ASTEROIDS AND COMPARATIVE PLANETOLOGY, F. P. Fanale, D. L. Matson, T. V. Johnson, G. J. Veeder, Jet Propulsion Laboratory, Pasadena, CA 91103.

Modern observations of the asteroids are providing an important new source of information for studies of the solar system. Already, with only a relatively small amount of data in hand, asteroid studies have: 1) provided and additional, independent check "corroborating" one of the major cosmochemical theories of solar system formation, and 2) discovered an apparent conflict with that theory which runs far deeper than that already recognized as being posed by the Moon.

The current increase of interest in asteroid studies can be attributed to the data obtained over the past five years by the application of techniques new to asteroid observations. Thermal emission photometry in the infrared (i.e. 10 to 20 μm), visible wavelength polarimetry and, most important, spectrophotometry (0.3 to 2.2μm) have painted an unexpectedly exciting picture of the asteroids. These telescope data permit the derivation of asteroid diameters, albedos, and spectral reflectances. Supportive laboratory and theoretical studies have enabled these data to be interpreted in terms of surface composition models. First results indicate that: 1) asteroids exhibit a very wide variety of surface compositions, 2) some of them resemble certain meteorites while others presently have no known compositional analogue, and 3) one of them, Vesta, has a surface composition resembling that of the Moon. (For a current review of asteroid research see C. R. Chapman, 1975.)

How does asteroid work relate to our understanding of the rest of the solar system, its origin, and evolution (i.e. comparative planetology)? The asteroids did not originate in isolation, but came from the same solar nebula as did the planets. Since they are too small for gross endogenic alteration (unless they are far richer in long lived radionucleides than the Moon, meteorites, or the Earth), they should contain good records of some of the various processes operative during and after the time of accretion; the same records which on the other planets have been obscured largely by subsequent differentiation.

While most of the asteroids fit very nicely in with the general cosmochemical framework developed by Cameron and Lewis, at least one large asteroid, Vesta, appears to be an anomaly. Vesta's surface apparently requires formation by events which are not spelled out in the current theory. Once these events are identified, then their effect on other planets and particularly on the Moon can be assessed.

Finally, asteroids and/or the asteroid-parent bodies themselves played an important role in the heavy cratering of the surfaces of at least the inner planets. Understanding asteroid genesis and history in detail will enable better modeling of planetary cratering processes, hence better interplanetary correlation of geologic time. Perhaps it will also provide new insights into the formation and evolution of planetary atmospheres.

The current Cameron/Lewis models do not predict the correct density or

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or apparent bulk composition for the Moon. This fact has been discussed intensively (e.g. Lewis, 1974a) and is a focal point for much on-going research (Lewis, 1974b).

The surface composition of Vesta is not explained by unmodified Cameron/Lewis models either. However, this fact is less widely known and has not yet been fully appreciated. Vesta was the first asteroid for which good visible and near infrared reflectance spectra were obtained and its surface is identified as having a mineralogy similar to that of certain achondritic meteorites (McCord et al., 1970). The most recent optical data makes the identification of Vesta's surface composition even more certain. Scans of the 0.95 μm absorption band (Veeder et al., 1975) and 1 to 2.5 μm spectroscopy (Larson and Fink, 1975) confirm the presence of pigeonite, as originally suggested by McCord et al. (1970).

The comparative planetology of Ceres and Vesta is an interesting and perplexing as that of Vesta and the Moon. Ceres has a carbonaceous chondritic surface (at the very least) and thus is in accord with the predictions of Lewis' models. Vesta, on the other hand, not only is considerably smaller than Ceres (500-600 km diameter versus 1,000 km) but has a basaltic achondritic surface composition (as discussed above). Thus we are faced with a striking cosmochemical anomaly: Ceres and Vesta -- both relatively large main belt asteroids -- have surface compositions representing the cosmochemical extremes seen among meteorites. Both objects are too small for any significant endogenically derived fractionation to have occurred, both are main belt asteroids and thus were exposed to approximately the same space environment, and yet, it was the smaller object which developed a differentiated surface while the larger remained unmodified. On the other hand, if Vesta was subjected to a surface-imposed heating process, then Ceres and most other asteroids must have been shielded from that process.

The most obvious relevant pieces of observational data bearing on this problem are the densities of Ceres and Vesta. Unfortunately, these are very poorly known at present. Our analysis of the current knowledge of the radius and mass of Ceres suggests Ceres has a density of 1.8 ± 0.9 g/cm^3 (where the error is the estimated 1 σ) which could be in harmony with a carbonaceous chondritic composition for Ceres or even some mixture of ice but not with a Vesta-surface-like material in the interior and covered with an altered carbonaceous chondritic-like surface. The data for Vesta are also ambiguous, and suggest Vesta has a density of 2.9 ± 1.4 g/cm^3 which hardly allows even preliminary guesses as to its bulk composition to be made.

Current hypotheses concerning early energy sources and subsequent evolution include 1) radiogenic heating by long-lived nucleids 2) induction-heating by a dense solar wind 3) accretional bombardment and 4) short-lived radionucleids such as ^{26}Al.

The wide diversity among the asteroids and particularly the facts that many asteroids are similar to carbonaceous chondrites and that Vesta is unique among telescopically studied asteroids in having an apparently modified surface pose severe problems for any of these hypotheses.

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