ASTEROID SURFACE MATERIALS. Michael J. Gaffey and Thomas B. McCord, Remote Sensing Laboratory, Room 24-413, Dept. of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Mass. 02139

The visible and near infrared (0.32-1.0 μm) reflectance spectrum of about 100 asteroids are now available in the literature (1). These spectra can be interpreted to determine the surface mineralogy of asteroidal bodies by utilizing diagnostic mineral absorption features arising from electronic transitions in Fe²⁺ ions located in specific crystallographic sites in the minerals which are found in meteoritic, lunar and terrestrial rocks (2). Radiometric diameters and albedos and phase-polarization curves (a measure of the opacity of particulate material) offer additional information about the nature of the surface materials (3).

McCord, Adams and Johnson (4) showed that the asteroid 4 Vesta (D=500 km) has a surface composed of basaltic achondritic-like material (high Ca pyroxene plus plagioclase). This implies that Vesta has undergone a melting and differentiation event during its history. Recent interpretive work has identified as asteroid surface materials additional mineralogical and petrological assemblages outlined below:

A) Opaque-rich assemblages with non-reduced silicates (Fe²⁺ & Fe³⁺) such as the layer lattice silicates (serpentine; chlorite) typical of low grade carbonaceous chondrites. Very low albedos (2-6%). Probably never heated to temperature in excess 300°C. Approximately equivalent to C2 (CM) meteorites with a range of variations of as yet undefined character. About 23 asteroids including: 10 Hygia (380 km), 19 Fortuna (220 km), 51 Nemausa (145 km), 324 Bamberga (230 km), 551 Davida (260 km) and 554 Peraga (97 km).

B) Partially reduced silicate assemblage with small grain size and some spectral blocking (opaque) phase. Intermediate albedo (9-16%). Approximately equivalent to C3V (CV) meteorites. Heated and metamorphosed but not melted. About 15 asteroids including: 11 Parthenope (150 km), 18 Melpomene (140 km), 29 Amphitrite (190 km), 32 Pomona, 674 Rachele (114 km), and 887 Alinda (4.4 km).

C. Very opaque-rich assemblage involving either magnetite (15-30%) plus silicate (olivine) or carbon (5-20%) plus silicate. Low to intermediate albedos (6-9%). The most probable interpretation is a metamorphosed, incompletely reduced, high total-iron assemblage similar to the meteorite Karoonda (C4). The second alternative represents a very high carbon (or very diffuse carbon), ultraprimitive carbonaceous material as yet unknown in terrestrial meteorite collections. About 7 asteroids including: 1 Ceres (1020 km), 2 Pallas (560 km), 85 Io, 213 Lilaea, 335 Roberta and 704 Interamnia.
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D) Metal (nickel-iron) and metal plus silicate minerals. Approximately equivalent to iron and stony-iron meteorites. Most probably represent cores or interior layers of melted and differentiated body. About 22 asteroids including: (Metal) 16 Psyche (250km), 170 Maria, 9 Metis (170km); (Metal + Pyroxene) 8 Flora (150km), 40 Harmonia (100km), 192 Nausikaa (92km); (Metal + Pyroxene + Olivine) 3 Juno (230km), 15 Eunomia (270km); and (Metal + Olivine) 7 Iris (190km) and 354 Eleonora.

E) Charge Transfer Materials: Non-reduced silicate or oxide (intervalent charge transfer between bi- and trivalent iron) with no significant opaque phase. Very low albedo \( \approx 3\% \). Approximately equivalent to augite achondrite or carbon-free low grade carbonaceous chondritic assemblage. Two asteroids, both Trojan Asteroids, 624 Hektor (210km) and 911 Agamemnon.

F) Silicate (pyroxene, olivine) assemblages. Approximately equivalent to ordinary chondritic assemblages of several metamorphic grades. Three asteroids: 349 Dembowska, 433 Eros (18km) and 1685 Toro (6km). The latter two are an Amor (Mars Crosser) and Apollo (Earth Crosser) asteroid respectively.

Three distinct thermal histories are evident among these asteroid groups. The surface material of the members of group 'A' has never undergone a significant thermal event; that of the members of groups 'B', 'C' and 'F' has been metamorphosed to at least some degree; and that of the members of group 'D' and Vesta has undergone a melting and differentiation event. Understanding the nature of this thermal event is an important key to understanding the thermal evolution of solar nebular condensate and the terrestrial planets. Those asteroids whose surface material has undergone a melting event tend to cluster toward the inner edge of the Asteroid Belt (2.2-3.2 AU's). Specifically, of these bodies, 50% lie within 2.45 AU and 75% within 2.6 AU while for Belt Asteroids in general, 50% lie within 2.7 AU and 75% within 2.8 AU. There does not seem to be a significant difference between the distribution of the unheated and unmelted asteroids and the distribution of general Belt asteroids at least at the level of statistics presently available. The slight concentration of asteroids with histories of significant thermal events toward the inner edge of the Belt may indicate that the thermal mechanism is dependant on distance from the sun or protosun. It is also clear that given a thermal event strong enough to melt a body, even the very weak gravitational field of a small asteroidal parent body (\(~200\text{km}\)) is sufficient to differentiate the body. These results may require a re-evaluation of models for magmatic differentiation of the smaller terrestrial planets.

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References


