The Case Against Mercury as the Angrite Parent Body (APB)

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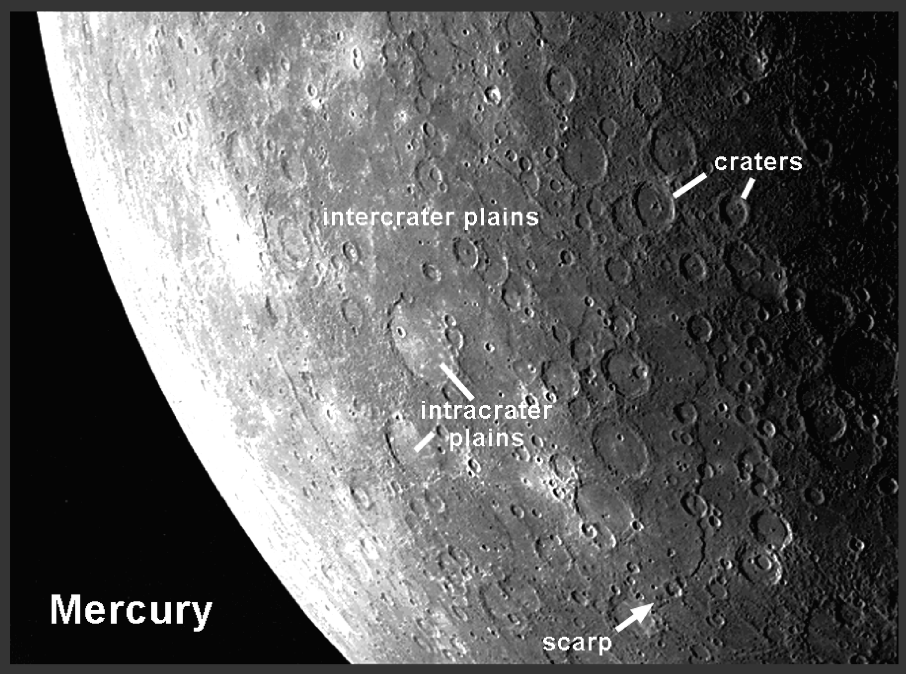
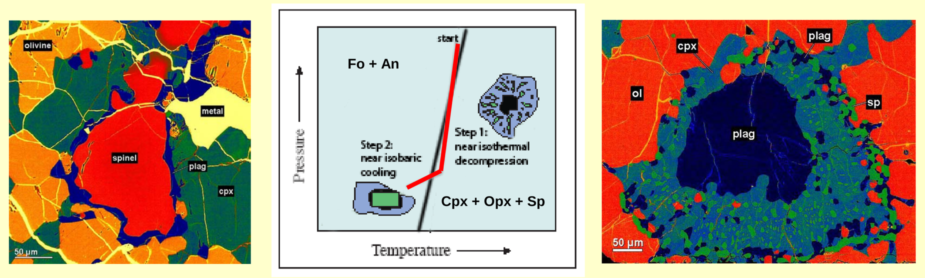


Typical Landforms on Mercury

The case for Mercury as the APB:

Recently it has been proposed that Mercury is the APB[1,2,3,4]. The authors of this proposal base their conclusions on the opinion that the presence of corona and symplectite textures and 120° triple junctions between grains in the angrite NWA 2999 indicate that this meteorite formed at great depth in a parent body capable of "km-scale tectonic uplift of lithospheric material"[1]; in other words, from a planetary-sized parent body. The authors propose that the symplectites and coronas in NWA 2999 formed via the forward and reverse metamorphic reaction Fo+An=Al-Cpx+Al-Opx+Sp, respectively, during rapid near-isothermal decompression from great depths along a Mercurian thrust fault[1,2], followed by near isobaric cooling.

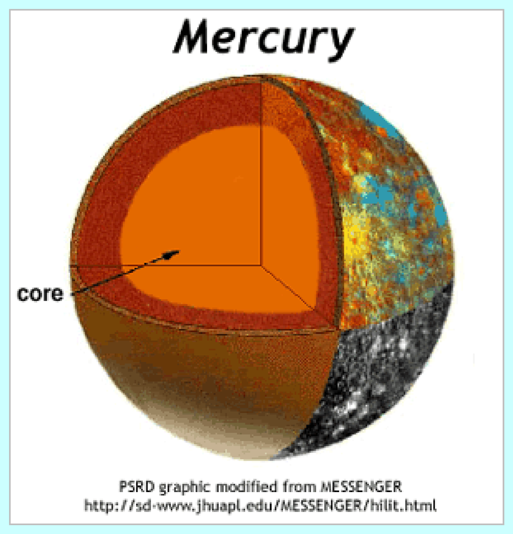


Figures from Kuehner et al.[2] showing a corona (left image) and symplectite (right image) and the proposed model for the origin of these textures. Red path interpreted from text of abstract.

Glasses along grain boundaries and exsolution lamellae possibly indicative of rapid melting and cooling in the angrite NWA 4950 are cited as additional evidence of rapid decompression along thrust faults[3]. The authors concede that the FeO-rich composition of the angrites does not match the FeO-poor nature of the Mercurian surface as inferred from spectral data, but suggest that angrites might "derive from early collisional stripping of its [Mercury's] outermost (possibly more ferroan) lithosphere"[3].

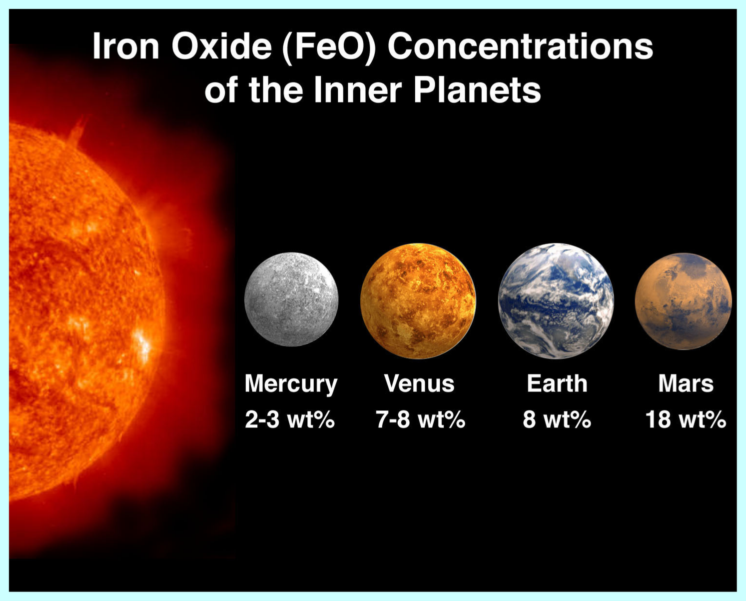
Fundamental ideas concerning Mercury:

1) Mercury's bulk density suggests that the planet has a very large metallic core[5].

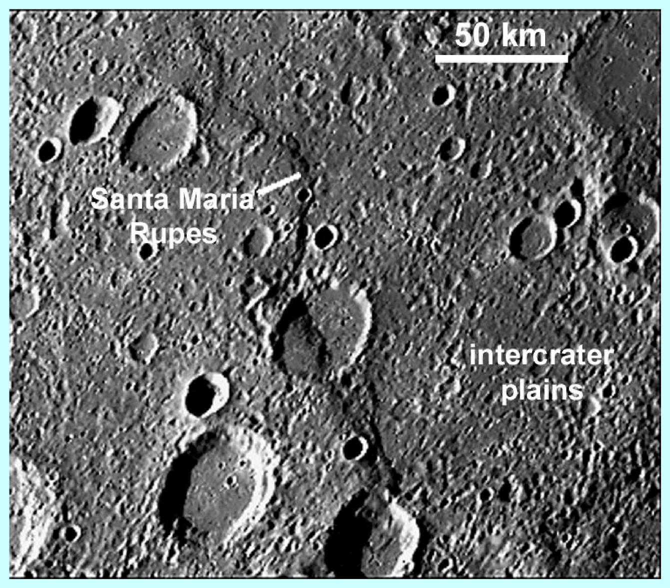


2) Spectroscopic observations suggest that Mercury's surface has ≤4 wt% FeO + TiO_2, with a best estimate of ~1.2 wt% FeO[6].

3) The combination of a large metal core and FeO-poor surface chemistry for Mercury compared to other terrestrial planets has led to the supposition that Mercury formed from reduced material (similar to enstatite chondrites) and that there was a gradient in oxidation state throughout the inner solar system[5].



4) The lobate scarps (Rupes) on Mercury are believed to be thrust faults resulting from global contraction due to core solidification[7]. A model of thrust faulting along Discovery Rupes concluded that the thrust faults on Mercury involved ~2 km of displacement and originated at a depth of 35-40 km[7]. This study also noted that the scarps formed after the period of heavy bombardment on Mercury and the formation of the intercrater plains (≤ ~4.0 Ga ago).

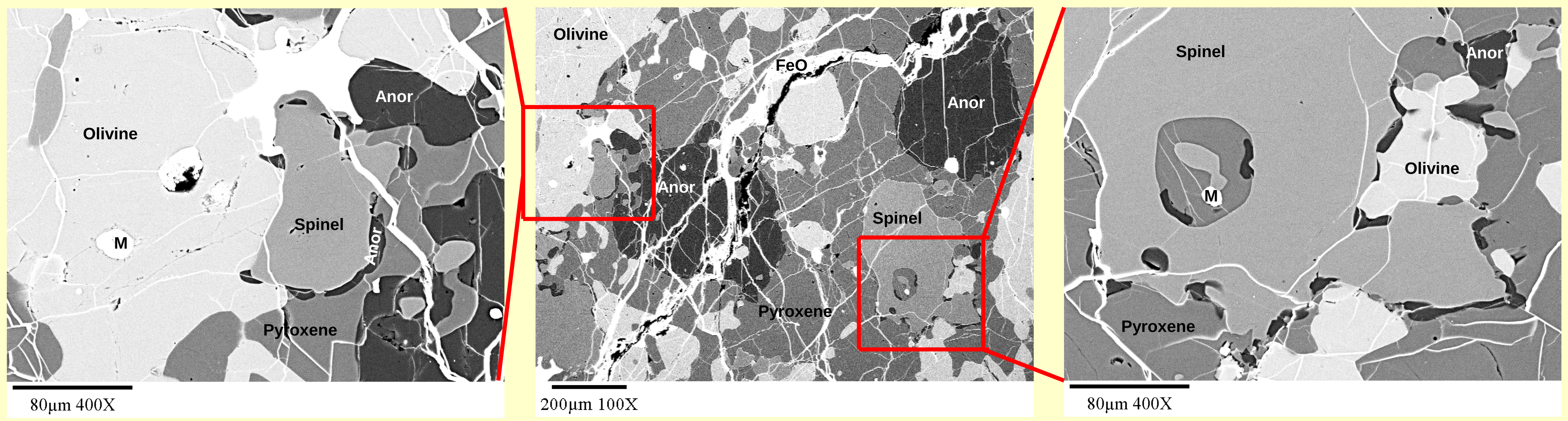


The case against Mercury as the APB:

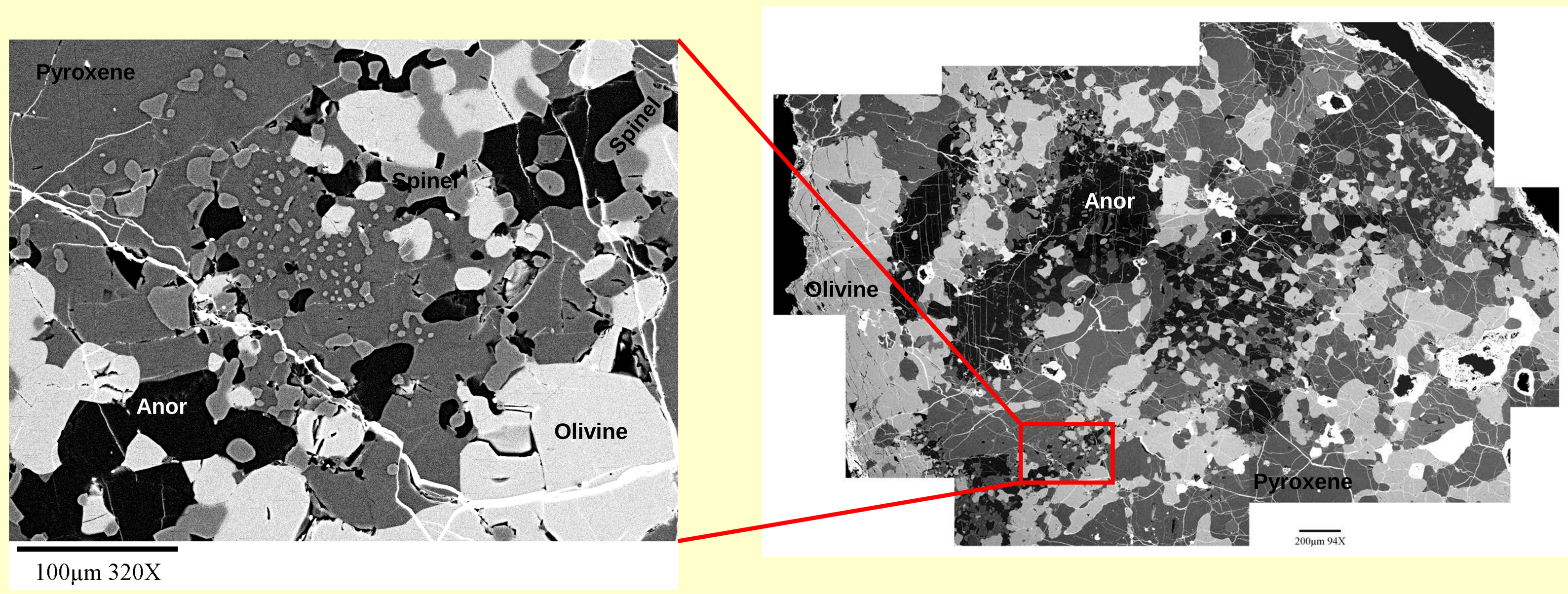
The textures in NWA 2999 do not require or support the idea of a large planet-sized parent body. The model proposed by Kuehner, Irving and coworkers[1,2,3,4] hinges on an interpretation that textures observed in one angrite (NWA 2999) are the result of metamorphic reactions that take place in a large planetary body.

➡ 120° triple junctions do not require a large parent body as they have been observed in many achondrites, including brachinites, acapulcoites, lodranites, ureilites, and winonaites[8,9].

➡ The observed relationships between mineral phases in NWA 2999 are not consistent with the proposed metamorphic reaction, which predicts that anorthite will be surrounded by a spinel/pyroxene symplectite, and that spinel and pyroxene will be surrounded by a reaction rim of anorthite and olivine. There are numerous examples where this is not the case, as shown in the BSE images below (phases are labeled – M=metal, FeO=terrestrial weathering, Anor=anorthite). The central image shows two large anorthite grains surrounded by pyroxene. Neither of these two large anorthites is surrounded by a symplectite as predicted by Kuehner et al.[2]. Also, while there are numerous examples of discontinuous coronas of anorthite surrounding spinel grains (left and right images), there is no evidence that this anorthite formed by reaction of forsterite and spinel as required by the Kuehner et al. model[2]. Indeed, olivine is often in direct contact with spinel, as shown in the left and right images below). Instead, it appears that anorthite preferentially nucleated on spinel.



➡ Low-pressure crystallization from an angrite-like melt can explain the disequilibrium textures observed in NWA 2999[10]. The first phases to crystallize under the oxidizing conditions inferred for angrites would be olivine and spinel. As temperature decreases, anorthite would begin to crystallize at the expense of spinel, giving rise to the "coronas". At lower temperatures, anorthite becomes unstable and spinel and pyroxene co-crystallize, giving rise to a late-stage, fine-grained intergrowth similar to the "symplectite" described by Kuehner et al.[2], as shown in the BSE images below.



The proposed model for Mercury as the APB requires an implausible change in planetary fO_2 during a multi-stage differentiation. In order to produce the FeO-rich basaltic angrites, Mercury would have to first differentiate under oxidizing conditions. Then to produce the currently observed crust and large metal core, Mercury would have to undergo additional differentiation under reducing conditions. There is no plausible mechanism for large-scale change of a planet's oxidation state in the middle of differentiation.

The proposed model requires that NWA 2999 experienced ~50 km of rapid uplift, for which there is no viable mechanism. It appears that there was only ~2 km of total displacement along the lobate scarps on Mercury, which is too shallow for Kuehner et al.'s model[2].

The Mercury=APB model requires implausible preservation of an early FeO-rich crust on Mercury. All of the angrites for which we have crystallization ages formed at the beginning of the solar system (4.54-4.56 Ga ago)[8]. The lobate scarps on Mercury are much younger (≤ ~4.0 Ga ago)[7]. If angritic material were removed from Mercury's interior by thrust faults, this material would have to be stored below the present reduced crust and not become mixed with it for the first ~0.5 Ga of solar system history, when impact fluxes were high. This is very unlikely.

Other arguments put forth in support of a Mercurian origin for angrites (such as mineral chemistry, oxygen isotopes, early crystallization ages, limited shock effects, and a wide range in cosmic-ray exposure ages) either do not require a Mercurian origin or argue against one.
In particular, old crystallization ages are found in angrites, acapulcoites, eucrites, and IIIAB irons, and argue for an origin in small asteroidal-sized bodies that accreted rapidly enough to experience substantial heating from short-lived radionuclides[9].

Reference List:

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