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ZINC-LEAD MINERALIZATION IN NORTHERN AND NORTHEASTERN IRAQ

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ABSTRACT

This is a review paper on zinc-lead deposits and occurrences in northern and northeastern Iraq. These deposits can be genetically classified as low-temperature hydrothermal strata-bound deposits composed of simple sulfide ores of Zn-Pb, commonly associated with barite in the Northern (Ora) Thrust Zone, and as volcano-sedimentary deposits, composed of Zn-Pb-Cu-Fe sulfide ores and Zn-Fe skarns in the Shalair Terrain, NE Iraq. The former deposits are hosted in carbonates of wide age range (Permian – Tertiary), whereas the later (Marabasta) is found in phyllites of the Triassic imbricates. The Zn-Pb mineralizations of Iraq form part of the Alpine Metallogenic Belt extending from the Atlantic Ocean in the west to Iran in the east. They are forming local metallogenic provenances in northern and northeastern Iraq, running parallel to the main fold and thrust belt direction in the north and the Zagros suture in the northeast. Most of them are classified as strata-bound deposits where structure and lithology were the main physical factors controlling the distribution of these deposits. Faults, joints, fractures and permeable strata acted as paths in the transportation of the ore-bearing solutions. Generally, the low-temperature strata-bound deposits of N Iraq are dominated by sphalerite, galena, barite and pyrite with smithsonite, cerussite and goethite as weathering products, while the ore mineralogy in the volcano-sedimentary and skarn deposits in NE Iraq is represented by galena, sphalerite, pyrrhotite, marcasite, arsenopyrite, pentlandite, magnetite, willemite, gahnite and garnet. Limonitic gossans are common phenomena in the oxidized zones of these deposits and occurrences. The mostly studied of these deposits are the Duri-Serguza deposit, described as epigenetic low-temperature strata-bound hydrothermal mineralization, and the Marabasta deposit which was described as a volcano-sedimentary strata-bound deposit, partly developed, by low-grade metamorphism, into a skarn deposit. The Iraqi Zn-Pb-barite deposits and occurrences have not yet been proved to be economic, but they may become a potential source for some metals after further exploration.

تمعدن الخارصين والرصاص في شمال وشمال شرق العراق

صالح محمد عوض

المستخلص

هذه ورقة مراجعة علمية عن رواسب وشواهد تمعدنات الخارصين والرصاص في شمال وشمال شرق العراق. يمكن تصنيف هذه التمعدنات حسب المنشا الى: رواسب حرمائية واطئة الحرارة مرتبطة طباقيا وذات تركيب معدني بسيط من كبريتيدات الخارصين والرصاص مع وجود شائع للبارايت وتوجد في نطاق الدسر الشمالي (اورا). النوع الثاني رواسب

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بركانية – رسوبية من كبريتيدات الخارصين والرصاص والنحاس والحديد مترافقة مع معادن السكارن االمتكونة من الخارصين والحديد وتوجد بشكل راسب منفرد في نطاق الشلير الزاحف في شمال شرق العراق. تعتبر تمعدنات الخارصين والرصاص في العراق جزءا من الحزام الألبي الممتد من المحيط الأطلسي في الغرب الى إيران في الشرق. تتركز هذه الرواسب والشواهد مناطق تمعدنية محلية في شمال وشمال شرق العراق تمتد موازية الى طيات الدسر الأساسية في الشمال ونطاق زاكروس في الشمال الشرقي. تعتبر معظم الرواسب العراقية من النوع المرتبط طباقيا وكان للوضع التركيبي الصخارية الدور الأساسي في تموضعها حيث عملت الصدوع والفوالق والتكسرات كممرت للمحاليل المعدنية.
تسود معادن السفاليرايت والغالينا والبايرايت والبارايت في الرواسب الحرمائية واطئة الحرارة في شمال العراق مع معادن ثانوية من نواتج الأكسده هي السمثسونايت والسيروسايت والغوثايت. وتتميز الرواسب البركانية-الرسوبية في شمال شرق العراق من معدنية أكثر تعقيدا حيث تتكون من الغالينا والسفاليرايت والبيروتايت والماركاسايت والأرسينوبايرايت والبنتللندايت مع مجموعه من معادن السكارن هي الماغنيتايت والوليمايت والغاهنايت والغارنت. تشيع الرواسب الغنية بالليمونايت في مناطق الأكسده في تكشفات كافة هذه الرواسب. تعتبر رواسب الخارصين والرصاص في دوري سركوزه في شمال العراق وماراباستا في شماله الشرقي الأكثر دراسة حيث يعتبر الأول من نوع الرواسب الحرمائة واطئة الحرارة والثاني من نوع الرواسب البركانية-الرسوبية المتحولة حراريا والاثنان مرتبطان طباقيا وعلى الرغم من ان اي منهما لم يرتقي الى مصاف الرواسب الاقتصادية غير انه بمزيد من التنقيب والدراسة يمكن ان يكونا مصدرا لبعض الفلزات المهمة.

INTRODUCTION

Zinc-lead deposits in the world are basically located on both sides of the equator with higher concentration north of the equator within the Alpine Orogeny Belt, which extends from France westward to Iran eastward (Dimitrov, 1978). The Zn-Pb-barite mineralization in the Northern Thrust Zone and Shalair Terrane in N and NE Iraq form part of this belt. The investigation of the metallic deposits in Iraq started in the 1930s by the Site Investigation Company (UK). McCarthy and Smith (1954) explored some of these mineralization sites during geological investigation in NE Zakho region. The exploratory works were followed up by Technoexport (former USSR) in the 1960s. The mineral exploration work and scientific research were continued by Iraq Geological Survey and scientific researchers from the Iraqi universities. They have been able to locate and study new mineralization sites, most notably the Duri Serguza and Marabasta deposits. The former was investigated further by Geozavod (former Yugoslavia) in 1981. The outstanding works done by Iraqi researchers in this respect need to be highlighted here, for example: (Akif *et al*., 1971; and Akif and Venecek, 1972); Sattran *et al.* (1973a and b) Al-Bassam and Akif (1977); Al-Qaraguhli and Lange (1978); Al-Bassam (1979); Al-Bassam *et al*., (1982); Hak *et al.* (1983); Ma'ala *et al*. (1990); Hassan *et al*., (1991); Al-Bassam and Hak (2006); Awadh (2006); Awadh *et al*., (2008a and b), Awadh and Nerbert (2016).

The zinc-lead mineralizations in northern Iraq are limited to the Northern Thrust Zone, where several mineralization sites have been reported, such as Duri-Serguza, Berzanik, Alanish, Marsis, Shiranish Islam, Batruma, Afgizi, Jabal Jalda, Lefan, Banik, and Menin. In the Shalair Terrane of NE Iraq, the Marabasta deposit is outstanding (Fig.1). This review paper includes description of the zinc-lead-barite deposits in N and NE Iraq in terms of geology, mineralogy, geochemistry and origin based on information available collected from the most important studies carried out in this field.

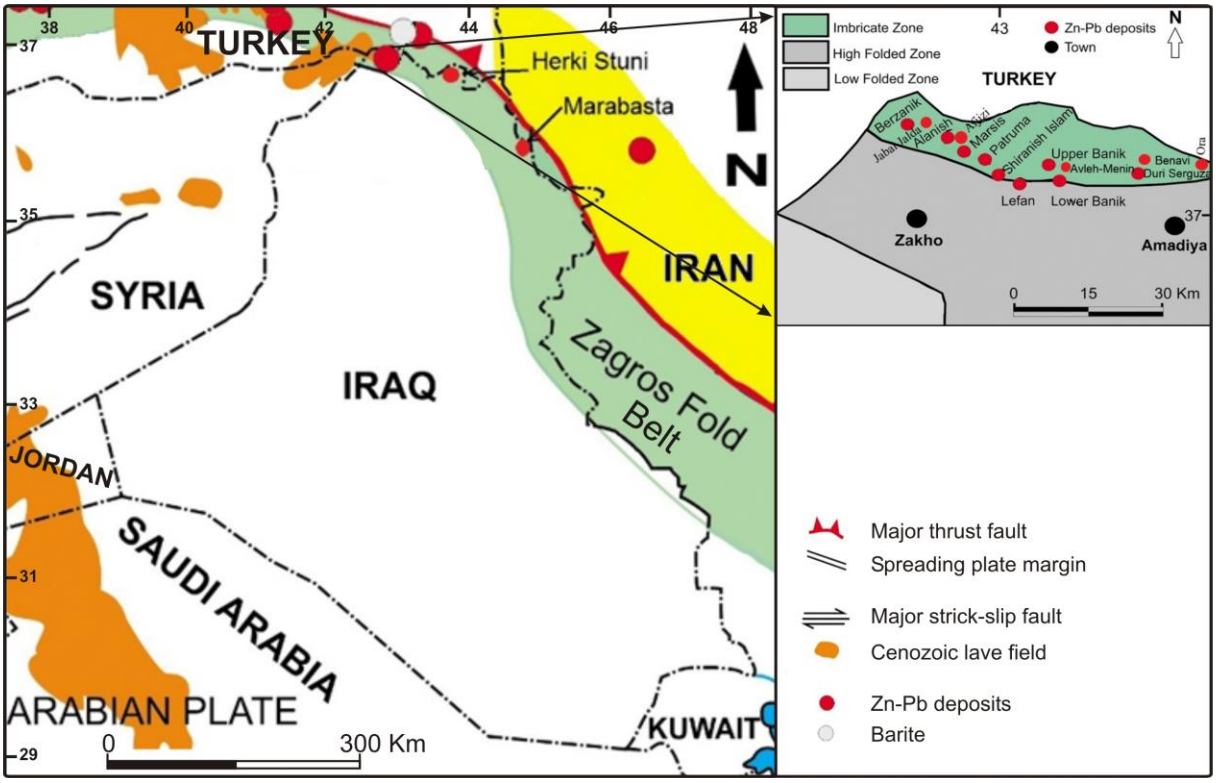

Fig.1: Simplified tectonic map showing the approximate locations of the zinc-lead deposits and occurrences along the major thrust zone in Turkey, Iraq, and Iran. The upper right figure displays zinc-lead deposits and occurrences district (Al-Bassam *et al*., 1982; Jassim and Buday, 2006 and Fouad, 2014)

PREVIOUS STUDIES

Zinc-lead mineralization has attracted the attention of various foreign geological missions in Iraq as well as that of Iraq Geological Survey. McCarthy and Smith (1954) constructed a geological map (scale of 1: 100 000), where some metallic deposit sites were located. Mironov and Sitchenkov (1962) studied the metallic mineral deposits in the Duri-Serguza area, located 17 Km to the north of Amadiya town. They noted that the mineralization is composed of barite with irregular masses and lenses of sphalerite and galena within carbonate rocks, related to a fractured zone in the major thrust fault. They mentioned that the Duri-Serguza mineralization is of epigenetic hydrothermal origin sourced from fluids that were derived from granitic dykes. Abbas (1971) conducted geophysical measurements on the polymetallic deposits of the Duri-Serguza locality. Akif *et al*. (1971) modified the geological map prepared by Mironov and Sitchenkov (1962) to a scale of 1: 2000 and confirmed the structural control on the mineralization in the Duri-Serguza deposit. Al-Bassam (1972) carried out a reconnaissance ore mineralogical study of lead and zinc deposits in northern and northeastern Iraq. Akif and Vanecek (1972) suggested that shear and brecciation zones were responsible for the mineralization in the Triassic dolomitic limestones. They also clarified that the deposits of lead, zinc and barite in the Berzanik region are hosted in limestones and related to the Upper Permian Chia Zairi Formation.

Sattran *et al*. (1973a) studied the Duri-Serguza deposit and made a short report on the mineralization. Sattran *et al*. (1973b) mapped the Marabasta area on a scale of 1: 5000. Akif and Al-Qazzaz (1973) wrote a report on exploration boreholes in Duri-Serguza in the prospecting for the lead-zinc deposit. Sattran *et al*. (1973a) reported that the average content of lead (2.9%) in Duri-Serguza is more than that of zinc (1.8%). Akif and Mustafa (1974) wrote a report on the exploration of lead-zinc mineralization in Marabasta and demonstrated that the deposit is a metamorphosed stratiform deposit of volcanogenic sedimentary origin, subjected to a low-grade metamorphism which resulted in the formation of skarn minerals. Al-Bassam and Akif (1977) proposed that the origin of the ore is hydrothermal metasomatism. Al-Qaraghuli and Lange (1978) interpreted the paragenetic sequence of the ore minerals in the Duri-Serguza locality as first deposition of the colliform-shaped barite, followed by sphalerite, galena and then idiomorphic barite. They also mentioned that the hypogene solution rich in bisulfide complexes with acidic nature at low temperature (less than 250 °C) acted as ore-bearing fluids and reacted with the host carbonates providing favorable environment for the deposition of ore minerals due to the change of the pH value to alkaline.

Al-Bassam and Shahata (1981) conducted geochemical exploration in the Berzanik Pb-Zn-Ba occurrence. Al-Bassam *et al*. (1982) identified more than one generation of sulfide minerals in the Duri-Serguza deposit and measured the absolute age of galena based on lead isotopes and suggested a strata-bound type of lead, zinc and barite deposit hosted by dolomitic rocks of Triassic age. Based on their results the ore (galena) was dated as 140 – 160 Ma, which correspond to Triassic–Jurassic times. Moreover, they have analysed sulfur isotopes in the ore minerals and concluded that the source of sulfur was mainly supplied from submarine volcanic exhalations mixed with normal marine sulfates. Hak *et al*. (1983) studied the mineralogy, paragenesis and origin of the Marabasta base metal deposit, NE Iraq. Based on Pb-model age, they have estimated the mineralization age by 180 – 200 Ma. Ma'ala *et al*. (1990) conducted detailed geological survey in the area near the Turkish border and prepared geological maps at a scale of 1: 20 000. Hassan *et al*. (1991) conducted a geological survey in the Hazel-Su River (Khabour area) which included lead-zinc-barite occurrences in several locations in Lefan-Avla area. Detailed mineral investigation and prospecting for lead, zinc and barite in Alanish, Berzanik and Lefan localities were carried out by Al-Ka'aby and Al-Azzawi (1992). Misconi and Benni (1992) conducted an exploratory geochemical exploration survey between Hazel-Su River and Al-Khabour River using stream sediments survey, and pointed out anomalies of lead, zinc and barium.

A geological and structural study using remote sensing technique has been carried out north of Zakho area by Zaini (2005) who declared the failure of this technique as a tool in the exploration of the lead, zinc and barite deposits. Awadh (2006) introduced a detailed study of some lead-zinc-barite deposits and occurrences N of Zakho area in terms of mineralogy, geochemistry and origin. The mineralogy, ore petrography, geochemistry and genesis of these zinc-lead-barite mineralizations have been investigated by Awadh *et al*. (2008a); Awadh *et al*. (2008b) and Awadh (2009). Tobia (2011) interpreted the origin of barite mineralization of Marsis and Lefan deposits using strontium isotope ratios. Shingaly *et al*. (2014) studied the mineralization in the Bekhme Formation (Upper Cretaceous) in N Iraq. Al-Ka'aby *et al.* (2011) interpreted the Jurassic carbonate-hosted barite deposits NE of Zakho in term of general geology and geochemistry. Awadh and Nejbert (2016) studied the polymetallic sulfide deposits in Alanish locality and concluded that the Zn, Pb, Fe, Cu, Ag, and Cd are epigenetic strata-bound deposits mainly hosted by dolostones of the Upper Permian Chia Zairi Formation in platform carbonate sequences located in the foreland thrust belt. Awadh (2018) mentioned that the Alanish locality represents an important geological site for polymetallic sulfide mineralization of base metals, including silver and cadmium beside the most common metals represented by zinc, lead, iron, copper and barium. Silver and cadmium are present as tiny grains of acanthite and greenokite respectively incorporated within the ore mineralization.

GEOLOGICAL SETTING

The area, north of Zakho is characterized by a complex symmetrical large anticline (Zaini, 2005), formed as a final response to the tectonics of the Arabian, Anatolian and Iranian Plates. The Tethys Ocean was almost closed in northern Iraq during the Lower Paleocene (Al-Sanawi, 2002), and disappeared completely since the Late Miocene (Numan, 2001). The powerful orogeny of the Laramide and the greatest tectonic episode of the Cretaceous, peaked in the Maastrichtian (Buday and Jassim, 1987), whereas, the Pyrenean Orogeny, started at the end of the Tertiary and built up the Northern Thrust Zone, moved the land masses of southern Turkey and northern Iraq southwards (Yazgan and Chessex, 1991). The zinc-lead-barite mineralization in N Iraq is emplaced in carbonates covering a wide age span extending from Late Permian to the Tertiary. The mineralization is part of the Alpine Orogeny Belt extending parallel to the Iraqi – Turkish border on the northern margin of the Arabian Plate. In northern Iraq, this belt marks the collision of the Arabian and Eurasian plates after the consumption of the Neo-Tethyan oceanic crust (Numan, 2001).

The Alpine Orogeny Belt in northern of Iraq is represented by two tectonic units; The Northern Thrust Zone (Taurus Mountains Series) and the Northeastern Nappe Zone (part of the Iranides Mountain Series) representing the Zagros Mountains Zone (Akif and Vanecek, 1972). The E – W trending high folds in the Taurus and Iranides are referred to as the Tethyan trend and those in the NW-SE direction are called the Zagros trend (Stockline, 1968). It is worthy to note the missing of igneous bodies in the Northern Thrust Zone, except of some small basic rocks in the Dira Shish village, small acidic dyke near the Ora village with an acidic tuff extrusion interbedded with green purple clay and black grey flint northeast of Amadiya town (McCarthy and Smith, 1954 and Akif *et al*., 1971). The zinc-lead-barite deposits and occurrences in northern Iraq have no apparent direct relation to igneous activities. The igneous activity in the region was estimated to be of Oligocene or Lower Miocene in age (Hall, 1956) and almost summarized by a series of volcanic igneous rocks, with thickness of 150 m northeast of Amadiya town, composed of acidic tuffs interbedded with a green-purple clay and black grey flint.

The geology in the NE part of Iraq is dominated by the tectonic units of the Zagros Suture Zone, comprised of thrust sheets with outcrops 5 – 70 Km wide forming belt along Iraq – Iran borders. They were emplaced during Late Cretaceous and Late Tertiary thrusting and were the product of complex geodynamic evolution along the Arabian Plate Tethyan margin. Three major tectono-stratigraphic units have been identified by Jassim *et al*. (2006): **(1)** Qulqula – Khwarkurk Zone comprised of deep water passive margin sediments and volcanics, sutured during Late Cretaceous, **(2)** Penjween – Walash Zone which represents the oceanic domain of the central part of the Neo-Tethys and comprises metamorphics and sediments of Cretaceous age and unmetamorphosed Paleogene fore-arc and volcanic arc rocks formed during final closure of the Neo-Tethys and **(3)** Shalair Zone (Terrane) which is part of the Sanandaj – Sirjan Zone of SW Iran, consisting of pre-Cretaceous metamorphic basement of largely Paleozoic pre-Hercynian age, overlain by Triassic rocks and metamorphosed volcanic arc and fore-arc sequences of probable Jurassic – Cretaceous age.

ZINC-LEAD MINEROGENIC DISTRICTS IN IRAQ

Al-Bassam (1986 and 2007) have identified two main Zn-Pb minerogenic districts in Iraq (Fig.2): **(1)** Marabasta Zn, Pb, Fe District in the Shalair Terrane (NE Iraq) where the rocks are mainly of Cretaceous age with Triassic imbricates, and includes the Shalair Group and the Katar Rash Volcanic Group. It is characterized by metamorphosed Zn, Pb and pyrite strata-bound deposits. **(2)** Ora Zn, Pb, Ba District, located N of Zakho city, which is characterized by: **a)** low-temperature hydrothermal vein Zn, Pb, Cu, Ba, pyrite and siderite deposits and **b)** syngenetic strata-bound Zn, Pb, pyrite deposits in carbonate rocks. The Late Triassic, Early Jurassic and the Late Cretaceous are specified by Al-Bassam (2013) as the main metallogenic periods in this district for strata-bound deposits. The zinc-lead mineralizations in the Permian, Triassic and Late Cretaceous carbonates in the Ora Minerogenic District are of low-temperature hydrothermal-vein origin; whereas the syngenetic strata-bound Zn-Pb ores are restricted to the Triassic carbonates (Al-Bassam, 2013).

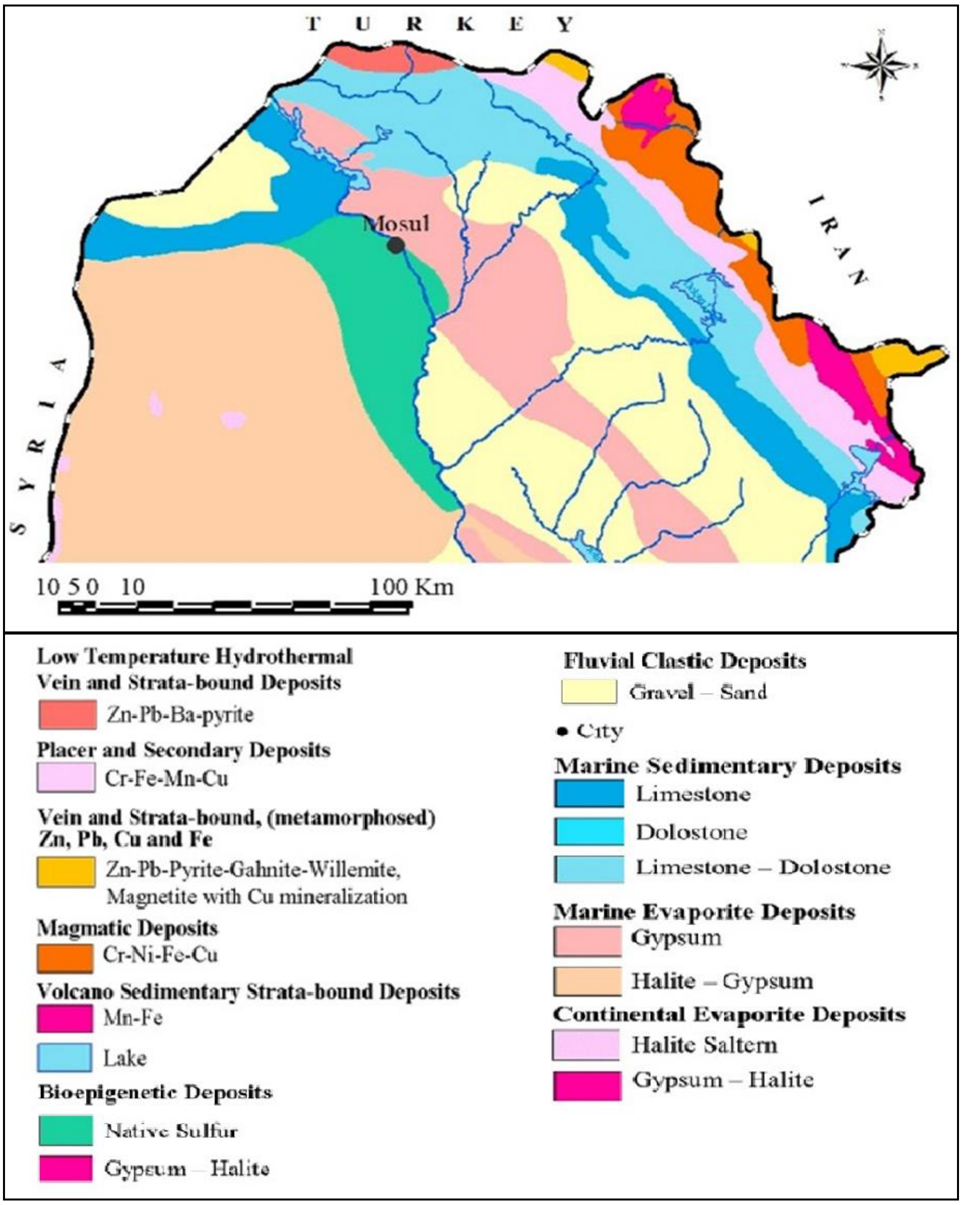

Fig.2: Minerogenic map showing the northern part of Iraq
(cut-off from the Minerogenic Map of Iraq by Al-Bassam, 2007)

The ore deposits and occurrences in the Ora Minerogenic District are numerous and exposed as scattered bodies in carbonate rocks. The ore mineralogy is simple and generally consists of sphalerite, galena and pyrite. Barite is often associated with the ore minerals but may also exist separately. On the other hand, the mineralization in the Marabasta Minerogenic District is more complicated by the presence of skarn minerals of Zn and Fe such as willemite, gahnite and magnetite, in addition to galena, sphalerite, pyrite and pyrrhotite (Hak *et al*., 1983; Al-Bassam and Hak, 2006). The age was suggested to be Late Triassic to Early Jurassic (based on Pb-isotopes) and the origin as volcanogenic strata-bound where the ore minerals were emplaced in the Triassic carbonates which suffered low-grade metamorphism in the later stages. The Marabasta deposit is the sole representative of Zn-Pb mineralization in the Marabasta Minerogenic District.

ZINC-LEAD MINERALIZATION IN THE ORA MINEROGENIC DISTRICT

Numerous Zn-Pb deposits and occurrences, commonly associated with barite, have been discovered and studied in this district. Among these, the Duri-Serguza is the most prominent.

- ***Duri-Serguza deposit and Benavi occurrence***

Tectonics and structure have played an important role in the ore precipitation and localization of the Duri-Serguza deposit. The dolomites of the Kurra China Formation and limestones of Upper Triassic age were thrusted on the Middle Miocene Fatha Formation, and the contact between Triassic and Tertiary rock units was mineralized with Zn-Pb ores over a length of 140 m at depth 30 – 40 m. The mineralogy is dominated by sphalerite, galena, pyrite and barite. Smithsonite, cerussite, limonite, siderite and goethite are the main weathering products (Akif and Al-Qazzaz, 1973). A simple geochemical evaluation of some elements was conducted by Sattran *et al*. (1973a). The mineralization was defined in the beginning as epigenetic deposits but later was suggested as a strata-bound deposit emplaced within carbonates based on ore textures and isotopic data (Al-Bassam *et al*., 1982). This site was described as economic and has the potential of exploitation (Hassan *et al*., 1991). The Benavi occurrence is located about 10 Km west of Serguza. Large cubes of galena were found disseminated within dolomite and limestone of the Jurassic and Triassic units (Mironov and Sitchenkov, 1962).

- ***Berzanik occurrence***

The site is located in a rigged area, 2000 m a.s.l, 25 Km north of Zakho city, 2.5 Km south of the Turkish border and 1.7 Km southwest of the Berzanik village. The mineralization is emplaced in Sirwan, Chia Zairi and Ora Formations with exposure of 20, 5 and 75 m respectively (Hassan *et al*., 1991). The mineralization is characterized by a large vein of barite and gossans occurring in association with the sedimentary succession, chiefly limestone and thin-bedded shales, where the mineralization appears to have been controlled by the main fault in the area (McCarthy and Smith, 1954). The main ore minerals are sphalerite, galena smithsonite and barite.

- ***Alanish occurrence***

Alanish locality has a very complex topography composed of rugged mountainous terrain, with a large change in elevation between the river valley floors and mountain peaks of up to 1000 m. The mineralization is located about 24 Km northeast of Zakho city, 2.4 Km to the north of Alanish village, and 6 Km SW of Berzanik village on an anticline limb extending E – W. The mineralization is exposed on the Late Permian recrystallized dolomitic limestone of the Chia Zairi Formation, along two separated veins which have NE – SE strike (Hassan *et al*., 1991). The mineralization extends within a zone of 100 m long and 2 to 5 m wide. Gossan, iron-rich siderite and barite occur over an area of 130 m long and 2 – 2.5 m wide. Much of the mineralization throughout the area is found along fault planes and appears to have accompanied the structure and dolomitization (Awadh and Nejbert, 2016). The mineralogy is characterized by polymetallic sulfide ores (Zn, Pb, Fe, Cu, Ag, and Cd) of pre- and post-tectonic mineralization stages. The primary sulfide ore minerals (sphalerite, galena, acanthite, pyrite, chalcopyrite, greenockit e, and marcasite) were precipitated from a brine solution derived from the sedimentary basin (Awadh and Nejbert, 2016). The non-sulfide minerals include smithsonite, cerussite and goethite which represent weathering products of the older sulfides in many areas due to supergene process. Open spaces and cavity filling of small paleo-karsts, replacement, veins, and veinlets are common features of the mineralization.

- ***Batruma occurrence***

The mineralization in this site is exposed on the northern slopes of the Khantur Mountain, 23 Km NE of Zakho city, 1300 m a.s.l. controlled by reverse fault at the contact between the Kurra China Formation (Upper Triassic) and the Sarmord Formation (Lower Cretaceous). A large quantity of bitumen interbedded in limestone, dolomite, marl and argillaceous sediments have been found at this site (Hassan *et al*., 1991). In addition, the main reverse fault and smaller faults as well as two sets of joints (35° NE and 80° NW) appear to have affected the mineralization. A mineralized area of up to 4.5 Km long with veins of barite containing galena blebs, have been recognized. Goethite and gossans can be used as field indicators of the mineralization in this site.

- ***Afjizi occurrence***

The mineralization is located near the village of Afjizi near the Iraqi – Turkish border, extending on a cliff between the Berzanik valley and the Mount Halis peak (Hassan *et al*., 1991). This mineralization is emplaced within the limestone rocks in the lower part of the Mirga Mir Formation (Lower Triassic). Smithsonite, barite, siderite and quartz are accessory minerals scattering in association with dolomitic limestone.

- ***Jabal Jalda occurrence***

The mineralization is located about 1.5 Km to the west of the Dira Shir village, on a slope of 1500 m a.s.l (Hassan *et al*., 1991). The mineralization is difficult to be recognized in the field because it is almost hidden under weathering products and dense vegetation. In the region, the dolomites of the Chia Zairi Formation (Permian) are thrusted on the shale beds of the Ora Formation (Carboniferous). Two sets of joints with 60° NE and 60° SE have affected the dolomites of the Chia Zairi Formation. Irregular veins of barite with galena and sphalerite are scattered in the region.

- ***Lefan and Lower Banik occurrences***

The ore occurrences are exposed in both of Lefan and Lower Banik villages (McCarthy and Smith, 1954). They are situated in a rugged terrain, as part of the main thrust zone, north of Zakho. The lead-zinc-barite occurrence in the Lefan locality is located at a height of 1332 m a.s.l (Awadh, 2006). Veins, veinlets and cavity filling represent the mineralization site, extending 10 m wide and 150 m long. The mineralization is exposed on a southern limb of an anticline (Khantour Mountain), striking E – W and dipping 50° S (Awadh, 2006). The mineralization is hosted in carbonates of Aqra – Bekhme Formation (Upper Campanian –

Upper Maastrichtian) and Shiranish Formation (Upper Campanian – Maastrichtian). The ore minerals were deposited preferably in the Aqra-Bekhme Formation rather than the Shiranish Formation due to the permeable rudistic facies of the former (Awadh, 2006; Awadh *et al*., 2008a and b). The Shiranish Formation is exposed at the Lower Banik locality as limestone and dolomitic limestone. In the Lower Banik occurrence the mineralization consists mainly of barite veins which are rarely associated with sphalerite. Barite, in this locality, exists as large veins and as a rose-like shape within the dolomite. The barite and sphalerite mineralization crop out within a shear zone located on a steep dolomite cliff of E – W strike and 65° S dip, mostly belong to the Shiranish Formation. The mineralization sites can often be inferred from the presence of gossans and limonitic stains in the weathered zones.

- ***Menin and Upper Banik occurrences***

The mineral occurrences are exposed in the Upper Banik and Menin villages within the lower part of the Sarmord Formation (Lower Cretaceous). The mineralization, situated at an elevation of 1040 m a.s.l (Awadh, 2006), is exposed in the Menin valley covering a semi-rectangular area of 4 Km long and 60 m wide between Banik and Perbila (Hassan *et al*., 1991). In the Upper Banik, the mineralization is mainly composed of white, highly crystallized barite hosted in brecciated limestones on a rugged mountain to the north of the Lower Banik village, within Unit B (Upper Jurassic) of the Sarmord Formation. It exists as a cavity-fill, up to 40 cm in diameter forming rose-like structure suggesting low-temperature hydrothermal mineralization **(**Paradis *et al*., 2004). Sphalerite and galena are associated with barite in some sites (Hassan *et al*., 1991).

- ***Ora occurrence***

The mineralization in this locality is located 6 km from the Ora village, near the contact between the Mirga Mir Formation (Lower Triassic) and Geli Khana Formation (Middle Triassic) with the Permian rocks of the Chia Zairi Formation. The ore minerals are found within a succession of sandstone, limestone and quartzite in the form of galena, malachite, azurite and chalcocite (Hassan *et al*., 1991).

ZINC-LEAD DEPOSITS IN THE SHALAIR TERRANE

- ***Marabasta deposit***

The Marabasta deposit is the sole representative of the Zn-Pb mineralization in the Marabasta Minerogenic District of the Shalair Terrane. It is located about 36 Km NE of Qala Dizeh town and 1.5 Km from Iraq – Iran border. The mineralization is comprised of a Zn-Pb-Fe mineralization with some skarn minerals of Zn and Fe, emplaced in the Triassic imbricates of phyllites and carbonates, which suffered low-grade regional metamorphism. Some mafic volcanic showings are found in the area. The Marabasta area was covered by geochemical and geophysical survys (Akif and Venecek, 1972; Al-Bassam, 1979). Geochemical anomalies of Pb, Zn, Cu, Ni, Ag, Mo, Sn and V were reported in the soils and stream sediments of the area and found related to the main fault systems (Al-Bassam, 1979). In outcrops, the mineralization was found, as outcrops, in three main sites; Seh-Kuchika, where skarn minerals are common, Darman, where banded sulphides are common and Narta where the sulphide ores are mostly weathered (Bolten, 1956; Hak *et al*., 1983; Al-Bassam and Hak, 2006). Two mineral assemblages have been recognized in the Marabasta deposit; galena-sphalerite-pyrrhotite-marcasite-arsenopyrite on one hand and magnetite-willemite-gahnite-garnet on the other hand (Hak *et al*., 1983). Weathering products are smithsonite, limonite and cerussite.

ORE PETROLOGY

The mineralization in the Ora Minerogenic District commonly consists of sphalerite, galena, pyrite and barite with or without siderite. The ore mineralogy is simple and almost similar in all occurrences. The mineralization at Alanish locality can be considered as an example of these occurrences, where the ore is dominated by sphalerite and galena with minor amounts of chalcopyrite, pyrite, and marcasite. Acanthite and greenockite are present only in this locality (Awadh and Nejbert, 2016). The supergene action resulted in the formation of smithsonite, cerussite, and goethite as weathering products. Two distinctive features of sphalerite at this site were identified; pre-tectonic and post-tectonic mineralization. Barite filled the post-tectonic brecciated sphalerite grains as shown in Fig.3-1. Galena displays an irregular massive and disseminated replacement bodies within the dolomite (Fig.3-2). A curvature cleavage in galena crystals with triangle pits of cleavage are good evidence of post-tectonic deformation (Fig.3-3). Triangular cleavage pits in galena are commonly used as a measure of deformation (Craig and Vaughan, 1981). Cerussite formed and developed along cleavage planes and outer rims of galena due to supergene oxidation (Fig.3-3). Pyrite exists as inclusions within sphalerite and also can be replacing dolomite. The idiomorphic grains of pyrite mostly indicat a pre-tectonic feature by displaying crushing texture (Fig.3-2). Marcasite crystals are found as open-space filling and sometime display dogtooth texture (comb structure). Alteration played an important role along crushed surfaces, producing weathering products; where pyrite and marcasite are altered to goethite (Fig.3-2).

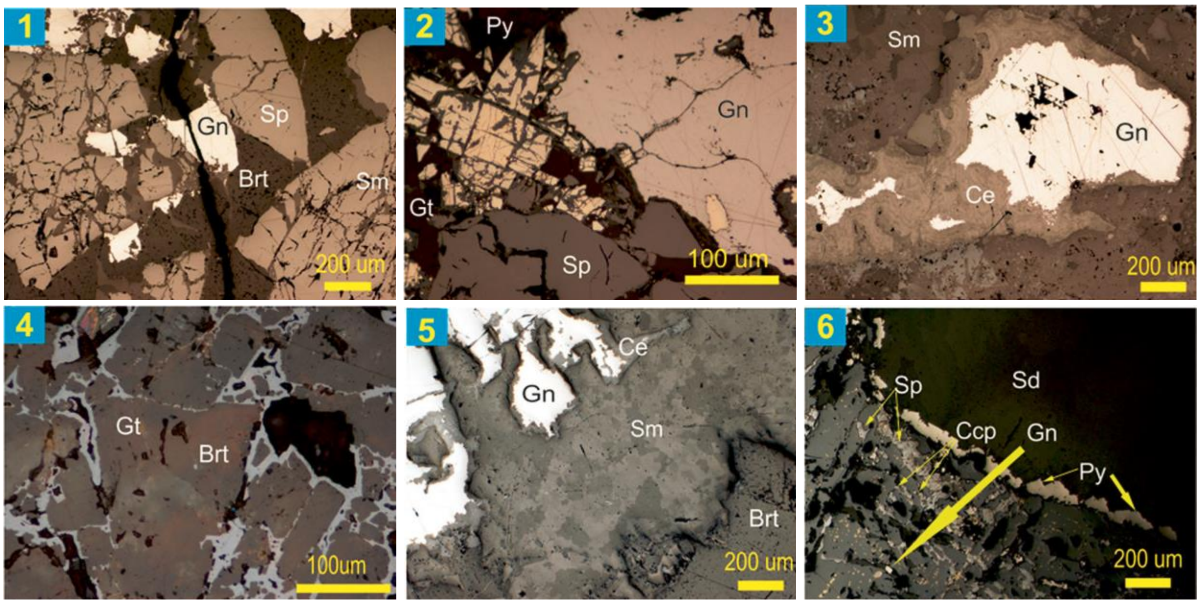

Fig.3: Reflected light micrographs of the ore minerals in the Alanish occurrence (Awadh and Nejbert, 2016): **1)** Barite (Brt) fills fractures of the post-tectonic decomposed sphalerite (Sp); **2)** Irregular mass of galena (Gn) in association with sphalerite enclose pyrite that was altered to goethite; **3)** Cerussite (Ce) replaces post-tectonic galena: **4)** Skeletal texture composed of space-filling goethite (Gt) around barite; **5)** Irregular mass of smithsonite after sphalerite enclosing galena and **6)** Veinlet in siderite shows a chalcopyrite (CCP) disease

Acanthite and greenockite are two ore minerals found in the Alanish locality, identified and studied for the first time by Awadh and Nejbert (2016). Acanthite (silver sulfide) is stable at low-temperature below 177 °C (Bruhwiler *et al*., 1999). It is present as tiny lenticular blebs included within galena and smithsonite. Greenockite was identified as small skeletal-shaped inclusion enclosed in smithsonite. Barite, sometime, forms rose-shaped clusters in dolomites characterized by elongated grains, surrounded by goethite forming a skeletal texture (Fig.3-4). In the oxidizing zone, sphalerite is altered to smithsonite and galena altered to cerussite (Fig.3-5). Chalcopyrite formed from epitaxial growth during sphalerite formation and also by replacement of sphalerite as copper-rich warmer fluids reacts with sphalerite after formation (Fig.3-6). Chalcopyrite cannot dissolve in sphalerite in significant amounts unless temperatures are above 500 °C (Barton and Bethke, 1987).

The mineralization in the Marabasta deposit is more complicated and consists of two mineral assemblages. One assemblage consists of galena, sphalerite, pyrrhotite, pyrite, marcasite, pentlandite and rare arsenopyrite (Fig.4; 1 – 10). The second assemblage is of skarn type and consists of magnetite, willemite, gahnite and rare garnet and nickeline (Al-Bassam, 1972; and Hak *et al*., 1983). The sulfide minerals show more than one generation, replacements, exsolution textures and deformation along cleavage lines of galena (Fig.4; 1 – 10). Secondary minerals include smithsonite, limonite and cerussite. The mieral assemblages show different textures; the first assemblage is characterized by oriented linear textures in massive and banded sulfides and found in Darman and Narta outcrops. The skarn assemblage appears in the She Kuchika ore exposure only.

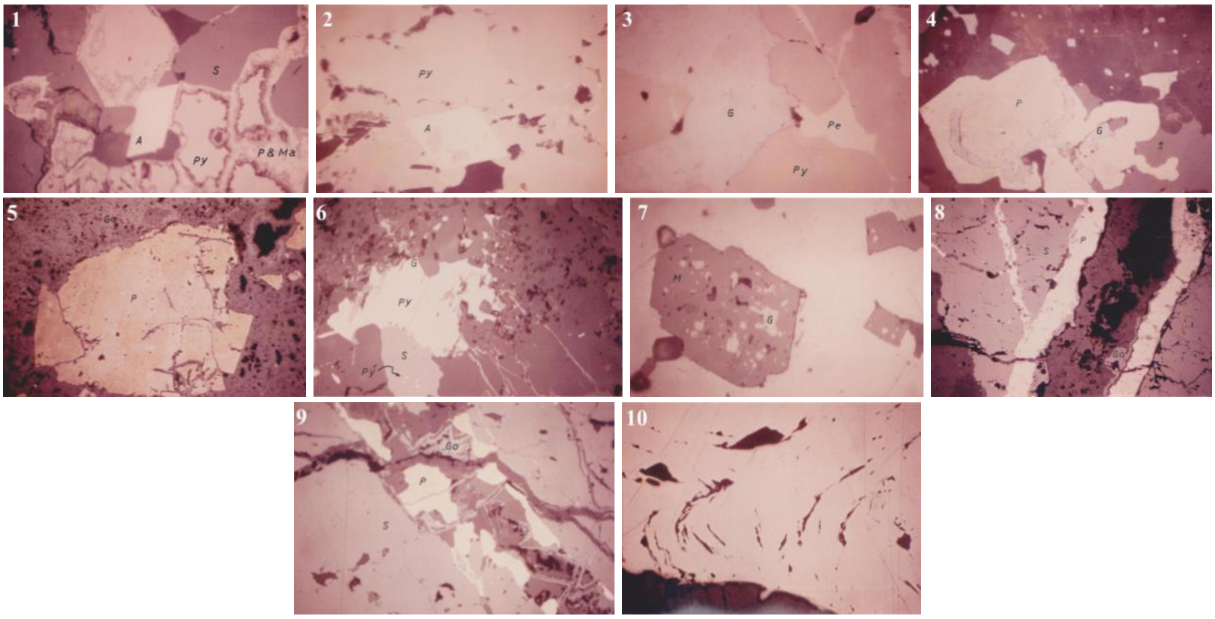

Fig.4: Reflected-light micrographs of ore minerals in the Marabasta deposit (Al-Bassam, 1972): **1)** Pyrrhotite (Py), Arsenopyrite (A), Sphalerite (S) the pyrrhotite has been replaced by pyrite (P) and marcasite (Ma) showing "birds-eye" texture, Darman locality, (X 1240); **2)** Pyrrhotite (Py) and arsenopyrite (A), (X 1240), Darman locality; **3)** Pyrrhotite (Py), pentlandite (Pe) and galena (G). Darman locality (X 1240); **4)** Syngenetic pyrite (P) replaced by galena (G) and sphalerite (S). Darman locality, (X 1240); **5)** Syngenetic pyrite crystal (P) replaced by goethite (Go). East of Seh Kuchika locality, (x120); **6)** Pyrrhotite (Py), sphalerite (S), galena (G) and a second generation pyrrhotite (Pý) occurring as exsolution bodies in the sphalerite, East of Seh Kuchika locality, (X 620); **7)** Magnetite crystals (M), replaced by galena (G), Seh Kuchika locality, (X 1240); **8)** Second generation pyrite (P), first generation sphalerite (S) and goethite (Go); Darman locality, (X 240); **9)** Second generation pyrite (P), sphalerite (S) and goethite (Go). Darman locality, (X 240); **10)** Galena showing deformation in cleavage lines, Seh Kuchika locality, (X 120)

GEOCHEMISTRY

- ***Geochemistry of bulk ore***

The results of the chemical composition of some Zn-Pb-barite deposits and occurrences in the Ora Minerogenic District are presented in Table 4. Geochemistry of bulk ores revealed the average ore grade up to 44.4% ZnO, and 4.1% PbO in Lefan, 27.4 wt.% ZnO, and 2.7 wt.% PbO in Lower Banik, 9.1 wt.% ZnO and 1.2 wt.% PbO in Menin, 1.9 wt.% ZnO and 20 ppm of Pb in Upper Banik. A considerable amount of Fe and Cd was distinguished in the early and second generations of sphalerite, whereas Ag content distinguished the multiple galena generations. The high content of zinc and lead reflects the presence of sphalerite and galena in significant amounts in the deposits. Zinc concentration is approximately 10 times greater than that of lead. Iron is a reflection of pyrite, goethite, siderite and sphalerite. Barite often accompanies these deposits, either as an associate mineral with sphalerite-galena assemblage or as an independent mineral in veins. The ore is often emplaced within the dolomitic limestone, where the concentration of magnesium is high (Table 4).

Table 4: Chemical composition of bulk Zn-Pb-pyrite-barite ores in some localities in the Ora Minerogenic District (Awadh, 2006)

Elements	Unit	Statistics	Lefan (21 samples)	Lower Banik (15 samples)	Menin (17 samples)	Upper Banik (20 samples)
ZnO	%	Range	20.15 – 53.21	18.02 – 39.1	1.99 – 16.62	0.25 – 3.95
		Average	44.4	27.4	9.1	1.9
PbO	%	Range	1.99 – 7.64	0.09 – 4.6	0.03 – 2.97	0.001 – 0.02
		Average	4.1	2.7	1.2	0.002
BaO	%	Range	0.33 – 25.0	0.001 – 3.11	n.d	35.0 – 65.0
		Average	4.1	1.0	n.d	47.5
Fe_2O_3	%	Range	3.32 – 18.0	1.05 – 20.12	0.51 – 5.61	0.09 – 3.35
		Average	8.3	10.6	2.8	1.3
CaO	%	Range	1.26 – 30.6	10.88 – 29.71	20.59 – 38.0	0.33 – 20.11
		Average	5.2	19.9	29.4	9.3
MgO	%	Range	0.06 – 3.2	1.91 – 6.83	12.2 – 20.91	0.01 – 6.73
		Average	1.0	4.0	14.0	2.58
K_2O	%	Range	0.001 – 0.03	0.005 – 0.71	0. 02 – 1.91	0.003 – 0.22
		Average	0.01	0.1	0.82	0.03
Na_2O	%	Range	0.001 – 0.05	0.002 – 0.09	0.002 – 0.06	0.001 – 0.2
		Average	0.01	0.01	0.02	0.05
L.O.I	%	Range	25.5 – 35.0	23.03 – 35.3	34.3 – 42.5	31.7 – 38.0
		Average	31.1	30.6	38.1	34.9
I.R	%	Range	0.4 – 2.6	1.02 – 3.33	1.09 – 3.51	0.4 – 3.0
		Average	1.4	2.3	2.4	1.7
Ag	ppm	Range	110 – 452	10 – 39	<10	<10
		Average	323	22	<10	<10
Cd	ppm	Range	320 – 1100	366 – 880	35 – 820	<10 – 115
		Average	831	579	222	71
Ni	ppm	Range	15 – 120	<10 – 39	<10 – 300	<10 – 29
		Average	68	19	39	11
Cr	ppm	Range	33 – 100	63 – 170	<10 – 130	<10 – 120
		Average	59	99	70	52
Cu	ppm	Range	80 – 198	190 – 780	75 – 200	<10 – 39
		Average	144	458	122	21
Mn	ppm	Range	120 – 850	205 – 760	35 – 210	20 – 150
		Average	360	358	125	78
Co	ppm	Range	60 – 175	30 – 105	10 – 35	<10 – 30
		Average	111	72	23	15

The Al_2O_3, K_2O and Na_2O reflect a low content of clay minerals; insoluble residue (IR) represent quartz and other silica forms. Trace elements appear within the typical concentrations known in this type of deposits with lack of silver. The highest concentrations of zinc and lead are found in Lefan and Menin occurrences. Cadmium, iron and manganese are minor elements hosted in the crystal lattice of sphalerite where more than 10% of iron can be found in sphalerite in solid solution with zinc (Ramdohr, 1980; Rose *et al*., 1981). Nickel, chromium, copper and cobalt are typically associated with iron in the sulfide ore deposits (Rose *et al*., 1981), accordingly, these elements are basically associated with pyrite which is common in the Zn-Pb-barite deposits. Ramdohr (1980) and Kelley *et al.* (2004) pointed out the association of silver with galena in the sulfide ore deposits.

Significant concentrations of silver were found in Lefan and Alanish ore occurrences; proved to be present as acanthite in the latter (Awadh and Nejbert, 2016). Ramdohr (1980) and Guilbert and Park (1986) reported that the high copper concentrations within the sulfide ores reflect the amount of chalcopyrite, which is only found in Alanish and Marabasta localities. Fluid inclusions composition in barite of Lefan deposit are very similar to those found in the barites of the Upper Banik deposits, and they consist of dense oilfield brine and connate waters containing 13% – 15.5% wt equ. NaCl, and suggests a low-temperature ranging between 50 – 60 °C (Awadh, 2006). In the Marabasta deposit the optical spectrographic analysis of ore minerals showed Ag, As, Ba, Co, Cr, Cd, Cu, Mn, Ni, Sn, V, Y and Yb consistently occur in higher concentrations than Mo, Sb, Sc, Sr, and Te which are present in very low concentrations. Bismuth was detected in one sample of galena and magnetite is characterized by relatively high contents of Ti and Ni, but Cr, Co, Mn and Zn are below detection limit (Hak *et al*., 1983; Al-Bassam and Hak, 2006).

- ***Mineral chemistry***

Sphalerite and galena were manually picked and analysed from the bulk ore samples collected from Duri-Serguza deposit (Al-Qaraguhli and Lange, 1978 and Al-Bassam *et al*., 1982), Benavi occurrence (Al-Qaraguhli and Lange, 1978), Lower Banik and Lefan occurrences (Awadh, 2006). The chemical results are presented in Table 5. The most important characteristic of these deposits is the abundance of iron found either in the form of pyrite, goethite or elemental iron incorporated in the crystal lattice of sphalerite. The sphalerite color is a function of iron content, where the color of the low-iron sphalerite is light, while the color of the high-iron sphalerite tends to be darker (Awadh, 2009). Cadmium, manganese, and cobalt are minor elements replacing zinc in sphalerite at Lefan and Lower Banik occurrences.

The sphalerite in the Duri-Serguza deposit is of different composition; characterized by high content of cadmium, antimony and copper with lack of iron, indicating that the high content of iron in the Duri Serguza sphalerites is due to the presence of pyrite and its weathering products. A considerable amount of silver was recorded in the Lefan, Duri Serguza and Benavi ores as a substitution for lead in galena, but in Alanish, silver was found as tiny grains of acanthite (Awadh and Nejbert, 2016 and Awadh, 2018). Galena in Lefan and Lower Banik localities is of high content of zinc, antimony, nickel and bismuth. The galena in the Duri-Serguza and Benavi ore mineralization is rich with antimony, copper and iron. The different composition between different generations of sphalerite and galena in Lefan and Banik (Awadh, 2006), and between the early and late generations of galena in Duri Serguza (Al-Bassam *et al*., 1982) are evidence of multi mineralization stages with a different chemical composition.

Table 5: Mineral chemistry of sphalerite (Sph) and galena (Gal) in the Zn-Pb deposits and occurrences of the Ora Minerogenic District

Locality	Mineral	Zn	Fe	Pb	S	Ag	Cd	Mn	Cu	Sb	Co	Ni	Fe	Zn	Bi
		%				ppm									
[1]Lefan	Sph	58.9	6.4	0.5	33	--	3768	222	37	250	50	<10	--	--	--
	Gal			84.4	13	630			4	250	9	39	185	3100	30
[1]L.Banik	Sph	58.6	5.6	0.3	32	--	1332	317	9	n.d	32	<10	--	--	--
	Gal	--	--	84	13	135	--	--	4	n.d	9	32	169	1900	n.d
[2]Duri Serguza	Sph	n.d	0.71	1.1	n.d	--	3655	153	526	926	n.d	n.d	n.d	n.d	n.d
	Gal	2.9	n.d	n.d	n.d	390	n.d	n.d	568	490	n.d	n.d	4000	--	n.d
[2]Benavi	Gal	n.d	n.d	n.d	n.d	300	n.d	n.d	220	n.d	n.d	n.d	4000	2900	n.d
[3]Duri Serguza	Early Gal	n.d	n.d	n.d	n.d	448	n.d	n.d	310	3000	n.d	n.d	---	n.d	n.d
	Late Gal	n.d	n.d	n.d	n.d	620	n.d	n.d	530	3000	n.d	n.d	---	n.d	n.d

[1]Awadh (2006); [2]Al-Qaraguhli and Lange (1978) and; [3]Al-Bassam *et al*. (1982). n.d.: not detected.

Some of the first-phase sphalerites were wholly altered to massive smithsonite (Fig.5-1). Iron content decreased in the second phases with smithsonite dropping from 6.2 wt.% (± 4.3%); to a mean of 1.5 wt.% (± 2.1%). This drop is attributed to the mobility of iron under supergene conditions. The Pb content of the galena ranged from 85.5 to 87.5 wt.% (mean = 86.2 wt.% ± 0.5) and the content of S ranged from 12.3 to 13.6 wt.% (mean = 13.1 wt.% ± 0.46), indicating a non-argentiferous galena. The elements As, Se, Sb, Cu, Fe, Co, Ni, and Zn are not detected in galena, Cd content varies from BDL to 0.11 wt.% (mean = 0.0007 wt.%), and Pb in the veinlets of galena in sphalerite (Fig.5-2) are characterized by very low variation. A simple chemical composition in the system (Zn, Fe, Cd) S was detected in the equigranular sphalerite interspersed with barite (Fig.5-3). Cerussite forms rims enclosing galena and sometime exists along cleavage planes (Fig.5-4).

The results of the EPMA of the ore minerals in the Alanish locality are listed in Table 6. Generally, pure sphalerite consists of Zn (67%) and S (33%), but it can also contain Fe, Cd, Mn, Hg, and rarely Pb, Sn, In, Ga, and Tl. Wide ranges of both Zn (40.3 – 55.5 %; mean = 55.5%) and Fe (1 – 14.9 %; mean = 6.2%) are a distinctive character of the two generations of sphalerite. Pre-tectonic sphalerite is characterized by high-Fe and low-Zn content. Some optical properties of minerals such as color, reflectance and internal reflections were clearly influenced by the amount of minor elements substitutions (Awadh, 2009). The results of EPMA analysis carried out by Hak *et al*. (1983) for various types of sphalerite in the Marabasta deposit are reported in Table 7. Zinc content varies from 56.57 to 67.93 wt.% and Fe content from 0.08 to 9.89 wt.%. The strata-bound sphalerites are characterized by consistent Fe content of about 9 wt.%, whereas the sphalerites of the skarn assemblage are low in Fe (<0.5 wt.%).

The fractionation of cadmium as a minor element between sphalerite and galena was used as a geothermal indicator of crystallization at the Alanish ore deposits and the temperature is estimated to be 120 °C (Awadh and Nejbert, 2016), in which acanthite is a stable phase. Greenockite and acanthite were formed in rare quantity as independent ore minerals in the Alanish locality. Acanthite contains much more Cd (0.43 wt.%) than galena (0.0007 wt.%), indicating a primary phase origin as opposed to re-mobilization under supergene weathering. Pure phases of acanthite (Ag_2S) and greenockite (CdS) were identified by Awadh and Nejbert (2016) (Fig.4-1 and 4-5 respectively). The average Ag concentration in acanthite is 83.9 wt.%, which is equivalent to 96.4% of Ag in the acanthite end-member.

Cerussite is a secondary sulfate after galena (Fig.4-6). Cerussite is composed of Pb (76.6 wt.%), C (4.6 wt.%), O (18 wt.%), Ca (0.11 wt.%), and Sr (0.03 wt.%); Zn, Fe, Ba, Mn, Mg, and Si are all below detection limits. The maximal Zn concentration (1.6%), found in chalcopyrite included within sphalerite, is comparable to concentrations around 1% reported from experiments between 400 and 500 °C in the chalcopyrite stability field (Lusk and Calder 2004). Chalcopyrite may originate from hydrothermal solution, where hydrothermal features (brecciation, recrystallization, dissolution, dolomitization, and silicification) are observed (Awadh and Nejbert, 2016). Goethite pseudomorphs replace pyrite due to the supergene action (Fig.4-6), this type of replacement was diagnosed in Lefan and Alanish localities. Siderite appears as a supergene mineral formed due to the mobility of iron released from pyrite and goethite at the latest stage of mineralization and contains 1.1% Mn and 2% Ca. Table 6 presents farther analyses of minerals including dolomite and barite.

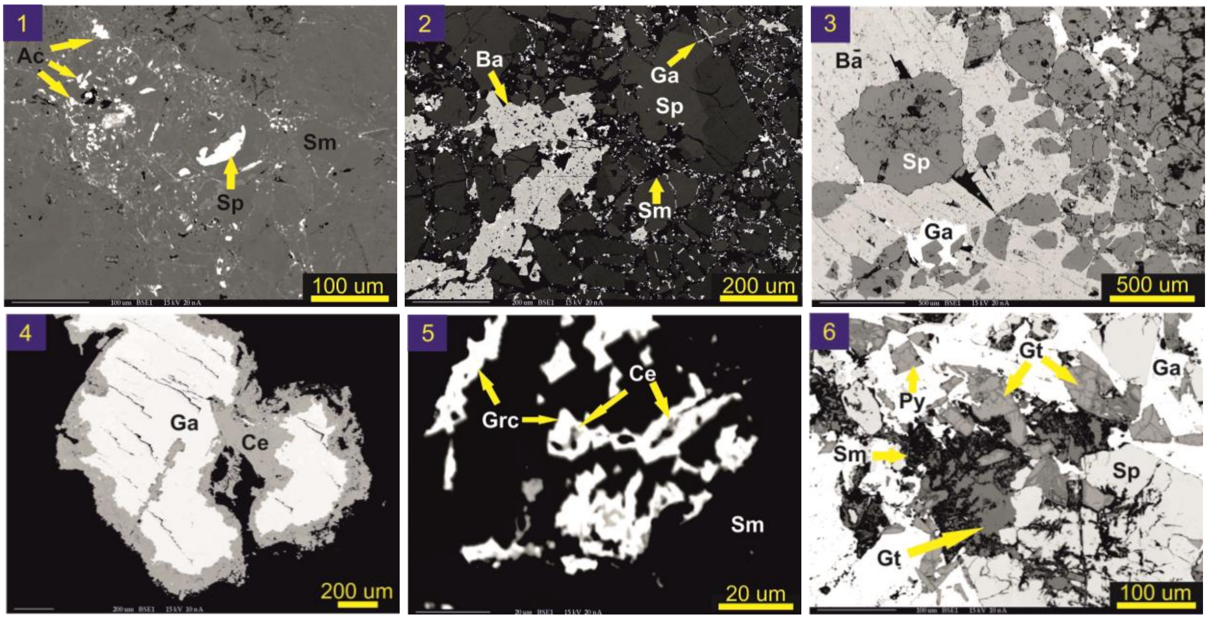

Fig.5: Back-scattered electron image micrographs of ore minerals in the Alanish occurrence (Awadh and Nejbert, 2016): **1)** Massive supergene smithsonite (Sm) after early sphalerite phase (Sp) showing a tiny grain of acanthite (Ac); **2)** Veinlets of the late stage of galena (Ga) in the early sphalerite stage; **3)** Equigranular, brecciated pre-tectonic sphalerite associated with early phase of galena and bladed barite (Ba); **4)** First phase of galena surrounded by supergene cerussite along rim cleavage planes; **5)** Greenockite (Grc) in association with smithsonite (Sm) and cerussite (Ce); **6)** pseudomorphic goethite after pyrite (Py) as inclusion in sphalerite and galena

Table 6: Mineral chemistry results (wt.%) of the polymetallic sulfide minerals in the Alanish locality (Awadh and Nejbert, 2016)

Minerals	n	Stat.	Zn	Fe	S	Cd	Cu	Co	Ni	As	Se	Sb	Pb	Ag
Sphalerite	54	Min	50.3	1.0	30.7	0	0	0	0	0	0	0	0	0
		Av	60.3	6.2	33.5	0.4	0.07	0.04	0.03	0.04	0.04	0.03	0.21	0.45
		Max	64.9	14.9	34.6	0.81	0.14	0.08	0.07	0.08	0.08	0.06	0.43	0.9
Galena	18	Min	0	0	12.3	0	0	0	0	0	0	0	85.5	0
		Av	0.01	0.01	13	0.05	0.07	0.01	0.005	0.003	0.01	0.01	86.2	0
		Max	0.11	0.06	13.6	0.22	0.7	0.11	0.04	0.03	0.02	0.05	87.1	0
Greenockite	2	Min	7.6	1.17	21.1	68.7	0	0	0	0	0	0	1.6	0.2
		Av	7.9	1.18	21.2	68.9	0	0	0	0	0.01	0	1.65	0.2
		Max	8.3	1.2	21.3	69.2	0	0	0	0	0.03	0	1.7	0.2
Pyrite	5	Min	0.2	46.3	53.3	0	0	0.005	0	0	0	0	0.16	0
		Av	0.6	46.3	53.3	0.03	0.01	0.03	0	0	0	0.01	0.16	54.3
		Max	0.9	46.4	53.4	0.06	0.03	0.06	0	0	0	0.03	0.16	0.06
Acanthite	5	Min	2.3	1.0	12.3	0.41	0.1	0	0.04	0.005	0.003	0	0.05	82.9
		Av	2.35	1.1	12.5	0.43	0.2	0.1	0.1	0.01	0.06	0	0.07	83.9
		Max	2.4	1.1	12.7	0.48	0.4	0.2	0.3	0.1	0.09	0	0.09	85.0
Chalcopyrite	6	Min	1.6	28.9	33.4	0.2	32.6	0.03	0.2	0	0	0	0.05	0
		Av	1.4	29.5	34.0	0.2	33.3	0.02	0.2	0.002	0	0	0.03	0
		Max	1.0	30.2	34.7	0.2	34.5	0.04	0.21	0.003	0	0	0.1	0
			Zn	**Fe**	**S**	**Ca**	**Ba**	**Mn**	**Mg**	**Sr**	**Si**	**C**	**Pb**	**O**
Smithsonite	10	Min	44.5	0	0	0.02	0	0	0.01	0	0	9.41	0.01	37.6
		Av	50.7	1.4	0.02	0.23	0.02	0.052	0.069	0	0.023	9.641	0.5	38.51
		Max	59.9	6.4	0.1	0.62	0.1	0.2	0.17	0	0.23	9.9	0.8	39.7
Cerussite	10	Min	0	0	0	0	0	0	0	0	0	4.3	74.3	---
		Av	0.011	0.01	0	0.11	0.04	0.01	0	0.03	0.003	4.57	76.6	---
		Max	0.11	0.06	0	0.36	0.2	0.09	0	0.13	0.02	5.4	78.4	---
Siderite	4	Min	0.03	45.4	n.d.	2.0	0.05	1.0	0	0.003	0	9.2	0.51	39.0
		Av	0.03	46.6	n.d.	2.0	0.06	1.1	0	0.005	0	9.7	0.57	39.8
		Max	0.04	47.0	n.d.	2.1	0.08	1.2	0	0.007	0	10.0	0.63	40.2
		SD	0.01	1.8	n.d.	0.02	0.03	0.9	n.d.	0.002	n.d.	1.4	0.9	1.6
		Av	0.3	0.79	n.d.	18.7	0.36	0.92	12.73	0.99	0	12.7	0.007	51.0
		Max	0.5	0.86	n.d.	19.1	0.50	0.97	12.9	1.0	0	12.8	0.009	52.1
			Zn	**Fe**	**U**	**Ca**	**Ba**	**Mn**	**Mg**	**Sr**	**Si**	**V**	**S**	**O**
Barite	11	Min	0	0	0	0	54.9	0	0	0.03	0	0	13.0	26.9
		Av	0.02	0.02	0.1	0.003	57.1	0.004	0	0.83	0.004	0.01	13.5	27.2
		Max	0.09	0.1	0.3	0.02	57.6	0.013	0	2.7	0.02	0.02	13.7	27.4

n.d.: not determined; n: number of spots analysed by EPMA

Table 7: EPMA analysis (wt.%) of various types of sphalerite in the Marabasta deposit (Hak *et al*., 1983 and Al-Bassam and Hak, 2006)

	1	2	3	4	5	6	7	8	9	10	11	12
Locality	**Seh Kuchika**	**Seh Kuchika**	**Seh Kutchika**	**Seh Kutchika**	**Darman**	**Darman**	**Darman**	**Darman**	**Darman**	**Darman**	**Darman**	**Darman**
No of analyses	5	2	2	1	5	3	1	3	3	3	2	2
Zn	66.14	67.93	66.40	64.82	57.69	58.28	57.37	57.29	56.95	57.78	57.20	56.57
Fe	0.45	0.08	0.10	0.40	8.16	8.42	9.66	9.60	9.89	9.69	9.36	9.68
S	33.03	33.61	33.20	32.37	33.72	33.25	33.83	33.76	33.39	33.79	33.96	33.79
Total	99.62	101.62	99.70	97.60	99.58	99.94	100.87	100.94	100.23	101.26	100.52	100.04

- **Isotopes composition**

The $\delta^{34}S$ in the Duri-Serguza ore minerals was found by Al-Bassam *et al*. (1982) to range from -2.6 to -1.8 ‰ for galena; -0.4 to 0.0 ‰ for sphalerite and 0.2 to 3.6 ‰, for pyrite. The trend of $\delta^{34}S_{py} > \delta^{34}S_{sph} > \delta^{34}S_{gal}$ was considered close to isotopic balance and the sulfur was originated from the mixing of normal marine sulfates with sulfur from submarine volcanic exhalations (Al-Bassam *et al*., 1982). On the other hand, the sulfur isotope compositions ($\delta^{34}S$) of the early generation galena in some Zn-Pb mineral occurrences in the Ora Minerogenic District is 0.36‰, which is close to the hydrothermal magmatic sulfur origin in contrast to the sulfur isotope compositions ($\delta^{34}S$) of the late generation of galena of 6.41‰ (Awadh, 2006 and Awadh *et al*., 2008b). This suggests a hydrothermal magmatic fluid partially mixed with oilfield brine connate waters. The sulfur isotope compositions ($\delta^{34}S$) of barite range from 16.64 to 24.23 ‰, which is consistent with the Upper Carboniferous and Permian sea water. These isotopic values indicate high isotopic fractionation caused by descending meteoric waters which dilute the ascending ore-bearing solutions, leading to the precipitation of barite in oxidizing condition.

GENESIS

The lead-zinc deposits located in the south Turkey, north Iraq and Iran represent the most important metallogenic provinces in the Middle East and most of them have been classified as Mississippi Valley Type (MVT) deposits. This type of deposits forms about 24% of the global resources of Pb and Zn hosted in sedimentary and volcanic rocks (Leach *et al*., 2010). The ion concentration, temperature and pH value are decisive factors that determine the metal ion capacities in solutions (Leach *et al*., 2005). Complex chloride compounds are most likely than sulfides and organic matters in transporting metals of fluids due to low solubility of sulfides and low availability of organic matter in the (MVT) (Liu *et al*., 2017).

The mineralogy, represented by sphalerite, galena, pyrite, chalcopyrite, with presence of barite and/ or fluorite gangue mineralization, is rather simple, but the paragenesis can be complex, with multiple precipitation and dissolution events (Leach and Sangster, 1993; Sangster 1995; Misra, 1999; Leach *et al*., 2001). These deposits are characterized by low-temperature of formation (50 – 200 °C, but mostly 100 – 150 °C) and usually precipitated from highly saline brines (Leach and Sangster, 1993; Sangster, 1995; Misra, 1999; Leach *et al*., 2001). They are also typically found far from, and lack a genetic relationship to igneous activity or igneous rocks (Heyl *et al*., 1959; Sverjensky, 1986). The associated country rock alterations consist mainly of dolomitization, brecciation, host rock dissolution, and dissolution/ crystallization of feldspar and clay minerals. The ore-bearing fluids were dense basinal brines, typically containing 10 to 30 wt.% salts. Isotopic data indicate crustal sources for metal and reduced sulfur. Sulfide mineral textures are extremely variable; ranging from coarsely crystalline to fine-grained, massive and disseminated.

The Zn-Pb-barite deposits in Iraq, Turkey and Iran are distributed around the margins of the tectonic plates and related to collision events, occurring as irregular replacement deposits in limestone, dolomitic limestone and dolostone more or less parallel to the bedding and affected by faults and fractures. Barite is often genetically associated with zinc-lead deposits, where Ba along with Hg, Sb, Au, Mo and Te are typically ore-forming metals. The structure, such as steep faults and type of sedimentary microfacies are also considered as a control for the ore mineral deposition (Awadh *et al*., 2008a; and Awadh and Nejbert, 2016).

The Zn-Pb-barite deposits in the Ora Minerogenic District are of simple mineralogy but complex paragenesis. They are dominated by sphalerite and followed by galena and pyrite and to a lesser extent barite, and with or without chalcopyrite. Generally, barite, calcite, dolomite, siderite and quartz are common gangue minerals. Alteration is mainly represented by dolomitization, brecciation, host-rock dissolution, karstification, collapse, and crystallization. The ore-bearing solutions were dense basinal brines, typically containing 13 – 15.5 % NaCl equiv. (Awadh, 2006). Lead isotope compositions (^{204}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb) of galena revealed that lead was derived from the crust reservoir (Awadh, 2006 and Awadh *et al*., 2008a and b).

Most of the Zn-Pb deposits and occurrences in the Ora Minerogenic District are of low-temperature hydrothermal veins and/ or strata-bound deposits (Al-Bassam, 1972). Microscopic studies of ore minerals in the Duri-Serguza deposit (Al-Bassam *et al*., 1982) revealed two generations of sulphides. The first generation shows sedimentary structures such as banding, lamination and micro-folding. The second generation appears in small veins and as impregnations in brecciated zones, frequently associated with secondary dolomite and quartz. Geochemical differences between the two generations of sulfides indicate different conditions of formation. The first generation, holding evidence of sedimentary structures, may have been low-temperature syngenetic strata-bound mineralization, whereas the second generation may have formed at higher temperature than the primary sulfides, following the intense Late Miocene tectonic deformation (Al-Bassam *et al*., 1982). The Duri-Serguza deposit, with its simple mineralogy, Triassic dolomitic host rock, strata-bound features and geochemical characteristics is similar to other Alpine strata-bound deposits of the Mediterranean Belt. The mineralization may have been the result of submarine volcanicity associated with the early rifting of the southern Neo-Tethys (Al-Bassam and Hak, 2006).

Lefan, Banik and Alanish, occurrences are characterized by low-temperature formation (120 °C) (Awadh, 2006). In some localities, such as Lefan, Banik, Menin, Alanish and Duri-Serguza, the paragenetic sequence shows a multi-stage mineralization where the ore minerals may have been epigenetically precipitated from different ore-bearing solutions of different origins under fluctuating reducing – oxidizing conditions. They are epigenetic strata-bound deposits hosted in dolostone, less commonly in limestone and were precipitated from epithermal solutions as strata-bound MVT deposits, under lithological and structural control (Awadh, 2006; Awadh *et al*., 2008a and b). The early sulfide generations in Lefan, Banik and Alanish ore occurrences are characterized by replacement textures and relatively high content of minor elements, while the late sulfide generations are often characterized by open space filling textures, and low content of minor elements (Awadh, 2006; Awadh *et al*., 2008a and b; and Awadh and Nejbert, 2016). The fluid inclusions composition in barite present in the Lefan occurrence are somewhat similar to those in the Upper Banik and may be evidence of oilfield brine connate waters as a source of ore-bearing solutions (Awadh, 2006; and Awadh *et al*., 2008a and b).

The Marabasta ore mineralization has been suggested in the early studies as the product of hydrothermal metasomatism (e.g., Al-Bassam and Akif, 1977), and later as metamorphosed strata-bound deposit of volcanogenic sedimentary origin subjected to a low-grade metamorphism resulted in forming skarn minerals (Hak *et al*., 1983). The skarn mineral assemblage appears to be either younger than the strata-bound assemblage or contemporaneous, but of different chemical composition. The massive or banded sulfide minerals have a metamorphic texture. The ore bodies at the Darman outcrop occur in phyllitic slates and marble in close association with mafic volcanic rocks which suggest that the ores were initially formed in a volcanogenic sedimentary environment. The ores and country rocks were later subjected to low-grade metamorphism. The older strata-bound Zn-Pb deposit may have been fractured allowing for the flow of silica- and oxygen-rich solutions which may have resulted in the formation of oxides and silicates of Zn and Fe. During this water-rock interaction, Zn and Fe would have been mobilized from the original strata-bound deposits to form secondary minerals which were later metamorphosed to willemite, magnetite, gahnite and garnet (Hak *et al*., 1983).

MINERAL RESOURCES

Among the reported mineral deposits and occurrences of N and NE Iraq, only the Duri-Serguza deposit in the Ora Minerogenic District and the Marabasta deposit in the Shalair Terrane have been investigated and their ore reserves of Zn and Pb were estimated according to Russian norms (Table 8). The reserves in the Marabasta deposit have been estimated by 100520 tons of Zn and 18117 tons of Pb (category C1) and 23265 tons of Zn and 4230 tons of Pb (category C2). In the Duri-Serguza deposit the reserves were estimated by Geozavod (1981). The C1 reserves were estimated by Akif and Venecek (1972) by 42968 tons of Zn and 36069 tons of Pb. The C2 reserves were estimated at 37000 tons Zn and 31000 tons Pb. The reserves indicate small deposits in both localities, but they may be enhanced by further exploratory work. Moreover, the other occurrences in the Ora Minerogenic District hold very high potential of locating Zn-Pb deposits of the MVT type in the carbonates of the Triassic – Upper Cretaceous rock units.

Table 8: Reserve estimation of the Zn-Pb ore in the Marabasta deposit (Akif and Venecek, 1972) and Duri-Serguza deposit (Geozavod, 1981)

Category	**Tonnage**	**Zn wt.%**	**Pb wt.%**	**Reserve Zn tons**	**Reserve Pb tons**
Marabasta					
C1	608953	15.5	3.0	100520	18117
C2	141000	---	---	23265	4230
Duri-Serguza					
C1	1971000			42968	36069
C2				37000	31000

CONCLUSIONS

The Zn-Pb deposits and occurrences in northern and northeastern Iraq are strata-bound and affected by tectonics related to the opening and development of the Neo-Tethys Ocean. They are genetically classified into non-magmatic, low-temperature MVT type deposits in the Ora Minerogenic District in N Iraq and volcano-sedimentary metamorphosed deposits in the Marabasta Minerogenic District in NE Iraq. They are related to the Zn-Pb deposits in Turkey and Iran forming a significant part of the Alpine Belt stretching from the Atlantic Ocean in the west to Iran in the east. In northern Iraq, the non-magmatic deposits are represented by zinc-lead-barite occurrences emplaced, as a strata-bound type, in carbonates of a wide age range stretching from Permian to Tertiary. The Zn-Pb deposits and occurrences in the Ora District of N Iraq form a metallogenic province where the ores are simple and comprised of sphalerite, galena and pyrite and often associated with barite. The Zn-Pb deposit of Marabasta, in the Shalair Terrane of NE Iraq shows more complicated mineral assemblages of sulfides and skarn minerals. In addition to sphalerite, galena and pyrite, there are other minerals reported including pyrrhotite, pentlandite and arsenopyrite. The skarn minerals include willemite, gahnite, magnetite and rare garnet. The Zn-Pb resources of Iraq are very small, but can be significantly increased with more detailed exploration, especially in the Ora

Minerogenic District, where the number of occurrences and deposits is very encouraging and worth following up.

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