ACCRETION OF A MASSIVE EDGEWORTH-KUIPER BELT. D. R. Davis[1], P. Farinella[2],and S. J. Weidenschilling[1] ([1]Planetary Science Institute, 620 N. 6th Avenue, Tucson AZ 85705 U.S.A., drd@psi.edu;[2]Dip. di Astronomia, Universitá di Trieste, Via Tiepolo 11, I-34131 Trieste, Italy, paolof@dm.unipi.it)

Understanding the origin and evolution of the small body populations, particularly main-belt asteroids and Edgeworth-Kuiper (E-K) transneptunian objects, provides fundamental insight into the formation and evolution of the solar system. Relative to the reconstruction of the mass surface density based on "smearing" out the masses of the known planets, the asteroid zone is depleted in mass by a factor of ~10^3, while there is a steep mass "shoulder" beyond the orbit of Neptune. If this mass distribution is primordial rather than being the product of subsequent processing, then a major problem exists in forming bodies as large as Ceres (diameter D ~900 km) or the largest E-K objects (D ~400-500 km) [1] by collisional accretion even in 4.5 Byr. The usual solution to this conundrum is that the mass depletions are not primordial, but there was initially substantially more mass in these regions which allowed accretion to proceed at a much more rapid pace. The additional mass was depleted by a subsequent process, possibly dynamical instabilities, and/or physical collisions.

Collisions have been shown to be an important process in the E-K belt [1-5]. The E-K belt was shown to be collisionally evolved at sizes smaller than ~50 km, but larger bodies (D ~50-100 km) represent an accretional signature, not a fragmented one. The actual mechanism that terminated accretion in the E-K belt is not known, but gravitational perturbations associated with the formation of Neptune are the most plausible possibility [5].

We have studied the growth of bodies in the semimajor axis range 24-50 AU using the multizone accretion code [6] in an attempt to produce a self-consistent model for the formation of the outer solar system. The initial population was assumed to contain 50 $M_\oplus$ of material, distributed according to a mass surface density $\sigma(r) = K r^{-\theta}$, where the constant K is determined from σ (5 AU) = 11 g/cm^2. This surface density distribution is the same one that was used in the collisional evolution work [3,4,7].

Figure 1 gives the size distribution of the population vs. semimajor axis at times of 10^8 yr, 10^9 yr, and 4.5×10^9 yr. In the present E-K region out to ~44 AU, it takes $3\text{-}5\times10^8$ yr to grow bodies as large as the largest known E-K objects (~500 km). Pluto-sized objects have formed out to a distance of 33 AU in this interval, while in the most distant zone, 48-50 AU, bodies up to 250-300 km in size have formed. For comparison, Stern and Colwell [5] required several 10^8 yr to grow QB_1-sized bodies at 40 AU, but only if they assumed that planetesimals are collisionally strong. However, growth of large bodies slows down as the system evolves enough to gravitationally "stir itself," i.e., to increase the mean eccentricities and inclinations. The largest bodies that formed in the region 24-50 AU in this simulation have masses of 1.2×10^{27}g and 1.1×10^{27}g, only about 20% of an Earth mass.

We also compare the size distribution of bodies in the 100-500 km range from our model with that inferred for the E-K belt. This size range is significant because, as noted earlier, there has been very little collisional depletion here, hence the signature in the size distribution is that of the accretion process. Gravitational depletion is not expected to change the size distribution, only the size of the population, and probably by less than a factor of 2. Figure 2 shows the calculated size distribution in the range 38-44 AU as a function of time. After 130 Myr, there are ~1.2×10^5 bodies in the 100-500 km size range, roughly consistent with the present population after allowing for dynamical depletion. However, the slope of the size distribution in this range is exceedingly steep, nearly -11 (cumulative diameter). For comparison, current observational estimates of the size distribution slope *b* are -3.8 [8] and -3.0±0.5 [9]. Clearly there is a mismatch between model results and observations on the abundance and size distribution of E-K objects in the ~100-500 km size regime.

Another major drawback with this simulation is that no Pluto-sized bodies, much less a Neptune, have yet formed; the first such objects take ~150 Myr to grow at ~25 AU; ~250 Myr at 28-30 AU, ~600 Myr to form at ~35 AU, and ~1 Byr at ~39 AU. If we assume that Pluto formed at 35 AU and migrated by resonance trapping to its present distance [10], there would be an overabundance of 100-500 km-sized bodies in the E-K belt by a factor of ~100 (see Fig. 2), with no plausible way of getting rid of them in order to match the present population.

Clearly there is no problem in forming E-K objects or even Pluto-sized objects in the outer solar system on a timescale $\leq$1 Gyr given a massive initial belt. However, forming Pluto-sized bodies at the same time that we grow the present population of QB_1-sized objects is difficult. The simulations run to date show a characteristic outcome: the growth of bodies is quite rapid initially, but with the formation of a population of large (>1000 km) bodies, there ensues significant orbital stirring of the small body population which still contains most of the mass in the system. With the higher orbital velocities, the growth rate slows down and the system essentially "stalls" out with the largest bodies still significantly smaller than Earth and a large fraction of the total mass still in bodies smaller than a few hundred km in size. While we have just begun to explore parameter space for the formation of the outer solar system, the challenges are clear. Much work remains to be done on this topic before we have a self-consistent scenario for how the outer parts of our solar system came to be.

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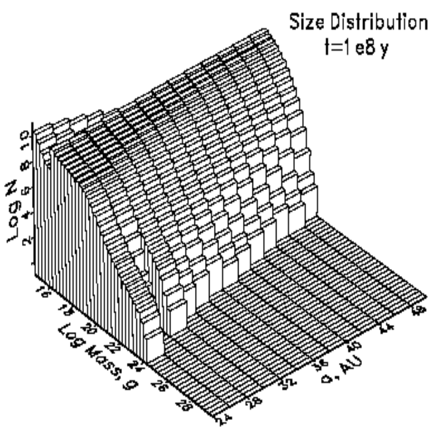
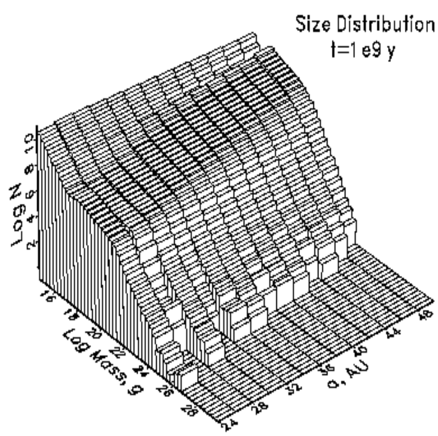
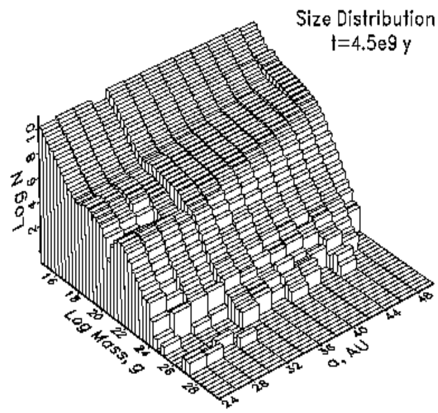
Figure 1. Size and orbit distribution of a 50 $M_\oplus$ population initially distributed in 3 km diameter bodies in the 24-50 AU region at times: (a) T = 100 My, (b) 1 By, and (c) T = 4.5 By. Bodies are assumed to have a low impact strength (S = 10^4 erg/gm) but are difficult to disrupt (f_{KE} = 0.03).



(a)



(b)



(c)

Figure 2. Evolution of the size distribution of planet-sized in the 38-44 AU zone. The distribution at T = 130 My contains ~1.2x10^5 bodies in the 100-500 km size range, however, the size distribution is much steeper than is inferred for the present E-K belt. At a later time, T ~1 By, the size distribution is a much better match to the present one, but the large size population is significantly overabundant relative to the present one.