IMPACT-DRIVEN MOBILIZATION OF DEEP CRUSTAL BRINES ON DWARF PLANET CERES.

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Introduction: Data collected by NASA's Dawn spacecraft provide evidence that global aqueous alteration of Ceres resulted in a chemically evolved body that remains volatile rich [1], while recent emplacement of bright deposits sourced from brines attests to Ceres being a persistently geologically-active world [2, 3, 4]. To better understand the contribution of impacts to the evolution of Ceres' crust, the final phase of the Dawn mission (XM2) was designed to investigate the 92-km Occator crater, which hosts extensive young bright carbonate deposits (faculae), with an imaging resolution ten times better than achieved during the prime and first extended mission. In XM2, the spacecraft achieved a minimum altitude below 35 km over Occator crater (20°N, 240°E), imaging most of the crater at resolution of 3.3-10 m/pixel, and increasing spatial sampling of all other instruments. In particular, it yielded gravity variations [5] at the scale of the geological units of the crater itself and surrounding areas (Fig. 1). XM2 data elucidate the interaction of the impactor with the ice-rich crust, and the processes by which brine deposits formed within the crater [4, 6, 2].

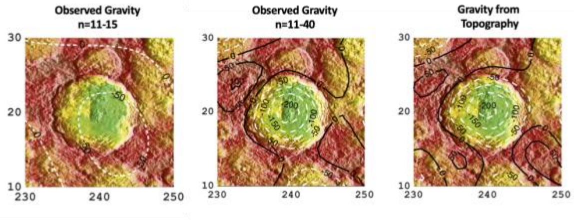

Figure 1. *Left*: Gravity of Occator crater (contours interval 50 mGal) from global field obtained at 385 km altitude. *Center*: with addition of XM2 data at ~35 km altitude. *Right*: gravity calculated from topography for comparison.

Occator crater is located within Hanami Planum, a discrete highland of ~555 km diameter with elevation reaching 6 km with respect to Ceres' reference ellipsoid (Fig. 2, left). It displays a broad-scale negative isostatic gravity anomaly (indicating excess light material) that is anti-correlated to topography [7, 8]. The amplitude of the negative isostatic anomaly distinguishes this region, indicating significant heterogeneity relative to surrounding areas [8]. Removing the degree 2 gravity field suppresses this large negative anomaly, and reveals a pattern of residual anomalies associated with craters and domes within the planum (Fig. 2, right).

We investigated the sources of gravity anomalies and find evidence for an extensive deep brine reservoir beneath Occator and the broader Hanami region, including heterogeneity in the deep mantle beneath Hanami Planum. Thermal and impact modeling shows that this endogenic brine reservoir could be mobilized by the heating and deep fracturing associated with the Occator impact, leading to long-lived extrusion of brines and the formation of the faculae. Moreover, the distribution of bright deposits suggest that pre-existing tectonic cracks may provide pathways for deep brines to migrate within the crust, extending the regions affected by impacts and creating compositional heterogeneity in the crust.

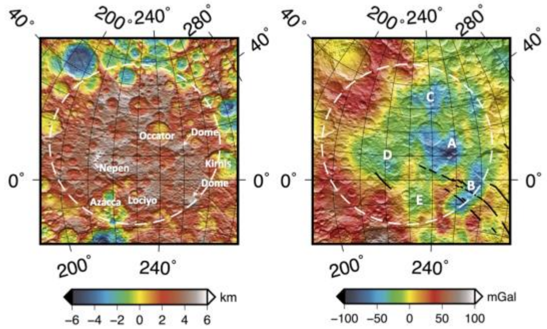

Figure 2. *Left*: Topography of the Hanami Planum region (dashed white line) plotted relative to the geoid, with four youngest craters annotated. *Right*: Isostatic gravity up to degree strength with the low-degree (n<3) field removed. Samhain Catenae indicated by black lines. Discrete local anomalies are labeled A-E.

Geologic Setting: The asymmetry of the -50 to -65 mGal isostatic gravity low within Occator crater (Fig. 2, right) and its merging with the larger negative anomaly to the southeast suggests the influence of regional crustal structure. The ~80 km diameter anomaly southeast of the crater (A, Fig. 2, right) is associated with a 70x30 km dome, that rises 2-3 km. Anomalies A and B coincide with domes and linear features associated with the Samhain Catenae (SC), a set of deep pit chains inferred to be the surface expression of deep-crustal fractures. XM2 data resolve the gravity signatures of these domes and indicate they comprise low-density material. Proximity of the domes to large fractures is consistent with fractures providing conduits to move brines into the shallow crust. As well, the depths of young craters in Hanami (Occator, Azacca, Lociyo and Nepen) are shallower than expected, and fracture patterns on their floors are consistent with uplift by intrusions [9].

Gravity Modeling: Markov Chain Monte Carlo (MCMC) modeling was performed assuming ellipsoidal source regions to investigate the sources of both the broad Hanami Planum anomaly and the deep low near Occator Crater (Anomaly A). Posterior distributions were derived for source dimensions, source center, total mass deficit and density contrast for each region, within the constrained parameter ranges. Hanami's total mass deficit was found to be ~0.1% of Ceres' mass ($-89.1^{+0.8}_{-0.8}$ x 10^{16} kg/m^3), and the Occator region's residual mass deficit is $-6.2^{+0.3}_{-0.3}$ x 10^{16} kg/m^3. A visualization of the anomaly's location and median density contrast is shown in Figure 3 for the Hanami source (left) and the Occator region (right). In order to compute the median density contrast, histograms of density contrasts are built point-wise on the cross-section using the chains of parameter values resulting from MCMC runs, then the median value of density contrast is computed from those histograms.

Results indicate a deep mantle source for the broad anomaly (Fig. 3, left), with a mass deficit of 30-60 kg/m^3 in the sub-Hanami mantle. This deep-seated source may reflect the effect of elevated mantle temperature in reducing brine density. The inferred position and extent of the local source near Occator (Fig. 3, right) suggests a low-density region in the lower crust and upper mantle. Low density in this local region could indicate a higher brine-to-silicate ratio, and/or overall higher temperature. This inferred brine-rich region likely contributed to, and prolonged eruptions within Occator crater. The association of negative isostatic anomalies with domes and fractures suggests that intrusions into the shallow crust may have been fed by similar lower crustal brine reservoirs connected to the deep Hanami source via pre-existing and impact-induced fractures.

Long-lived Brine Activity: The inferred presence of mobile brines beneath Hanami Planum supports the prediction of warmer temperatures in the sub-Hanami crust and mantle, driven by the preservation of a large fraction of its original clathrate hydrate content [10]. Thermal evolution modeling was performed to link the derived anomalies to brines mobilized by the Occator impact as well as pre-existing brines. The post-impact temperature field was calculated using methods of [11] by rescaling the hydrocode modeling results of [12] for lower thermal conductivity of the crust. The result is that partially-molten sodium carbonate can persist for >5 My beneath the crater center and a broad region of partially molten ammonium chloride persists beyond 10 My.

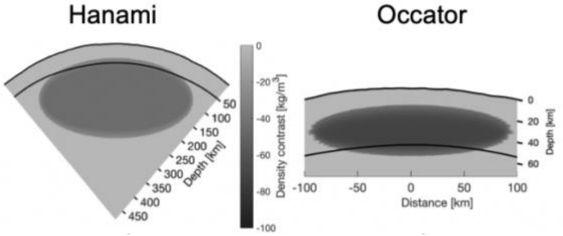

Figure 3. Cross-sections of median values of density contrast. Top surface is observed topography and crust/mantle boundary at ~55km is shown by solid black line.

Summary and Conclusions: Dawn gravity data are consistent with a shallow low-density region near Occator crater and a broad, deep low-density region beneath Hanami Planum, interpreted to be warmer and/or more plentiful brines than in surrounding areas. Association of local gravity lows with domes and both deep and shallow fractures suggest the fractures provide pathways to feed brines to the surface from deeper reservoirs. Brine preservation in regions of lower thermal conductivity (higher proportion of clathrates) can account for the heterogeneous distribution of brines in the subsurface. Impact heating and fracturing both contribute to local brine enrichment and provide pathways for their migration to and eruption onto the surface. The long-lived hydrological system created by the Occator impact within Hanami Planum represents a potential analog for large impact craters in icy moons, with implications for the creation of transient habitable niches over time.

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