CHROMIUM ON EROS: FURTHER EVIDENCE OF ORDINARY CHONDRITE COMPOSITION. C. N. Foley[1], L. R. Nittler[1], M. R. M. Brown[2,3], T. J. McCoy[2], L. F. Lim[4] [1]Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, NW, Washington DC, 20015-1305 USA, (foley@dtm.ciw.edu), [2]Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington DC, 20560-0119 USA, [3]Dept. of Geological Sciences, Arizona State University, Tempe AZ, 85287-1404 USA, [4]NASA Goddard Spaceflight Center, Bldg. 2, Code 691, Greenbelt MD, 20771 USA.

Introduction: The surface major element composition of the near-earth asteroid 433-Eros has been determined by x-ray fluorescence spectroscopy (XRS) on the NEAR-Shoemaker spacecraft [1]. The abundances of Mg, Al, Si, Ca and Fe match those of ordinary chondrites [1]. However, the observation that Eros appears to have a sulfur abundance at least a factor of two lower than ordinary chondrites, suggests either sulfur loss from the surface of Eros by impact and/or radiation processes (space weathering) or that its surface is comprised of a somewhat more differentiated type of material than an ordinary chondrite [1]. A definitive match for an ordinary chondrite parent body has very rarely been made, despite the conundrum that ordinary chondrites are the most prevalent type of meteorite found on Earth. Furthermore, Eros is classified as an S(IV) type asteroid [2] and being an S, it is the second most prevalent type of asteroid in the asteroid belt [3].

We have undertaken a search for minor elements in the NEAR XRS data, specifically Cr, Mn, and Ni, to help resolve the question of whether Eros is comprised of ordinary chondrite material which has simply lost its sulfur due to space weathering or if it has experienced some level of partial melting with subsequent loss of a S-rich melt. The abundances of these elements vary between different meteorite classes due to differences in initial abundances and to differentiation processes that segregate them into different phases [4]. As is the case for major elements, these elements have widely varying abundances in differentiated meteorites, compared to undifferentiated ones.

Here we focus on the Cr abundance, because Mn and Ni have thus far not been resolvable due to poor counting statistics. Nevertheless, the Cr/Si and/or Cr/Fe ratio may be particularly diagnostic for resolving the difference between partial differentiation and space weathering as the major cause of the observed sulfur depletion. Early partial melting of the Fe,Ni-FeS cotectic can alter chromite abundances. Chromite participates with metal and sulfide during this early partial melting. Mineral mapping of Acapulco and Lodran suggests that the residual Lodran (0.7 vol.%) contains half as much chromite as the broadly chondritic Acapulco (1.6 vol.%) from which it may be derived [4]. Further, calculations for removal of individual minerals suggests that chromite removal would dramatically alter Cr abundances (or Cr/Si ratios). This is consistent with Lodran exhibiting lower bulk Cr/Si and Cr/Fe ratios than Acapulco.

Impact processing is expected to have a negligible effect on Cr abundances. This is supported by bulk chemical analyses of the regolith breccia Dwaleni [5], which exhibits Cr/Si ratios typical of all ordinary chondrites. Further, elemental mapping of Dwaleni suggests no significant difference in chromite abundance between the light and dark lithologies, with the latter sampling the regolith material.

Thus, coupled with the previously documented S depletion, a broadly chondritic Cr abundance would favor an impact origin for the S depletion, while a non-chondritic Cr abundance, in particular a depletion, would favor a partial melting origin.

Methodology: We use a methodology broadly similar to that described in [1], but focus primarily on the higher-energy portion of the NEAR XRS (>2.5 keV) since this region is less sensitive to uncertainties in the incident solar x-ray spectra [1, 6]. In addition to the cosmic ray background subtracted by [1], theoretical scattered solar x-ray spectra are also subtracted from the Eros spectra. Gaussian areas are then computed by spectral fitting and these areas are converted to actual photon ratios by accounting for the detector efficiencies [7] for different elements. Photon ratios are converted to element ratios using calibration curves derived from theoretical models of x-ray spectroscopy, using a range of elemental abundances and incident solar spectra derived from NEAR solar monitor data for the appropriate flares.

In [1], a “mineral mixing correction” was applied to the XRS element ratios to take into account the fact that the surface of Eros is not likely to be perfectly homogeneous on a μm scale, having many elements concentrated within specific minerals. X-ray fluorescence models of ordinary chondrite compositions suggest such a correction could increase the measured Cr/Fe weight ratios by as much as a factor of 2. However, such a large correction is not supported by x-ray calibration data from the Mars Pathfinder APXS [8]. APXS x-ray mode data for Murchison (CM2), Allende (CV3), and Bruderheim (L6) indicate no difference between the determined Cr/Fe ratios and those determined by standard methods. This suggests that no large mineral mixing correction is necessary for Cr/Fe during x-ray analyses of roughly chondritic materials with a range of metal abundances, and hence is probably not necessary for the Eros data. Furthermore, ultimately the degree of heterogeneity on Eros is not known and its surface may indeed be comparable to a well-mixed homogeneous fine-grained sample, like those analyzed with the APXS, due to impact processing. Thus, it is unlikely that a mineral correction for Cr/Fe is necessary and was not performed for these analyses. However, experimental work is ongoing to further understand the effect of "mineral mixing".

Initial results and discussion: We have determined the Cr/Fe and Ca/Si ratios from NEAR XRS data generated during two of the solar flares (May 4th and Dec. 27th of 2000). Since both flares yield nearly identical results (with a standard deviation << the error for the average), the average value of the two flares is plotted in Fig. 1. These ratios clearly overlap those of ordinary chondrites.

The Cr/Si ratio computed for these two flares is ~0.02, also overlapping that of the ordinary chondrites. This, coupled with the ~chondritic Cr/Fe and Ca/Si ratios, implies that no significant partial melting and melt segregation has occurred on Eros' surface. Even if the mineral correction described above is applicable, this would raise the Cr/Fe ratio above values measured in ordinary chondrites, inconsistent with loss of chromite during melting of FeS. Thus, our initial results support a space weathering explanation for the observed S depletion.

Although NEAR XRS results thus far have indicated a relatively high Fe/Si ratio for Eros, similar to H chondrites, this result depends strongly on the mineral correction used and on the solar spectrum used to generate calibration curves [1]. Moreover, [9] showed that surface roughness and particle size effects can lead to anomalously high Fe/Si photon ratios at the high Sun-Eros-spacecraft angles obtained during the NEAR XRS data collection. This effect (and uncertainties in the solar spectra) will have a much smaller impact on Cr/Fe ratios since the characteristic x-ray lines have relatively similar energies (5.41 keV for Cr Kα, 6.40 keV for Fe Kα). A lower Fe/Si ratio than that determined previously by [1] would result from either having no mineral mixing correction or from correcting for surface roughness. This lower Fe/Si would be in better agreement with the NEAR γ-ray results [10], indicative of a match with LL chondrites. However, as discussed by [1, 10], regolith processes occurring within "ponded" materials at the γ-ray measurement site may well lead to a surface Fe abundance there that is different from that of the bulk asteroid's surface and a comparison between the results may therefore be unwarranted.

Conclusions: We have obtained the first determination of an asteroidal Cr abundance by remote-sensing XRS. The Cr/Fe, Ca/Si, and Cr/Si ratios determined for the surface of Eros provide further support for a link between S(IV) asteroids and ordinary chondrite meteorites. This conclusion is consistent with the other major element ratios derived from [1]. The chromium results are inconsistent with the observed sulfur depletion on Eros being caused by partial differentiation. Therefore, sulfur loss during space weathering of ordinary chondritic material due to effects of irradiation and/or impact processes is likely to have taken place on Eros.

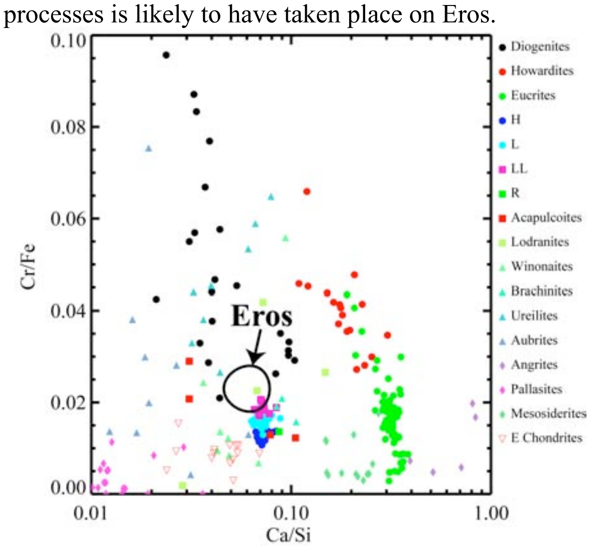

Figure 1: The weight ratio of Cr/Fe versus Ca/Si for a number of meteorites [11] and the average result from Eros for two solar flares (described in text). Errors are 2σ statistical errors. Systematic errors in the solar model [12] may slightly shift the value.

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