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Sediment-Hosted Zinc-Lead Ores – An Introduction

L. Fontboté[1] and M. Boni[2]

1 Introduction

Sediment-hosted ore deposits are the main source of lead and zinc, representing more than 50% of the world production and more than 60% of the reserves of these metals (see Wellmer et al., this Vol.). They include two main types of ore deposits, the definitions of which in part overlap (Fig. 1).

1. Sediment-hosted massive sulfide deposits of Zn and Pb (Large 1980, 1988; Sangster 1983). These massive to semimassive deposits occur in extensional basins characterized by a strong thermal subsidence and are hosted by clastic sedimentary rocks, mainly shales (hence, also the term "shale-hosted") but also by other sedimentary lithologies, including carbonate rocks. They are typically fine-grained and stratiform down to the hand-specimen scale. They are also commonly referred to as "sediment-hosted stratiform deposits" or "sedimentary-exhalative lead-zinc", or "sedex" deposits because they are considered to mainly have formed through exhalation of basinal brines at the sea floor and/or "inhalation" into poorly consolidated sediments below the surface.
2. Mississippi Valley-type ore deposits (e.g. Anderson and Macqueen 1988). These stratabound zinc-lead (F-Ba) deposits are mainly, but not exclusively, hosted by carbonate rocks hosted by carbonate rocks deposited at the margins of tectonically stable platforms. Even if at the deposit scale they may present in places tabular morphologies parallel to bedding, closer examination often reveals cross-cutting relationships at outcrop and hand-specimen scale. In comparison with the former type, they are generally coarser-grained. Vein-type morphologies with similar mineral assemblages are considered to be the analogous product of mineralization processes. Mississippi Valley-type deposits are usually interpreted as having been formed by precipitation from saline hot basinal brines during burial diagenesis and later evolutionary stages of the host rocks.

A detailed comparison between these two types of ore deposits has been published by Sangster (1990) which gives abundant references. Additional recent reviews can be found in Eidel (1991) and Russell and Skauli (1991).

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This volume dedicated to Prof. Dr. G.C. Amstutz on the occasion of his 70th birthday presents recent achievements in the research on zinc-lead deposits. In fact, a significant part of G.C. Amstutz's scientific research, as well as teaching activity/PhD tutorship, has been dedicated to Zn-Pb deposits (e.g. Amstutz 1958, 1959, 1982; Amstutz et al. 1964; Amstutz and Bubenicek 1967; Amstutz and Park 1967, 1971; Amstutz and Bernard 1973; Amstutz et al. 1982).

2 Classification Problems

Sediment-hosted massive sulfide deposits of zinc and lead, in particular if they display a clear stratiform geometry, are often referred to as "sedimentary-exhalative" or "sedex" deposits. Quoting Brown (1989, p. 41) we also think that "most geologists would agree that a deposit-type name should normally be based on descriptive rather than genetic terms". We prefer, for this reason, to avoid as much as possible the use of the genetic term "sedex" as a deposit type. The example of the Irish deposit of Navan, which bears many of the characteristics of sediment-hosted stratiform deposits, but which does not appear to be completely "sedimentary-exhalative" but rather largely a product of replacement (Ashton et al. 1986), should prevent excessive eagerness in attributing genetic names to deposit types.

On the other hand, it could be argued that since the term Mississippi Valley type implies generally an epigenetic origin, the genetic neutral term "carbonate-hosted lead-zinc" deposits should be preferred. This would present two problems. Firstly, there are several significant examples of MVT districts hosted in carbonate units developed as transgressive sequences overlying a detrital base which in places is also ore-bearing. This is the case, for instance, in southwest Missouri concerning the Lamotte sandstone-hosted Old Lead Belt and the carbonate-hosted Viburnum Trend. A similar situation can be recognized in southern France where the Triassic sandstone-hosted lead-zinc deposit of Largentière (Foglierini et al. 1980) and the nearby carbonate-hosted Les Malines district (Charef and Sheppard 1988) occur. Both these clastic- and carbonate-hosted deposits share many geometrical and geochemical characteristics and their genesis is normally regarded to involve different aspects of an essentially similar process. Thus, current use considers sandstone-hosted ore deposits of this kind as a variant of the Mississippi Valley type (Bjørlykke and Sangster 1981). Another obvious reason for not using the descriptive "carbonate-hosted zinc-lead" as a synonym of Mississippi Valley type is that several examples of sediment-hosted massive sulfide deposits are also hosted in carbonate rocks. For example, we should mention again the Irish deposits zinc-lead province, which bear "prototypes" of sedimentary-exhalative types as Silvermines (Andrew 1986), which is mainly carbonate-hosted.

In Europe, an additional ambiguity exists regarding the Mississippi Valley-type definition. In occasions, the term "Alpine-type" or "Bleiberg-type" is used for lead-zinc deposits in the Eastern Alps, e.g., Bleiberg-Kreuth in Austria, Mežica in Slovenia and Raibl and Salafossa in Italy, which are hosted by Middle-Upper Triassic carbonate successions. A problem with this is that the term "Alpine-type" has often been accompanied by a genetic connotation.

Several authors (e.g. Schneider 1964; Brigo et al. 1977; Klau and Mostler 1983) interpreted the Alpine lead-zinc carbonate-hosted deposits at least in part syngenetically in opposition to the American Mississippi Valley-type deposits which were admittedly epigenetic. However, recent investigations on Bleiberg and on other deposits in the Eastern Alps (e.g. Zeeh and Bechstädt, this Vol. and references therein) show that the main characteristics of these ore deposits are similar to the typical MVT and that also the Alpine deposits appear to have formed long after sedimentation of the carbonate host rock.

Thus, we prefer to include these deposits under the general term "Mississippi Valley-type" without referring specifically to an "Alpine-type". In this sense, already Sawkins (1990, p. 322) writes that the "Alpine-type" deposits "... appear to be of fairly typical Mississippi Valley-type affiliation, but their tectonic setting can be related to widespread rifting events in the area".

The main difficulties in the classification derive from the fact that the two types mentioned above are two end members within the broad group of sediment-hosted zinc-lead deposits. Sangster (1990) in his "comparative examination of Mississippi Valley-type and sedex lead-zinc deposits" concluded that the two types "... are most dissimilar in their morphological characteristics. In all other features examined, however, large overlaps exist, probably reflecting the common ultimate derivation of both deposit types from fluids that emanated from sedimentary basins". The example of the Irish zinc-lead province with its coexistence of exhalative and diagenetic replacement ores

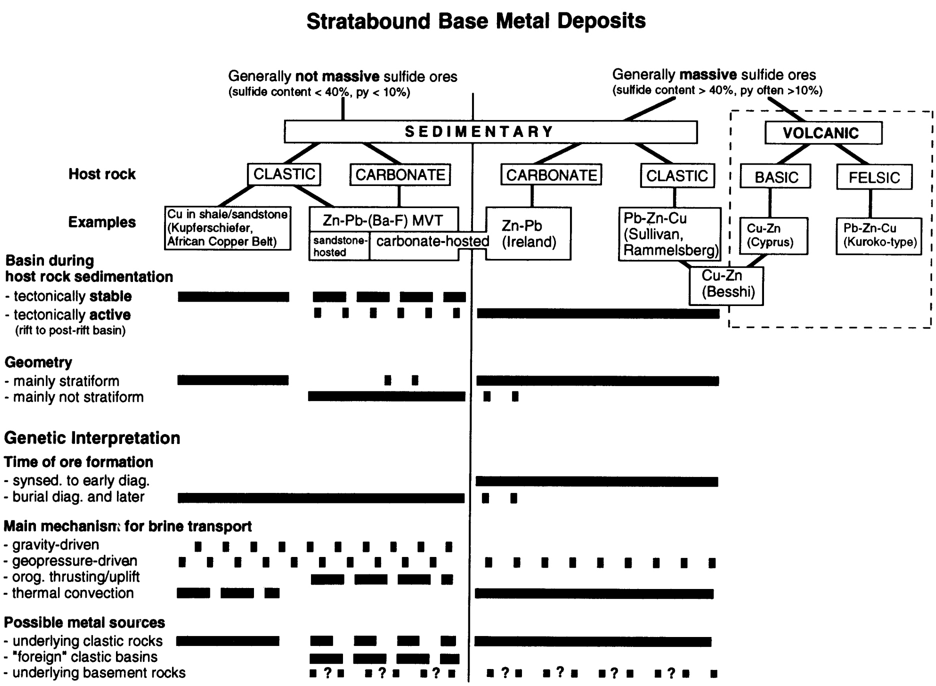

Fig. 1. Selected characteristics and current genetic hypotheses of sediment-hosted base metal deposits. Stratabound volcanic-associated ore deposits are shown for comparison. Ore deposit classification modified from D. Large (pers. comm., 1985)

supports Sangster's conclusion. In the present volume two contributions may provide additional examples of possible coexistence of exhalative-sedimentary processes and epigenetic late diagenetic replacement. They concern deposits in the Lower Cretaceous Basque-Cantabrian basin (Velasco et al., this Vol.) and the carbonate sequences of the same age in the Tunesian Atlas (Orgeval, this Vol.).

A problem occurring when only descriptive terms are considered, however, is that obvious similarities with deposits containing other commodities not included in the description may be overlooked. It appears that processes essentially equivalent to those controlling lead-zinc deposits may not only form fluorite and barite ores, but also iron deposits as in the Basque-Cantabrian basin (Velasco et al., this Vol.). In this sense, the iron ores could be regarded as "MVT Fe" deposits, similar to the term "MVT F-Ba" proposed by Sangster (1990, p. B23) for the F-(Ba) dominant districts in Illinois, Kentucky, and the English Pennines (see also Jones et al., this Vol.).

The existence of transitions to and similarities with other types of deposits, in particular sediment-hosted stratiform copper deposits (Kirkham 1989), should be underlined. Some of the mechanisms of brine migration proposed for the Kupferschiefer and red-bed deposits may be not very different than those forming sediment-hosted zinc-lead deposits.

That the classification into types, although necessary, is particularly difficult when discussing sediment-hosted lead-zinc deposits, can be seen in the regional syntheses included in the present book. Legge and Lambert (this Vol.), in their comprehensive critical review of Australian world class sediment-hosted Zn-Pb deposits, like Broken Hill, Mount Isa, Hilton, McArthur River, and Century, build the conceptual bridge to other types of ore deposits, in particular volcanic-associated massive sulfides. A review of the less well known sediment-hosted Pb-Zn deposits in China is presented by Song (this Vol.).

3 Fluid Transport, Precipitation Mechanisms, and Other Genetic Considerations

Consensus exists that most sediment-hosted zinc-lead deposits were formed by hot metalliferous saline basinal brines (Sverjensky 1986; Hanor 1987; Anderson and Macqueen 1988; Sangster 1990). The different morphologies would mainly result from different times of hydrothermal discharge, the stratiform deposits being typically a product of early diagenetic and exhalative-sedimentary processes, the MVT deposits having formed later in the evolution of the basin, under considerable burial.

A main point are the transport mechanisms of the ore-forming brines. This subject is dealt with in several contributions of this volume. The main accepted mechanisms of transporting brines in sedimentary basins are geopressure drive, thermal convection, and gravity drive.

Compaction-driven migration firstly proposed in Pine Point by Jackson and Beales (1966) has been subsequently shown (e.g. Cathles and Smith 1983) as not explaining the temperature gradients between fluid and host rock recognized in many ore deposits, because of possible thermal reequilibration between fluids and host rock. Other authors suggest episodic dewatering from geopressure zones enabling rapid fluid transport and thus preventing thermal reequilibration, e.g. through seismic pumping (Sibson et al. 1975). Fowler and Anderson (1991) suggest that geopressure zones can act as proximal sources of hot mineralizing fluids in shale-dominated basins. In these models the fluids could be rapidly injected from depth, thus conserving their heat.

It should be noted that compaction-driven fluid migration was a mechanism already proposed by different authors in the 1950s and 1960s. For instance, Amstutz (1964, Fig. 5) explains "late diagenetic galena fillings" in Missouri through fluids moving as the result of differential compaction between shales and carbonate rocks. Another example of geological phenomena possibly controlled by overpressure-driven base metal-bearing fluids is the Decaturville sulfide breccia in Missouri (Zimmerman and Schidlowski, this Vol.).

In sediment-hosted massive sulfide ores, which form mainly in tectonically active rift to post-rift extensional basins (Large, 1988), thermal convection is possibly the main fluid transport mechanism. Russell (1988) and Russell and Skauli (1991) propose that the Irish lead-zinc deposits and the F-dominated district in the English Pennines were formed by brines circulating in convective cells at great depths, affecting the basement. This assumption, which in the case of the ore deposits in Ireland is mainly based on the need of temperatures higher than those reached at the bottom of the basin, is discussed and partly rejected by Jones et al. (this Vol.) on the basis of the existence of high geothermal gradients during the formation of the Irish deposits. According to Jones et al., the Irish deposits formed during early Carboniferous crustal extension and were associated with high geothermal gradients. In contrast, the Pennine deposits would have formed during a period of a declining geothermal gradient. As illustrated by the example of the Cobar basin deposits in Australia, discussed in the contribution of Legge and Lambert (this Vol.), the question whether the basement is permeable enough to enable effective mass transport and can serve as an ore source, is one of the main issues presently under debate.

For a long time it was considered that MVT deposits did not have any relationship with orogenic events. A different view emerged from the studies of Leach and Rowan (1986) and Oliver (1986, 1992), who suggested that the formation of foldbelts is an effective mechanism to initiate the migration of large amounts of fluids. Gravity-driven migration (Garven 1985; Bethke 1986) may be caused by hinterland recharge at a tectonic uplifted hydraulic head. Kesler (this Vol.) evaluates the possible importance of regional thrusting as a mechanism controlling brine transport. Taking the example of the Appalachian-Caledonian orogen, he supports the hypothesis that large-scale thrusting is the dominant factor for expulsion of basinal brines and the development of MVT mineralization in the East Tennessee area of the southern Appalachians.

Further evidence in this respect is given again by Leach (this Vol.) in his contribution on the Ozark region in the United States which includes the Old Lead Belt, the Viburnum Trend, and the Tri-State deposits and other smaller districts. He presents multidisciplinary data supporting a large-scale regional fluid migration in Late Paleozoic in response to convergent plate tectonics in the Ouachita foldbelt.

In contrast to "sedex" deposits where fluid transport is essentially vertical along synsedimentary faults, Sangster (1990) notes that large-scale lateral fluid transport as great as several hundred kilometers would help to explain, for example, anomalously radiogenic leads determined in a number of MVT deposits. Without denying the existence of large-scale lateral brine transport, it should be pointed out that many MVT deposits are locally controlled by high-angle fractures (e.g. Leach, this Vol.; Jones et al., this Vol.; Pelissonier 1967; Rowe et al. 1993). The recent discovery of the carbonate-hosted Lisheen Zn-Pb-Ag deposit in Ireland (Hitzman 1992) illustrates the essential role played by fractures for fluid transport at the district scale. In addition, it should be noted that vertical transfer along faults is one of the few mechanisms to produce significant thermal anomalies in sedimentary basins (e.g. Vasseur and Demongodin 1993).

Diapiric salt structures may also vertically channel hydrothermal fluids. The relationship between zinc-lead ores and salt diapirs is the topic dealt with in the contributions by Posey et al. (this Vol.) and Orgeval (this Vol.). Although the spatial relationship between salt domes and base metal deposits has been recognized for a long time, in particular in southern Europe and North Africa (see references in Rouvier et al. 1985 and in Nicolini, 1990), only recently have they been studied in detail. Posey et al. (this Vol.) note that although known salt dome-hosted zinc-lead metal deposits are of modest grade and tonnage, they provide an excellent laboratory for the study of other classes of sediment-hosted base metal deposits. This is mainly because the evolution of the salt domes gives more precise physicochemical and time constraints for the ore formation than is usually the case in other environments. Orgeval (this Vol.) presents the first extensive description of the peridiapiric metal concentrations of the Bou Grine Zn-Pb deposit (Tunesian Atlas) which will enter in production shortly.

The different hypotheses suggested to explain fluid transport are difficult to test because of the problems faced when trying to date directly the mineralization process. Symons and Sangster (this Vol.) give an overview of the different analytical dating methods applied to MVT deposits and present a summary of paleomagnetic methods that have been proven successful in selected North American examples. From their results the age of mineralization can be correlated with an adjacent orogenic event, thus supporting the gravity-driven flow from an adjacent orogenic uplift.

Two contributions in this volume address the role played by organic matter in the precipitation mechanisms of zinc-lead carbonate-hosted ore deposits. Gize and Barnes (this Vol.) note that MVT deposits appear to be associated with thermally altered Type I kerogen of phytoplankton origin but not to Type III kerogen derived from terrestrial plant organics. Although Type I kerogens are inadequate to cause ore deposition, they may play an important role by selectively complexing metals. Spirakis and Heyl (this Vol.) point out the importance of thiosulfates, as they can be transported together with metals without sulfide precipitation. According to the model presented in their contribution, where the thiosulfate-bearing hot solutions encounter organic matter, thiosulfates may be reduced to provide reduced sulfur for precipitation of sulfides. It can be added that Kucha and Viaene (1993) report peak shifts in microprobe analyses, indicating the presence of thiosulfates in different MVT deposits.

4 Textural Aspects, Geochemistry, and Exploration

One of the main scientific interests of G.C. Amstutz, is the objective description of geometric relationships in ores, in particular the study of ore textures. In the present book this field is less developed compared to other aspects. However, a detailed textural study is found in the contribution by Sass-Gustkiewicz and Mochnacka (this Vol.) on certain rhythmic ore fabrics in the Upper Silesian zinc-lead deposits.

It is often disregarded that minor occurrences of zinc and lead sulfides occur, without an apparent association to ore deposits, as a "normal" result of basin evolution in different geological situations. Two contributions illustrate this. Friedman (this Vol.) reports on dolostone-hosted sulfide occurrences in Silurian strata of the Appalachian basin of New York. Swaine (this Vol.) presents a review of galena and sphalerite occurrences hosted by coal seams.

Two contributions of this volume try to characterize geochemically ore and host rock of some ore deposits in the Triassic of the Eastern Alps. Brigo and Cerrato (this Vol.) present a case study on the fracture-controlled lead-zinc deposit of Raibl, northern Italy. They are able to recognize a distribution zoning for Ge, Cd, Ga, Tl, As, and Sb which can be correlated with major structures controlling the ore deposit. Schroll et al. (this Vol.), on the basis of abundant trace element and isotope data available for the MVT deposit of Bleiberg (Austria), introduce the concept of "geochemometry" in an attempt to characterize geochemically ore and host rock with the help of statistical tools.

One of the main difficulties in defining exploration programs for carbonate-hosted ore deposits is the frequent absence of easily interpretable alteration patterns. Lavery et al. (this Vol.) present an extensive summary of lithogeochemical and other geochemical investigations applied to the exploration for sediment-hosted Zn-Pb deposits. They present a broad survey of geochemical signatures commonly considered to be associated with the formation of ore and observe that designing an exploration program based on the mechanical superposition of a large number of *necessary* anomalies may lead to failure. Rather, the recognition of the sufficient anomaly related to the ore-forming processe(s) may be the key issue.

In conclusion, research on sediment-hosted zinc-lead deposits increasingly shows that we are confronted with different aspects of the global process of ore precipitation from fluids at different stages of basin evolution. Therefore, integrative approaches interfacing research on the origin and nature of fluids, fluid transport, and interaction with host rock, both in the hydrocarbon and ore mineral fields, as attempted in the Geofluids Conference in Torquay (Parnell et al. 1993), may be a step in the right direction. This research direction was decisively influenced by G.C. Amstutz, who 30 years earlier, in 1963, first brought earth scientists of different backgrounds together with economic geologists at a meeting of the International Sedimentological Congress in Delft (Amstutz 1964).

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