GEOMORPHIC EVIDENCE FOR SUBSURFACE VOLATILE RESERVOIRS IN THE ELYSIUM REGION OF MARS

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Since the return of the Mariner 9 images of Mars, numerous investigators have pointed to geomorphic evidence for the existence of large and small reservoirs of volatiles (principally water) beneath the surface of the planet. The spatial and temporal distribution of these subsurface volatile reservoirs is important for understanding the evolution of martian landforms, climate, and perhaps even large-scale tectonism.

The Elysium volcanic province contains a variety of evidence for the existence of large volatile reservoirs beneath the surface. Geomorphic study of these landforms yields insight into the distribution and size of these reservoirs and how they interact with the surface environment and will ultimately place constraints on the geometry, constitution, origin, time of formation, and temporal evolution of these important components of the martian crust. Three principal types of landforms appear to be related to subsurface volatile reservoirs in the Elysium region of Mars : 1) small outflow channels; 2) large lahars; and 3) vast expanses of knobby terranes around the margins of the Elysium dome.

Outflow Channels.

The most obvious expressions of the presence of a subsurface volatile reservoir in this region are two relatively small outflow channels--Hebrus Valles and Hephaestus Fossae (1). Located southwest of Elysium Mons, both channel systems arise and cut across a broad expanse of older plains dotted by irregular mesas and smaller knobs (knobby plains).

The anastomose Hebrus Valles system of channels is 250 km long and emerges full-strength from an elongate depression. The source depression is 10 km across and has narrow finger-like projections. Individual sinuous channels are less than 100 m deep and about 1 km wide; a braided reach is about 10 km wide. Streamlined bedforms are abundant in the middle reach. The channels become narrower and shallower downslope. Hebrus Valles terminate as a series of narrow distributaries. No sedimentary deposits are obviously related to the development of the channels. Hebrus Valles are similar to other small martian outflow channels and appear to result from fluvial erosion following the outbreak of a confined aquifer.

Hephaestus Fossae are a connected series of linear valley segments which branch and cross downslope but have high junction angles. Locally, the valley pattern is polygonal. Hephaestus Fossae are parallel to Hebrus Valles but are considerably deeper and longer (600 km). The rectilinear pattern of the valleys has suggested to some that the fossae are tectonic in origin. However, unlike graben systems, Hephaestus Fossae originate in an isolated depression very similar to the source of Hebrus Valles. At least two sinuous, apparently fluvial, channels also arise from this depression. It is suggested that like Hebrus Valles, Hephaestus Fossae are also of fluvial origin as a result of catastrophic flooding and draining of water from beneath the surface. Hephaestus Fossae channels appear to have cut through the knobby plains unit which overlies a polygonally fractured terrane like that exposed at the NW end of the fossae in Adamus Labyrinthus. Downcutting to, or subsurface flow at this pre-existing surface led to a channel pattern that was strongly controlled by the polygonal troughs buried beneath the younger knobby plains materials. Hebrus Valles channels did not excavate this deposit and hence show more typical outflow features.

Mega-lahars.

Photogeologic studies of the Elysium volcanic province provide specific examples of the importance of the interaction of volcanism and subsurface volatile reservoirs to produce distinctive landforms (2). Three sets of volcanic debris flows or lahars issue from the same northwest-trending system of fractures that localized the three major volcanic constructs in the Elysium province. These deposits are lobate in plan and have steep well-defined snouts. Evidence that these mass flow deposits were wet slurries and not lava or ash flows include: 1) the intimate association of channels with their surfaces--these channels are sinuous, form anastomose distributary patterns, and have streamlined features on their floors. These features are consistent with the flow of water across the deposits. 2) discrete channels issue from the base of the lobate masses suggesting draining of water from wet sediments; 3) short reticulate systems of sinuous valleys cut portions of the deposits' margins and look like seepage channels (3); and 4) numerous irregular depressions mark other areas of the flows and have clearly developed from a formerly smooth and more extensive deposit. These pits may be created by the removal of volatiles by sublimation or seepage.

We explain the presence of the lahars as the result of the melting of ground ice and liquefaction of subsurface materials. The development of the Elysium volcanoes is the most reasonable source of heat and is consistent with the stratigraphic evidence that lavas and lahars were nearly contemporaneous. The contact of magma with liquid water may have resulted in hydrovolcanic explosions which produce large quantities of easily mobilized fine-grained material (4). The intersection of this fluid reservoir with the regional fracture system led to the rapid expulsion of a muddy slurry down the steep western slope of the province.

These sedimentary deposits extend nearly 1000 km down the regional slope to the northwest and cover 10^6 km^2. The deposits are less than 200 m thick near their sources and are probably much thinner on average. The total volume of the lahars may then be approximately 10^5 km^3. Taking a value of 30% water by volume--a figure typical of terrestrial lahars and non-volcanic debris flows (5)--implies that over 10^4 km^3 of water were involved.

Knobby Terranes.

Knobby terrane provinces consist of relatively smooth surfaces with variable proportions of knobs and flat-topped mesas. Broadly similar knobby terranes cover approximately 3 million km^2 in the Elysium region. The knobs and mesas appear to be erosional remnants of a formerly thicker deposit. The polygonally troughed terrane of Adamus Labyrinthus underlies the knobby terrane in the Amenthes quadrangle. In southern Amenthes quadrangle, the knobby plains have developed at the expense of an extensive plateau marked by irregular depressions and pits. Layering is visible in the walls of these ragged depressions. Erosional stripping of the knobby deposit has exhumed large impact craters. North of the volcano Hecates Tholus, knobby plains are developed at the expense of lava plains that partially bury the knobby plains (or its smooth undegraded precursor). Here, large lava-capped blocks give way to smaller mesas which grade northward into smaller knobs. Even farther north the knobby plains disappear and reveal underlying polygonally troughed terrane.

The knobby plains precursor appears to have developed in middle martian history. It overlies the polygonal plains of Adamus Labyrinthus which are post-Lunae Planum in age (6) and is in turn buried by Elysium lavas and lahars. The knobby plains are also cut by the two large outflow channels noted above and numerous small seepage channels on the western flanks of the Elysium dome. However, evidence for fluvial erosion is not extensive and the volume missing from the knobby plains precursor must have been either stripped away by eolian processes or it may represent the sublimation of water that had been sequestered in the layered deposits. The spatial coincidence of the knobby plains with other water-related landforms lends credence to the latter hypothesis. The degradation of the knobby plains precursor appears to have occurred mostly before Elysium volcanism because vast tracts of smooth lava plains bury knobby terrane; but at least in the small region north of Hecates, knob development appears to have persisted until the later stages of Elysium volcanism. Assuming that most of the missing volume represents removal of volatiles, and ignoring the extent of the knobby plains that must underlie the Elysium volcanic province, the amount of water lost from this region may be approximately 10^5 km^3.

Implications for Sub-Surface Volatile Reservoirs at the Surface of Mars.

The evidence provided by these landforms is internally consistent with the presence of a large relatively shallow volatile reservoir in the Elysium region of Mars. If the geologic features described above are reliable indicators of subsurface volatiles in this region, they imply that:

- the precursor of the knobby plains is an important volatile reservoir.
- volatile reservoirs lie relatively close to the surface.
- volatile reservoirs underlie millions of km^2 in this region.
- volatiles may be lost in a variety of ways from these reservoirs.
- volatiles were incorporated in an easily eroded surficial deposit in the middle history of Mars.

The ultimate origin of the water in this reservoir is uncertain, but the evidence is at least consistent with the polar wandering model described by Schultz (7). Otherwise, a model to explain the preferential entrapment of volatiles into one regions' surface materials is needed.

References.

(1) Christiansen, EH (1985) Geol. Soc. America Abstr. Prog. 17, p. 545.
(2) Christiansen, EH, and Ryan, MP (1984) Geol. Soc. America Abstr. Prog. 16, p. 470.
(3) Higgins, CG (1984) in RG LaFleur, Groundwater as a geomorphic agent, Allen and Unwin, p. 18-58.
(4) Sheridan, MF, and Wohletz, KH (1983) J Volcanol Geotherm Res 17, p. 1-29.
(6) McGill, GE (1985) LPSC XVI, p. 534-535.
(5) Pierson, TC (1985) Geol Soc America Bull 96, p. 1056-1069.
(7) Schultz, PH (1985) Scientific Amer 235, no. 6, p. 94-102.