THE COMPOSITIONS OF PLANETARY CORES AND MANTLES; J.S. Kargel, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721

Introduction. A technique has been developed which uses available rock samples to determine the bulk compositions of differentiated planets and their cores. Applications to date include the case of Earth (Kargel and Lewis 1992), the results of which are summarized here. Variants of certain aspects employed in our technique have been applied by others, but the present approach is more systematic and consistent.

Volatility trends. It is well known that depletions of iron and many siderophile elements (e.g., Ni, Au, and Pt) in Earth's crust and mantle relative to cosmic elemental abundances are due to extraction of the Earth's Fe-rich core. Certain other nonsiderophile elements are also depleted in Earth's crust and mantle. These include highly volatile elements (e.g., noble gases and N) and moderately volatile elements (e.g., K, Cs, and Zn). Depletions of nonsiderophile volatile elements are understood to be related to processes occurring early in the history of the solar system such as partial condensation, selective sublimation, and impact volatilization during accretion. Element abundances in H-chondrites provide important information on the effects of volatility without superimposed effects of core formation. Element abundances in H-chondrites define a sloping trend when plotted against condensation temperature. Such a trend is termed a "volatility trend" (VT). Chalcophile elements (e.g., S and Se) are also generally sharply depleted in Earth's crust and mantle, suggesting partitioning of a sulfide liquid into the core. However, many siderophile elements and most chalcophile ones are also volatile, and it is not immediately obvious to what extent these elements are depleted in the whole Earth due to volatility, or are depleted just in the crust and mantle due to core formation.

Our approach to learning the core's composition starts with the best available information on the composition of the silicate portions of our planet. An intensive scrutiny of the literature has resulted in derivation of a "Best Bulk Silicate Earth" (BBSE) composition (Kargel and Lewis 1992). BBSE is plotted against condensation temperature in Figure 1. It has been used for quite a while that element abundances in Earth's silicate portion show the combined effects of volatility and core formation. Despite first appearances, the distribution of elements in Fig. 1 is highly systematic and obeys periodic chemical patterns of behavior well known since the days of Mendeleev. Figure 1 provides abundant information on the nature of core formation, condensation, and accretion. Similar plots for the Moon and several meteorite parent bodies indicates that certain elements constrain the "top" of the element abundance cloud. The abundances of these elements, notably Mg, Si, Na, Zn, and several others, are thought to be controlled almost entirely by volatility. That is, they are strongly lithophile and display very little affinity for the core, and thus define a VT. Three plausible VTs are shown in Figure 1. The slope of VT for Earth and the other planets are much less sensitive to temperature than one predicts based on simple condensation under a discrete set of temperature-pressure conditions. The implication is that each planet accreted matter condensed over a wide interval of environmental conditions. Probably this involved large-scale radial mixing of condensed matter in the Solar Nebula. Our preliminary data show surprisingly little variation of the slopes of planetary VTs. For instance, the VT of H-chondrite parent bodies display a slope comparable to Earth's VT, indicating that accretion of radially mixed material was not entirely dependent on the size of a planet and the effectiveness of that planet's gravitational stirring.

Earth's core composition. Element abundances in the whole Earth may be predicted from VT given knowledge of the elements' condensation behavior. Any elements which fall significantly below this trend are assumed to have been partitioned into the core in amounts proportional to the distance the abundance in BBSE plots beneath VT. Knowing the mass of Earth's core and mantle, it is possible to calculate the abundances of each element in the core (Figure 2) and in the entire Earth.

Figure 3 offers one indication of the highly systematic pattern of element partitioning between the core and BBSE. The periodic pattern of siderophile/chalcophile vs. lithophile behavior is a direct and consistent reflection of the periodic properties of the elements. We have examined some of these basic elemental properties to try to gain some insight into the physicochemical processes behind core/mantle partitioning. A semicircular "siderophility index" describes this partitioning, to a first approximation: siderophility index = EVP^p/Ar, where E is Pauling's electronegativity, V is the first ionization potential, P is the period in the periodic table, A is the atomic number, and r is the covalent ionic radius. Core/BBSE partitioning is plotted against the siderophility index in Figure 4. This index describes core/mantle partitioning quite well, with the notable exceptions of alkali elements. It is thought that these exceptions, and several more subtle deviations involving Cr, Mn, and V involve high-pressure (megabar) partitioning, implying segregation of at least some of the core's material under high pressures, that is, after Earth had substantially accreted. Preliminary evidence suggests that Mars did not suffer the consequences of high-pressure core/mantle segregation, consistent with its smaller size relative to Earth.

Figure 1. Composition of Best Bulk Silicate Earth (BBSE), and three plausible volatility trends.

Figure 2. Model composition of Earth's core.

Figure 3. Core/mantle partitioning as function of atomic number.

Figure 4. Core/BSE abundance ratios vs. siderophility index.