THE ISOTOPIC AND CHEMICAL EVOLUTION OF PLANETS: MARS AS A MISSING LINK; D. J. DePaolo, Department of Earth and Space Sciences, University of California, Los Angeles, California, 90024

The study of planetary bodies has advanced to a stage where it is possible to contemplate general models for the chemical and physical evolution of planetary interiors, which might be referred to as UMPES (Unified Models of Planetary Evolution and Structure). UMPES would be able to predict the internal evolution and structure of a planet given certain input parameters such as mass, distance from the sun, and a time scale for accretion (1,2). Such models are highly dependent on natural observations because the basic material properties of planetary interiors, and the processes that take place during the evolution of planets are imperfectly understood. The idea of UMPES was particularly unrealistic when the only information available was from the earth. However, advances have been made in the understanding of the general aspects of planetary evolution now that there is geochemical and petrological data available for the moon and for meteorites (2,3).

The difficulty in constructing UMPES is that planetary behavior is complicated by the fact that the interiors are at temperatures and pressures where phase changes (including melting) are common and because the differences in density that contribute to the stability of individual structural states of the planet are about as dependent on chemical composition as on phase transitions (4). In addition, the distribution of chemical elements in the solar system at the time the planets were forming, the nature of the accretion process (5, 6) and its effect on the net composition of the planet (particularly the volatile content), the degree of retention of gravitational energy from accretion (1), the rheology of the planetary interior and the efficiency of transport processes within the planet (7), and other factors are all still sufficiently unknown that new observations have a large effect on our understanding of the planetary evolution process.

Despite the complications there are some parameters that are generally agreed to be important determinants (2). Planet size is important because it determines the initial heat budget and the length of time needed for cooling. Distance from the sun also appears important because it is related to the accretion temperature and thus to the ratio of volatile-to-refractory elements in the planet. Observations of the moon have greatly helped in addressing the planet size problem (1,2,3), but even so there are doubts that the moon's origin is typical of planetary bodies in the solar system. The distance parameter has not been seriously tested.

Mars represents a serious test of all aspects of the current understanding of planetary evolution. The body is both smaller than the earth and accreted at a different distance from the sun. Its internal volatile content appears to be different from that of the earth and moon (8). The combination of differing chemistry and gravitational field makes it likely that the nature of its internal chemical diffentiation is substantially different from that of the earth (9). It appears to have had a considerably longer geological lifetime than the moon, but one that is shorter than that of the earth (10).

A valid question with regard to a Mars sample return mission concerns how a limited sampling of the planetary surface could be sufficient to make substantial headway against the complexities of a planet's evolution. However, the answer with regard to geochemistry is that there are certain fundamental properties of the planet that can be deduced from a few carefully chosen samples. The geochemical studies of the moon provide an adequate example of the power of the techniques (1,2,3,11).

Two particularly important and straightforward questions about Mars are 1) How old is the Martian crust? (or What is the mean age of Martian crust-mantle differentiation?), and 2) How differentiated is the Martian mantle? These questions could be answered to first order by as few as two samples. For example, a landing site near the fringes of Olympus Mons could allow sampling of the lavas of the volcano and sampling of both rock outcrop and wind-blown dust from the pre-volcanic basement. With isotopic measurements of Sm-Nd, U-Pb, Rb-Sr, Lu-Hf, and K-Ca, it should be possible (in addition to determining an age for Olympus Mons) to use the isotopic composition of the lava to understand the mean state of differentiation of the Martian mantle, and use the dust sample (partly corroborated by an outcrop sample) to determine the mean age of the Martian crust. If a similar experiment were done for the earth, using a sample of typical mid-ocean ridge basalt and a sample of loess from almost anywhere on the earth's surface (12,13), the deduced values for the mean age of the continents and the crust/mantle mass ratio would be correct to as well as we currently know them; and the need for heterogeneity in the earth's mantle and for an early degassing of the earth (14,15) would be apparent. Consideration of the trace element chemistry of Olympus Mons lava would tell much about the composition of the planet, relating to the effect of heliocentric distance and planetary composition, and the trace element fractionations deduced by comparing the chemical composition of the lava to the initial isotopic ratios of Sr, Pb, Nd, Hf, Ce, Ca, and so on, would elucidate aspects of the mineralogy of the mantle and of magma genesis in Mars.

Clearly, more extensive sampling would be desireable to gain confidence in the interpretations and to understand the petrogenetic evolution of a Martian volcano and the degree of heterogeneity of the crust. Nevertheless, existing isotopic and geochemical methods would certainly yield strong constraints on Martian evolution and would greatly enhance our understanding of several general aspects of planetary evolution.

Existing data on SNC meteorites (16), thought to have come from Mars (17), suggest that Martian internal evolution might not fit very cleanly into the existing framework of solid earth evolution. Trace element fractionations and their relation to isotopic systematics are greatly diffent from typical terrestrial rocks (18). Fundamental parameters like the oxygen isotopic composition are different (19). Interpretation of many aspects of the meteorite data, however, are difficult because of shock effects; and there is of course no guarantee that they are in fact from Mars. Nevertheless, some of the properties would have been predicted, such as the low U/Pb ratio (20) and high Rb/Sr ratio (18) of the sources of the "Martian" igneous rocks.

A sample return from Mars would be one of the most exciting possible developments in planetary science from a geochemical viewpoint. Geochemical tools and analytical capabilities are sufficiently well developed to extract an enormous amount of unique information from even a few small samples of Martian rock.

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