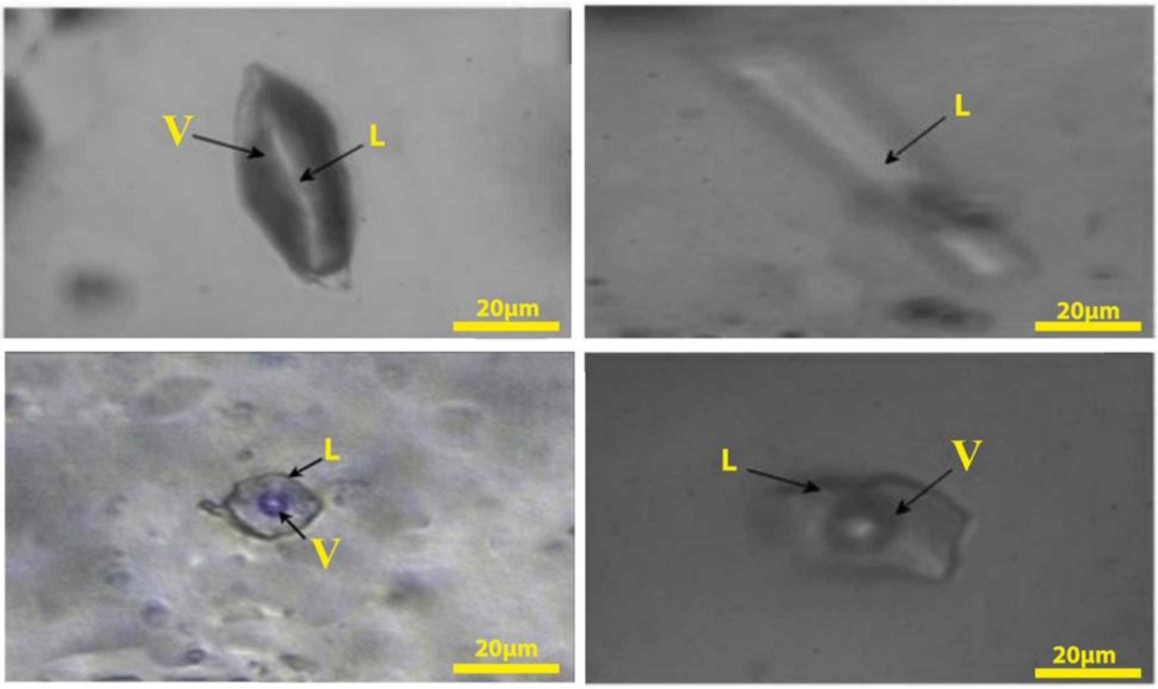
p-ISSN 0854-1418
e-ISSN 2503-426X

This type of fluids contains H2O – CO2. The presence of slightly soluble CO2 in water causes that during the freezing process and measurement of the final melting point of ice (Tm ice), CO2 dissolved in water is seen as clathrate formation and causes positive values to be measured for Tm.

Type L, single phase involved fluids

In this type of involed fluid, the liquid phase occupies the entire volume of the fluid and it is not possible to observe the gas phase, so this type of fluid cannot be used for studies.

Based on the criteria of Roedder (1984), three types of primary fluid inclusion (two-phase liquid-rich (L+V), single-phase aqueous (L) and single-phase vapor (V) inclusions) were distinguished in the ore-veins, without evidence of daughter minerals. In the ore-veins, quartz-hosted LV inclusions have homogenization temperatures ($T_{h)}$ between 270 ˚C- 408 ˚C for stage-1 and 265 ˚C- 385 ˚C for stage 2. These LV inclusions show salinities between 11.1-13.4 wt.% NaCl equivalent in quartz of stage1 and 15.9-19 wt.% NaCl equivalent in quartz of satage-2.



Microthermometry studies

Microthermometry studies are carried out using a microscope equipped with a microthermometry stage in two stages, including heating and cooling, and the data obtained from this stage provide information on temperature, pressure, salinity, density and depth of formation of the deposits. The first stage is to obtain the homogenization temperature or mineralization temperature, in which the fluid inclusions are heated enough to homogenize all their phases into a single main phase, which is called the homogenization temperature (Th). In the measured samples, the temperature when the gas bubble disappears is recorded, which is the homogenization temperature (Th), which is, with some allowance, the same as the mineralization temperature (Bongiovanni et al., 2024; Li et al., 2022; Roedder, 1980) .

In the inclusion freeze test, the fluid is cooled until its liquid phase changes to a solid phase. After cooling the sample again, it is heated until the ice crystal melts. The melting temperature of the last piece of ice is called (Tm), and using (Tm), the salinity of the fluid can be determined. Based on the classification of the origin of the ermacophase, the involved fluids are divided into three types: primary, secondary, and pseudo-secondary. The fluids studied for thermobarometry are primary involved fluids. In the studied samples, the homogeneity temperature of the two-phase involved fluids was measured by converting vapor to liquid, and in two-phase samples with a higher amount of vapor, by converting liquid to vapor. Salinity and temperature are the most important characteristics of a fluid that distinguish between mineral-bearing fluids. The homogenization temperature of the fluid inclusions varied in the temperature range between 115-215 degrees Celsius, and this wide range of homogenization temperatures of the involved fluids indicates that fluid cooling was an important mechanism that caused the precipitation of the relevant minerals in the Dare Qile lead and zinc deposit.

Based on studies conducted on the samples, the salinity of the fluids involved is 10 to 22% by weight equivalent to common salt. The density of the fluids also varies from 0.8 to more than 0.9. According to the data obtained, it can be said that the mineralization sedimentation was due to the mixing of different hot secondary magmatic fluids with atmospheric water, with different temperatures and salinities, and in general, mineralization in the Dareh Qileh lead and zinc deposit is influenced by the mixing of secondary magmatic fluids and atmospheric fluids.

Discussion and Conclusion

The Dareh Qileh lead and zinc deposit is located 10 km northeast of Aligudarz and northeast of Lorestan Province at the contact of the Cretaceous and Jurassic faults and in the Jurassic metamorphosed sandstones. It is located in NW Iran the middle part of the Sanandaj-Sirjan zone in the division of Iranian tectonic basins. The Aligudarz region, located in the middle part of the Sanandaj-Sirjan zone, close to the Zagros thrust, has granitoid intrusive masses, andesitic volcanic rocks, and Precambrian-Paleozoic complexes.

The occurrence of lead and zinc mineralization in Triassic to Jurassic metamorphic rocks northwest of Aligudarz, close to the Middle Jurassic Aligudarz granite (Galindo-Ruiz et al., 2025; Esna-Ashari et al., 2012; Mazhari and Klotzli, 2023), indicates a difference in the host rock and origin of this deposit with other lead and zinc deposits in the Sanandaj-Sarjan zone. It is worth mentioning that lead and zinc and other metal mineralization has not been observed in the vicinity of this granitoid mass. The reason for this is the lack of influence of the heat flux of the intrusive mass on mineralization (Farhadinejad, 1998; Kanellopoulos et al., 2024; Saez et al., 2024). Therefore, petrological and mineralogical evidence indicates that the outcrop of the intrusive mass in the studied area has only caused low-grade deformation and metamorphism in the rock units of the region, as well as the mobility of mineral matter and its placement along quartz veins.

Metals were deposited from hydrothermal fluids in a marine environment. Metal ores were deposited simultaneously by hydrothermal fluids and deposition along vein quartz. The metamorphic phase in the region was the only dynamic one that occurred at very low temperatures, so it is not the cause of mineralization, but only caused deformation and folding in the region, resulting in the mobility and migration of fluids and the creation of mineralization along faults and fractures. Since mineralization has not been observed around the granites of the region, these igneous rocks are not the intended source of hydrothermal activity in the region. Petrographic, mineralogical and geochemical evidence indicates mineralization in a marine environment and the deposition of mineral-forming elements transported to the host rock in the Triassic-Jurassic sedimentary environment.

In order to better understand the genesis and mineralization type of Dareh Qileh deposit, the characteristic features of this deposit have been compared with the characteristic features of MVT and Irish deposit types, considering its carbonate host rock. Some researchers believe that Sedex deposits with carbonate hosts that form in the seabed as a replacement are in a subgroup called Irish-type deposits. Based on the comparison made in MVT type deposits, compressional orogeny stimulates regional fluid flow, because compressional orogeny causes faulting, thrusting, and uplift. Fluids driven by orogeny and topography flow into the sedimentary basin and MVT lead and zinc deposits are formed in them (Asti et al., 2024; Garon et al., 1993; Tavazzani et al., 2024), and mineralization is limited to faults resulting from post-collision tension in the orogeny and and drifting belts.

This is while Irish deposits occur in the continental margin tensile basins and normal faults simultaneously with Sedimentation (Brandl et al., 2024; Wilkinson, 2014; Xu et al., 2024). Since the Isfahan-Malayer belt is considered a back-arc extensional basin (Mohajal and Fergusson, 2014), the geological setting of mineralization in the study area can be similar to Irish-type deposits. and Fergusson), so in terms of The geological position of the mineralization in the study area can be similar to that of the Irish-type cancers. The main cause of the

p-ISSN 0854-1418
e-ISSN 2503-426X

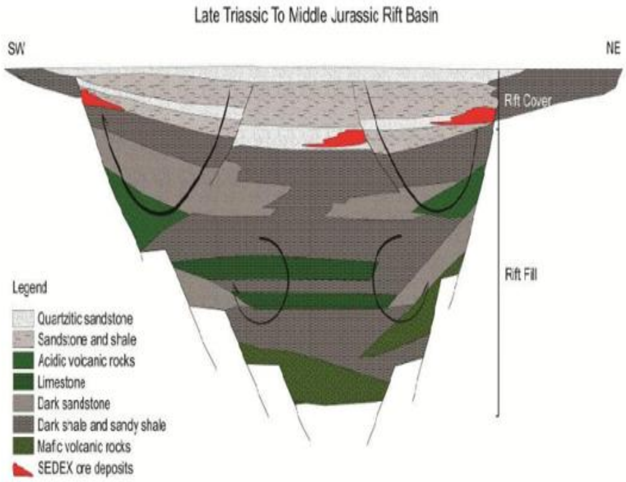
sedimentation of minerals in lead and Irish-type rocks is the mixing of fluids of the hot brine type with cold water (Ma et al., 2024; Walter et al., 2024).

According to the results of the studies, based on the geological environment, the type of host rock, the structure and texture of the mineral, and the homogenization temperature and salinity of the fluid inclusions, which expresses a wide range of homogenization and salinity temperatures, between 115 and 215 degrees celsius and between 10 to 22 weight percent equivalent to common salt, respectively. And also the fluid density varies from 0.8 to more than 9.0 and it can be said to be the bottom line of the mineralization sediment ,due to the mixing of various hot magmatic secondary fluids with atmospheric water, has different temperatures and salinity degrees; and in general, mineralization in lead and zinc deposits in the Dare Qila is influenced by the mixing of secondary magmatic fluids and atmospheric fluids.

It can be said that the main stage of mineralization was formed under the seabed and in the diagenesis stage in the carbonate host rock. Evidence indicates that mineralization occurred in a marine environment and the mineral-forming elements were transported to the Triassic-Jurassic sedimentary environment. The deposition of metallic minerals occurred simultaneously from the hydrothermal fluid transported to the region and deposition along the vein quartz left by these fluids, and then the metamorphism in the region caused the movement and migration of fluids, which caused the minerals to settle along faults and fractures.

(Lower Cretaceous back-arc extensional environment), tectonic setting (formation adjacent to normal faults in subsurface basins), host rock type (platform carbonates), geometric shape of mineralization (consistent with layering), its large lateral extension, the presence of ore facies (vein- veinlet, massive and layered), structural and textural characteristics (shear, replacement, vein- veinlet, dispersed grain), association of mineralization with carbonate-silica alteration, mineralogy and also the temperature characteristics of the fluid affecting mineralization, have a great similarity to the Irish-type zinc and lead deposits. Therefore, considering the above characteristics, the Dareh Qileh deposit can be considered a type of sedex deposits formed under the seabed with a carbonate host, that belongs to Irish type.

A future key aspect for the understanding of the basement exposures of NW Iran lies in the improvement of the age database for the various igneous and sedimentary rocks. Finally, the question of how the Neo-Tethys remnants of NW Iran and Central Iran are related needs to be addressed.



تصویر شماتیک از جایگاه تشکیل کانسارهای SEDEX در حوضه ملایر- اصفهان. این کانسارها در توالی پوشاننده ریفت (واحدهای ماسه‌سنگ، کوارتزیت و شیل دگرگون) تشکیل شده‌اند. رسوبات پرکننده ریفت شامل سنگ‌های آواری و آذرآواری (توف) گروه شمشک (تریاس بالایی- ژوراسیک میانی) هستند. (زمین‌شناسی بر اساس محجل و همکاران، ۱۳۷۱، سهیلی و همکاران، ۱۳۷۱ جعفریان و همکاران، ۱۳۷۸، خلقی و واعظی پور، ۱۳۸۳، کهنسال و همکاران، ۱۳۸٤، غریب و همکاران، ۱۳۸۵) (تصویر برگرفته از Lydon, ۱۹۹٦).

p-ISSN 0854-1418
e-ISSN 2503-426X

Schematic image of the formation site of the Sedex deposits in the Malayer Basin of Isfahan. These deposits are formed in the rift-covering sequence - quartzite ,sandstone and metamorphic shale units. The rift filling sediments inbclude lithoclast and pyroclastic - Tuff - Shemshak Group - Upper Triassic-Middle Jurassic. Geology based on Mohajal et al. 1992 and Soheili et al. 1999 Jafarian et al. 1999 Khaleghi and Vaezipour 1984 and Kohnsal et al. 1985 and Gharib et al. 1996 - Image taken from Lydon 1996

References

[1] Agha Nabati, A. (2004). Geology of Iran, Ministry of Industries and Mines, Geology and Mineral Exploration Organization of the country, 586 pp.

[2] Ahya, F. (2008). Geochemistry and origin of lead and zinc deposits of Emarat and Baba Qoleh- South of Arak, PhD thesis, Islamic Azad University, Science and Research Branch, 178 pp.

[3] Asti, R., Bonini, S., Viola, G., Vignaroli, G. (2024). Reconciling post-orogenic faulting, paleostress evolution and stractural inheritance in the seismogenic Northern Apennines (Italy): Insights from the Monti Martani Fault System. Egusphere,1: 2319:2329.

[4] Bigdeli, A.; Maghsoudi, A.; Ghezelbash, R. (2024). A comparative study of the XGBoost ensemble learning and multilayer perceptron in mineral prospectivity modeling: A case study of the Torud-Chahshirin belt, NE Iran. Earth Sci. Inform. 17: 483–499.

[5] Bonjiovanni, M., Fusswinkel, T., Marks, M.A.W. (2024). Unravelling the effects of magmatic fractionation, fluid phase separation and dilution on the composition of magmatic-hydrothermal fluids of the Cornubian Batholith (SW England). Chemical Geology, 658: 1221-1231.

[6] Boyeri, M., Rastad, A., Mohajal, M., Nakini, A. and Haqdoost, M. (2015). Structure, texture, mineralogy and formation of sulfide facies in zinc-lead-silver deposit (Tepeh Sorkh) with clastic-carbonate host rock, South Isfahan, Quarterly Journal of Earth Sciences, 97: 221-236.

[7] Brandl, P.A., Hannington, M.D., Kratschell, A., Peterson, S., Baxter, A.T., Stewart, M.S., Galley, Ch., Emberley, J., Sander, S.Y. (2024). A new Geological Map of the Marginal Basin of Eastern Papua New Guinea: Implications for Crustal Accretion and Mineral Endowment at Arc-Continent Collisions. Lithosphere, 4(145): 40-50.

[8] Crespo, J., Holley, E., Pfaff, K., Thompson, J.A., Fulton, A., Jilly-Rehak, Ch., Huamani, R., Guillen, M. Characteristics and evolution of quartz-calcite-sulfide veins in the Nazca-Ocona belt, Peru. Ore Geology Reviews, 165: 1058-1068.

[9] Dolnicek, Z., Ulmanova, J., Vrtiska, L., Maly, K., Kotlanova, M.K., Koutnak, R.(2024). Mineralogy and Origin of Vein Wolframite Mineralization from the Pohled Quarry, Havlickuv Brod Ore District, Czech Republic: Interaction of Magmatic and Basinal Fluids. Minerals, 14(6): 610-620.

[10] Farhadinejad. I. (1998). Geology, Mineralogy and Genes of the Gole Zard Zinc and lead deposit, North of Aligudarz, Master's Thesis in Economic Geology, Tarbiat Modares University, Tehran.

[11] Frenzel, M., Rohner, M., Cook, N.J., Gilbert, S., Ciobanu, C.L., Guven, J.F. (2025). Mineralogy, mineral chemistry, and genesis of Cu-Ni-As-rich ores at Lisheen, Ireland. Mineralium Deposita, 143(60): 113-143.

[12] Galindo-Ruiz, J., Ramirez-Montoya, E., Madhavaraju, J., Gonzalez-Leon, C.M., Grijalva-Noriega, F.J., Solari, L., Monreal, R., Espinoza-Maldonado, I.G. (2025). Influence of Triassic and Jurassic arc magmatism in lower jurassic sierra de santa rosa formation, northwestern Mexico: Constraints from geochemistry and U-Pb geochronology. Marine and Petroleum Geology, 171: 1071-1081.

[13] Garven,G. Ge, S. Person, M.A., Sverjensky, D.A. (1993). Genesis of stratabound ore deposits in the Midcontinent basins of North America, American Journal of Science 293(6): 497-568.

[14] Ge, Z., Gu, X., Zhang, Y., Ma, Ch., Hao, D., Zheng, Y., Zhang, X., Wang, L., Liu, M., Chen, W. (2023). Ore Mineralogy, Fluid inclusion Geochemistry, and Zircon U-Pb Geochronology of the Nanmingshui Gold Deposit in East Junggar, Xinjiang, Northwest China: Implications for Ore Genesis, Minerals, 13(10): 1296-1311.

[15] Ghorbani, M. (2002). Introduction to the Economic Geology of Iran, Publications of the Geological and Mineral Exploration Organization of the Country, 695 p.
[16] Gonzalez-Esvertit, E., Canals, A., Bons, P.D., Murta, H., Casas, J.M. (2023). Geology of giant quartz veins and their host rocks from the Eastern Pyreness (Southwest Europe). Journal of Maps, 19(1): 2133-2144.
[17] Goudarzi, M., Zamanian, H., Klotzli, U., Lentz, D., Ullah, M. (2024). Genesis of the Mamuniyeh copper deposit in the central Urumieh-Dokhtar Magmatic Arc, Iran: Constraints from geology, geochemistry, fluid inclusion, and H-O-S isotopes. Ore Geology Reviews, 175: 1062-1072.
[18] Hosseinejad, M.R., EsnaAshari, A. (2013). Applied Issues in Exploration Geochemistry, Isfahan University of Technology Publications.
[19] Kanellopoulos, Ch., Sboras, S., Voudouris, P., Soukis, K., Moritz, R. (2024). Antimony's significance as a critical metal: the global perspective and the Greek deposits. Minerals, 14(2): 121-131.
[20] Karimi, H., Gevorgyan, H., Ratschbacher, L., Yang, Z., Gerdes, A., Etemadi, A. (2025). Decoding the evolution of Paleo-Tethys: Geochemical and geochronological reinterpretation of the Paleozoic ultra-mafic to felsic rocks in Northeast Iran. Lithos, 1: 494-495.
[21] Kilias, A. (2024). The Alpine Geological History of the Hellenides from the Triassic to the Present-Compression vs. Extension, a Dynamic Pair for Orogen structural configuration: A synthesis, Geosciences, 14(1): 10-20.
[22] Lak, F., Zamanian, H., Sameti, M. (2018). Formation of the Lead and Zinc Deposit in the Dareh Qileh, North-East of Aligudarz, National Conference on Knowledge-Based Research in Earth Sciences, Ahvaz.
[23] Lamont, T.N., Loader, M.A., Roberts, N.M.W., Cooper, F.J., Wilkinson, J.J., Bevan, D., Gorecki, A., Kemp, a., Elliott, T., Gardiner, N.J., Tapster, S. (2024). Porphyry copper formation driven by water-fluxed crustal melting during flat-slab subduction. Nature geoscience, 17: 1306-1315.
[24] Lawley, Ch.J.M., McCafferty, A.E., Graham, G.E., Huston, D.L., Kelley, K.D., Czarnota, K., Paradis, S., Peter, J.M., Hayward, N., Barlow, M., Emsbo, P., Coyan, J., SanJuan, C.A., Gadd, M.G. (2022). Data-Driven prospectivity modelling of sediment-hosted Zn-Pb mineral systems and their critical raw materials. Ore Geology Reviews. 141: 111-121.
[25] Lefeuvre, B., Beaudoin, N.E., Centrella, S., Gallais, T.L., Ducousso, M., Callot, J.P. (2024). Dynamic investigation of high-temperature dolomitization of polycrystalline Carrara marble. Chemical Geology, 646, 20: 1219-1230.
[26] Sharma, S. R., & Sharma, M. (2025). Environmentalism of the poor in the face of hydropower expansion in South Asia. South Asian Journal of Social Studies and Economics, 22(5), 188–203. https://doi.org/10.9734/sajsse/2025/v22i51021
[27] Li, B., Zhang, W.D., Zhao, J.X., Liu, P., Feng, J.P., Feng, Y.X., Xiao, Y. (2024). U-Pb geochronology of carbonate-hosted Pb-Zn ores reveals plate-tectonic evolution of eastern Asia during the early Paleozoic. Scientific Reports, 14: 2513-2523.
[28] Li, W.CH., Zhang, X.F., Yu, H.J., Tao, D., Liu, X.L. (2022). Geology and mineralization of the pulang supergiant porphyry copper deposit (5.11 Mt) in Shangri-Ia, Yunnan Province, China: A review. China Geology, 5(4): 662-695.
[29] Liu, L., Xiao, W., Liu, X., Zhao, Z., Wang, Y. (2023). Early Triassic S-Type Granitoids in the Qinzhou Bay Area, South China: Petrogenesis and Tectonic Implications. Minerals, 14(1): 22-33.
[30] Ma, Y., Qin, X., Pan, T., Chen, J., Jiang, Z., Ding, Ch., Zhang, D., Zhang, F., Feng, N., Liu, Ch., Li, Q., Ren, E. (2024). Sedimentary Environment and Source Analysis of Sedimentary Lithium Deposits in Dezong Mahai Salt Lake, Qaidam Basin, Sustainability, 16(23): 10561-10571.
[31] Madani, H. (2007). Principles of Prospecting, Exploration and Evaluation of Mineral Reserves, Khaneh Farhang Publications.
[32] Mahdavi. A. Rahimi B. (2010). Lead and zinc deposits with carbonate hosts in the Malayer-Isfahan axis and their relationship with fault structures, application of Fry analysis method Treatise on Geochemistry 2nd edition. p. 219-249.
[33] Mazhari, S.A., Klotzli, U. (2023). The composition of zircon trace elements in the various Cadomian granitoid types of Taknar zone, south of Sabzevar. Petrological journal, 54: 89-116.

[34] Mehrabi, H. (2023). Deposition, Diagnesis, and Geochemistry of Upper Cretaceous Carbonates (Sarvak Formation) in the Zagros Basin and the Persian Gulf, Iran. Minerals, 13(8): 1078-1088.
[35] Mehrabi, B., Chaghaneh, N., Tale-Fazel, E., Corfu, F. (2024). Geology, fluid inclusions and C-O-S-Pb isotopic compositions of the Chahmileh Pb-Zn deposit, Central Iran: Implications for Ore genesis. Geological Magazine, 160(11): 1953-1974.
[36] Mork, M.B., Mork, A., Johansen, S.K., Drivenes, K., Luidschien, B.A. (2024). Sedimentary facies and mineral provenance of Upper Triassic sandstones offshore Kvitoya, Svalbard: implications for palaeogeographic interpretations in the northern Barents Shelf area. Polar Research, 43: 9715-9725.
[37] Mousavian, S. E., Farhadinejad, T., Shahrokhi, S. V. (2014). Investigation of the Characteristics of Mineral-Forming Fluids in the Zinc and Lead Mineral Indice of Dareh Qileh Aligudarz Using Involved Fluids.
[38] Nejadhadad, M., Taghipour, B., Lentz, D.R. (2023). Implications of multiple fluids in the deposition of Pb-Zn-Ba deposits in the Alvand Mountain, Golpaygan, Iran: Evidence from fluid inclusions and O, C, S isotopes. Ore Geology Reviews. 153:1053-1063.
[39] Pe-Piper, G., Piper, D.J.W., Skarpelis, N., Papoutsa, A. (2024). Chromian minerals and talc veins in the metasandstones of the Ochi nappe, southern Evia, Greece: The role of fluids in retrograde metamorphism during exhumation, Lithos, 1: 482-483
[40] Pir Najmuddin, H., Rastad, E., Rajabi, A. (2018). Structure and texture, mineralogy and study of fluid inclusions, The lead-zinc-barite deposit of Mount Kalangeh, Malayer-Isfahan metallogenic belt, south of Arak, Journal of Earth Sciences, Year 27(107): 287-302.
[41] Rajabi, A., Mahmoodi, P., Alfonso, P., Canet, C., Andrew, C., Azhdari, S., Rezaei, S., Alaminia, Z., Tamarzadeh, S., Yarmohammadi, A., Khan-Mohammadi, Gh., Saeidi, R. (2024). Barite Replacement as a Key Factor in the Genesis of Sediment-Hosted Zn-Pb+Ba and Barite-Sulfide Deposite: Ore Fluids and Isotope (S and Sr) signatures from sediment-hosted Zn-Pb+Ba Deposites of Iran. Minerals. 14(7): 671-681.
[42] Roedder, E., Bodnar, R. J. (1980). Geologic pressure determinations from fluid inclusion studies. Annual Review of Earth and Planetary Sciences, 8: 263-301.
[43] Wilkinson, J. J. (2014). Sediment-hosted zinc-lead mineralization: processes and perspectives.
[44] Ruban, D.A. (2024). Exposure of Carboniferous Granitoids on Triassic-Jurassic Seashores in the Western Caucasus: A Stratigraphical Review. Journal of Marine Science and Engineering. 12(9): 1623-1633.
[45] Saez, R., Gonzalez, F., Donaire, T., Toscano, M., Yesares, L., Almodovar, G.R.D., Moreno, C. (2024). Updating Geological In formation about Metallogenesis of the Iberian Pyrite Belt. Minerals, 14(9): 860-875.
[46] Salvioli-Mariani, E., Boschetti, T., Vescovi, F.M., Scacchetti, M., Toscani, L., Mattioli, M. (2024). Hydrothermal lead-zinc-copper mineralizations in sedimentary rocks of Northern Apennines (Italy). Journal of Geochemical Exploration. 257: 1073-1083.
[47] Sameti. M. (2012). Determination of the Yield of the Gole zard Lead and Zinc Deposit, Northeast of Aligudarz, Lorestan Province, Master's Thesis, Shahid Chamran University of Ahvaz, Iran.
[48] Silwal, B.R., Gyawali, B.R., Yoshida, K. (2024). Geochemical and mineralogical analysis of low-grade metamorphic rocks and their response to shallow landslide occurrence in Central Nepal. Geoenvironmental Disasters, 11(37): 104-114.
[49] Shahabpour, J. (2006). Economic Geology. Kerman Shahid Bahonar University Publications, 470 p.
[50] Simmons, W. (2012). Geochemistry of Sedimentary Deposits, Tabriz University Publications.
[51] Sindhuja, C.S., Manikyamba, C., Saha, S., Narayanan, S., Sridhar, B. (2022). Geochemical and carbon isotopic studies of carbonaceous phyllites from Dharwar craton, India- Reconstruction of Precambrian depositional environment. Precambrian Research, 372: 1065-1075.
[52] Soheili, M. Jafari, M. Abdolhai, M. (2012). Geological Map 1:100,000 Aligudarz, Geology and Mineral Exploration Organization of the Country.
[53] Sun, H., Ouyang, H., Wu, Y., Zhang, Y. (2023). Sulfide Pb-Zn mineralization in the Tianshuihai terrane, northwest Tibetan plateau: A case study of the Huoshaoyun Pb-Zn deposit. Ore Geology Reviews. 163: 1057-1067.

[54] Tale-Fazel, E., Nevolko, P.A., Pasava, J., Xie, Y., Alaei, N., Oroji, A. (2023). Geology, geochemistry, fluid inclusions, and H-O-C-S-Pb isotope constraints on the genesis of the Atash-Anar epithermal gold deposit, Urumieh-Dokhtar magmatic arc, central-northern Iran. Ore Geology Reviews, 153: 1052-1062.

[55] Tavazzani, L., Guillong, M., Giuliani, A., Fontbote, L., Chelle-Michou, C. (2024). Not so fast: Million-years of metal precipitation in Mississippi Valley type deposits inferred from in-situ petrochronology of hydrothermal carbonates, Earth and planetary Science Letters, 636: 1187-1197.

[56] Vukovski, M., Spelic, M., Kukoc, D., Troskot-Corbic, T., Grgasovic, T., Slovenec, D., Tomljenovic, B. (2024). Unravelling the tectonic evolution of the Dinarides-Alps-Pannonian Basin transition zone: insights from structural analysis and low-temperature thermochronology from Ivanssica Mt., NW Croatia. Swiss Journal of Geosciences, 117(16): 1011-1020.

[57] Walter, B.F., Giebel, R.J., Arthuzzi, J.CL., Kemmler, L., Kolb, J. (2024). Diatreme-hosted fluorite mineralization in S-Namibia- A tale of cryogenic brine formation and fluid mixing below an unconformity in the context of Pangea rifting. Journal of African Earth Sciences, 210: 1051-1061.

[58] Xia, M., Yang, X., Hou, Zh. (2024). Preparation of High-Purity Quartz Sand by Vein Quartz Purification and Characteristics: A Case study of Pakistan Vein Quartz. Minerals, 14(7): 727-737.

[59] Xu, H., Sun, X., Xiao, K., Suo, Sh., Huang, X., Liu, S., Zheng. (2024). Classification of volcanogenic massive sulfide deposits in North Qilian, China: Evidenced from lithostratigraphy and geodynamic setting. Ore Geology reviews, 173: 1062-1072.

[60] Yousefi, M., Kreuzer, O. (2024). Towards an effective exploration information system–new concepts and ideas aimed at improving mineral exploration targeting. Appl. Geochem, 106053.

[61] Yousefi, M., Lindsay, M.D., Kreuzer, O.P. (2024). Mitigating uncertainties in mineral exploration targeting: Majority voting and confidence index approaches in the context of an Exploration Information System (EIS). Ore Geol. Rev. 165, 105930.

[62] Zhag, H., Cheng, Sh., Wang, G., Defliese, W.F., Liu, Zh. (2024). Tectonic Inversion in Sediment-Hosted Copper Deposits: The Luangu Area, West Congo Basin, Republic of the Congo, Minerals, 14(11): 1061-1071.

[63] Zhou, J.x., Zheng, Y., Li, Y.J., Ulrich, T., Zhou, L.L. (2024). Mineralization of Zn-Pb-Ag and associated critical metals: An introduction. Ore Geology Reviews, 174: 1063-1073.

[64] Zulauf, G., Dorr, W., Albert, R., Martha, S.O., Xypolias, P. (2024). Provenance of far-traveled nappes in the eastern Mediterranean (Uppermost Unit, Crete): constraints from U-Pb zircon ages of detrital and igneous zircons. International Journal of Earth Sciences, 113: 23-47.