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DISCUSSION

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Discussion on "Mississippi Valley-type lead–zinc deposits through geological time: implications from recent age-dating research" by D.L. Leach, D. Bradley, M.T. Lewchuk, D.T.A. Symons, G. de Marsily, and J. Brannon (2001) *Mineralium Deposita* 36:711–740

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Introduction

In their comprehensive and interesting summary of recent research on ages of MVT mineralization, Leach et al. state that "Evaluating the possible fluid-flow mechanisms for the East Tennessee ores with respect to the Rb–Sr dates is difficult because the Acadian orogeny did not greatly affect the southern Appalachians and Appalachian Valley and Ridge province." This statement ignores recent isotopic age measurements in the Appalachian hinterland and thereby misses an opportunity for additional insights into the relation between MVT mineralization and contractional tectonics.

The Rb–Sr ages of interest here are isochrons obtained on sphalerite from the Coy and Immel mines, which yielded ages of 377 ± 29 and 347 ± 20 Ma, respectively (Nakai et al. 1990, 1993). These Rb–Sr ages are significantly older than several paleomagnetic, K–Ar and Ar–Ar measurements indicating that widespread fluid–rock interaction took place in the southern Appalachians between about 320 and 280 Ma (Bachtadse et al. 1987; Elliot and Aronson 1987; Hearn et al. 1987; Symons and Stratakos 2000). These younger ages coincide with the Alleghanian orogeny, which produced widespread stratigraphic and structural features in the southern Appalachians and could have been an important driving force for MVT-mineralizing fluids. In contrast, the Rb–Sr ages coincide with the Acadian orogeny, which did not produce obvious stratigraphic or structural features in the southern Appalachians. Until recently, this absence of prominent Acadian features has weakened the case for widespread basinal fluid migration and MVT ore formation during Acadian time.

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Evidence for an Acadian event in the southern Appalachians

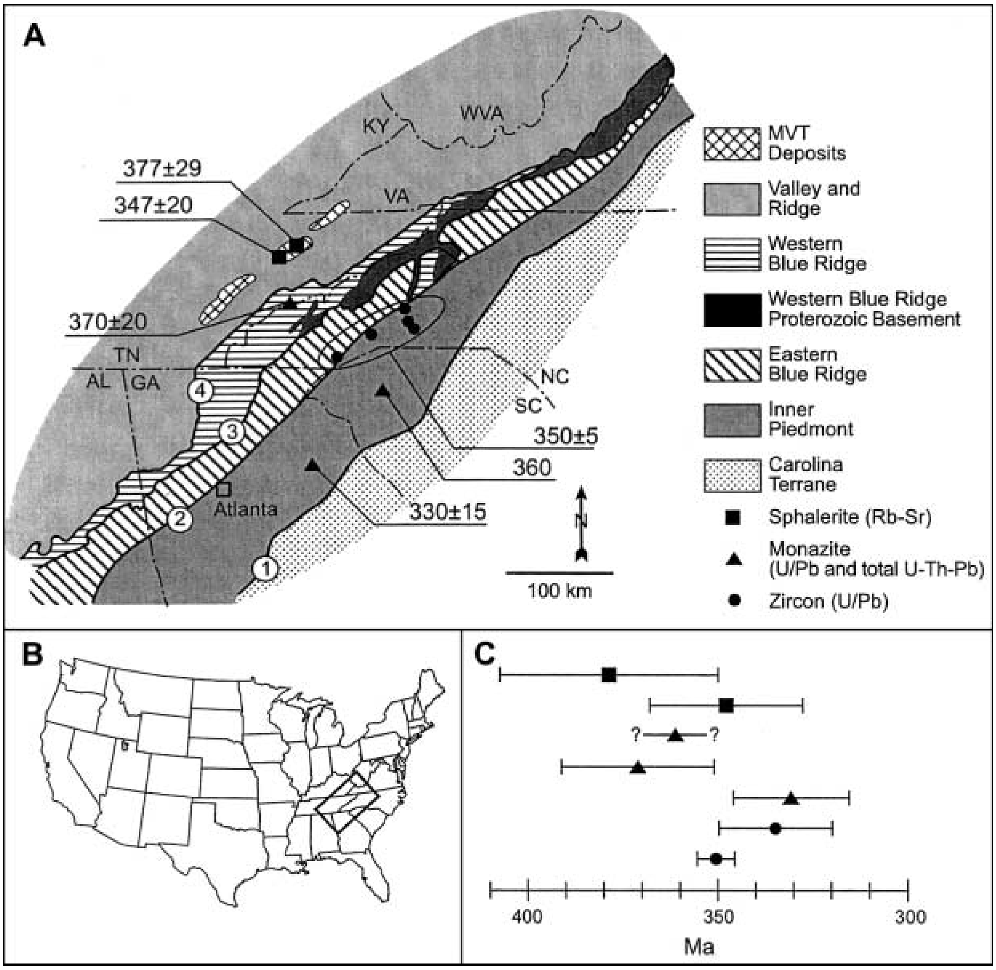
The southern Appalachian Inner Piedmont (IP) terrane is now considered the Acadian metamorphic core (Hatcher 1998). Recently, multiple workers using a variety of geochronometers have obtained Acadian metamorphic ages in the IP, and also across the orogen in the western and eastern Blue Ridge (WBR and EBR; Fig. 1). Ion probe U–Pb analyses of homogeneous, metamorphic zircon rims from the EBR and IP of North Carolina yielded a well-defined age of ~350 Ma (Bream et al. 2001; Carrigan et al. 2001) that agrees well with a previous U–Pb zircon lower intercept of 334 ± 15 Ma from basement in the EBR (Quinn and Wright 1993). Although the exact timing and mechanism for zircon recrystallization is still a matter of debate, it undoubtedly occurs during high-grade metamorphism (e.g., Fraser et al. 1997; Roberts and Finger 1997; Schaltegger et al. 1999; Moecher and Miller 2000; Rubatto et al. 2001). These Acadian metamorphic zircon rims are found in a variety of rock types and ages, including Grenville basement, Neoproterozoic metasedimentary rocks, and early Paleozoic (Taconic) intrusions. Additionally, electron microprobe total U–Th–Pb ages on monazites from the IP of Georgia yield ages of 330 ± 15 Ma (Mirante 2001), and conventional U–Pb analyses of monazite from the IP of South Carolina also yield Acadian ages of ~360 and ~320 Ma (Dennis and Wright 1997).

Metamorphic zircon rims in the western EBR are Taconic (~470 Ma; Moecher and Miller), suggesting that Acadian metamorphism did not reach the high-grade conditions required to recrystallize zircon in the western regions of the southern Appalachian orogen. However, other chronometers record similar Acadian metamorphic ages in the WBR, indicating that Acadian metamorphism did extend across the orogen. Electron microprobe total U–Th–Pb ages on monazite from the Great Smokey Mountains of Tennessee and North Carolina yielded an age of 370 ± 20 Ma (Kohn 2001). Additionally, Sm–Nd and Rb–Sr mineral isochrons yielded Acadian ages of 375 ± 27 and 397 ± 14 Ma in the Spruce Pine thrust sheet of the WBR (Goldberg and Dallmeyer 1997), and $^{40}Ar/^{39}Ar$ methods have yielded ages of ~385–320 Ma on muscovite from the Mt. Mitchell area (Hames et al. 2001). In addition to these isotopic ages, Unrug et al. (2000) have reported fossil assemblages indicating a Silurian or younger age for the Walden Creek Group, a part of the Ocoee Supergroup in the WBR, and have suggested that it was deposited in a pull-apart basin that formed during an Acadian transtensional event.

Significance of the Acadian event to MVT mineralization

These data clearly provide strong evidence for a widespread Acadian-age tectonothermal event in the southern Appalachian Blue

Fig. 1 **A** Generalized tectonic map of the southern Appalachians modified from Hatcher (1989) showing major terranes and locations of Acadian zircon and monazite metamorphic ages (Dennis and Wright 1997; Carrigan et al. 2001; Kohn 2001; Mirante 2001) and MVT deposits (Nakai et al. 1990, 1993); sample locations are approximate. Major terrane boundary faults include *1* Carolina suture, *2* Brevard fault zone, *3* Hayesville-Gossan Lead-Burnsville suture, *4* Great Smokey fault. **B** Map of the United States showing location of tectonic map (**A**). **C** Timeline showing ages of zircon, monazite and sphalerite related to the Acadian orogeny in the southern Appalachians. No errors available for Dennis and Wright (1997) monazite ages. Other published Sm–Nd, Rb–Sr, and $^{40}Ar/^{39}Ar$ age data are not show in **A** or **C**; see text for discussion



Ridge and Piedmont terranes at about 360–340 Ma. Rocks that reflect this Acadian event comprise the hinterland for the sedimentary sequence that hosts MVT mineralization in the East Tennessee and nearby Copper Ridge and Sweetwater districts (Fig. 1A). With the exception of the Rb–Sr mineral isochron in the Spruce Pine thrust sheet, all of these Acadian hinterland ages are similar within analytical error to the Rb–Sr isochron ages on MVT-sphalerite (Fig. 1C). These observations indicate that MVT deposits in eastern Tennessee formed during the Acadian orogeny. Foreland sequences hosting these MVT deposits underwent a second fluid flow event during the Alleghanian orogeny, which produced the widespread effects noted above, but that did not form the East Tennessee MVT deposits.

These relations confirm that orogenic events can generate important MVT deposits, but leave little or no structural and stratigraphic evidence in the MVT-hosting foreland and be largely obliterated by later orogenic events in the hinterland. This is particularly true if the MVT-forming orogeny is followed by another orogeny, as was the case in the southern Appalachians. This, in turn, provides an important note of caution as we attempt to link MVT-formation to global tectonic events. The Pine Point district provides an example of the problems that we face. Here also, Rb–Sr ages for sphalerite are older than the major fluid flow event of Cordilleran age, which has been linked to MVT mineralization by theoretical models of fluid flow and paleomagnetic and fission track measurements (Garven 1985; Symons et al. 1993; Ravenhurst et al. 1994). If insights from the Appalachians can be transferred to this area, the simplest interpretation of these measurements is that the Rb–Sr ages on sphalerite record the fluid flow event that formed MVT mineralization, whereas the more indirect age measurements record a later flow event (Symons et al. 1996; Leach et al. 2001).

There is no reason that MVT deposits were formed by the latest or even the most pervasive fluid-flow event in an area, and this underscores the need for continued efforts to measure the isotopic age of actual ore minerals in these deposits.

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