
Introduction. The large (93 km diam) crater Copernicus is on the lunar nearside just south of Mare Imbrium. The mineral assemblages determined by spectral-reflectance studies for areas on the crater rim, continuous ejeeta, and floor are typical of most highland areas — low-Ca pyroxene is the primary mafic component of a presumed feldspathic material (1,2). In contrast, olivine is the dominant mafic material and pyroxene is not detected (5,6) in three areas on the crater's central peaks. Cratering studies show that the pyroxene-bearing crater facies were derived from shallow levels of the target, whereas the olivine-rich peak material was derived from deeper levels, probably about 10 km below the target's surface (3).

Concentrations of olivine are commonly believed to characterize cumulates of the mantle or lower crust, not the upper 10 km (4). The apparent sharpness of the stratigraphic contrast between underlying olivine-rich and overlying pyroxene-rich assemblages is also problematic.

Geologic setting. Formation of the terra crust was accompanied and followed by a series of basin-forming impacts. It has been suggested that one of the earliest and largest impacts excavated the Procellarum ("Gartenant") basin (5-8), possibly 3200 km in diameter and centered 450 km NW of Copernicus (6). If real, this impact permanently thinned the crust in the Copernicus region and caused a compensating mantle uplift. Smaller basins and craters later redistributed the crustal material exposed by Procellarum; the Insularum ("South Imbrium") basin encloses the Copernicus region, and the youngest nearby basin, Imbrium, covered the region with ejecta (9), whose thickness is estimated as 0.4 to 3.0 km depending on the assumptions used (10). Reexcavated Imbrium ejecta (and possibly some mare basalt) undoubtedly constitutes at least part of the Copernicus ejecta. Even if the Imbrium deposit is as thick as 3 km, however, the central peak was derived from beneath it. This sub-Imbrium, pre-Imbrian material probably includes discrete basin and crater deposits, but such deposits are unlikely to contain olivine concentrations.

The crustal material beneath these impact deposits is undoubtedly strongly brecciated and deformed, but probably retains much of the structure acquired during early igneous activity. After the ultramafic mantle and feldspathic crust differentiated, Mg-rich megmas generated by partial melting of the mantle may have intruded the basal (4) or entire (11) thickness of the older ferroan-smorhinite crust, where they formed layered plutons composed mostly of norite rock overlying troctolitic rock, with some dunite and other types (4,11).

These concepts of crust and basin formation suggest to us three alternative scenarios that can account for the inferred stratigraphy exposed by Copernicus (fig. 1).

Scenario a: Layered plutons in the upper crust (fig. 1a). The lunar crust is assumed to be 60 km thick in the entire region and to contain layered plutons at all levels. Copernicus pierced the basal deposits and penetrated a layered pluton high in the crust, ejecting the upper norite and uplifting the lower troctolite or dunite to form the central peaks. No pre-Imbrian basin impacts are required.

Scenario b: Mantle uplift (fig. 1b). The sub-Copernicus crust is thin (<10 km) and the mantle correspondingly elevated as a result of the Procellarum and Insularum impacts. Copernicus ejected noritic crustal rock (not necessarily in a discrete pluton), penetrated nearly to the mantle, and uplifted ultramafic mantle material to form the central peaks.

Scenario c: Layered plutons in the lower crust (fig. 1c). As in b, basins thinned the crust. As in a, Copernicus excavated norite and uplifted olivine-rich rock from a layered pluton.
SOURCE OF COPERNICUS OLIVINE

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We prefer some version of hybrid scenario c — probably with a thicker crust than shown in figure 1c — because (i) much evidence supports the existence of the Procussion basin, (ii) a layered Mg-suite pluton offers the observed contrast between mineral assemblages, (iii) we believe that the Mg-suite rocks are likely to be concentrated low in the crust, and (iv) the locally shallow Moho required by scenario b is not documented by geophysical evidence. Additional remote sensing information for surrounding areas will be sought to test this hypothesis. Ultimately, more geophysical and geochemical information about the entire Moon will be needed to resolve this and other questions about the crust and mantle.

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Fig. 1. Hypothetical cross section from Mare Imbrium (18°N, 20°W) to Mare Insularum (1°S, 20°E), illustrating alternative hypotheses for the observed olivine in Copernicus' central peaks and nortic components of the ejecta and floor. The unit "Crustal Material" refers to ferroan anorthosite. Layered plutons in the crust are modeled after James (11). The crust is brecciated by accumulated impacts. Horizontal and vertical scales equal except that surface relief is exaggerated. See text, scenarios a, b, c.