CLASSIFICATION OF REMNANT EXTRATERRESTRIAL CHROME-SPINEL GRAINS FROM JURASSIC SEDIMENTS. C. E. Caplan[1,2*], G. R. Huss[2], K. Nagashima[2], and B. Schmitz[3,2], [1]Department of Earth Sciences, University of Hawai‘i at Mānoa, 1680 East-West Road, Honolulu, HI 96822, [2]Hawai‘i Institute of Geophysics and Planetology, University of Hawai‘i at Mānoa, 1680 East-West Road, Honolulu, HI 96822, [3]Department of Physics, University of Lund, P.O. Box 118, Lund SE-22100, Sweden. *caplance@hawaii.edu.

Introduction: The study of meteorites helps us understand the formation and evolution of the solar system. Recent falls and finds provide us with physical samples of solar system building blocks, but this only gives us information about what has fallen in the past few thousand years. Each meteorite type has its own unique chemistry and isotopes, but these characteristics can be altered due to weathering once the meteorites reach Earth's surface. Fortunately, remnant extraterrestrial chrome-spinels resist weathering and retain their original characteristics [1-2]. The spinels originate from meteorites or micrometeorites and are preserved in terrestrial limestone. The host meteorite type of each grain can be determined by measuring major- and minor-element abundances and oxygen isotopes. The overall objective of studying chrome-spinel grains is to understand how meteorite populations have changed throughout Earth's history. This may include changes in relative abundances of known meteorite types or the discovery of a new meteorite type (e.g., Öst 65 from the Ordovician [3]). This study focuses on samples from the Jurassic using limestone from the Callovian-Oxfordian boundary (~160 Ma) in Southern Spain, near Carcabuey. Here we compare previously presented data for the large-size fraction grains (63-220 μm) [4] with new data for the small-size fraction grains (32-63 μm).

Experimental: Chrome-spinel grains for this study were extracted at Lund University from Spanish limestone [e.g., 1]. The grains were mounted with epoxy in quarter-inch-diameter stainless steel cylinders at the University of Hawai'i (UH). The surfaces of the mounts were ground flat and polished using multiple grades of diamond lapping papers. Major- and minor-element abundances were collected using the JEOL JXA-8500F field emission electron microprobe at UH. The measurements used an accelerating voltage of 20 keV, a beam current of 20 nA, and various beam diameters (1-10 μm). Oxygen isotopes were measured using the Cameca ims 1280 ion microprobe (SIMS) at UH, with Stillwater chromite as the standard [e.g., 5].

Results: Here we present electron microprobe and SIMS data for large and small grains. Where possible, multiple measurements were made on each grain. Measurements of a single grain typically showed good reproducibility. The data were assessed for instrumental errors and the SIMS pits were examined using a scanning electron microscope. Measurements from pits that intersected cracks or secondary alteration were eliminated from the data set, leaving 62 large grains and 52 small grains.

An example of the chemical distribution of large- and small-size fraction grains is shown in Figure 1. The two size fractions show similar distributions. Figure 1 also shows data from our compiled chrome-spinel database for modern meteorites (grey circles). A majority of the large- and small-size fraction grains plot amongst the database data, but there are a number of Jurassic grains with few database counterparts. A group of these grains have high Al_2O_3 and MgO and low TiO_2 and V_2O_3 (dashed ovals, Figs. 1 and 2).

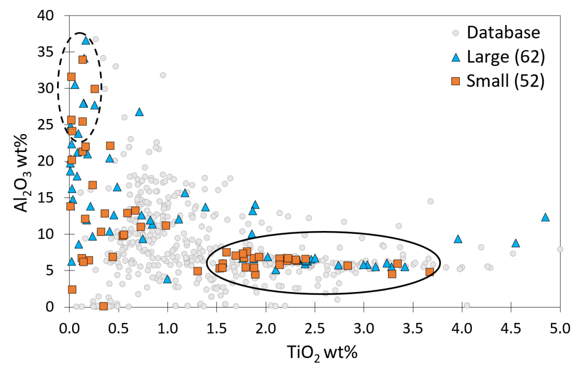

Figure 1: Large (blue triangles, n=62) and small (orange squares, n=52) size fractions of Jurassic chrome-spinels from this study. Grey circles show chromite data for modern meteorites from our own measurements and from the literature [e.g. 6-9].

Oxygen isotopes are also important for classifying the parent meteorites of Jurassic chrome-spinels. Each meteorite type has a characteristic O-isotope signature given by the parameter $\Delta^{17}O$ ($=\delta^{17}O-0.52x\delta^{18}O$). Figure 2 uses color coding to correlate $\Delta^{17}O$ values with chemical compositions. The data points within the solid-line ovals on Figs. 1 and 2 are ordinary chondrites, as shown by their reddish color in Figure 2. The high-Al_2O_3 grains also fall within very limited fields and have a lime color in Figure 2. Figure 2 illustrates that chemistry and oxygen-isotope compositions are related among Jurassic chrome-spinel grains.

Discussion: In [4], we used a preliminary classification scheme in which a grain was classified if the oxygen isotopes and 5 out of 8 elements matched an entry from our database of modern meteorites. Among the extraterrestrial grains studied, we found that 31% were likely from ordinary chondrites [4].

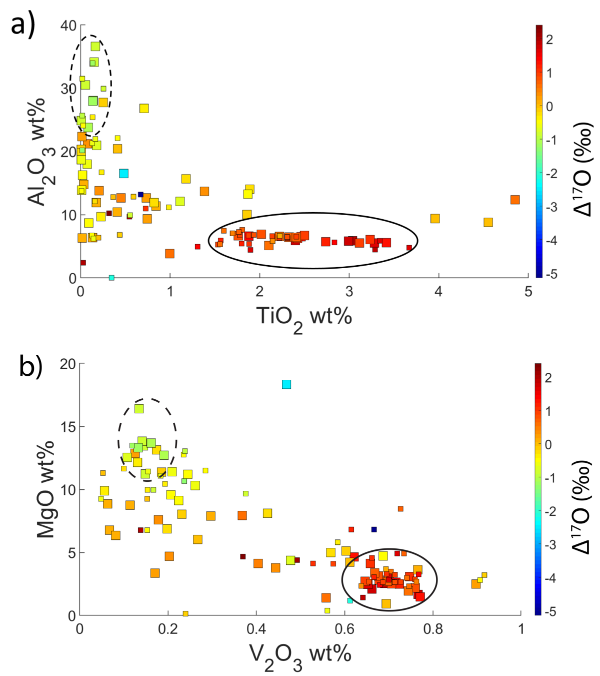

Figure 2: Large (big squares) and small (little squares) chrome-spinel grains in a) TiO_2 versus Al_2O_3 wt% and b) V_2O_3 versus MgO wt%. The $\boldsymbol{\Delta}^{17}O$ color bar in both figures has an error of ±0.36‰ (2$\boldsymbol{\sigma}$).

As more Jurassic grains were measured and more data were added to the database, a different method for classifying grains was needed. Hierarchical clustering was utilized because it can look at multiple dimensions (elements) simultaneously and determine the closest matches. This clustering method groups data into multi-level hierarchies, where closely related grains form low-level clusters and less related grains branch out to form a higher-level cluster (dendrogram). Five out of 8 elements were used in the clustering analysis because MnO, V_2O_3, and ZnO abundances were not available for most database entries. Once element matches were made for the Jurassic grains, oxygen isotopes were referenced to determine a reliable match.

With this method, ~50% of the grains are tentatively classified. Ordinary chondrites made up ~30% of classified grains, and ureilites, acapulcoites/lodranites, or carbonaceous chondrites made up the rest. The remaining grains matched either none or more than one type of meteorite or oxygen isotopes did not give the same classification as the chemistry. There were also cases where the mismatch appeared to be attributable to very high ZnO, an indicator of terrestrial alteration.

Two distinct groups appeared throughout the classification process: ordinary chondrite and high-Al_2O_3 grains. Within the ordinary chondrites, outlined by solid-line ovals in Figures 1 and 2, the large grains are evenly distributed across the ordinary chondrite range (~1.5 to 3.5 TiO_2 wt% [6]), whereas the small grains tend to have compositions with lower TiO_2 contents (~1.5 to 2.5 TiO_2 wt%). Lower TiO_2 abundances are associated with H chondrites [6].

The high-Al_2O_3 grains, outline by dashed ovals in Figures 1 and 2, have similar TiO_2, Al_2O_3, V_2O_3, MgO, and MnO content, Fe#, Cr# and $\Delta^{17}O$ values (lime colored). This clustering may suggest that the grains originated from a distinct meteorite type. The chemical compositions of grains from this group match some entries in the database, but they do not match based on $\Delta^{17}O$ values. The inability to classify the Al_2O_3-rich grains may reflect gaps in the database, but we are working to make our database more comprehensive. Alternatively, the Al_2O_3-rich grains may originate from a type of meteorite that is not represented in modern meteorite collections.

The relative abundances of meteorite types represented by our Jurassic grains are significantly different than those from modern falls and from other time periods that have been studied. For example, the abundances of ordinary chondrite grains changes and generally increases throughout time: ~56% in the Ordovician (>466 Ma) [10] (before the L-chondrite breakup [2]), ~30% in the Jurassic (~160 Ma, this study), ~80% in the Early Cretaceous (145-133 Ma) [11], and 90.6% today. The fraction of ordinary chondrites from the Jurassic may increase as more grains are classified.

Conclusions: Analyses of the Jurassic grains show two distinct clusters based on chemical compositions and oxygen isotopes. An enhanced database may uncover more ordinary chondrites and possibly define the parent meteorite type of the high-Al_2O_3 grains. An updated database may also determine if some of the grains are from unknown meteorite types. More time periods are needed in order to fully understand this evolution, but even now we can see significant differences among the time frames.

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