THE FOMATION AND DIFFERENTIATION OF ASTEROIDS: A HOLISTIC APPROACH. Timothy J. McCoy, Dept. of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington DC 20560-0119 USA (mccoyt@si.edu).

Introduction: The past 25 years have seen a revolution in our undersanding of the formation and differentiation of planetesimals. By the mid-1980's, iron meteorites and the howardite-eucrite-diogenite (HED) suite guided thinking on asteroid differentiation [1]. Debate centered on fractional crystallization vs. low-degree partial melts, with corresponding implications for the nature and timing of core formation. The understanding of the full range of differentiation was only emerging from studies of aubrites [2], ureilites, and the newly-termed "primitive achondrites" intermediate between chondrites and achondrites [3]. Asteroid spectroscopists proposed the early link between HED's and Vesta [4] and between iron meteorites and M asteroids.

Today, our understanding of planetesimal formation and differentiation has been transformed by three major influences: (1) the dramatic advancement in analytical capabilities, (2) the explosion of samples from differentiated asteroids, and (3) spacecraft missions that are providing context for these samples.

Analytical Capabilities: Focused ion beam (FIB) allows unprecedented sampling for TEM studies. Goldstein and colleagues [5] used these techniques to measure metallographic cooling rates suggesting the cooling of metallic cores after removal of the silicate shell by impact. Partitioning studies have been transformed by LA-ICP-MS. Partitiong studies now routinely involve more than a dozen elements doped at natural abundances [6]. These new partition coefficients allow modeling of a broad array of processes during core crystallization. Asteroid spectroscopy has benefited from the advent of the SpeX spectrograph at the NASA IRTF. Data from SpeX can support more detailed and quantitative analyses. Some A-type, olivine-rich asteroids previously thought to sample pallasite-like compositions have fayalitic olivine akin to R chondrites or brachinites, perhaps representing a case of melting of an oxidized asteroid [7].

New Samples: A wealth of new samples have transformed out sampling and understanding of differentiation. Primitive achondrites are now recognized as samples of incomplete differentiation, with acapulcoites, lodranites, ureilites and brachinites as well-established, abundant groups. Angrites are reasonably well-sampled. New chondrite groups, including the oxidized R chondrites, expanding our sampling of the precursor materials. Studies of these meteorites point to four major influences controlling asteroid differentiation – bulk composition of the starting material, oxygen fugacity, peak temperature attained, and size of the parent body (Fig. 1). Among these, bulk composition and fO_2 are linked, as incorporation of ice during accretion dramatically influences each.

Spacecraft Missions: Together with samples, spacecraft missions to bodies of different composition and size allow us to fully understand differentiation (Fig. 1). Bodies formed from largely anhydrous materials near an fO2 of IW evolve from primitive asteroids like 433 Eros, through differentiated small bodies like Vesta and the M-asteroid Kleopatra, to large planets like the Earth and Mars. In contrast, highly-reduced enstatite chondrites and aubrites formed on bodies like Steins are more closely related to Mercury, where the low fO_2 likely partitions Si in the core and S in the crust [8]. Owing in large part to poor or incomplete sampling of ice-rich bodies, the evolution from primitive, now-hydrated chondrites and their parent asteroids (Bennu?) to larger asteroids like Ceres to the outer planet satellites is less completely understood, but will be the major focus of future missions.

An improved knowledge of planetesimal formation and differentiation is emerging, relying not simply on technological innovation, but new sampling and exploration of differentiated bodies and a holistic approach synthesizing data from disparate viewpoints.

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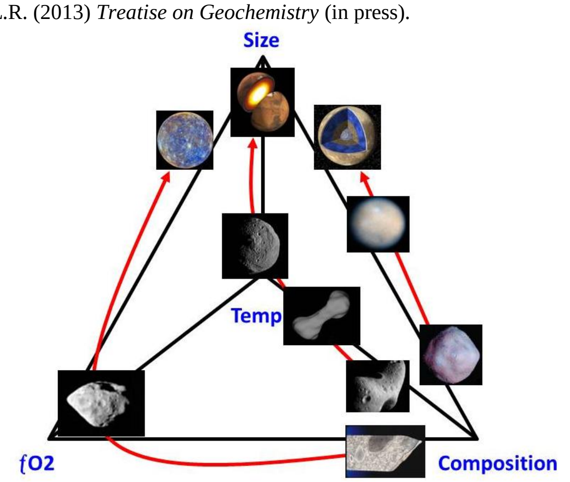

Fig. 1 Theoretical construct showing linked pathways between different bodies and meteorites in X, T, fO2, parent body size space.