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Discussion of "Tectonic Controls of Mississippi Valley-type Lead-Zinc Mineralization in Orogenic Forelands" by D.C. Bradley and D.L. Leach

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The interesting and useful study by Bradley and Leach (2003) of tectonic controls on Mississippi Valley-type (MVT) mineralization in orogenic forelands is marred by a surprising disregard for published evidence for the age of these deposits. This problem is of major importance, because the ages of the deposits control their relation to tectonic features. Here are three examples of the problem, showing how they relate to the suggested tectonic models.

1) Bradley and Leach (2003, p. 657, 663) cite the Canadian Rockies as an example of MVT deposits formed in an Andean-type orogen based on Laramide-age paleomagnetic poles for Pine Point, Kicking Horse and Robb Lake. They ignore Devonian Rb/Sr ages for sphalerite from Pine Point because they “may date late Devonian clays entrapped in the much younger sphalerite”. This statement is referenced to Symons et al. (1998b), which contains nothing about Pine Point. Perhaps they meant to refer to Symons et al. (1998a), which states (p. 79) that “Garven and Sverjensky (1994) noted that the (Rb-Sr) method is prone to contamination by colloidal clay particles entrapped in sphalerite…”. However, Garven and Sverjensky (1994, p. 1150) say only that “Other workers dated early-stage sphalerite at Pine Point as Devonian using a Rb-Sr method, but this type of analysis may be prone to contamination by clay particles incorporated during rapid precipitation of colloform aggregates of metal sulfides.” None of these studies contains any information on clay minerals at Pine Point. Nakai et al. (1990; 1993), which were omitted by Bradley and Leach (2003), deal with this issue specifically and show that inclusions of clay minerals are unlikely to account for Rb-Sr compositions of MVT sphalerite. If Cordilleran MVT deposits are Devonian in age, they could have formed when the western margin of North America was “…dominated by long-lived regional extension” (Nelson et al., 2002).
2) Bradley and Leach (2003, p. 657 and Fig. 5) cite the Cevennes and Maestrat areas as examples of MVT deposits formed in an inversion-type orogen of Santonian to Miocene-age in the Pyrenees. In support of this interpretation, they refer to U-Pb dating by Grandia et al. (2000), isotopic ages on fluorite in Leach et al. (2001), and paleomagnetic measurements by Lewchuk et al. (1998). Sample and analytical data on the fluorite dated by Leach et al. (2001) are, to our knowledge, not published or available for evaluation. However, the U-Pb isochron age of about 62.6 Ma for calcite and galena from the Avecilla mine in the Maestrat basin has been interpreted to indicate that mineralization took place during a rifting or post-rifting interval and before Oligocene-age inversion to form the Pyrenees (Grandia et al., 2000, 2003).
3) Bradley and Leach (2003, p. 662) suggest East Tennessee as an example of MVT mineralization that could have formed after thrust faulting. They note that this would require that the famous “sphalerite sands” (Figure 1), which indicate that ore formed before folding (Kendall, 1960; Matlock and Misra, 1983), ”actually formed by grain-by-

> grain replacement of pretectonic carbonate sands". In support of this revised origin for the sphalerite sands, they cite a paleomagnetic study that contains no information about the sands and says only that "…epigenetic sphalerite could easily replace a clastic carbonate grain…" (Symons and Stratakos, 2000, p. 376), as does a longer version of the same study (Symons and Stratakos, 2003). Thus, Bradley and Leach (2003) and references therein provide no information to support the contention that "the timing of mineralization with respect to thrusting in East Tennessee is debatable" and that the Devonian Rb-Sr ages for sphalerite in the district (Nakai et al., 1990; 1993) should be ignored.

These conclusions and others by Bradley and Leach (2003) about tectonic controls of MVT mineralization in orogenic forelands reflect a clear preference for MVT-age estimates based on paleomagnetic measurements over those based on geologic observations or isotopic age analyses (unless they agree with the paleomagnetic ages). However, <u>there is no proof that remnant magnetism measured in MVT deposits is actually associated with the ore minerals</u>. The carrier for remnant magnetization in most deposits is magnetite or pyrrhotite, both of which are extremely rare in MVT ore. In the Viburnum Trend, which is commonly cited in support of the coexistence of magnetite and MVT ore minerals, only a few magnetite grains have been observed in thousands of polished sections, and its paragenetic relation to other minerals is uncertain (Hagni, 1986, p. 123). In East Tennessee, micron-size magnetite is associated with authigenic feldspar that formed after MVT mineralization (Suk et al., 1990a, b; Aleinikoff et al., 1993). Post-ore magnetite and pyrrhotite of this type probably form when small amounts of iron are released from minerals such as dolomite or sphalerite during alteration caused by new pore fluids or deeper burial. Because so little magnetite or pyrrhotite is needed to produce a magnetic signature in carbonate rocks, this alteration is very difficult to recognize.

Evidence that paleomagnetic ages for MVT deposits are susceptible to alteration and resetting is seen in their relation to isotopic ages. In East Tennessee, Pine Point, and Silesia, paleomagnetic ages are younger than Rb-Sr ages on sphalerite; only at Polaris do the two methods yield the same age (Nakai et al., 1990, 1993; Symons and Sangster, 1992; Symons et al. 1993, 1995; Christensen et al., 1996; Christensen et al., 1995; Symons and Stratakos, 2000, 2003; Heijlen et al., 2003). Where paleomagnetic measurements can be compared to Sm-Nd ages on fluorite in the Illinois-Kentucky fluorite district, the paleomagnetic age is much younger and the Sm-Nd age agrees with Rb-Sr ages on sphalerite from the possibly related Upper Mississippi Valley district (Brannon et al., 1992; Chesley et al., 1994; Symons, 1994). Finally, in Central Tennessee, the age indicated by paleomagnetic poles is the same as that obtained from

Th-Pb isotopes in ore-stage calcite (Brannon et al., 1996; Lewchuk and Symons, 1996). In all cases, the paleomagnetic age is the same as or younger than the isotopic age, suggesting that paleomagnetic measurements frequently reflect later fluid events. (It is important to note that this relation is the same for minerals such as fluorite and calcite in which the crystallographic position of the radioactive isotope is well understood and sphalerite where its exact crystallographic setting remains unclear.) A few recent paleomagnetic studies have found evidence for multiple events in complex orogens (Weil and Van der Voo, 2002), but most studies lack this resolution and reflect only late events. The fact that paleomagnetic age estimates are older than some orogenic events that did not form MVT deposits (Leach et al., 2002), tells us only that paleomagnetic signatures can survive some events, not that they provide an age for MVT mineralization.

In their closing statement, Bradley and Leach (2003, p. 664) indicate that "…other tectonic models are needed for MVT genesis…" outside obvious convergent-margin settings with well-defined foreland basins. In particular, their selective rejection of isotopic measurements and heavy reliance on questionable paleomagnetic age constraints appears to have obscured the number and distribution of MVT deposits that formed in an extensional setting. In addition to the Nanisivik and Canning Basin deposits that were noted by Bradley and Leach (2003) and those of the Canadian Cordillera and Pyrenees mentioned above, Rb-Sr ages for MVT mineralization in the Upper Silesian district of Poland indicate that it formed "…in response to Early Cretaceous crustal extension preceding the opening of the northern Atlantic Ocean" (Heijlen et al., 2003), and a similar extensional setting is thought to have prevailed for Mesozoic-age MVT mineralization in the Verviers-Aachen MVT district in Belgium (Heijlen et al., 2001). If MVT deposits in extensional settings are as widespread as this growing list suggests, then tectonic and fluid flow models related to orogenic forelands will have to be revised. Answers to this important question will require a more balanced evaluation of all data that constrain the age of MVT deposits.

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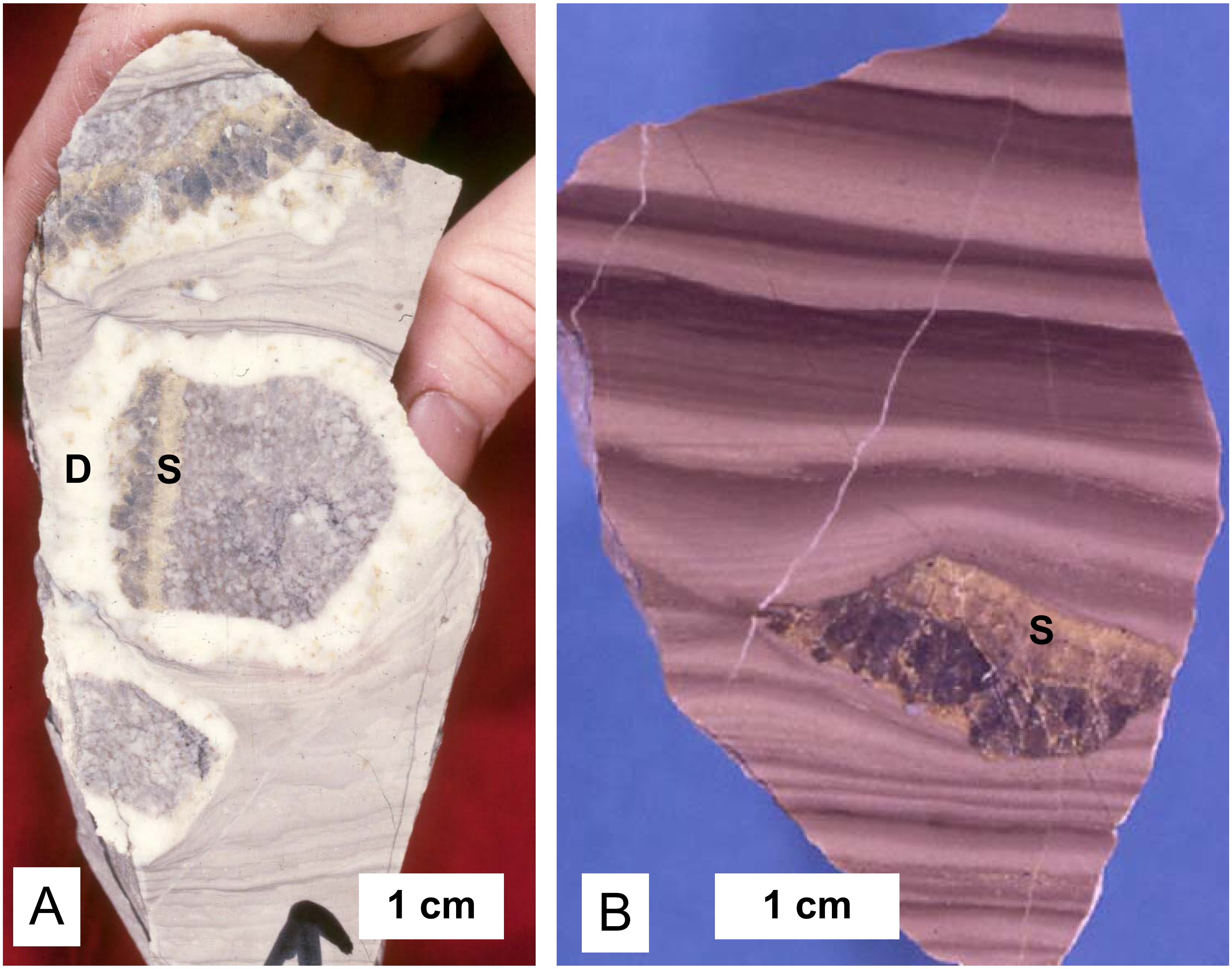

Figure 1. Hand-samples of “sphalerite sand” from East Tennessee showing relation between sphalerite-bearing clasts and dolomite sands. Note that large clasts consist only partly of sphalerite (S) and some are mantled by sparry dolomite (D) of post-sphalerite age, making a replacement origin particularly unlikely.