**ARE K-CLASS "ORE-BEARING" ASTEROIDS? RARE EARTHS AND PRECIOUS METALS IN CO CHONDRITES BY USING ICP-MS BULK CHEMISTRY.** M.J. Herrero-Pérez[1], J.M. Trigo-Rodríguez[1], and J. Alonso-Azcárate[1]. [1]Meteorites, Minor Bodies, and Planetary Sciences Group, Institute of Space Sciences (CSIC-IEEC), Campus UAB Bellaterra, c/Can Magrans s/n, 08193 Cerdanyola del Vallès (Barcelona), Catalonia, Spain (trigo@ice.csic.es), [2]Universidad de Castilla-La Mancha (UCLM), Campus Fábrica de Armas, 45071 Toledo, Spain.

**Introduction:** Two currently ongoing space missions Hayabusa 2 and OSIRIS-REx have the goal to achieve sample return from two primitive carbonaceous asteroids, respectively 162163 Ryugu and 101955 Bennu [1,2]. Both missions try to make an accurate characterization of these asteroids in order to improve our assignation of asteroidal materials to carbonaceous chondrite (CC) meteorites. The latter is a challenging goal, despite that we have thousands of CC specimens in our collections with extraordinary scientific interest [3-6]. Space weathering is affecting the surfaces of the parent bodies of CCs, so their reflectance properties can differ significantly from these measured for CCs [7-8]. Because of that, it is obvious that the search of space resources can be challenging. We wish to get better answers concerning the amount of commercially profitable material that might be in pristine undifferentiated asteroids [9-10].

In order to learn about the reliability of asteroid mining during the last decade we have performed ICP-MS bulk chemistry of tens of CCs, most of them from the NASA Antarctic collection. To avoid the effects of terrestrial alteration in finds, we also compare the measured mean bulk elemental composition of Antarctic finds with recovered falls. As the outcome of this effort, realized in the framework of two Spanish research projects (AYA2011-26522 and AYA2015-67175-P, P.I. J.M. Trigo-Rodríguez), we present here quite encouraging results about some of the most pristine CCs, associated with the CO (Ornans) group.

In view of our results, we think that future projects of asteroid mining should be focused in the study of pristine asteroids, probably of the K spectral class. This latter assignment is inferred from the study of reflectance spectra and by noticing that K-class asteroids exhibit marked olivine and spinel absorption bands like those found in CO chondrites [7-8].

**Experimental procedure:** The meteorites studied in our ICP-MS (Inductively coupled plasma mass spectrometry) analyses, which we include in this preliminary work, are members of the CO chondrite group (Table 1). The samples were analyzed by an ICP-AES (Inductively coupled plasma atomic emission spectroscopy), ICAP 6500 ThermoElectron for major elements, and an ICP-MS Thermo Electron X Series II for minor and trace elements.

Solutions were prepared from ~0.025 g of each sample fluxed with 0.05 g of Li-metaborate and dissolved in 100 ml of 1M $HNO_3$, together with 1 drop of HF. Four standard US Geol. Survey reference materials were used for external calibration; while internal calibration was made before the measurements using Rh as standard.

| Meteorite | Petrologic group | Fall/find (year) |
|---|---|---|
| ALH 82101 | CO3.4 | f (1982) |
| ALH 83108 | CO3.5 | f (1983) |
| ALHA 77003 | CO3.6 | f (1977) |
| ALHA 77307 | CO3.0 | f (1977-1978) |
| DOM 08006 | CO3 | f (2008) |
| Kainsaz | CO3.2 | F (1937) |
| MIL 03377 | CO3 | f (2003) |
| MIL 05024 | CO3 | f (2005) |
| MIL 11118 | CO3 | f (2011) |
| MIL 11213 | CO3 | f (2011) |

Table 1. The CO chondrites studied by alphabetical order. Complete names are Allans Hills 82101, 83108, A77003, A77307, Dominion Range 08006, Kainsaz, and Miller Range 03377, 05024, 11118, and 11213.

**Results and discusion:** Our results indicate that the most pristine CO chondrites exhibit much higher abundance of Rare Earths (REEs) than ordinary chondrites [11] as well as the CI chondrite group usually taken as chemical reference [3,12] (Figure 1). The exact values change for each element (Table 2), but we observe general trends that make the CO chondrites as valuable materials to mine (Figure 2). This could be explained in an evolutionary context as CO chondrites are considered very pristine meteorites that experienced little aqueous alteration or metamorphism. Our sample study contains ALHA77307, one of the most pristine meteorites known. We think that the reason for such differences with the abundance of these valuable elements in comparison with other ordinary or CC groups is the relative absence of thermal metamorphism and aqueous alteration experienced by the parent body of CO chondrites (COs) that make them to preserve their native metals. On the other hand, absence of aqueous alteration makes water relatively absent from the CO group members, so we should certainly not look for the liquid element in the CO parent asteroid.

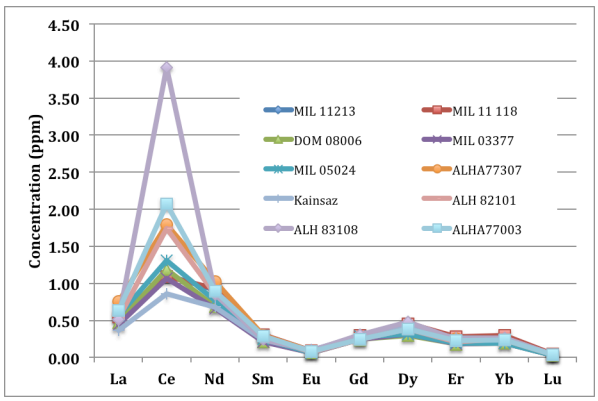


Figure 1. Chemical concentration obtained for each element analysed in the meteorite chips.

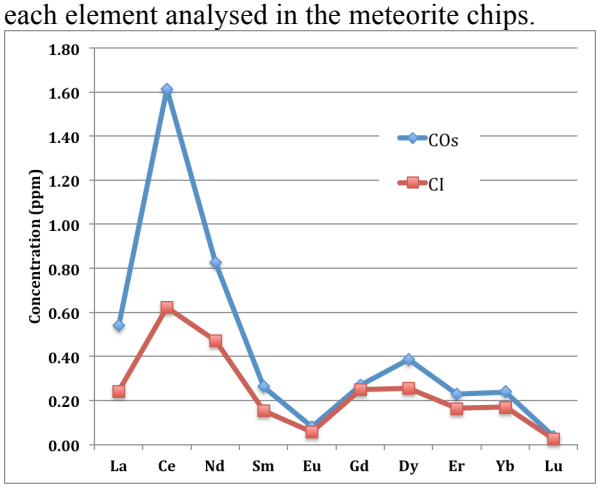


Figure 2. Presence of Rare Earths in all sample CO meteorites as compared to concentrations in CI [12].

| Meteorite | La (ppm) | Ce (ppm) | Nd (ppm) |
|---|---|---|---|
| ALH 82101 | 0.54 | 1.75 | 0.85 |
| ALH 83108 | 0.52 | 3.91 | 0.85 |
| ALHA 77003 | 0.63 | 2.07 | 0.89 |
| ALHA 77307 | 0.76 | 1.79 | 1.03 |
| DOM 08006 | 0.47 | 1.18 | 0.69 |
| Kainsaz | 0.37 | 0.86 | 0.68 |
| MIL 03377 | 0.45 | 1.07 | 0.66 |
| MIL 05024 | 0.57 | 1.31 | 0.77 |
| MIL 11118 | 0.55 | 1.09 | 0.93 |
| MIL 11213 | 0.57 | 1.11 | 0.91 |
| *CI group* | *0.24* | *0.62* | *0.47* |

Table 2. ICP-MS results obtained for the elements found to have (on average) significantly larger concentrations than the CI chondrite group (last row) [12]. Note that Ce is the one differing to a greater extent.

**Conclusions:** Consequently, if we look for asteroids from which mining can be worth, we should be putting our efforts in the study of pristine asteroids, probably of the K spectral class. The latter is inferred from the study of reflectance spectra, because K-class asteroids exhibit marked olivine and spinel absorption bands like those found in CO chondrites [7,9]. To confirm this provisional assignment between COs and the K-class of asteroids we think that a sample return mission from the 221 Eos family could have a great scientific and economic potential [10]. The potential of such a mission is particularly relevant for two main, and complementary reasons: 1) The identification of the parent asteroid of CO chondrites will provide a pleyade of significant scientific information concerning the accretion of planetesimals with many implications in Cosmochemistry, and 2) It could provide a relative fragile target to test mining procedures, and sample return at a massive scale, perhaps at circun-Lunar orbit. In other words, by finding the right target we could achieve that scientists and industry representatives join in a profitable enterprise. We are currently performing a more comprehensive study of the bulk elemental chemistry of other CC groups in order to identify future targets for space mining in the NEA region.

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