ARE TI-RICH PARTICLES IN LATE PLEISTOCENE SEDIMENTS FROM PATAGONIA DISTAL EJECTA FROM AN ATACAMA AIRBURST? R. S. Harris[1] and P. H. Schultz[2], [1]Department of Space Sciences, Fernbank Science Center, 156 Heaton Park Drive, Atlanta, GA 30307, [2]Department of Earth, Environmental, and Planetary Sciences, Brown University, 324 Book Street, Box 1846, Providence, RI 02912; scott.harris@fernbank.edu.

Introduction: Beginning with the first article [1] that proposed that an impact with global consequences occurred at the Younger Dryas Boundary (YDB), titanium-rich microspherules and nuggets have been cited among the evidence for an extraterrestrial event. Despite observations supporting the hypothesis that they condensed or quenched rapidly from ultra-high temperatures indicative of impact processes, these particles are enigmatic primarily because they are unfamiliar as products of known impact events. While the abundance of iron-rich species in meteorites coupled with the strong immiscibility of iron in molten silicates commonly lead to the formation of metallic and iron oxide spherules in both impact and ablation events, Ti-rich analogs would seem to require exceptional titanium concentrations in either the target or the bolide, neither of which are typical.

Pino et al. [2] have recently reported Fe-Ti oxide spherules and nuggets in YDB sediments from Osorno in Patagonian Chile. We have had the opportunity to examine some of these particles using SEM/EDS. We have identified phases that not only suggest an impact provenance for these particles but also raise the possibility that they are distal ejecta from the airburst responsible for the formation of the Pica glasses, 2700 kilometers to the north, in the Atacama Desert [3,4].

Microanalysis: A few dozen magnetic particles were analyzed using backscattered electron microscopy using a Hitachi SU-3500 VP-SEM at Fernbank Science Center employing accelerating voltages between 15 kV and 25 kV. Chemical compositions of selected phases were determined using an EDAX Element EDS detector, an accelerating voltage of 15kV, and a working distance of 10 mm.

The particles can be divided into three categories. The first category is composed of quenched FeO-rich spherules approximately 50 to 100 µm in diameter that contain Ti-rich inclusions (Fig. 1). The second category consists of blocky, elongated to subrounded titanomagnetite nuggets of similar sizes. They commonly have scalloped edges and are coated by clays exhibiting a "crackled" texture (Fig. 1). Agglutinates of predominately acicular silicates and glass comprise the third category (Fig. 2)

Notwithstanding their detailed chemistry, the first and third groups superficially resemble some cosmic spherules and micrometeorites, respectively. Although anomalous concentrations of cosmic spherules, atmospheric ablation spherules, and meteoritical debris at any given stratum might support identification of impact ejecta horizons, they alone are not sufficient to demonstrate impact provenance. But the second group are more promising, not because of the FeO-TiO phase, but rather because of their coatings, inclusions, and a few objects that appear to have collided with them.

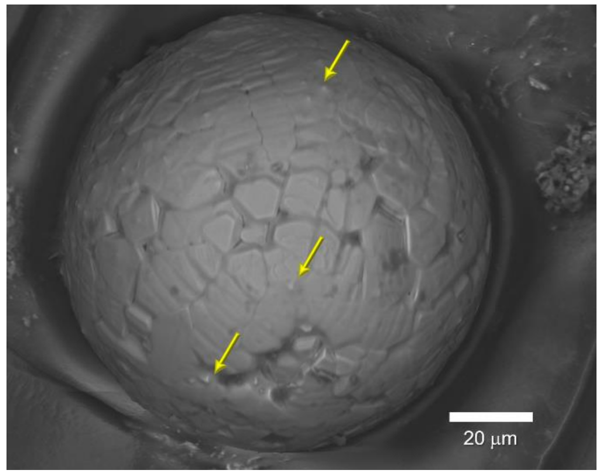

Figure 1. Electron backscattered (BSE) photomicrograph of a quenched FeO-rich spherule with Ti-rich inclusions (arrows).

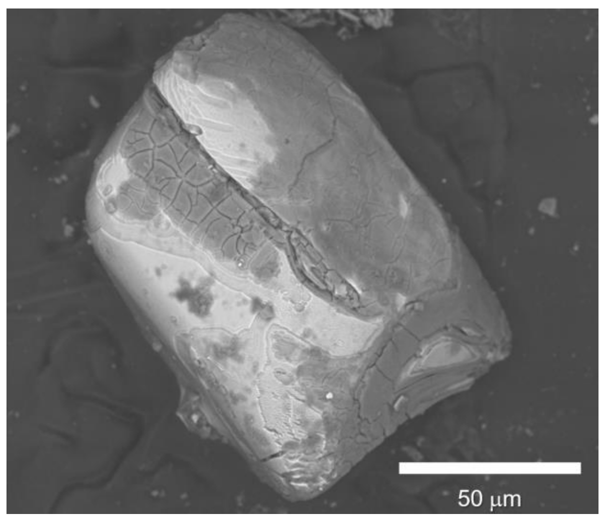

Figure 2. Electron backscattered (BSE) photomicrograph of an Fe-Ti oxide (bright) nugget partially coated in "crackled" clay (dark). Bright spots in the clay are zircon and Ni-Cr-rich spinel (see Fig. 4).

The "crackled" clay coatings have major element compositions that resemble heterogeneous melts rather than any specific clay mineral. The anhydrous equivalent concentrations suggest that the clay is altered from glass with original concentrations of SiO_2 between approximately 50 and 70 wt%. They resemble the compositions

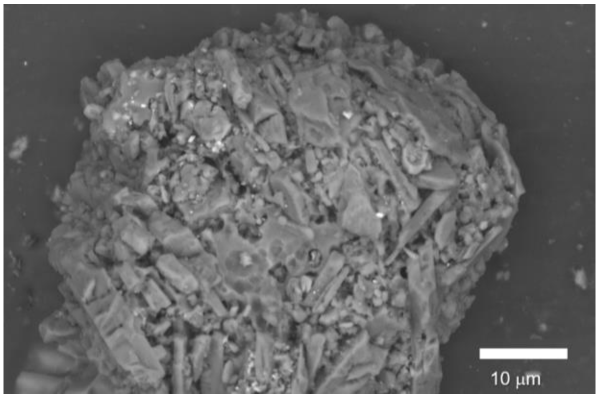

Figure 3. Electron backscattered (BSE) photomicrograph of a glassy agglutinate particle composed largely of Na-Al-clinopyroxene, labradorite, and alumino-silicate glass ranging from ~50 wt% to 76 wt% SiO_2. Some of the bright spots are Ni-Cr-rich oxides.

of many impact glasses including those likely produced at about the same time, c. 12,800 ka, by an airburst near Pica in the Atacama Desert [3,4]. The coatings are especially similar to Pica glasses in that they contain EDS-detectable concentrations (>0.1 wt%) of phosphorus and sulfur, which are not usually observed in energy dispersive spectra of impact glasses.

The "crackled" clay coatings also contain both relict refractory inclusions and quenched phases similar to those commonly observed in high-grade impact glasses. Tiny (<5 μm) zircon grains and Ni-Cr ulvöspinel grains are particularly abundant in the nuggets examined (Fig. 4). Some of the spinel grains appear to contain appreciable silica, which supports the hypothesis that they are quenched rapidly from ultra-high temperatures, perhaps even under high transient pressure.

Although most of the Ni-Cr-rich grains occurs as inclusions in the clay coatings, a few are inside the edges of their Fe-Ti oxide hosts. Some larger spherical objects also are embedded into the host nuggets, as if they collided inflight (Fig. 5). These objects are composed of Cu-rich iron sulfide with detectable nickel and phosphorus, similar to the compositions of Fe (±Cu, Ni) sulfides that are observed coating vesicles in the Pica glasses.

Implications: We propose that Fe-Ti oxide nuggets from the late Pleistocene sediments in southern Chile originated as high-temperature melts or condensates from the same event that produced the Pica glasses and were in fact coated during ejection by aluminosilicate impact melt. If these particles were created during an impact, then the other two categories might share the same petrogenesis. Pino et al. [2] argue that the wüstite mineralogy of the first group demonstrates an impact origin. While [2] they suggest that the agglutinates are basaltic ash from Andean volcanoes, our preliminary analyses show that some of these have a more complex

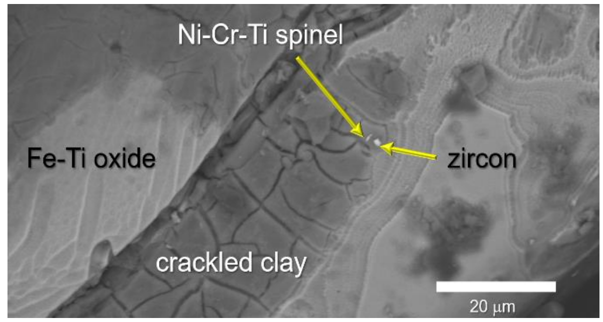

Figure 4. Electron backscattered (BSE) photomicrograph of a portion of the nugget shown in Figure 2. We interpret the "crackled" clay to be altered impact glass containing relict refractory grains (e.g., zircon) and high-temperature condensates (e.g., Ni-Cr ulvöspinel).

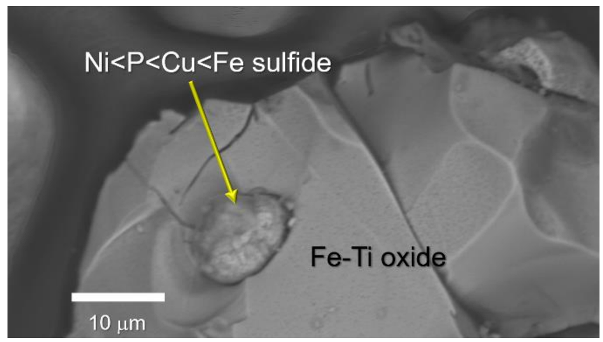

Figure 5. Electron backscattered (BSE) photomicrograph of an Fe-Ti oxide nugget that appears to have been impacted by a Ni and P-bearing Cu-Fe sulfide spherule.

petrology, including high-silica melt, quenched Ni-Cr-rich phases, and meteoritical silicates that would support an impact origin. Given the possibility that these particles represent distal ejecta from the Pica event, it is worth noting that many of the Pica glasses contain unusually high concentrations of titanite (sphene). Perhaps this could help explain the peculiar enrichment in titanium observed in the ejecta. The Pica glasses also contain CAI-like objects, themselves enriched in refractory titanium-bearing phases, likely inherited from the bolide. Consequently, the provenance of even the titanite is still being investigated. If the titanium source ultimately is the impactor, possibly a primitive body containing an abundance of early solar system condensates, that could have broader implications for understanding purported late Pleistocene impact ejecta beyond Chile.

References: [1] Firestone, R. B. et al. (2007) *Proc. Natl. Acad. Sci.,104*,16016-16021. [2] Pino. M. et al. (2019) *Scientific Reports*, in press. [3] Harris, R. S. et al. (2018) *Geol. Soc. Am. Abstracts with Programs, 50,* 320072. [4] Schultz, P. H. et al. (2018) *Geol. Soc. Am. Abstracts with Programs, 50,* 323386.

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