TRACE ELEMENTS IN REFRACTORY ELTANIN IMPACT SPHERULES.

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Introduction: Eltanin impact deposits record the only known km-sized asteroid impact into a deep-ocean (5 km) basin (at 2.5 Ma [1]). Two oceanographic expeditions explored ~80,000 km^2 of the impact region. Locally, meteoritic ejecta (mm-sized shock-melted asteroid and unmelted meteorites; a low-metal mesosiderite) can be 5 to 50 kg/m^2. Here we report new electron and ion microprobe data on impact spherules.

Samples and Procedures: Eltanin impact spherules are a trace component of the meteoritic ejecta, occurring mainly in the <500 µm fractions of the impact deposit. We assume that their chemical constituents other than seawater salts, are derived entirely from the projectile, as is the case with the larger shock-melted and unmelted asteroidal materials [2,3]. Spherules can be significantly crystallized with magnesioferrite spinel, low-Ca pyroxenes, and/or olivine. A significant fraction of spherules are primarily glass: some with a rim of micron-sized spinel and some are entirely glass. The spinel-free glass spherules are easily recognized as they typically have a translucent, light brown glass, and rarely occur as clear transparent glass. The latter have highly refractory compositions.

Ten spherules (labeled A to J) from the 125 to 250 µm fraction from *Polarstern* core PS281-1KOL, were mounted in polished section. Approximate bulk compositions were determined by electron microprobe, averaging points from a 20-spot grid of with a 10 µm beam diameter. Five spherules have significant crystallization of abundant spinel (A,F), pyroxenes (H), or glass with cryptocrystalline pyroxene(?) and a spinel rim (C,D). One is mainly glass with a spinel rim (B). Three are translucent glass without a spinel rim (E,I,J), and one is a transparent glass (G).

Trace elements were measured on the UCLA Cameca 1270 ion microprobe using high mass resolution and moderate energy filtering to discriminate potential interferences from oxide ions. The oxygen-ion beam was ~40 µm diameter and we had some analytical difficulties as the beam current drifted from 30 to 12 nA during the course of the analysis session. NIST trace element glass 610 was used as a standard and NIST glass 612 and an in-house glass made from USGS standard powder BHVO-1 basalt were used as controls [4,5]. We measured Sc, Y, Zr, Ba, and REE. Analytical precision at the 1 sigma level was <1% for Sc, Y, Zr, Ba, commonly 1 to 10% for light REE (La, Ce, Pr, Nd, Sm) and up to 20% for heavier REE. In some specimens with low concentrations heavy REE uncertainties were as much 40% or higher. We plan additional measurements to improve these statistics.

Results and Conclusions: Compositions of the spherules, normalized to bulk Eltanin meltrock [2] show that all spherules are at least slightly enriched in refractory oxides of the elements Al, Ca, and Ti (Fig. 1). Two of the translucent glass spherules (I,J) are enriched by a factor of ~2 and the transparent glass spherule (G) is enriched by nearly a factor of 5 in Al_2O_3. Spherule G has a bulk composition similar to that of meteoritic CAIs with 37% Al_2O_3 and 23% CaO. We attribute this refractory composition to distillation and/or condensation within the impact plume. Because the starting material was a basaltic asteroid, spherule G has not been fractionated to the same degree as CAIs [e.g., 6], but it is more fractionated than the most refractory CAT-type cosmic spherules [7]. Spherule G is so strongly fractionated that it is somewhat depleted in Mg, and strongly depleted in Si, Mn, and Fe relative to bulk Eltanin.

We measured the trace elements to test the hypothesis that the fractionated major element oxides resulted from distillation/condensation in the impact plume. Sc, Y, Zr and most REE are positively correlated with refractory oxides, such as Al_2O_3 and in particular these elements are most highly concentrated in spherule G (Fig 2-4). Barium is not well correlated with Al_2O_3 but correlates with MgO (Fig 5), which is enriched in refractory spherules I and J, but depleted in G. One notable exception is Ce, which correlates negatively with Al_2O_3, exhibiting a negative Ce anomaly relative to CI abundances with Ce/Ce* (Ce* is the concentration of Ce if there were no anomaly, interpolated from La and Nd abundances) as low as 0.12 in spherule G (Fig. 6-8). Negative Ce anomalies are significant as they are also found in FUN-type CAIs. In FUN inclusions this anomaly is attributed to formation under relatively oxidizing conditions where Ce is oxidized to +4 valence and forms the more volatile oxide CeO_2 [e.g., 8] which is then depleted relative to more refractory REEs. Since the Eltanin impact plume consisted mostly of asteroid and seawater, it was more oxidizing than typical nebular environments, and this depletion of Ce in oxidized glass spherules is easily explained by depletion of volatile CeO_2. One interesting observation is that in spherule G we also appear to observe a negative anomaly for Pr (Fig. 8). Given the low precision (7% 1-sigma for Pr in G) for some of our REE measurements, we will need to confirm this with additional analyses on these and other spherules. However, it is worth noting that Pr can also be oxidized to Pr^{+4}.

Our data are consistent with the spherule compositions reflecting fractionation in the impact plume. We also plan isotopic analyses to see if isotopic fractionation as is observed in CAIs and CAT cosmic spherules occurs in the impact environment [e.g., 7,9,10]. Eltanin spherules are uniquely suited to studying these types of processes as the spherules are derived directly from the projectile and are not significantly contaminated by terrestrial silicates.

References: : [1] Gersonde, R. et al. (1997) Nature 390, 357-363. [2] Kyte F.T. (2002a) Deep Sea Res. II 49, 1029-1047. [3] Kyte F.T. (2002b) ibid., 1063-1071. [4] Pearce J.G. et al. (1997) Geostand. Newsl. 21, 115-144. Govindaraju K. (1989) [5] Geostand. Newsl. 13, 1-113. [6] Grossman L. et al. (2000) GCA 64, 2879-2894. [7] Alexander C.M.O'D. et al. (2002) GCA 66, 173-183. [8] Davis A.M. et al. (1982) GCA 46, 1627-1651. [9] Ireland T.R. et al. (1992) GCA 256, 2503-2520. [10] Engrand C. et al. (2005) GCA 22, 5365-5385.