Compilation of Mineral Resource Data for Mississippi Valley-Type and Clastic-Dominated Sediment-Hosted Lead-Zinc Deposits

By Ryan D. Taylor, David L. Leach, Dwight C. Bradley, and Sergei A. Pisarevsky

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Introduction

This report contains a global compilation of the mineral resource data for sediment-hosted lead-zinc (SH Pb-Zn) deposits. Sediment-hosted lead-zinc deposits are historically the most significant sources of lead and zinc, and are mined throughout the world. The most important SH Pb-Zn deposits are hosted in clastic-dominated sedimentary rock sequences (CD Pb-Zn) that are traditionally called sedimentary exhalative (SEDEX) deposits, and those in carbonate-dominated sequences that are known as Mississippi Valley-type (MVT) Pb-Zn deposits. In this report, we do not include sandstone-Pb, sandstone-hosted Pb, or Pb-Zn vein districts such as those in Freiberg, Germany, or Coeur d’Alene, Idaho, because these deposits probably represent different deposit types (Leach and others, 2005). We do not include fracture-controlled deposits in which fluorite is dominant and barite typically abundant (for example, Central Kentucky; Hansonburg, N. Mex.) or the stratabound fluorite-rich, but also lead- and zinc-bearing deposits, such as those in southern Illinois, which are considered a genetic variant of carbonate-hosted Pb-Zn deposits (Leach and Sangster, 1993). This report updates the Pb, Zn, copper (Cu), and silver (Ag) grade and tonnage data in Leach and others (2005), which itself was based on efforts in the Canadian Geological Survey World Minerals Geoscience Database Project (contributions of D.F. Sangster to Sinclair and others, 1999). New geological or geochronological data, classifications of the tectonic environment in which the deposits formed, and key references to the geology of the deposits are presented in our report. Data for 121 CD deposits, 113 MVT deposits, and 6 unclassified deposits that were previously classified as either SEDEX or MVT in the Leach and others (2005) compilation, are given in appendix table A1. In some cases, mineral resource data were available only for total district resources, but not for individual mines within the district. For these districts, the resource data are presented in appendix table A2. In addition, numerous figures (appendix figures B1–B9) displaying important grade-tonnage and geologic features are included.

These mineral deposit resource data are important for exploration targeting and mineral resource assessments. There is significant variability in the resource data for these deposit types, and ore controls vary from one region to another. Therefore, grade-tonnage estimations are best evaluated as subsets of
the data in appendix table A1 where local mineralization styles and ore controls characterize the region being evaluated for grade-tonnage relations. Furthermore, consideration should also be given to the tendency for MVT resources to occur in large mineralized regions.

Clastic-Dominated and Mississippi Valley-Type Lead-Zinc Deposits

Classifications of the SH Pb-Zn ores in Leach and others (2005) were organized around traditional subgroups—MVT and SEDEX deposits—and were further subdivided based on classifications in the literature. A fundamental concern with the genetic-model-based classification of “SEDEX” is that it imparts an inherent “exhalative” genetic component to deposits. Most deposits classified as SEDEX lack unequivocal evidence of an exhalite in the ore or alteration component. Consequently, the presence of laminated sulfides parallel to bedding is commonly accepted to be permissive evidence for exhalative ore. However, some deposits traditionally classified as SEDEX did not form from sulfide exhalites. In this report, we avoid process-related, interpretive- and model-driven features to classify the deposits. Deposits are instead characterized by the nature of the sedimentary sequences and their interpreted tectonic environment within which the ores formed. This approach uses the relation that ores classified as SEDEX in Leach and others (2005) are hosted in clastic-dominated sedimentary rock sequences in mainly passive margin, continental rifts and sag basins. We use the term “clastic-dominated lead-zinc” (CD Pb-Zn) for these deposits and avoid genetic and temporal (for example, syngenetic, diagenetic, syn-diagenetic) attributes to the deposits. The ores can be hosted in shale, sandstone, siltstone, mixed clastic units, or as carbonate replacement ores within a clastic dominated sedimentary rock sequence. The CD deposits may be further subdivided based upon specific tectonic or geologic settings in which the deposit formed, which include passive margins (PM), continental rifts (RF), continental sag basins (CS), and back-arc basins (BA). An alternative classification of BHT (Broken Hill-type) is listed for some deposits, a subtype with unique characteristics similar to the Broken Hill, Australia, deposit (Leach and others, 2005).

We retain the traditional term of MVT Pb-Zn for sediment-hosted Pb-Zn deposits in carbonate-dominated platform sequences because this terminology does not include a genetic component. Although the traditional use of the term MVT does imply a broad time component of simply being epigenetic with respect to its host rocks, we recognize that some MVT ores may have a syngenetic, diagenetic, or burial metamorphic temporal component to deposit or ore district formation. The most important characteristic of MVT deposits is their location, mainly hosted in dolostone and limestone in platform carbonate sequences and typically located at flanks of basins, orogenic forelands, or foreland thrust belts inboard of the clastic rock-dominated passive margin sequences. They have no spatial or temporal relations to igneous processes, which sets them apart from skarn or other magmatic Pb-Zn ores.

Many subtypes or alternative classifications have been applied to MVT deposits since their inception as a distinct ore type by Bastin (1939). These alternative classifications reflect geographic and/or specific geological features that some workers believe set them apart as unique (for example, Appalachian-, Alpine-, Reocin-, Irish-, and Viburnum Trend-types). However, we do not consider these alternative classifications or subtypes to be sufficiently distinct to warrant using them in this report.

Limitations of the Data Compilation

Criteria used to classify the deposits and districts as MVT versus CD in appendixes A and B were based on the classifications assigned to the deposits in the literature and the opinions of the authors
that relied on personal observations of the deposits or, in many cases, on descriptions of the geological setting and lithology of the ore-hosting sedimentary rock sequences. Six deposits are included in appendix A as “Unclassified” because the descriptions of the tectonic setting and host rock sequences were insufficient to allow confident discrimination between the two major types of Pb-Zn deposits.

The resource information for the deposits is limited to publicly accessible resource information from sources cited in appendix tables A1 and A2. Some deposits and districts are not presented in the compilation (for example, Central Missouri and Northern Arkansas districts, U.S.A.), because publicly accessible resource information was not available for a variety of reasons. It should be noted that many factors (for example, metal prices, location, corporate policies, national politics, and so forth) influence the determination of the resource data in appendix tables A1 and A2. Furthermore, publicly available data (on which table A1 is based) are not necessarily the most recent. Therefore, the data in table A1, although considered to be the best currently available, do not necessarily reflect the true nature of mineralization in the ground.

Care must be taken with the usage of this data compilation because there are limitations to the data. Some resource data are old and have not been recently updated. Different deposits listed will be characterized by different metal cut-off grades in their definition of ore tonnages. Some deposits are still in the exploration phase and in the future are likely to have more accurate mineral resource estimates.

Many of the deposits do not have absolute mineralization ages listed, because of the difficulty of directly dating the ore minerals. Numerous papers have been published presenting dates of ore deposition, and careful consideration went into determining if the methods shown accurately reflect the age of ore formation, or something else. Dates deemed unreliable by the authors of this report have been excluded from this data compilation. Some deposits also have ambiguous or conflicting classifications reported in the literature. Caution was exercised in determining the correct deposit-type classification. Because this is a global compilation, aspects such as location, metal prices at the time of resource estimation, and regional politics all play roles in the resource estimates. Lastly, reporting of resource estimates is not as strictly controlled in some countries relative to others; therefore, overestimation of metal tonnages may characterize some deposits hosted in certain countries.

Data Fields

The attributes within the tables are defined below.

District and Deposit

The most commonly used names are provided in appendix table A1. Mississippi Valley-type deposits are characteristically distributed throughout larger districts. Many of these districts do not have resources defined for individual deposits; therefore, these are summarized in appendix table A2.

Location

The country and geographic location (latitude-longitude) for each deposit is listed. Latitude and longitude coordinates are provided in decimal format that were calculated using degrees, minutes, and seconds. Southern latitudes and western longitudes are listed as negative values.

Classification

Every deposit is identified as CD, MVT, or UN (unclassified). Alternative classifications (Alt. Class.) are supplied for select deposits as BHT (Broken Hill-type), carbonate-hosted/replacement, or sh-
(shale) or cc- (coarse clastic) hosted. Also listed in the last three columns are the deposit-type classifications as cataloged in Leach and others (2005).

**Tectonic Setting**

When known, the tectonic settings (Tect. Setting) are listed as PM (passive margin), UN (unclassified), BA (back arc basin), CS (continental sag), or RF (rift).

**Grades and Tonnage**

The data listed include average grades and tonnage. If multiple cut-off grades were provided, our reported values are based on the lowest cut-off grade. Lead, zinc, and copper grades are shown as percentages. Silver and some other listed commodities are shown as grams per tonne (g/t). Deposit size and amount of metal are listed as Mt (million metric tonnes).

**Age Determinations**

Mineralization ages are all listed as Ma (million years ago). The method of age determination is listed. Host rock ages are listed using the geologic time scale (Walker and Geissman, 2009). Mineralization ages of CD deposits are typically coeval with host rock age.

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<td>Canada</td>
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<td>0.4</td>
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<td>Viburnum Trend</td>
<td>United States</td>
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<td>-91.12</td>
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<td>Qinling</td>
<td>China</td>
<td>33.10</td>
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<td>22.5</td>
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<td>Turkey</td>
<td>38.33</td>
<td>36.32</td>
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<td>Qinling</td>
<td>China</td>
<td>33.75</td>
<td>106.84</td>
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<td>7.4</td>
<td>9.4</td>
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<td>Zawarmala</td>
<td>India</td>
<td>24.33</td>
<td>73.68</td>
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<td>5.9</td>
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Table A1: Compilation of Data from Global MVT and SEDEX Deposits
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<tr>
<th>Mineralization Age and Method</th>
<th>Dep. type A</th>
<th>Dep. type B</th>
<th>Dep. type C</th>
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<tr>
<td>338.3±5.8 Ma (Re-Os on pyrite)</td>
<td>Morelli and others, 2004</td>
<td>≈ Pasminco Limit ed, 2000; 2001; 2002; Walt ho and ot hers, 1993</td>
<td>≈ Pan and Symons, 1993; Nakai and others, 1993; Hall and others, 1989</td>
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### Table A1. Compilation of Data from Global MVT and SEDEX Deposits

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<tr>
<th>Age Range</th>
<th>Dep. type (Classification)</th>
<th>Dep. type (Misclassification)</th>
<th>Dep. type (Classification)</th>
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<td>Early Cambrian</td>
<td>sedex carb-hst</td>
<td>MVT</td>
<td>Irish</td>
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<td>Irish</td>
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<td>Neoproterozoic</td>
<td>860-980 Ma (Rb model age)</td>
<td>Khiltova and Pleskach, 1997</td>
<td>sedex carb-hst</td>
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<td>Late Devonian</td>
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<td>Early Mississippian</td>
<td>MVT Irish</td>
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<tr>
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<td>MVT</td>
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<td>Paleoproterozoic</td>
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<td>sedex sh-hst unclassified</td>
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<td>sedex cc-hst</td>
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<td>Ordovician-Silurian</td>
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<td>Mesoproterozoic</td>
<td>sedex VMS</td>
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<td>Paleoproterozoic</td>
<td>1285-1198 Ma (geological relations)</td>
<td>Cornell and others, 2009</td>
<td>sedex BHT</td>
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<td>Neoproterozoic</td>
<td>1800 Ma (geological relations)</td>
<td>Deb and Thorpe, 2004</td>
<td>sedex unclassified</td>
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<td>1800 Ma (geological relations)</td>
<td>Deb and Thorpe, 2004</td>
<td>sedex carb-hst</td>
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<td>Mesoproterozoic</td>
<td>MVT</td>
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### References
- See list above for detailed references.
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<th>General References</th>
<th>Prod. or Res. References</th>
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<th>Dep. type B</th>
<th>Dep. type C</th>
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<tr>
<td>Van Stone</td>
<td>Cox, 1968</td>
<td>Zieg, 2001; Cox, 1968</td>
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<td>Vangorda</td>
<td>Jennings and Jilson, 1986; Abbott and others, 1986</td>
<td>Goodfellow and Lydon, 2007 (reference cited within)</td>
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<td>Viburnum #27</td>
<td>Hagni, 1995</td>
<td>Grundmann, Jr., 1977</td>
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<td>Villemagne</td>
<td>Macquar and others, 1981; 1990</td>
<td>Macquar and others, 1981; 1990</td>
<td>Early Jurassic Late Paleocene to Early Eocene (paleomagnetism)</td>
<td>Henry and others, 2001; Rouvier and others, 2001</td>
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<td>Walton</td>
<td>Goodfellow and Lydon, 2007; Kontak and others, 2006</td>
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<td>Song, 1994 CNNC</td>
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<td>Longitude</td>
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*Note: Data for Central Tennessee represents production for 1975 to 1985, 1993 to 2003, and unmined resources as of 2003. Production data for the years 1986 to 1992 were not available at the time of compilation.*

*Plus oxidixed ore reserves of 57 Mt*
Figure B1. Global distribution of clastic-dominated lead-zinc deposits and ancient passive margin sequences (shown as purple lines).
Figure B2. Global distribution of Mississippi Valley-type lead-zinc deposits and districts.

**Explanation:**
- Districts
- Deposits (Cambrian and younger)
- Deposits (Proterozoic and older)
Figure B3. Clastic-dominated lead-zinc deposits through time. Ages based on direct dating of ore mineralization or age of host-rock. Explanation list ordered from oldest to youngest deposits.
Figure B4. Secular distribution of clastic-dominated lead-zinc deposits classified by their tectonic setting during mineralization. The number of passive margins through time are shown for comparison. Passive margins through time from Bradley, 2008.
Figure B5. Grade/tonnage for 121 clastic-dominated lead-zinc deposits. Diagonal lines represent total tonnage of contained zinc and lead metal. Select deposits are labeled as: BH=Broken Hill, South Africa; BHA=Broken Hill, Australia; BS=Big Syncline, South Africa; C= Century, Australia; CA=Cannington, Australia; CL= Changba-Lijagou, China; D=Dongshengmiao, China; DR=Dugald River, Australia; F=Filizchai, Azerbaijan; G=Gamsberg, Germany; HGF=Hilton-George Fisher, Australia; HP=Howards Pass, Canada; HYC=HYC, Australia; I=Mount Isa, Australia; K=Kholodninskoye, Russia; R=Rammelsberg, Germany; RA=Rampura-Agucha, India; RD=Red Dog, USA; S=Sullivan, Canada; SI= Saldipura, India; SK= Sindesar Kalan East, India.
Figure B6. Secular distribution of Mississippi Valley-type metal and age of host rock. Data for 107 deposits and 10 districts are summarized from the Neoproterozoic to present. Mesoproterozoic deposits include Bulman and Nanisivik. Paleoproterozoic deposits include Black Angel, Esker, and Nunngarut. Archean deposits include Bushy Park-Pering. Inset shows a more detailed distribution of metal content from 600 Ma to present.
Figure B7. Grade-tonnage for 113 Mississippi Valley-type deposits and 10 districts. Diagonal lines represent tonnage of Pb and Zn metal. Select districts and deposits are labeled as: AB=Admiral Bay, Australia; AI=Austinville-Ivanhoe, USA; CT=Central Tennessee, USA; ET=East Tennessee, USA; F=Fankou, China; M=Mehdiabad, Iran; ME=Metaline, USA; N=Navan, Ireland; OLB=Old Lead Belt, USA; P=Pavlovskoye, Russia; PP=Pine Point, Canada; R=Reocin, Spain; S=Schmalgraf, Belgium; TS=Tri-State, USA; UMV=Upper Mississippi Valley, USA; US=Upper Silesia, Poland; VT=Viburnum Trend, USA; W=Walton, Canada.
Figure B8. Age of mineralization for Mississippi Valley-type districts and deposits. Ages determined by paleomagnetism and/or radiometric dating.
**Figure B9.** Ages of mineralization and host-rock for Mississippi Valley-type deposits and districts. The two shaded columns represent periods of tectonic assimilation and deposition of 97 percent of the total lead and zinc mineralization in dated Mississippi Valley-type deposits and districts.