

ISIDIS BASIN - A POTENTIAL FOCUS OF CRYOVOLCANIC ACTIVITY ON MARS. *N. Hoffman¹, J.S. Kargel² and K.L. Tanaka² ¹Victorian Institute of Earth and Planetary Science, La Trobe University, Melbourne 3086, Australia. Email: n.hoffman@latrobe.edu.au ²U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001

Introduction: Isidis Basin on Mars is filled by a smooth-surfaced unit of relatively young age, coeval with the main northern plains depocentre but probably filled by a separate set of flows [1]. The nature of these flows is at present indeterminate with fluvial, volcanic, marine, pyroclastic, and other exotic processes invoked. Key to understanding the deposits is the observation that many tens of thousands of small cones dot the plains in strings and chains [2] - an area described as "thumbprint terrain". Most cones have a small summit depression and they bear strong similarities to tuff cones on Earth. Nonetheless, there are dissimilarities too. For instance none of the 30,000 cones shows a lava tongue or flow emerging from it, nor are any young flows seen on the plains surface.

One possible explanation is that these are pseudocraters formed by expansion of volatiles from a buried layer, and that the cones are formed by secondary processes without the direct involvement of magma [3, 4]. Within this context, two alternative models exist: The cones may have been formed by high temperature expansion of water, requiring near-magmatic temperatures and implying that the basin fill is essentially volcanic, perhaps a massive ignimbrite [4]. An alternative is that the cones were formed at substantially lower, possibly cryogenic, temperatures and that the responsible volatile is CO₂. This latter model implies a cold emplacement mechanism for the deposits. Similar terrains elsewhere on Mars, for instance across the northern plains, are likely to have similar origins.

Alternatives also exist where the cones are formed in relation to much younger heating or fluid invasion events. These do not appear likely due to the lack of specific foci for this distributed phreatic process.

Tuff cones on Earth: Cones commonly form on Earth either by direct association with lava at a primary vent or a littoral cone where oceanic entry leads to explosive steam activity. In either case, there is a clear association with lava flows emerging from the cone or leading to it. Although some primary cones remain lava-free, these are much in the minority and tuff cones are generally found within volcanic fields where lava activity is clearly demonstrable.

Alternative features where such an association is not clear include Maars - relatively large features ranging up to a few km across where volatile-rich magmas have emerged, mixed with groundwater, and

erupted into ash-rich products that have largely dispersed, leaving a wide low rim and a central depression, often water-filled. The features on Mars are not of this nature.

Better analogues are pseudocones or phreatic cones, which occur where extensive lava flows, hot ashfalls or pyroclastic flows (collectively "ignimbrites") have buried a groundwater zone. As thermal equilibrium occurs between the cooling igneous layer and the underlying fluid layer, explosive eruptions build cones with summit craters, often without associated lava flows.

These analogues have been well-studied on Earth and commonly proposed for Mars as an explanation for features such as are seen in Isidis [4].

The role of CO₂: Water is not the only available volatile on Mars. CO₂ is readily available in the atmosphere, polar caps, and polar permafrost and may well saturate the regolith planetwide as either permafrost or CO₂ liquifers [5]. The saturation vapor pressure of CO₂ is about 500 times more than that of water at prevailing Mars temperatures, and it could be a powerful agent of explosive phreatic volcanism. As such it may be a logical alternative to water as the source of the phreatic volcanism in Isidis Planitia and other areas where similar features occur. However, there is an alternative explanation for the entire system that also involves CO₂ but does not require any volcanic input.

Fluidised Debris flows: The fill of Isidis basin does not appear to be a series of lavas, since neither central vents nor fissures have been identified. The adjacent giant stratovolcano Syrtis Major clearly overlaps the very western rim of the basin, but there are no signs of massive lava channels or pyroclastic flows of sufficient scale to have filled the basin. Indeed, the surface of the basin slopes down towards the southwest [1], not away from it as a depositional surface would, and there is a clear break in slope at the base of the volcano where its deposits effectively end. Thus, neither lavas nor ignimbrites seem adequate explanations for the fill of Isidis basin. Instead, it seems to have been filled in the same debris flow and sedimentation process that filled the rest of the northern plains with a few km of sediment [1].

Recent work [6, 7] shows that the fill of the northern plains occurred on a remarkably short timeframe of 10³ to 10⁵ years and Isidis basin is assumed to share this chronology [1]. The deposition

of ~ 2 km thickness of fluidised sediment in this timeframe leads on Earth to considerable fluid overpressure, undercompaction, and fluid escape. Whatever the nature of the lubricating fluid, it will be squeezed up through fissures and cracks and ejected into upper layer or expelled at surface.

On Earth, water escape structures associated with energetic events such as earthquakes can build small sand or mud volcanoes. If fluid escape persists in one spot, a feature hundreds of metres across and a few tens of metres high can be constructed. The margins of these features are marked by viscous mudflows and occasionally by more fluid flows emerging from the cones and traversing surrounding terrain.

Chains of larger mud volcanoes occur in large fields on the Earth's seafloor in some subduction-zone and accretionary tectonic settings [e.g., 8, 9]. These volcanoes typically are one to several kilometers across and a couple hundred meters high and often have summit craters. The fields of mud volcanoes and mud diapirs where they occur are in some cases hundreds of kilometers across. Such occurrences form where oceanic sediments are subducted and compacted. Water - often assisted by gases - is squeezed out and mud and other debris is extruded along faults. The same tectonic process is inapplicable to Mars, but the basic phenomenology of structurally-controlled mud extrusion complexes associated with fluidized, gas-rich, over-pressurized sediments can be applied to Mars in areas where volatile-rich debris flows were emplaced rapidly.

Candidate mud volcanoes have been identified elsewhere on Mars, associated with large debris flows [10]. The features in Isidis Planitia and other similar locations do not show all of the surface textures expected from mud volcanoes; they are notably lacking obvious mud flows, although such finer features may have been eroded. They do exhibit summit craters or depressions, as is characteristic of mud volcanoes.

Despite the lack of magmatic features or a source for widespread ignimbrites, the cones resemble in scale and proportion those found in volcanic terrains on Earth where explosive escape of superheated steam at many tens of bars pressure is responsible for building the cones.

CO₂ cryovolcanism: An alternative to water as the fluidizing agent is CO₂, which may work without water or in combination with it to achieve fluidization. Liquid CO₂ at Mars' ambient temperatures has an intrinsic vapour pressure of a few bars to tens of bars, without a need for heating. It requires for its existence an impermeable seal, which might be provided by salt or ice cementation, or impermeable clay or very fine-grained layers. Whilst so trapped and pressurized,

liquid CO₂ is stable planetwide. If the sediment or crustal mass shifts and fissures open to the surface, the CO₂ will jet out and explosively erupt at the surface - a form of cryovolcanism, a term originally defined by Steve Croft for eruptions of aqueous or nonaqueous fluids on icy satellites [11]. In this instance we do not require subsurface fluids to be heated, but only to exist in thermal equilibrium with its rock surroundings under the pressurisation due to lithostatic load of the upper crust. When the liquifer is exposed by deep fractures, energetic jets of CO₂ and regolith particles are expelled and mounds of considerable dimension are constructed.

The future: The Beagle-2 Lander has been targeted for Isidis Planitia. It is unlikely to land in the near vicinity of a cone or chain, but one may well be visible near the horizon on surface images. Debris from the cones will certainly have been mixed across the plain by the initial explosive eruptions or extrusions and by subsequent aeolian transport. The chemistry of Isidis Basin soils and rocks will have clues to the origin of its materials, and the input of fluids from the pseudocones.

The CO₂ model presented here - if it operates in endmember form without the additional involvement of water - suggests that H₂O-related minerals and volcanic debris will be absent in the surface samples. Instead, the material will be similar sedimentary debris to the Pathfinder and Viking lander sites, with similar surface chemistry. However, CO₂-driven eruptions of water-fluidized mud may present a similar phenomenon - in which case, hydrous minerals then would be expected.

Further differences between water-driven and CO₂-driven mud volcanoes are likely. For instance, the sedimentologic fabric and depositional nature of CO₂-driven deposits ought to resemble non-welded pyroclastic ash flows and falls, whereas distinct mud flows, with clear channel forms and imbricate clasts, ought to issue from water-driven mud volcanoes.

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