

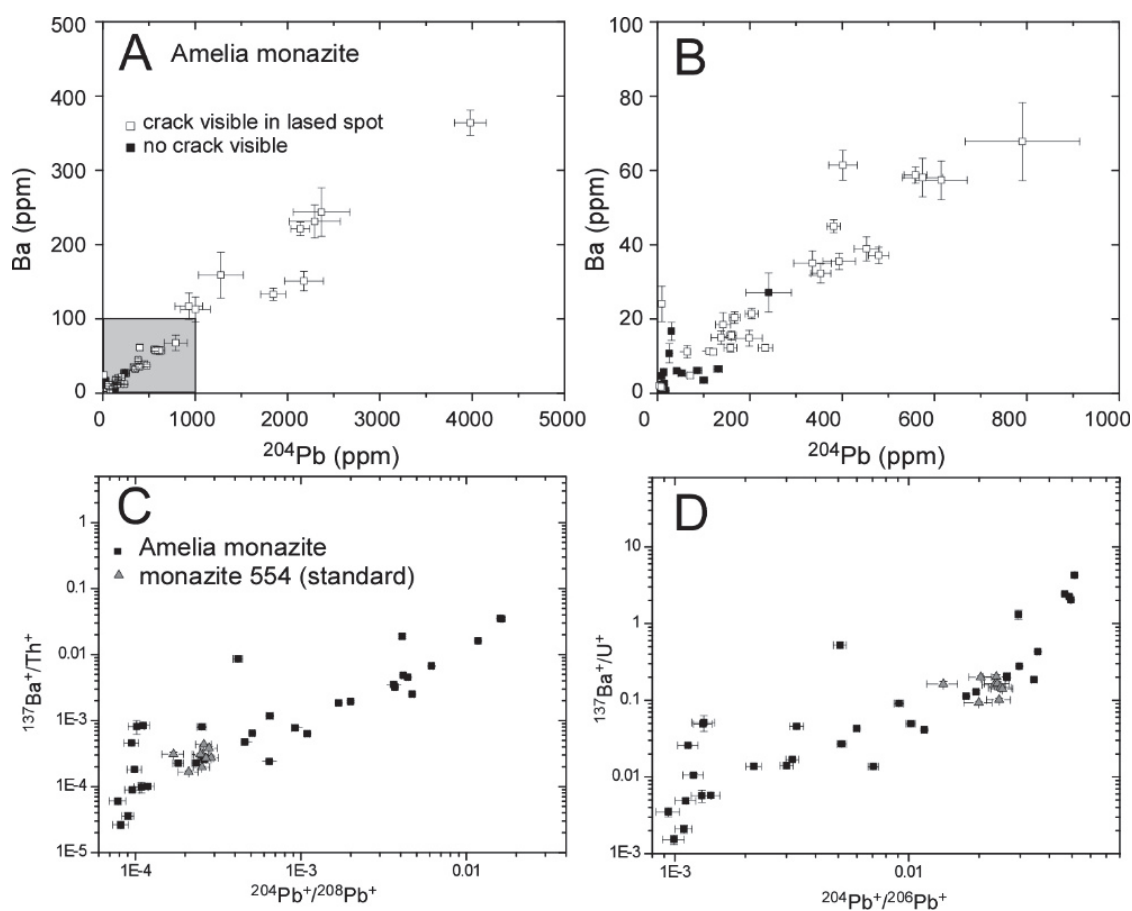
# Insight from high common Pb monazite: Llallagua Tin Ore Deposit (Bolivia) and Amelia Pegmatite (Virginia, USA)

Catlos, Elizabeth J.<sup>1,\*</sup>, Miller, Nathan R.<sup>1</sup>

<sup>1</sup> The University of Texas at Austin, Jackson School of Geosciences, 1 University Station C1100, Austin, TX, 78756, USA

\* E-mail: ejcatlos@jsg.utexas.edu

Monazite [(Ce,Th)PO<sub>4</sub>] is commonly reported to contain low amounts of common Pb and thus is ideal for U-Th-Pb geochronology. However, the Llallagua tin ore deposit in Bolivia and a pegmatite in the Amelia mining district of Virginia have monazite with unusually large and variable amounts of bulk abundance of common Pb or percentage of common to radiogenic Pb. Understanding if common Pb is accommodated in the monazite structure deserves attention because the mineral is a commonly used geochronometer in methods that avoid the measurement of Pb isotopes. Herein, we analyze monazite from these locations by electron microprobe (EMP), laser ablation-inductively coupled plasma mass spectrometry (LA-ICP-MS), and secondary ion mass spectrometry (SIMS) to determine whether common Pb resides within the primary monazite structure, along microcracks, or as contamination by other mineral phases.

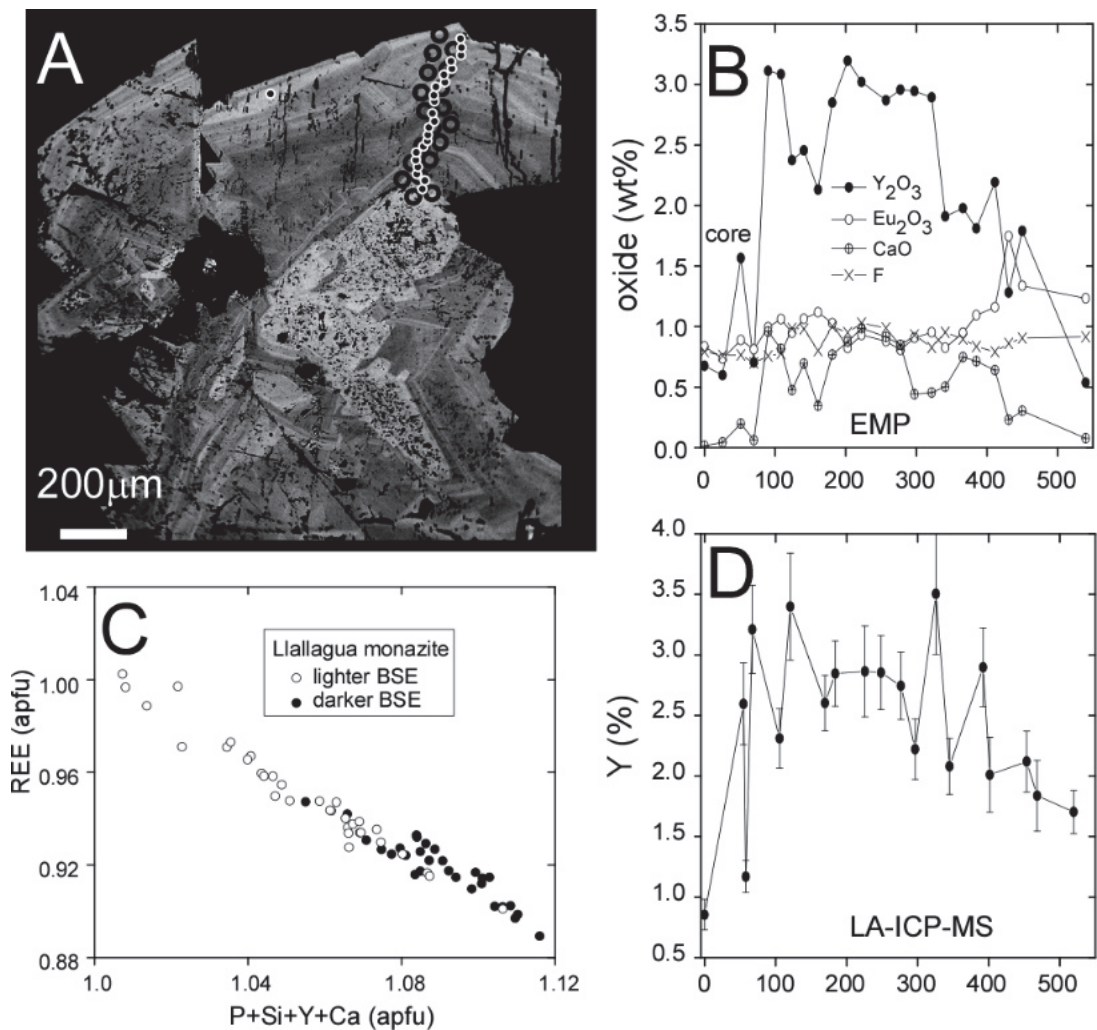


**Fig. 1.** (A)  $^{204}\text{Pb}$  (ppm) vs. Ba (ppm) from the Amelia monazite obtained using LA-ICP-MS. The shaded region is shown in panel (B). (C)  $^{204}\text{Pb}^+/\text{^{208}Pb}^+$  vs.  $^{137}\text{Ba}^+/\text{Th}^+$  and (D)  $^{204}\text{Pb}^+/\text{^{206}Pb}^+$  vs.  $^{137}\text{Ba}^+/\text{U}^+$  from the Amelia monazite obtained using SIMS (after Catlos and Miller, 2016)

A large single crystal of Amelia monazite is high in Th ( $8.54 \pm 1.63$  wt%) and has numerous microcracks adjacent to compositional discontinuities with respect to primary zoning, consistent with recrystallization (see Catlos and Miller, 2016 for details). The amount of  $^{204}\text{Pb}$ , a proxy for common Pb in the Amelia monazite, linearly correlates with Ba, suggesting the presence of a stoichiometric phase or possible substitution mechanism (Fig. 1).

Common Pb in the Amelia monazite may be related to the presence of gorceixite  $[(\text{BaAl}_3(\text{PO}_4)(\text{PO}_3\text{OH})(\text{OH})_6)]$ , Ba-bearing plumbogummite  $[\text{PbAl}_3(\text{PO}_4)_2(\text{OH})_5 \cdot \text{H}_2\text{O}]$ , or other Ba-bearing phase in association with microcracks as the result of alteration.

Monazite from the Llallagua tin ore deposit in Bolivia formed via direct precipitation from hydrothermal fluids as evidenced by oscillatory zoning, low radiogenic element contents, field evidence, and textural relationships (Fig. 2). Monazite compositions should thus provide insight into characteristics of the fluids from which it formed. As expected, the Llallagua monazite has low and variable concentrations of radiogenic elements, with higher amounts of U ( $177 \pm 42$  ppm) than Th ( $63 \pm 30$  ppm). This is commonly observed with hydrothermal monazite and presents analytical challenges for geochronology. High common Pb reported for this monazite is likely due to the difficulty of measuring low levels of Pb in the mineral overall (near instrument detection limits).



**Fig. 2.** (A) BSE image a Llallagua monazite grain. Dark circles are locations of LA-ICP-MS spots, whereas white circles are EMP analyses. (B) Transects across this grain in  $\text{Y}_2\text{O}_3$ ,  $\text{Eu}_2\text{O}_3$ ,  $\text{CaO}$  or  $\text{F}$  obtained using an electron microprobe. (C)  $\text{P}+\text{Si}+\text{Y}+\text{Ca}$  vs.  $\text{REE}$  (apfu). (D) Transect in  $\text{Y}$  obtained using LA-ICP-MS

The Llallagua grains contain some of the highest amounts of fluorine ever reported for monazite ( $0.88\pm 0.10$  wt%) (Fig. 2B), indicating fluids from which it precipitated were likely rich in F, an effective mobilizer of REE, Y, and Th. The monazite also has high Eu contents and positive Eu anomalies, consistent with formation in a highly reducing back arc environment. Fluorine, Ca, Si and REE may have been supplied via the dissolution of pre-existing fluorapatite. Both minerals share substitution mechanisms and positive Eu anomalies. Monazite oscillatory zoning is controlled by an interplay of low (P + Ca + Si + Y) and high atomic number (REE) elements.

Common Pb in monazite may be hosted in fractures, along grain boundaries, and/or as surface contamination, rather than in the monazite structure. The results reported here have implications for those seeking to avoid common Pb and, as both study localities are historically important mining districts, detailed compositional data from these monazite grains may aid new evaluations of these localities as potential ore resources for rare earth elements.

**References:**

Catlos, E.J., Miller, N.R. (2016) Ion microprobe  $^{208}\text{Th}$ - $^{208}\text{Pb}$  ages from high common Pb monazite, Morefield Mine, Amelia County, Virginia: Implications for Alleghanian tectonics. *American Journal of Science* 316: 470-503