SEARCHING FOR CHIPS OF KUIPER BELT OBJECTS IN METEORITES. M. E. Zolensky[1], G. Briani[2], M. Gounelle[2], T. Mikouchi[3], K. Ohsumi[1], M. K. Weisberg[4&5], L. Le[6], W. Satake[3] & T. Kurihara[3], [1]ARES, NASA Johnson Space Center, Houston, TX 77058, USA (michael.e.zolensky@nasa.gov); [2]Muséum National d'Histoire Naturelle, 57, rue Cuvier, 75005, Paris, France; [3]University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan; [4]Kingsborough Community College, Brooklyn, NY 11235, USA; [5]Department of Earth and Planetary Sciences, American Museum of Natural History, NY, NY 10024, USA; [6]ESCG Jacobs, Johnson Space Center, Houston, TX 77058, USA.

Introduction: The Nice model [1&2] describes a scenario whereby the Jovian planets experienced a violent reshuffling event ~3:9 Ga – the giant planets moved, existing small body reservoirs were depleted or eliminated, and new reservoirs were created in particular locations. The Nice model quantitatively explains the orbits of the Jovian planets and Neptune [1], the orbits of bodies in several different small body reservoirs in the outer solar system (e.g., Trojans of Jupiter [2], the Kuiper belt and scattered disk [3], the irregular satellites of the giant planets [4], and the late heavy bombardment on the terrestrial planets ~3:9 Ga [5]. This model is unique in plausibly explaining all of these phenomena. One issue with the Nice model is that it predicts that transported Kuiper Belt Objects (KBOs) (things looking like D class asteroids) should predominate in the outer asteroid belt, but we know only about 10% of the objects in the outer main asteroid belt appear to be D-class objects [6]. However based upon collisional modeling, Bottke et al. [6] argue that more than 90% of the objects captured in the outer main belt could have been eliminated by impacts if they had been weakly-indurated objects. These disrupted objects should have left behind pieces in the ancient regoliths of other, presumably stronger asteroids. Thus, a derived prediction of the Nice model is that ancient regolith samples (regolith-bearing meteorites) should contain fragments of collisionally-destroyed Kuiper belt objects. In fact KBO pieces might be expected to be present in most ancient regolith-bearing meteorites [7&8].

Clasts: We have previously searched through regolith-bearing meteorites, to locate and characterize the most common types of meteorite xenoliths (Figure 1). At that time these materials were generally called "C1-," "C2-clasts", or "dark inclusions" in the literature, and were reported in all types of chondrites in addition to HEDs and other achondrites. We concluded that these xenoliths were most commonly similar to CM2 and CR2 chondrites [9-12], but that significant differences exist, and in fact similarities to unmelted Antarctic micrometeorites were more apparent [13&14]. Following a long search, the meteorites we have since found clasts in are: **HEDs**: MAC 02666, EET 87513, Bholghati, Jodzie, Kapoeta, LEW 85441, LEW 85300, Malvern, Lew 87295, Mundrabilla 020, LEW 87015, Y-793497, Elemeet, Y-791834; **Ordinary Chondrites**: Wells, Abbott, Willard (b), Parambu, Y-790048, Zag, DAG 577, Plainview, DAG 581, NWA 1848, Sahara 98328, NWA 4846, DAG 369, Oubari, Mezzo Madaras, NWA 4686, NWA 5386, Parnalee, Siena, St. Mesmin, Leighton, Dahmani, Y-82055, Cynthianna, Sharps, Broken Hill, Tsukuba; **Carbonaceous Chondrites**: Cold Bokkeveld, El Djouf 001, Al Rais, Renazzo, ALH 85085, PAT 91546, PCA 91467, QUE 94411, HaH 237, Isheyevo, Tagish Lake, NWA 2086, NWA 760, NWA 2364, EET 96026, Ningqiang, NWA 801, NWA 2140, Vigarano, Allende, LON 94101, Bencubbin; **Aubrite**: Cumberland Falls; **Ungrouped**: Kaidun.

We are performing a complex suite of bulk compositional and mineralogical analyses to test the hypothesis that KBO pieces are present in meteorites, especially regolith-rich meteorites, and that these pieces (xenoliths) can be recognized and exploited for cosmochemical information on the earliest history of the outer solar system, and by extension, other solar systems.

A few of these xenoliths have previously undergone thorough mineralogical work - we don't list the references for much of this work because of length limitations, but important work has been performed by Keil, Krot, Weisberg, Prinz, their coworkers and many others. None of these materials have had major-, minor- or trace-element compositions analyzed and few have experienced any kind of isotopic investigation. We recognize several distinct classes of xenoliths (in addition to many unique xenoliths), which we briefly describe here. All types are shown in Figure 1. These types are preliminary groupings only, and will certainly change as we gather more detailed information on all clasts.

Type FGA (fine-grained anhydrous) xenoliths are widespread. These are fragmental breccias with a bimodal size distribution. Coarse (1-100 µm), generally fragmented grains of olivine, low-Ca pyroxene, Fe-Ni sulfides are set within a fine-grained, anhydrous (which we need to verify) groundmass principally of ferromagnesian silicates. Some classes also have microchondrules of all types, but principally barred, microcrystalline or glassy. These xenoliths have received little detailed characterization. The fact that they are anhydrous leads us to believe they may have the greatest potential to be KBO pieces, since the Wild 2 samples are to date anhydrous.

Type FGH (fine-grained hydrous) xenoliths are perhaps the most widespread type and are often called "C1", "CR" or "CI" in past studies. These xenoliths tend to be rather small, probably reflecting low-strength. The ones that have been analyzed typically consist of 0.5-10 µm sized Fe-Ni sulfides and magnetite set within serpentine and saponite. Occasional fragmented grains of olivine are found in the larger xenoliths, which indicate that these are not truly petrologic type 1. Gounelle et al. [13&14] have pointed out that these xenoliths are mineralogically most similar to hydrous micrometeorites though some differences are apparent. One clast from Leighton which we studied contains abundant Ca-carbonate grains and Fe sulfides which synchrotron X-ray diffraction (SXRD) showed to be very poorly crystalline or amorphous – the probable result of shock.

Type CGH (coarse-grained hydrous) xenoliths are almost as widespread as FGH and have frequently been called "C2"or "CM". These xenoliths tend to be significantly larger than the FGH. The ones that have been analyzed typically consist of 0.5-10 µm sized Fe-Ni sulfides and partially-aqueously-altered chondrules, fragmented olivine and low-Ca pyroxene set within serpentine and (lesser) saponite. These xenoliths have long been recognized as being very similar to CM2 in terms of mineralogy [9-12], but a definite relationship has never been established (but could be by bulk compositional measurements, including O isotopes).

Could these clasts derive from KBOs? Can we reliably identify certain xenoliths with a KBO origin? How would this be done? Campins and Swindle [15] recommend looking for dark, weak, porous lithologies which have nearly solar abundances of most elements, and have elevated C, N, and H contents. We are also comparing the mineralogical components and petrographies of these clasts with Wild 2 samples. One potential strategy is to look at compositional variation of major and minor elements in olivine and low-Ca pyroxene, which we are systematically doing. As we have recently shown [16&17], Wild 2 olivine and low-Ca pyroxene have the widest possible compositional ranges for Mg/Fe, and elevated minor element compositions, as compared to all known chondritic materials, except anhydrous chondritic IDPs. In addition, a significant degree of shock in clasts (as we have seen for the hydrous Leighton clast), since impacts between KBOs and main belt asteroids would be at a generally higher velocity than those purely between main belt asteroids. We are assessing the shock state of these clasts using SXRD and Electron Backscattered Electron Diffraction. Finally, isotopic compositions may be reliable indicators. For example, it will be interesting to measure the D/H ratios and O isotopic compositions of the fluid inclusions in halite which accompany the Zag clast, which is work in progress.

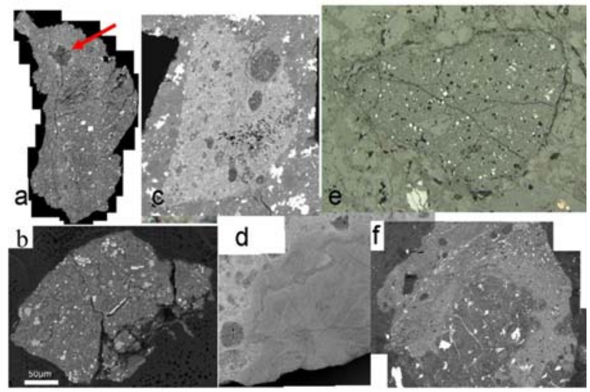

Figure 1. Several xenoliths we have identified in chondrites – all except (e) are BSE images, showing a fraction of the diversity of possible KBO chunks. (a) A 1 cm-long FGH xenolith from the Zag (H5). A large carbonate suitable for Mn-Cr dating is arrowed. (b) A FGH cast from the Tsukuba chondrite (H5-6), which measures 0.9 cm across. (c) A large CGH xenolith from Plainview (H5), measuring 2 cm across. (d) A fine-grained xenolith in NWA 2364 (CV3), measuring 3 cm across. (e) Reflected light image of a generally fine-grained xenolith in Y-791834 (eucrite) (5 mm across). (f) Strange xenolith of uncertain mineralogy from the Cumberland Falls aubrite (1 cm across).

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