WHOLE ROCK COMPOSITIONS OF AUBRATIC METEORITES: IMPLICATIONS FOR THEIR ORIGIN; Taro K. Shimaoka, K. Shinotsuka, M. Ebihara and M. Prinz, Department of Chemistry, Faculty of Science, Tokyo Metropolitan University, Hachioji, Tokyo 192-03, Japan and Department of Mineral Sciences, American Museum of Natural History, New York, NY 10024, USA.

Introduction: Aubrites (enstatite achondrites) are heterogeneous assemblages of nearly iron-free enstatite and a variety of rare minerals which formed under highly reducing conditions. Considering the similarities in bulk chemistry of the major and minor mineral phases, and an inferred oxygen fugacity, Watters and Prinz [1] concluded that EL6 chondrites may be the most suitable parent material for aubrites. They further suggested that aubrites formed through the fractional crystallization of such materials. Examining the correlations of several pairs of the elements having great differences in volatility, Wolf et al. [2] also inferred that aubrites may have originated by igneous processes in a differentiated parent body. Okada et al. [3] concluded that the Norton County precursor materials were igneous rocks, mostly plutonic orthopyroxenites, which were formed by extensive melting and igneous differentiation. Brett and Keil [4] and Keil [5] argued that aubrites were produced by melting and fractionation, but not from any known enstatite chondrite group. Recently, Lodder et al. [6] analyzed the whole rock and mineral separates, including oldhamite, from the Pena Blanca Spring aubrite and concluded that the distribution of the REE among the minerals could not be the result of equilibrium fractional crystallization processes. They concluded that a short non-equilibrium melting event, rather than a large degree of equilibrium partial melting, is the best explanation for what occurred on the aubrite parent body. In order to contribute to an understanding of the origin of aubrites, we have analyzed, by instrumental neutron activation analysis (INAA), six aubrites (Bishopville, Cumberland Falls, Khor Temiki, Mayo Belwa, Norton Co. and Pena Blanca Spring), which are all observed falls. In addition, we also analyzed three enstatite-rich meteorites (Happy Canyon, Ilafegh 009 and Mt. Egerton). Most of the meteorites in this study were also analyzed by inductively coupled plasma mass spectrometry (ICP-MS) for REE (including Y) and U. Since these meteorites are highly heterogeneous in their mineral abundances and compositions, an effort was made to reduce the bias in sampling small chips of the individual meteorites, so that conclusions as to the petrogenesis of aubrites can be more meaningful.

Experiments: Several chips (weighing 200 to 400 mg) were samples from representative samples of each meteorite, and each was broken into fragments in an agate mortar. For aubrites, some fragments were used to prepare polished sections for SEM-EDS study. The residual fragments (100-200 mg) were further pulverized in an agate mortar for chemical analyses by instrumental neutron activation (INAA) and inductively coupled plasma mass spectrometry (ICP-MS). For INAA, we followed the basic procedures described by Ebihara and Ozaki [7]. A part of each powdered samples (about 40 mg) was used for INAA to determine the bulk chemical composition. REE (lanthanoids and Y) and U were determined by ICP-MS for the samples except Mt. Egerton, Happy Canyon and Ilafegh 009. About 10 mg of each powdered sample was decomposed with HF and HNO3 under high pressure using a teflon bomb. The solution thus prepared was introduced directly into the instrument (modified VG PQ-1). The accuracy of the data was evaluated by analyzing the Allende reference standard. A detailed description of the ICP-MS analysis procedures for meteorite samples will appear elsewhere.

Results and Discussion: Elemental abundances obtained by INAA are shown in Fig. 1, where the data are normalized to CI values [8]. Na and Al show large variations in their abundances, over a factor of 70. However, they are highly correlated with one another, indicating that albitic plagioclase is the main host for Na and Al. Mn, Cr and V, which behave as chalcophiles in aubrites, are generally depleted in the aubrites, and their abundances are fairly variable. Siderophiles (Au, Fe, Ni, Co, Ir) also are depleted, and show large variations in their abundances. It is noteworthy that the degree of variation becomes larger from Fe (0.15 - 0.01 x CI) to Co (0.15 to 0.001 x CI), and possibly further to Ir. However, depletions for the chalcophile elements are relatively small, being within two orders of magnitude. The amount of sulfide loss seems to be somewhat correlated with that for the metal for the aubrites in this study. Khor
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Temiki has the smallest loss, while Bishopville has the largest, with the others being intermediate, except for Cumberland Falls, in which the siderophiles are relatively enriched.

The REE and U abundances for five aubrites and two enstatite-rich meteorites were precisely obtained. Our results confirm several trends pointed out in preceding studies (e.g. [2], [9]); the aubrites have either negative or positive Eu anomalies and the REE are heterogeneously distributed. The important point is that, aside Eu, the REE show little variation and are near chondritic for most aubrites. As expected, the Y abundances are in the range of the lanthanoid abundances, almost equal to those of the heavy REE. This suggests that Y resides in the same host phase(s). U is not much fractionated from the REE, and is also near-chondritic in abundance. Because the REE are highly enriched in oldhamite, compared with plagioclase, oldhamite strongly dominates the bulk abundances of the REE in aubrites, as shown by Wheelock et al. [10]. This is especially true for aubrites which are relatively enriched in REE. On the other hand, Eu anomalies in aubrites are more or less dependent on plagioclase abundance.

In order to explain how metal and sulfide phases, as well as plagioclase, were incompletely segregated, and the variable degree of segregation of different aubrites, we suggest that the aubrite parent body did not undergo large-scale equilibrium melting. Impact-induced melting seems to be a reasonable possibility. Upon impacting, some phases were melted. Metal would be the first major phase to melt, as would some but not all of the sulfides. The density of these melts would be higher than that of the residual solids, and if the aubrite parent body was large enough to have a gravity field, these melts may have descended within the body. In addition to metal and sulfide, plagioclase may also have melted, to some extent, but the amount was much less than that for the metal and sulfide. As the density of the plagioclase melt is less than that of the metal and sulfide melts, and even that of silicate residue, it may have moved upward in the parent body. Thus, no correlation between plagioclase, metal and sulfide abundances need be expected. REE, mainly in oldhamite, may have been locally redistributed and the chondritic abundances preserved on a large scale, because oldhamite has a high resistivity to heating. While the overall pattern of differentiation has some parallels with equilibrium partial melting due to internal heating processes, the non-equilibrium characteristics of the mineral distribution (which is not due to inadequate sampling) is better explained by impact-induced melting.


Fig. 1 Elemental abundances of six aubrites, and three enstatite-rich meteorites relative to CI-chondrite abundances.