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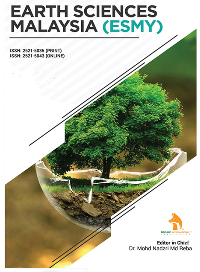

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REVIEW ARTICLE

A PRELIMINARY REVIEW ON THE METALLOGENY OF SEDIMENT-HOSTED PB-ZN DEPOSITS IN BALOCHISTAN, PAKISTAN

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ABSTRACT

Lead and Zinc deposits are very much important economic booster for the country all over the world. Economic geologists are engaged in the search of these economy booster minerals and rocks for three decades. Lead and zinc are profuse resources in the Lasbela-Khuzdar belt of Balochistan province of Pakistan, with reserves of about 50 million tons all over the country. In this paper, we have presented field observations of the Dudder mine area and summarised the work of earlier papers to provide the salient features of these ore mineralizations and deposits. The tectonic settings and important ore controls have been discussed based on field observations and previous work. The Pb-Zn dominantly occupied by exposures of rocks of the Ferozabad Group of Jurassic age in the Mor range, which is comprised of Lower-Middle-Upper Jurassic carbonates and deep-marine siliciclastics rock sequence. This group contains syngenetic and epigenetic Pb-Zn mineralization classified as a stratiform replacement, and vein-type fissure fillings observed at various places of Duddar, Gunga, and Surmai deposit areas. Generally, these deposits are hosted pyrites nuggets with fine-grained sphalerite matrix with galena in black shale, argillaceous limestone, and mudstone. We construct a Pb-Zn deposit predictive tectonic model that regards mineralization as the primary factor and the ore rock as secondary. The tectonics were more active when sedimentation of the Anjira Formation started in a disturbing third-order basin. The Hydrothermal solution comes into the basin along faults and gave rise to syngenetic mineralization of sulfides in the Anjira Formation, and epigenetic one in the underlying Spingwar and Loralai Formations. These deposits are considered as SEDEX deposits according to the distribution of Pb-Zn deposits, we concluded that a multi-period, multi-cycle orogenic environment is the most positive for lead-zinc deposit growth. With this, we analyze the association between tectonic evolution, geological mineralization, and Pb-Zn metallogenic epoch. The tectonic and mineralization mechanism models are expected to ease the detailed study on the geological and geochemical conditions of mineralization in the Ferozabad Group and economic assessment of the resources.

KEYWORDS

Metallogeny, SEDEX deposit, MVT deposit, Duddar, Gunga, Surmai.

1. INTRODUCTION

Lead and zinc (Pb-Zn) are considered important economic ore minerals globally (Steve et al., 2018). Pb-Zn resources are abundant in the world; these ore minerals are widely deposited throughout the world. These ore minerals are extracted from more than 50 countries across the world like; China, Australia, Peru, America, Europe, India, Kazakhstan, Iran, Germany, Spain, Mexico, Japan, Sweden, and Canada. The biggest Pb-Zn ore minerals are being mined from all over the world and China is one of the largest producers and consumers of lead and zinc in the world. In 2014 there were estimated to be more than 2.0×109t Lead (Pb) resources with 8.7×107t reserves and estimated to be more than 1.9×109t Zinc (Zn) resources with 2.3×108t reserves (USGS, 2015). Compared to the starting of the 21st century, Zn reserves have risen by 2.3×107 t and Pb reserves by 4.0×107t (USGS, 2015; USGS, 2000). Pakistan has also huge potential and prospects to host these deposits within the sedimentary and igneous hosted rocks in the Western part of Pakistan. The Pb-Zn major deposits are present in the Lasbela-Khuzdar region of Baluchistan province. In this region, Bela ophiolitic thrust belt is also present and called as richest and most geologically complex regions of Pakistan. The mineralization is found in the Jurassic Anjira Formation. The main deposits are named as Shekran, Ranj Laki, Malkhor (NW of Khuzdar), Gunga, Surmai (SW of Khuzdar, and Duddar (SE of Bela) Shown in (Fig. 2). Along with those mentioned rich ore mineral deposit areas, minor deposits and showings are found in other areas of Pakistan from Parabeck, Imirdin, Muzhigram, Tashker and Pakhturi of Tirich Mir zone, and Baig, Madashil, Awireth of Chitral; Faqir Mohd (Hazara), Hal, Kokal, Mihal, Paswal, Lahor, Pazang and Ushu, only

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small, sporadic mining of the smaller deposits in Chitral and Chagai districts have been carried out. The estimated Pb-Zn reserves (metal content) of Pakistan are identified by about 50mt (Malkani, 2016; Mastoi et al., 2016). Several papers have given attention to focused on sediment-hosted Pb-Zn deposits all over the world (Sangster, 1990; Goodfellow et al., 1993; Leach et al., 2001, 2005b; Lydon, 2004; Kesler, 2006; Lyons et al., 2006; Goodfellow et al., 2007). So far, there are two main sub-types of the Pb-Zn deposit explored and exploited in the world. The first sub-type is clastic-dominated (CD) Pb-Zn ores, which are hosted in shale, sandstone, siltstone, and mixed clastic rocks, which occur as carbonate replacement, within a CD sedimentary rock sequence. This sub-type includes deposits that have been traditionally referred to as sedimentary exhalative (SEDEX) deposits (Leach et al., 2010). The CD Pb-Zn deposits occur in passive margins, back-arcs and continental rifts, and sag basins, which are tectonic settings. In some cases, are transitional into one another. The second sub-type of sediment-hosted Pb-Zn deposits are the Mississippi Valley-type (MVT Pb-Zn) that occurs in platform carbonate sequences, typically in passive-margin tectonic settings (David, 2010). In other words, it can be discussed as the most important sediment-hosted Pb-Zn deposits; those are clastic rock-dominated sedimentary sequences traditionally called sedimentary exhalative (SEDEX) and those in carbonate-dominated sequences that are mainly of the Mississippi Valley-type (MVT), (Fig. 2). The sediment-hosted deposits historically endow with the world's best Pb-Zn resources (Leach et al., 2005b). In recent years in Pakistan, theoretical research on Pb-Zn mineralization has been restricted, due to the increasing uncertainty surrounding metallogenic epoch, ore-forming material source, ore-forming fluid evolution, and metallogenic mechanism, which leads to a research deficiency in such aspects metallogenic regularity, metallogenic types, tectonic and metallogenic relationship. This review paper attempts to provide an introduction to the Pb-Zn deposit, its type, and tectonic settings as well as important ore controls in Pakistan, based on new observation and Published information, to shed some light on the country's research into the metallogenic regularity of Pb-Zn deposits. Additionally aspiring to guide Pakistan's strategic work of Pb-Zn prospecting and a fundamental contribution of this research work is the compilation of basic mineral resource data on known deposits.

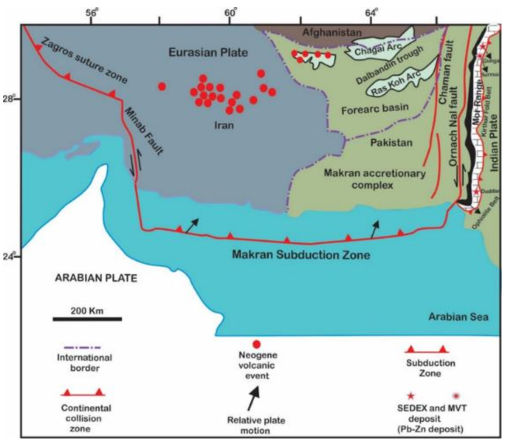

Figure 1: Tectonic framework of the southern Pakistan and distribution of major Pb-Zn deposits of pakistan (modified After USGS).

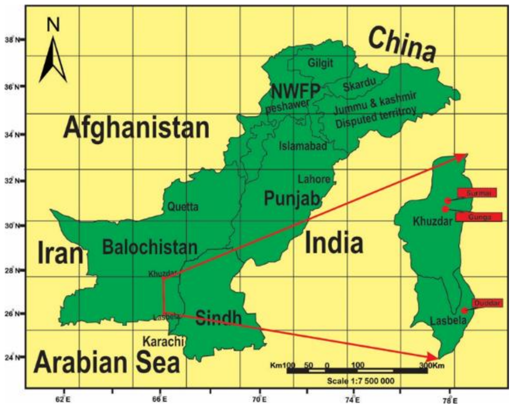

Figure 2: Map showing distribution of Pb-Zn deposits in Balochistan, Pakistan (Modified after Ahsan and Mallick., 1999)

2. Sediment-Hosted Pb-Zn Deposits in Balochistan

Sediment-hosted Pb-Zn deposits in Pakistan occur in the N-S-trending 300km long Lasbela-Khuzdar belt, the westernmost province of the Islamic Republic of Pakistan. These two are the richest and most geologically complex regions of Pakistan (Ahsan, 1997), These are commonly containing vast prospects of Pb-Zn and barite ± fluorite deposits but the association between barite and Pb-Zn sulfides is not clear (Jankovic, 1984). The diverse rocks of igneous, sedimentary, and metamorphic origin of early Jurassic to late Tertiary ages together with structural complexities make the area not unique but challenging for researchers and investigators (Fig. 3).

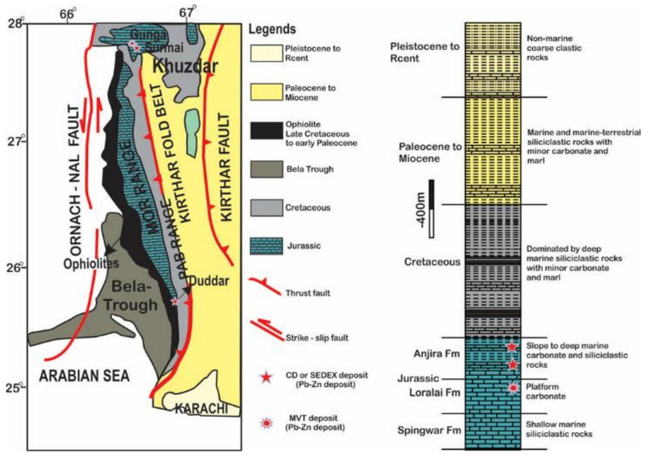

Figure 3: Geological map of Lasbela-Khuzdar belt of Balochistan, Pakistan with a stratigraphic column of the Pb-Zn deposits, (modified from Sillitoe, 1978; Naseem and Sheikh, 2002; Khan et al., 2002, Yu-cai Song et al., 2019)

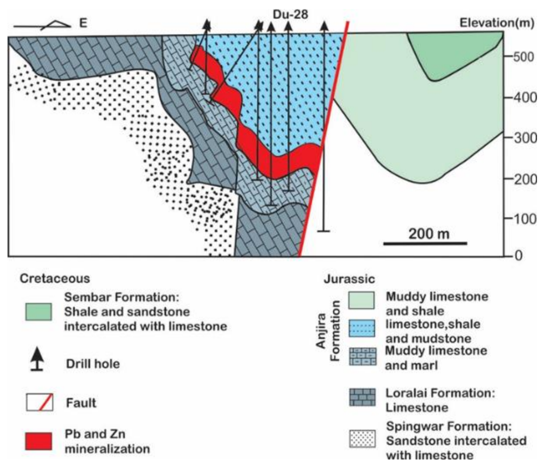

Figure 4: A cross-section of Duddar deposit, showing stratigraphy and Pb-Zn orebodies, (modified after Kazmi and Abbas, 2001 and Yu-cai Song et al., 2019).

2.1 Geological Background

The N-S-trending Lasbela-Khuzdar belt lies on the northwestern Indian continental margin, which is the result of a collision between Indian and Eurasian plates(Yu-cai Song et al., 2019), The Bela Ophiolite, Mor, and Pab ranges bounded by to the west. Meanwhile, the major Pb-Zn deposits are located in the Mor range of the Jurassic age shown in (Fig. 3). Lasbela-Khuzdar belt received sediments from the passive continental margin during the Jurassic to Cretaceous period(Umar et al., 2011). The Jurassic strata of the Ferozabad Group comprise of sedimentary rocks that start from bottom to Spingwar Formation shallow marine siliciclastics rocks, Loralai Formation Platform limestones, and thin shales, and Anjira Formation deep-marine Limestone and siliciclastic rock sequence is shown (Fig. 3 and 4), (Ahsan, 1999). There oxidized bed belemnite basal disconformity/structural contact b/w Cretaceous and late Jurassic strata are shown in (Fig. 3). At the top of the Ferozabad Group is disconformable overlain by shales and siltstones of the Early Cretaceous age of Sember

Formation exposed in the Lasbela area but in the vicinity of Khuzdar, whichever the Sember Formation is absent or scarcely exposed (Zaigham, 1995). The stratigraphic sequence of rocks according to (Fatmi et al., 1986 and Anwar et al., 1991) Fig. 3. Economically Lasbela-Khuzdar belt hosts syngenetic and epigenetic Zn–Pb–Ba mineralization's of Stratiform Sediment-Hosted (SSH), clastic dominated (CD) or SEDEX type and Mississippi Valley Type (MVT) deposits in the platform carbonate sequence and the Anjira Formation deep-marine siliciclastic rock sequence (Jankovic, 1984; Ahsan, 1997). The oblique collision between the Indian continent and the Pakistan block began in the Paleocene (Warwick et al., 1998). Since that time, large-scale folding and thrusting, coeval with N-S striking sinistral strike-slip faulting, have developed on the northwestern Indian continental margin (Arlegui, 2001). The thrusting migrated to the east and accompanied the formation of off-shore land basins (Khan et al., 2002; Yu-cai Song et al., 2019) shown in Fig. 3.

2.2 Type of Mineralization

The Pb-Zn deposits have been formed through the processes of syngenetic or epigenetic and through replacement or fissure fillings observed at various places of Duddar, Gunga, and Surmai, in these areas the following types have found: i) stratiform, ii) strata bound-replacement type, iii) vein and cavity fillings. The deposits are hosted pyrites nuggets with high-grade zinc ore with galena in black shale, argillaceous limestone, and mudstone of the Anjira Formation. The strata bound replacement type mineralization is confined to the selective coarse-textured limestone beds of the Spingwar, Loralai, and Anjira Formations. The deposits are hosted pyrite and fine-grained sphalerite matrix with calcite vein in Duddar Kanraj-Zibro Dhoro and Shekran, Ranj Laki, Malkhor, Surmai on the eastern and western flanks of the Mor Range in the Lasbela-Khuzdar district. The vein/fissure and cavity filling types are widespread throughout the Lasbela to Khuzdar District. These are hosted by all three formations; the promising ones are massive galena with high-grade zinc chunks and fine grain pyrite Matrix are presented in silica-clastic rocks. The stratiform Pb-Zn and barite deposits, occurring at Duddar and Gunga are huge in quantity and good in quality. These are being commercially exploited.

2.3 Important Pb-Zn Deposit in Balochistan

The Geological Survey of Pakistan has been discovered several deposits of lead and zinc ore in Balochistan province, Pakistan that is shown in (Fig. 2). The Jurassic rocks of the Lasbela-Khuzdar belt have the potential to host several World-class Lead-zinc ore deposits. These deposits are associated with carbonate rocks of the Ferozabad Group and Anjira Formation shown in (Fig. 3). There are three chief deposits namely Gunga, Surmai, and Duddar have been investigated in some detail by GSP with the help of UNDP and JICA(Ahsan, 1997).

2.3.1 Duddar deposit

The Duddar deposit is located on the eastern flank of the Mor Range at latitude $26^{0}05'$N and longitude $66^{0}50'$E. It is approximately by road distance 200km away from Karachi (Ahsan, 1997). The detailed Geological Mapping and Drilling at (4600m), and inferred geological reserve indicated of 14.31Mt; 8.6% Zn and 3.2% Pb has been calculated. Mineralization of Duddar south extends over 1,100m along strike, from 10-200m in vertical extent and 200m in width Individual ore lenses range from 10m to 40m in true thickness and high-grade mineralization extends from 75m to 1,000m below the surface (Hudson, 1997). These reserves are hosted by the Jurassic carbonate and clastic sediments of Anjira Formation, and that is a major record of marine transgression during rifting and the breakup of Gondwanaland. The prospect area lies in the westerly verging Paleocene-Eocene collision zone between the Indian and the Iranian/Afghani plates shown in (Fig. 1). The host rocks are similar to those of CD deposits (Leach et al., 2010). Sulfide ores consist of laminated or massive sphalerite, galena, pyrite, marcasite, and calcite, Quartz, and barite bodies that occur above the sphalerite-rich zone, with a thickness of up to 30m (Ahsan, 1997; Ahsan, 1999) shown in (Fig. 4). The strata above the mineralization zones in the Anjira Formation contain breccias composed of barite, pyrite, and sphalerite clasts in the muddy and calcareous matrix. This indicates that sulfide mineralization was coexistent with the sedimentation of the Anjira Formation, and the Duddar deposit is therefore probably SEDEX type deposit. (Yu-cai Song et al., 2019)

2.3.2 Gunga deposit

The Gunga deposit is located at about 3.5 km south-southeast of the village Gunga at latitude $27^{0}44'$N and longitude $66^{0}33'$E. It is accessible from Khuzdar by traveling 11 km to the southeast on an unmetalled road. The distance from Khuzdar to Karachi is approximately 350km respectively. The Gunga deposit has 6.86 Mt; 2.1% Pb, 11.4% Zn reserves, The mineralization is mainly stratiform, strata-bound, and open space-filling, Based on the Geological information obtained from 14 drill holes, two main mineralized zones were demarcated in the prospect area in the lower section of the Jurassic Anjira Formation of the Ferozabad (Ahsan, 1997). The host rocks are predominantly black carbonaceous shale, siltstone and mudstone, subordinate limestone, and local synsedimentary breccia and conglomerate. The upper mineralization zone immediately underlies a shale unit and overlies silicified rocks. It is dominated by massive and concordant barite that varies in thickness from a few meters to >70 sphalerites and galena are locally concentrated in the lower bed of the upper mineralization zone. Paragenetic relations between the sulfides and barite are unclear (Yu-cai Song et al., 2019). The lower mineralization zone has contained conformable lenses and irregular veins formed along a brecciated bed, and sphalerite and galena are found with epigenetic fracture-filled and open space sulfide veins (Ahsan, 1997)shown in (Fig. 5). The deposit occurs in a deep-marine clastic-dominant sequence, which is consistent with the host rocks of typical CD deposits (Leach et al., 2010). This indicates that sulfide mineralizations of Stratiform Sediment-Hosted (SSH), clastic dominated (CD) possibly a Mississippi Valley Type (MVT) deposit in Gunga (Ahsan, 1997).

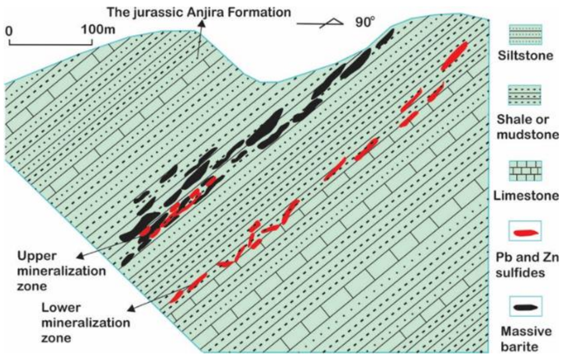

Figure 5: A cross-section showing Geology and mineralization of the Gunga deposit, (modified after Jankovic 1984 and Yu-cai Song et al., 2019)

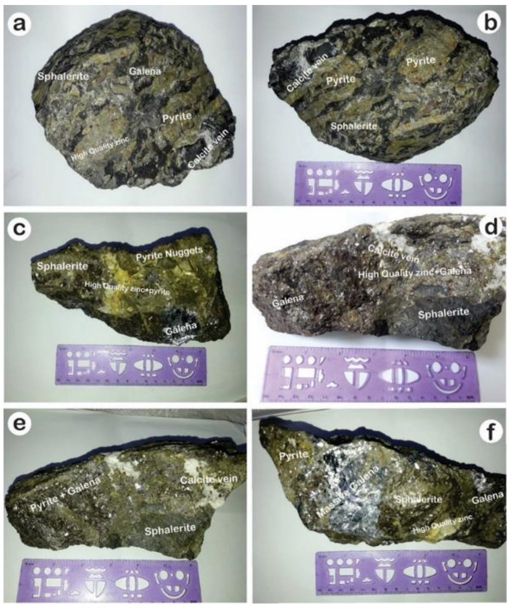

Figure 6: Photographs showing ores samples of Duddar deposit. (a), (b) A massive sulfide ore composed of pyrite and fine-grained sphalerite, locally with dark mudstone fabrics. (c) pyrites nuggets with high grade zinc ore with galena, (d) high grade galena with calcite vein and fine grain sphalerite matrix, (e) pyrite and galena with calcite vein are presented, (f) massive galena with high grade zinc chunks and fine grain pyrite Matrix are presented.

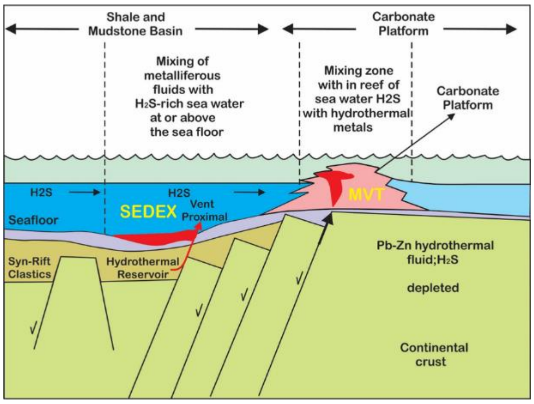

Figure 7: Genetic model for the formation of sediment-hosted Pb-Zn and coeval Mississippi Valley-type (MVT) and SEDRX type deposit (modified after Goodfellow, 2007).

2.3.3 Surmai

The Surmai deposit lies at about 1 km south of Ganga deposits latitude 27⁰43′17″N and longitude 66⁰31′27″. It has (30.51 Mt; 0.7% Pb, 3% Zn) reserves. However, the mineralization is extending discontinuously from north to south about 1km, and it is hosted in the Limestone ofLoralai Formation of Jurassic age (Ahsan, 1997). These are considered to be Mississippi Valley-type (MVT) deposits, where the sphalerite and galena are seen to be replaced the limestone along bedding planes or occur in fractures and fissure filling type as the host rock of platform carbonate (Yu-cai Song et al., 2019).

3.1 Overview of Tectonic evolution and Lead-zinc mineralization

The geological history of the Lasbela–Khuzdar belt can be split into two major periods. And it is a part of the Tethyan domain and it has comprised of two orogenies that separated from the earlier breakup of the supercontinental Gondwanaland during the late Triassic- Jurassic period of 170 million years ago (Johnson et al., 1976; Powell, 1979; Lydon, 1990). The key processes operating at the time were rifting and extensional tectonics. The host rocks of the mineralization of lead-zinc sulfide deposits are sediments within extensional tectonics (Ahsan, 1995). The rifting process is reflected by the vertical facies transition of the rocks of the Jurassic Ferozabad Group. This group was deposited in a transgressive continental shelf environment with a landmass to the southeast. It records progression from the relatively proximal clastic and platform shelf and slope carbonate environments followed by the distal, quiescent conditions of the Early Cretaceous Sember Formation. Following the breakup of Gondwanaland, the second orogeny was caused when the Indo-Pakistan plate was separated from the Turan block (Powel, 1979; Mastoi et al., 2016; Mastoi et al., 2019). The Indo-Pakistan plate collided with the Afghan and Central Iran-Lut microplates of the Eurasian plate in the west, shown in (Fig. 1) and led to the development of the fold belt and obduction of the Bela-Khuzdar and Ophiolitic complexes at the western boundary of the Indo-Pakistan plate during Late Cretaceous-Early Tertiary period. The Mineralization is hosted by limestone, mudstone, shale, claystone, siltstone, and sandstone of Early-Middle Jurassic in the Ferozabad Group. The stratigraphic sequence of rocks according to (Fatmi et al., 1986; Anwar et al., 1991) is shown in Table 1.

Table 1: The stratigraphic sequence of Lasbela-Khuzdar belt area.

Group	Formation	Member	Description	Thickness	Age
	Anjira	Kharrari		150-200	Jurassic
		Duddar	Platformal and basinal bioturbated limestones, shales and debris flow breccias. Hosts stratiform mineralisation at base. Cross cut by stockwork mineralisation.	600	Jurassic
Ferozabad		Bambh	Interbedded nodular limestone and shale. Cross cut by stockwork mineralisation.	50-70	Jurassic
	Loralai		Platformal limestones, thin shales. Cross cut by stockwork mineralisation.	>200m	Jurassic
	Spingwar		Shallow marine sandstones	>400m	Triassic-Jurassic

3.2 Lead-Zinc Deposit Types

The Ore deposit scientist proposed numerous classification principles and schemes on Pb-Zn deposit types and it is always been highly a controversial topic worldwide. Meanwhile, taking into account the sediment-hosted Pb-Zn deposits primary divide into four subtypes,1)Mississippi Valley-type (MVT), 2) sedimentary exhalative (SEDEX deposit), 3) sandstone-lead (Sst-Pb) and 4) sandstone-hosted deposits. These deposits have not any genetic relation to igneous activity. The sandstone-lead and sandstone-hosted deposits are small form deposits of sediment-hosted Pb-Zn deposits, both of which were briefly discussed by (Bjorlykke et al., 1981). The authors of this paper are unable to produce the more appropriate classification, a particular assignment of a subtype to some deposits may not be universally accepted; therefore, we discuss the terms which are used in the literature or found in Pakistan and worldwide that are MVT and SEDEX deposits type. The Characteristics of both subtype deposits are briefly presented below and discussed in more detail in the text.

3.2.1 MVT deposit

The MVT type deposit was found in the Gunga deposit in Lasbela to Khuzdar belt of Balochistan. MVT stands for Mississippi Valley-type deposit and it is known for hosts' the major sulfide mineralization, which has been an important, source of sphalerite, galena, barite, and fluorite. The most important general characteristics of Mississippi Valley-type deposits (Leach, 1993; Bastin, 1939; Ohle, 1959; Ohle, 1980; Roedder, 1967; Roedder, 1977; Snyder, 1968; White, 1968; White, 1974; Leach et al., 2005) (1) they are epigenetic (2) they are not associated with the igneous activity (3) they are hosted mainly by dolostone and limestone, rarely in sandstone (4)They consist of bedded replacements, vuggy ores, and veins, but the ore is strongly controlled by individual strata. They contain dominant minerals are sphalerite, galena, pyrite, marcasite, chalcopyrite, dolomite, and calcite and barite is typically minor to absent and fluorite is rare (5) they occur in platform carbonate sequences commonly at flanks of basins or foreland thrust belts (6) they are commonly strata bound but may be locally stratiform (7) they typically occur in large districts (8) the ore fluids were basinal brines with ~10 to 30 wt percent salts (9) they have crustal sources for metals and sulfur (10) the temperatures of ore deposition are typically 75° to about 200°C (11) the most important ore controls are faults and fractures, dissolution collapse breccias, and lithological transitions (12) the sulfides are coarsely crystalline to fine-grained and massive to disseminated (13) the sulfides occur mainly as replacement of carbonate rocks and to a lesser extent, open-space fill (14) The alteration consists mainly of dolomitization, host-rock dissolution, and brecciation. They always occur in areas of mild deformation, expressed in brittle fracture, broad domes and basins, and gentle folds. The ore is at shallow depth generally less than 600 m relative to the present surface and was probably never at depths greater than about 1500 m. It is well established that Mississippi Valley-type deposits formed from hot, saline, aqueous solutions sometime after the lithification of their host rocks (Sverjensky, D.A., 1986).

3.2.2 SEDEX deposit

The SEDEX stands for sedimentary exhalative deposit, this term proposed by (Carne and Cathro, 1982) that included laminated, exhalative sulfides in fine-grained clastic, carbonate, and metasedimentary rocks. Regardless of the exhalative component inherent in the term SEDEX, we do not require direct evidence of an exhalite in the ore or alteration component to be classified as a SEDEX. Rather, the presence of laminated sulfides parallel to bedding is assumed to be permissive evidence for exhalative ores. Some SEDEX deposits are known to have replaced carbonate host rocks (Kelley et al., 2004). The most important general characteristics of SEDEX deposits are summarized (Gustafson and Williams, 1981; Large, 1983); Sangster, 1990); Goodfellow et al., 1993; Lydon, 1996; Lydon, 2004b; Sangster and Hillary, 1998; Large et al., 2002; and Goodfellow, 2004). The key features are (1) they occur as tabular Zn-Pb-Ag deposits that contain laminated, stratiform mineralization (2) they are hosted by marine sedimentary rocks of intracratonic or epicratonic rift basin. (3) they have hosted mainly carbonaceous shales, siltstones, and (or) carbonates, sandstones, siltstones, and conglomerates(4) spatially and/or genetically associated igneous rocks are generally absent or volumetrically minor (5) they form in intra- and/or epicratonic rift and passive margin environments (Large, 1980; Large et al., 2002). (6) Ore bodies are generally tabular or stratiform and are localized in smaller fault-controlled sub-basins near the margins of major epicenters and outboard of shallow-water carbonate platforms margins (7)Laminated or bedded sulfides ores in carbonaceous, pyritic, fine-grained shales and siltstones are characteristic of this deposit type. (8)The principal ore minerals, sphalerite, galena, pyrite, marcasite, chalcopyrite,(9)the temperatures of ore deposition are typically 100 to about 200°C (10)the ore fluids were basinal brineswith~17to 30wt percent salts, basin brines that ascended along basin-controlling synsedimentary faults. (11)The ore is at shallow depth generally less than 600 m relative to the present surface and was probably never at depths greater than about 1500 m. (12) the majority of SEDEX deposits formed in intracontinental rifts or passive continental margin tectonic settings. (13) They are not reported from either magmatic arcs or subduction zones (Large, 1980; Large, 1983; Werner, 1989; Werner, 1990; Goodfellow et al., 1991). Sedimentary exhalative (SEDEX) deposits account for more than 50 percent of the world's zinc (Zn) and lead (Pb) reserves (Tikkanen, 1986) and more than 25 percent of the world's current production of these two metals and a significant amount of silver (Ag) (Goodfellow, 2007). More than 129 deposits of this type have been recognized in sedimentary basins around the world (Leach et al., 2005b; Goodfellow, 2007). A compilation by (Taylor et al., 2009; Taylor et al., 1982) shows that deposits occur in 25 sedimentary basins, 8 of which contain more than 10 million metric tons (Mt) of combined Pb+Zn. (these basins are the Mt. IsaMcArthur basins, Australia (7 deposits containing 112 Mt of Zn+Pb metal); Selwyn basin, Canada (17 deposits, 55 Mt); Brooks Range, Alaska, United States (3 deposits, 40 Mt); Kholodninskoye deposit, Russia (1 deposit, 23 Mt); Rajasthan basin, India (5 deposits, 20 Mt); Belt-Purcell basin, United States and Canada (1 deposit, 19 Mt); and Rhenish basin, Germany, Lasbela-Khuzdar belt, Pakistan (3 deposit, 50Mt). Previously Sedex deposits have been compiled reviewed by (Kelley, 1995; Lydon, 1995; Leach et al., 2005b; Goodfellow and Lydon, 2007; Poul Emsbo et al., 2010).

4. Concluding Remarks

4.1 Proposed Models for Mineralization in the Jurassic Sedimentary Sequences

Based on an integrated study, the geological models explain the processes for the deposition of the massive lead-zinc sulfides in the Jurassic sedimentary rocks (Fig. 8). According to the model (Fig. 8A), Early to Middle Jurassic sediments was deposited on Gondwana at a time when extensional forces thinned and broke up the brittle upper crust, and were ultimately intruded by hydrothermal solutions. The spreading environment provided an opportunity for seawater to enter the upper portion(s) of the upwelling magma and subsequently caused the circulation of metal-rich hydrothermal solutions. This mechanism was operative due to thermal convection related to hot basaltic magma beneath the active zone of crustal injection, identical to the idea presented by (Bonatti, 1975). The syngenetic precipitation of the Mesozoic metal sulfides and related mineralization were probably derived from hydrothermal springs oozing at the sea bottom along the tensional faults and from the subsequent burial by the Jurassic mud deposited on the seafloor. The proposed model (Fig. 8B) illustrates the activities and modes of the hydrothermal solution rising along the major crustal tensional fault during the deposition of the Anjira Member of the Ferozabad Formation (Jurassic). The lowermost member, i.e., the Spingwar Member, was mainly clastic where mineralization took place as veins. On a limited scale, strata bound mineralization also occurred in the upper part of this member, where the clastic facies changes into a calcareous one. The middle Loralai Member mainly consists of limestones in which dominantly stratabound mineralization took place. Where thick and massive limestones existed, vein mineralization was also developed. Because the hydrothermal solutions were leaking at the seafloor during the time the Anjira Member was deposited, stratiform mineralization occurred.

The mineralization stages have further been subdivided into the Ci, Cii, Ciii, and Civ stages of mineral formations (Fig. 8C). Stage Ci refers to the mixing of hydrothermal solutions with fine-grained sea-floor mud. Stage Cii refers to mineralogical conversion and precipitation with the overlying sediments. During the process of lithification of sediments, the sulfide bodies were unevenly distributed in the sedimentary sequence. Stage Ciii started after a temporal break in the hydrothermal activities. At this stage, a renewed influx of hydrothermal solutions took place and formed the barite deposits in the upper mineralized zone of the Jurassic rocks with a concordant relationship to the host rocks. Stage Civ is not significant with respect to mineralization, but at this stage the hydrothermal activities ceased and tectonic activities increased, which resulted in lithification and diagenesis of the Jurassic sediments.

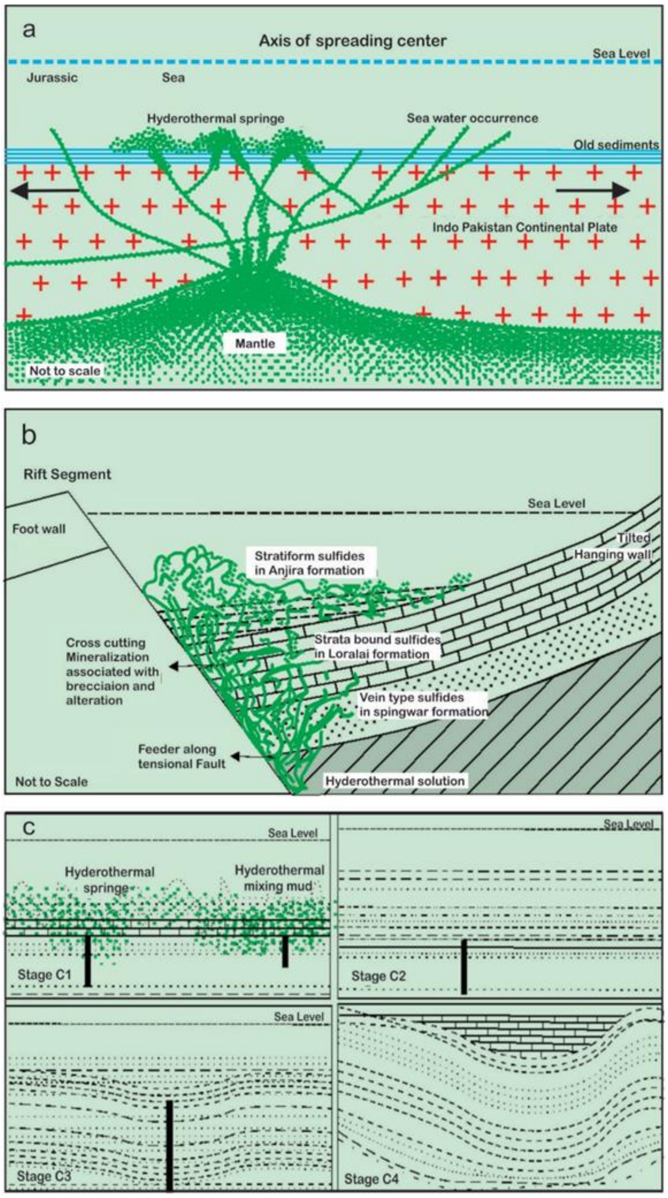

Figure 8: The Proposed models for zinc-lead sulfides mineralizations hosted in the Jurassic Anjira formation of Ferozabad Group in the Bela-Khuzdar region of Balochistan Province, Pakistan. (A) Incipient rift model illustrating the development of hydrothermal springs, rich in zinc-lead sulfides mineralizations on the floor of Jurassic sea. (B) Hypothetical model showing rise of hydrothermal solution along the tensional fault(s) developed under divergent tectonic processes of Gondwana deformation. Section of rift basin is not to scale. (C) Models showing the stages of evolution of barite and lead-zinc sulfides mineralization in Jurassic rocks. (Nayyer Alam Zaigham and Khalil A. Mallick., 2000)

4.2 Possible Mechanism of Geotectonic setting and mineralization of sediment-hosted lead-zinc sulfide deposits of Lasbela -Khuzdar belt of Balochistan, Pakistan

The proposed pictorial model which represents the first order basin is characterized by a thick sequence of clastic and/or carbonate sediments that were deposited during a long period of relative crustal stability and explains fairly well the Geotectonic setting of sediment-hosted sulfide deposits (Fig. 9). It is clear from the figure that mineralization both strata bound and vein-type took place in the Loralai Formation after faulting which served as channels for the hot solution oozings from exhalative centers at the sea bottom. This process caused mineralization of Pb, Zn sulfides, and barite in fracture zones and replaced part of limestones. It is predicted that marine water of the second-order basin developed within the first order basin due to penecontemporaneous local vertical tectonism had sufficient enrichment of metallic ions due to the oozing of the remaining hydrothermal solutions along faults and simultaneous precipitation during the deposition of the Anjira Formation. Thus, lead and zinc sulfides and barite were formed as stratiform in the third-order basin developed as morphological traps due to continuous vertical tectonism. The barite also precipitated as strata bound and in veins. The nodules occurring in the upper part and at the top of the Anjira Formation are most probably of late-stage diagenetic origin. In light of the occurrence of sulfate and the sulfides mentioned it is justified to anticipate that the hot solutions bearing lead, zinc, and barium as sulfides and sulfates moved actively along the faults from the exhalative centers from the bottom of the geosyncline and gave rise to mineralization. The solutions appear to be more active in the second and third-order basins when the Anjira Formation was deposited. This assumption may not be rigorously true but explains logically the possible conditions.

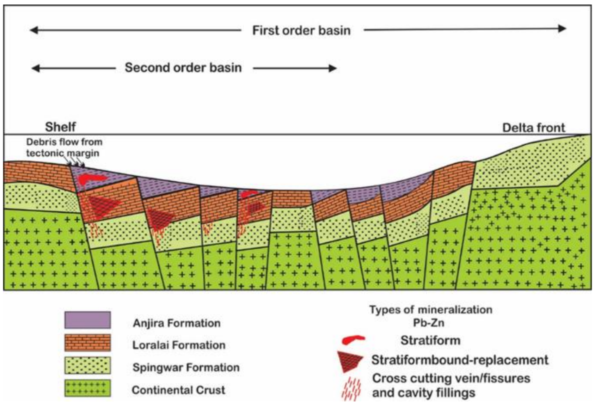

Figure 9: Possible Mechanism of Geotectonic setting and mineralization of sediment-hosted lead-zinc sulphide deposits of Lasbela -Khuzdar belt of Balochistan, pakistan (modified after Large, 1980 and Ahsan, S.N., Mallick, K.A., 1999).

5. Conclusion

The abundant sediment-hosted Lead-zinc sulfides occurred as stratiform, strata bound and vein types found in the Indian passive margin of Lasbela-Khuzdar belt of Balochistan, these sulfide mineralizations have been formed through the processes of syngenetic or epigenetic and through replacement or fissure fillings observed at various places of Duddar, Gunga and Surmai deposits and hosted by siliciclastics and carbonate sedimentary rocks of Mor range of Jurassic Ferozabad Group.

The tectonics were more active when sedimentation of the Anjira Formation started in a disturbing third-order basin. The Hydrothermal solution entered the basin along faults and gave rise to syngenetic mineralization of sulfides in the Anjira Formation, and epigenetic one in the underlying Spingwar and Loralai Formations.

The Carbonate-fine clastic rock type (SEDEX) deposit has been found in Duddar and Surmai deposits and carbonate-hosted type (MVT) deposit found in Gunga and these are the chief deposits types for future prospecting in Pakistan.

The tectonic and Mineralization mechanism models are expected to facilitate a detailed study on the geological and geochemical conditions of mineralization in the Ferozabad Group and economic evaluation of the resources.

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