MARTIAN VOLCANOES AND GROUND-ICE: EVIDENCE FOR THE LOCALISED ENRICHMENT OF SUB-SURFACE ICE BY JUVENILE VOLATILES.

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The results of crater analyses and a landform survey have been used to construct a comprehensive account of the distribution and importance of water within the Elysium region (1). Evidence of a widespread ground-ice has been obtained. The ice-distribution is shown to be strongly dependent upon latitude, though its concentration varies with depth and is strongly influenced by geological setting. Important differences have been detected in the distribution of Southern Highland and Northern Lowland ground-ice (2). In addition, the ice is enriched at depth in the Elysium Lavas, and nearer to the surface to the north-west of Elysium Mons. The apparent distribution suggests that several ice-emplacement mechanisms have operated on Mars, including the enrichment of the deeper ice by juvenile water from beneath the Elysium volcanic province.

Introduction:

The crater database used in this study contains the dimensions and detailed morphological characteristics of 7289 craters (1,3). Ejecta mobility (4,5,6) and crater morphology analyses of these data have been used to investigate the distribution of sub-surface ice between longitudes 245°-155° and latitudes 20°S-45°N, an area incorporating all of the Elysium Quadrangle and large portions of Amenthes, Amazonis, Mare Tyrrhenum, Aeolis, Memnonia, Cebrenia and Diacria Quadrangles.

To examine ejecta mobility the gradients of ejecta versus crater diameter graphs of sub-divisions of the data, and the positions of apparent gradient discontinuities (break-points) were obtained (7). These are presumed to reflect the relative proportion of volatiles incorporated into the ejecta and the depth to the volatile-rich material respectively. The data subsets were then further divided into craters larger and smaller than the calculated break-point diameters so that the properties of the upper and deeper layers of Mars can be examined separately. The onset diameters of features thought to indicate the involvement of sub-surface ice, such as distal ramparts, jagged-edged ejecta, central pits or partial extra layers of ejecta are, in places, smaller than the calculated break-point diameters: the proportion of these features is, however, clearly greater in the larger than the smaller crater populations, reinforcing the interpretation that the larger craters are in general more mobile than the smaller craters owing to the excavation of greater concentrations of ice at depth.

The following discussion assumes that the observed variations in ejecta mobility and crater morphology generally reflect variations in the total ice-content of the excavated material. The ‘near-surface’ materials are, therefore, interpreted as having either discontinuous ice masses in an ice-poor matrix or a more (temporally or spatially) continuous but low ice-content permafrost. ‘Deeper’ layers were presumably richer in ice (both in its concentration and spatial distribution).

The location of break-points and subsequent diameter-division of the data allows the comparison of the morphology of small and large craters in different regions without biasing the results because of uneven crater size-distributions, and has allowed the comparison of materials at different depths. The results of the crater morphology surveys will, however, be to some extent dependent upon the accuracy of the break-point determination (7). In the following discussion small crater and large craters refer to craters with diameters smaller and larger than the relevant calculated break-point diameter respectively.

The characteristics of craters on the Ael1 unit (The lava plains surrounding Elysium Mons):

Compared with the total population of large craters, the large craters within the Ael1 unit exhibit extremely high percentages of rampart craters (70.5% compared with 50.1%), jagged perimeters (47.5% compared with 25.3%), and central pits (19.1% compared with 2.4%)(1). (The percentage for central pits is the percentage of all craters, whereas features relating to ejecta characteristics are expressed as a percentage of all craters which have ejecta.) In addition, the ejecta diameter versus crater diameter gradient of craters above the break-point (at 9.4 km) is high (8), and the unit contains 11 of the 42 large double ejecta craters found within the study area. The influence of the Ael1 lavas is also apparent in a latitudinal analysis (1), which shows clear peaks in the occurrence of several features at around 17.5° N.

It appears, therefore, from the crater characteristics, that there are substantial amounts of ice at depth.
within the area covered by the Elysium lavas. Smaller craters on this unit display far lower proportions of these features, and indeed, the upper layers of this geological unit appear relatively 'dry'; in particular, several radial ejecta craters are seen in the proximity of Elysium Mons, though they are rare elsewhere, and the craters on the construct itself have low ejecta mobilities (1,8).

The presence of fluidized and rampart ejecta and central pit craters does not unequivocally prove that ice was present, but the abundance of these features in the majority of large craters on the Elysium Lavas, together with the localised occurrence of collapse features and channels (1) suggests that a large concentration of sub-surface water/ice was present here. The higher-than-average fluidity of these craters suggests that liquid water may have been present here since the most strongly fluidized, large craters are restricted to the Highlands and to the Ael1 unit (1,2).

In addition, the deposits associated with the Elysium channels to the northwest of Elysium Mons have been shown to be rich in ice (8) and to have morphologies suggestive of their emplacement as lahars (9), whose source of water was beneath Elysium Mons. This is consistent with the conclusions of (11), who argued that the closely spaced troughs on the northwest flanks of Elysium Mons probably intersected an extensive, volatile-rich layer at depth. It is feasible that not only was the presence of an enhanced volcanic heat flux responsible for the generation of channels and chaotic terrain in the area, but more importantly, that the volcanic activity itself appears responsible for the localised enrichment of sub-surface ice (2). It is therefore suggested that a substantial proportion of the enhanced ice deposit under the lavas originated from the emplacement of juvenile water from the underlying magma body.

Discussion:

The apparent enrichment of sub-surface ice in a volcanic region is contrary to intuition, since it would seem reasonable that ground-ice near to volcanic activity would tend to be driven away from the locally enhanced geothermal heat (as suggested by 10). This may indeed have occurred in the immediate surroundings of Elysium Mons, where there appears to be little near-surface ice (1,11). The presence of the ice layer at depth suggests, however, that the ice has been preferentially enriched by water from below the volcanic region, i.e., by juvenile water. Several authors have noted the apparent association of volcanic and channel features on Mars (e.g., 12) and a juvenile water origin has been proposed to explain the distribution of martian channels of various ages following a planetwide survey of the association of volcanic and fluvial features (13). Within the region studied here, with the exception of Hebrus Valles, all channels with Lowland sources are closely associated with Elysium Mons. This work has provided further evidence that this association is not coincidental, and strongly suggests that, in the case of this volcanic province, juvenile water has contributed to the formation of a substantial sub-surface ice reservoir.

Greeley (12) used an estimate of 1% by weight of water to predict that an amount of water equivalent to a 46 m-deep planetwide layer, may have been released in association with extrusive volcanic activity. Boyce (14) noted that the apparent global distribution of the martian ground-ice rules out the ascent of juvenile water from the interior of the planet as the source of the ground-ice water since such ascending water would be expected to be localised. It is suggested here that juvenile water is responsible for the apparent ice-enrichment of the Elysium Lavas, with the rising water collecting beneath relatively impermeable surface lavas. It is now important to investigate this possibility further, since juvenile water may have provided a substantial proportion of the martian ground-ice: it would provide a particularly attractive explanation of the build-up of ice at depth. In addition, the stratigraphical and spatial association of volcanism and channel activity of various ages on Mars (13) suggests that the build-up and release of sub-surface water by volcanic activity was a common process on the planet.