THE PROPOSED LUNAR PROCELLARUM BASIN: SOME GEOCHEMICAL INCONSISTENCIES.

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Introduction. Over a decade ago, Cadogan [1] proposed that a giant impact basin (Gargantuan), encompassing Oceanus Procellarum and Mare Imbrium, was responsible for the asymmetric distribution of KREEP-rich rocks in the lunar crust. Whitaker [2] outlined specific morphological and structural evidence as proof of the existence of the giant basin, which he named Procellarum. Wilhelms [3,4] suggested that many apparently perplexing relations of lunar geochemistry could be adequately explained by the presence of this proposed basin. Subsequently, several investigators (e.g., [5-7]) have used this concept as a working hypothesis to explain various lunar geologic relations. The purpose of this paper is to suggest that the geochemical evidence for the existence of the Procellarum Basin is not conclusive and is subject to alternative interpretations; a companion paper [8] describes the ambiguous nature of morphologic and structural evidence for the basin. We do not attempt to "prove" the nonexistence of Procellarum; we merely assert that the principle of multiple working hypotheses should not be abandoned.

Geochemical relations cited as evidence for Procellarum Basin. The following are summaries of several lines of geochemical evidence that are cited by proponents of the Procellarum Basin as consequences of a giant basin impact: (A) The concentration of KREEP in the Procellarum region [1-5]. Cadogan [1] proposed that crustal unloading produced by the Gargantuan Basin impact induced partial melting of near-surface mantle materials. Volcanic KREEP basalt resurfaced the basin interior, thereby accounting for the high levels of KREEP in the Procellarum region. (B) The Al "gradient" [3,4]. Wilhelms has suggested that the abundance of ferroan anorthosite at Apollo 16 and its paucity at Apollos 14, 15, and 17 reflects the location of these landing sites outside and inside the Procellarum excavation basin, respectively. In this model the Procellarum impact removed ferroan anorthosite crust. (C) Similarity of geochemical relations at Procellarum with those around the South Pole - Aitken (Big Backside) Basin [2-4]. The major KREEP-rich anomaly of the lunar farside (Van de Graaf region) occurs within a large, 2000-km-diameter basin whose existence is well established. This relation is cited as having been produced by a process analogous to the proposed Procellarum impact. (D) Crustal overplating of circum-Procellarum regions by basin ejecta [3,4]. Wilhelms suggested that highly aluminous zones of thick crust surround Procellarum as a result of both removal of crust at the basin target site and addition of several km of ejecta from the Procellarum impact. (E) Most young maria occur within Procellarum Basin [3,4]. Oceanus Procellarum has a remarkable diversity of volcanic complexes and young flows, which Wilhelms suggested is a consequence of an anomalously thin lithosphere induced by the Procellarum impact. (F) Al-rich mare basalt flows [3,5]. Al-rich mare basalts supposedly occur in Maria Smythii and Fecunditatis [9]. Wilhelms suggested that this occurrence is a consequence of emplacement through an anomalously thick highland crust outside Procellarum Basin (see D above).

Another look at the geochemical evidence for Procellarum basin. The six points listed above would seem to support the Procellarum Basin hypothesis. On close examination, however, they are equivocal or invalid. All are discussed as follows: (A) KREEP is distributed Moonwide and is not confined to Procellarum; moreover, its presence correlates inversely with crustal thickness [10,11]. The crust is thinnest in the Imbrium/Procellarum region and hence, has the highest KREEP concentration. The existence of KREEP basalts in the Balmer and Marginis Basins [11,12] negates the theory that KREEP extrusion was limited to Procellarum [1]. On the basis of petrology [13], Cadogan's model for KREEP petrogenesis [1], whereby KREEP magmas were generated in the lunar mantle, is unlikely. (B) Although it is true that there is a paucity of ferroan anorthosite at landing sites within the Procellarum Basin [3,4], this is also true for several farside regions unrelated to either Procellarum or South Pole-Aitken Basins.

Plutonic Mg-suite provinces occur near but outside the Balmer [14], Mendeleev [15], and Korolev [16] Basins and do not appear to be consistently related to basin interiors. Mg-suite intrusive activity was probably Moonwide, dependent on a number of factors that are not presently well understood. Moreover, ferroan anorthosite is present at Apollo 15, although it is a minor component (5%). It is difficult to explain the fact that it is present here, close to the center of the Procellarum Basin, but virtually absent at the Apollo 17 site, on the rim of Procellarum [17,18]. (C) The anomalous chemistry near 25° S, 170° E is directly related to the Van de Graaf-Ingenii region, not to the South Pole - Aitken Basin; specifically, no clear petrologic anomaly occurs where the eastern part of the basin ring is crossed at 24° S, 149° W. Its absence here suggests that the zone of anomalous chemistry is localized and is not necessarily related to the South Pole-Aiken Basin. (D) The concept that the crust is anomalously thick surrounding Procellarum is not supported by a crustal thickness map derived from gravity data [19]. The results of this map are sometimes rejected because it is based on an extreme Airy compensation model. Its rejection on this basis, however, implies a Pratt crustal model, i.e. a laterally heterogeneous region where anorthositic crust is surrounded by Mg-rich crust, a model exactly the reverse of that implied by Procellarum Basin plutonism [3,4]. Moreover, studies of basin ejecta composition [15] demonstrate that the Smythii Basin, outside Procellarum Basin, displays ejecta compositions comparable to other lunar basins. Thus, evidence is not compelling for an anomalously thick crust surrounding the Procellarum Basin. (E) Although numerous young mare units occur within Procellarum Basin, they also occur outside the basin; specifically, maria in Smythii Basin are as young as all but the very latest flows in Procellarum [20]. Additional young maria occur in Mare Marginis and southeastern Mare Tranquillitatis, both of which are outside the Procellarum Basin. (F) The Al-rich mare flows proposed by [9] are probably the result of mixing of anorthositic highland rock with mare basalt. Such composition can be clearly seen in the high-Al signature of eastern Mare Tranquillitatis, where vertical mixing of highland debris into the mare regolith provides a simple explanation. The main objection to point F comes from the landing site (Apollo 14) where high-Al mare basalt was first identified. These basalts must have been extruded into the Procellarum Basin regardless of the origin of the Fra Mauro Formation--whether it is primary Imbrium ejecta or of local origin. As such, the existence of these basalts is not predicted directly by the Procellarum Basin hypothesis.

Conclusions. We find that most of the geochemical arguments advanced in favor of the proposed Procellarum Basin are, at best, inconclusive. The Procellarum Basin hypothesis, although attractive as a paradigm, suffers from numerous inconsistencies that most likely reflect the complexities of the geologic processes and history of the Moon.

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