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# Testing the Icy Pebble Accretion Hypothesis: Constraints from Volatile Delivery to Large Main Belt Asteroids

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The main asteroid belt is a relic of the early Solar System, preserving crucial evidence from the planetary accretion epoch. Notably, large asteroids (D > 120 km) exhibit a taxonomic gradient with heliocentric distance—reflecting a transition from anhydrous to volatile-rich surfaces[1]. One hypothesis suggests that some formed in a cold, distant reservoir and were implanted into the main belt during giant planet formation and migration[2]. Alternatively, volatiles may have been delivered via inward-drifting icy pebbles in the protosolar disk[3,4]. While this scenario remains untested in detail, recent advances in observations, including potential finding of ammonia-bearing compounds on large main belt asteroids[5,6], provide opportunities to evaluate theoretical predictions. Here, we examine whether rocky asteroids formed in situ and acquired volatiles through pebble accretion as $H_2O$ and $NH_3$ snowlines migrated inward.

Using a simplified disk model with a given snowline migration scenario[7], we treat the turbulence strength of the disk, radial pebble flux, and pebble size (characterized by the dimensionless stopping time: Stokes number, *St*) as free parameters. We employ analytical expressions to calculate pebble accretion on rocky planetesimals[8]. The model results are compared to topographic (the minimum thickness of the volatile-containing layer) and mass constraints for bodies in the main belt derived from observations[5].

Results indicate that volatile delivery to asteroids via pebble accretion requires a moderate pebble flux ($<20M_\oplus$/Myr). Water accretion is feasible with $St<10^{-3}$(<1 mm). Under such conditions, only the largest asteroids ($D \gtrsim 230$ km) such as Ceres can accumulate sufficient ammonia. For most asteroids with diameters of 100–200 km, ammonia accretion requires $St\sim10^{-5}$(~10 μm). Given that observations suggest significant dust growth to sizes larger than 10 μm [9], maintaining a sufficiently high flux of small grains required for ammonia accretion on small planetesimals is challenging. This may suggest that ammonia-bearing asteroids (*D*~100–200 km) in the main belt originated from distant migration.

[1] DeMeo & Carry 2014
[2] Takir et al., 2023
[3] Nara et al., 2019
[4] De Sanctis et al., 2015
[5] Rivkin et al., 2022
[6] Usui et al., 2019
[7] Oka et al., 2011
[8] Visser & Ormel 2016
[9] Andrews 2020