Models for the origin of the Earth and other terrestrial planets generally assume accretion from a population of chondritic planetesimals[1-4]. This "chondritic" assumption actually includes several distinct and independent assumptions concerning the nature of the accreting flux. In the strict sense "chondritic" refers only to the bulk composition, and stipulates approximately solar proportions of the non-volatile elements. This assumption appears well justified, since the bulk chemistry of the Earth is generally consistent with a chondritic composition. But "chondritic" is also a textural/genetic definition when applied to meteorites, a usage indicating an undifferentiated assemblage. Accretional models have not generally distinguished between the explicit compositional assumption and the implicit textural/temperature assumptions.

Two general types of terrestrial accretion models have arisen depending upon assumptions concerning the retention of the accretional energy within the growing planet. The "iron catastrophe"-type end-member model (no significant retention of accretional energy) assumes that at the end of accretion the interior of the body is composed of an intimate metal-silicate mixture at subsolidus temperatures. Subsequent heating from the decay of long lived radionuclides eventually raises the internal temperature to above the Fe-FeS eutectic. This produces a dense melt phase which migrates downward converting gravitational potential energy to heat in a positive feedback process which rapidly raises the temperature of the Earth's interior by 1500-2000 K. In this type of model the Earth is "turned on" - i.e. transformed from solid planet to a molten one - approximately 0.5-2 Gyr after its formation, initiating outgassing as a significant contributor to the atmosphere and oceans. The "magma ocean"-type end-member model assumes that after a nucleus has grown to a critical size, the retention of accretional energy is sufficient to melt or partially melt the near surface regions, resulting in a primordial Earth with a cold core beneath a hot, differentiated mantle. Outgassing would begin during the late stages of accretion, providing an early ocean and atmosphere.

In both of these classes of models, the "chondritic" assumption presumes cool planetesimals whose internal heat does not contribute to rising the temperature of the accreting planet. Based upon what was inferred about the planetesimal population from meteorite studies, this was a reasonable and plausible assumption. However, recent asteroid studies indicate that most - if not all - of inner solar system planetesimals underwent strong early heating. Thus, the Earth and other terrestrial planets apparently accreted from a population of differentiated planetesimals with chondritic compositions.

The asteroids are the remnants of a system-wide planetesimal population from which the satellites and terrestrial planets accreted. More than 600 of the larger asteroids have been classified into a variety of types based upon color and albedo data[5]. Analysis of visible and near-infrared spectral reflectance data obtained for individual members of each type has produced general mineralogical characterizations for these asteroid classes. These classes can be broadly divided into a "heated" group and an "unheated" group.

The differentiated [heated] asteroids exhibit surface mineral assemblages produced by magmatic processes (melting and segregation of different phases) within their parent planetesimals. The surface assemblages of these asteroids are analogous to the meteorites formed by igneous processes (i.e. the irons, stony-irons, and achondrites). The undifferentiated [unheated] asteroids show surface assemblages consistent with some type of chondritic mineral assemblage. Among the fourteen asteroid types, six are differentiated: types A, V, R, M, E and S. There is a general consensus among asteroid investigators that the types A, V, R, M, E and S are differentiated. There has been considerable controversy on whether the S-type is differentiated. Since the S-type is the most common of the six differentiated types and dominates the inner belt, the basis for this interpretation is briefly reviewed.

The reflectance spectra of S-type asteroids indicate surface assemblages composed of NiFe metal, olivine, and pyroxene. This is not diagnostic of evolutionary history since both ordinary chondritic (undifferentiated) and stony-iron (differentiated) meteoritic assemblages exist with these phases present. While there are meteoritic and dynamical reasons to prefer that the the S-asteroids are similar to the ordinary chondrites[6], the telescopic investigations of specific main belt S-type bodies have produced no cases where the data requires or even prefers the ordinary chondritic interpretation. Conversely, most of the specific data on S-type asteroids prefers - and in some cases, requires - the presence of differentiated surface assemblages. The two S-asteroids studied in most detail
(Flora, Eunomia) are both unambiguously differentiated bodies[7,8]. Although such detailed investigations are not yet complete for most S-type asteroids, the five available diagnostic spectral parameters for S-asteroid surface materials all point toward a differentiated interpretation[7,9]. None point toward the alternate interpretation. Although all available direct evidence on the S-asteroids indicates that they are predominantly differentiated, the presence of a minor component of undifferentiated bodies within the S-population cannot be eliminated by present data.

The top portion of the figure (below) shows the relative proportion of differentiated (A, V, R, E, M and S) types among 423 classified asteroids in eleven orbital subdivisions [11] of the asteroid population. The asteroidal distribution is shown on lower portion of the figure. The straight line fit to the 2.2-3.5AU points shows a steep, nearly linear decrease from 100% at 1.8-2.0AU to 0% at >3.5AU. This line indicates heating to above the Fe-FeS solidus, and can be considered an approximate 1000-1100°C isotherm of postaccretionary heating. This heating event was superimposed upon and modified any compositional gradient inherited from the solar nebula. The location and slope of this isotherm should provide an important test of the proposed heat source models[12].

It is most probable that all planetesimals formed inside 2AU were subjected to strong heating and differentiation prior to incorporation into the Earth and other terrestrial planets. The nature of plausible heat sources in small bodies and the chronology of the differentiated meteorites constrains the heating event to the first few million years of solar system history[12], prior to or at the very onset of terrestrial planet accretion [13]. Since the time for significant internal cooling of planetesimals in this size range is long compared to the probable duration of planetary accretion[14], the bulk of the material contributed by the planetesimals will be near or above 1000°C, and substantial fractions of the accreting material should be in the form of magma and liquid metal.

Models for the accretion and early evolution of the terrestrial planets should consider hot planetesimals as the baseline case. Most of the accreting material will have undergone at least some degree of degassing prior to incorporation in the terrestrial planets, and the exposure of planetesimal magmas during impacts onto the embryonic planets may incorporate particular gases from any ambient atmosphere. The volatile and rare gas inventory of the Earth thus may represent the net results of several different processes.

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