Martian tuyas: a link to a frozen past on the red planet?

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Abstract. The Martian surface displays several table mountains in the northern hemisphere that are interpreted to be volcanic in origin. Martian tuyas have been identified in Chryse Planitia, Acidalia Planitia, Elysium Region, and Amazonis Planitia, and subice volcanic features have been interpreted in the Valles Marineris chasmata. The structure of terrestrial tuyas consists of pillow lavas at the base, a medial hyaloclastite deposit, capped by subaerial flows, with domes and calderas present on the cap rock. Martian tuyas exhibit features similar to terrestrial tuyas including flat tops, steep sides, calderas, domes, cap rock layer, and glacial-like valleys, but defining characteristics, such as pillow lavas, are too small to image.

1. Introduction

Tuyas are very distinct structures formed from subice volcanic eruptions. Allen (1979) has identified 8 features suspected to be tuyas in the northern plains on Mars and Chapman and Tanaka (2001) have interpreted subice volcanic features in the Valles Marineris chasmata. The interpretation of tuyas on Mars holds great implications for locations of volcanic activity on the red planet and past climate conditions. A positive identification of tuyas on Mars would indicate that thick masses of frozen water were once present on the surface. Today, the north and south poles on Mars are capped with water-ice and carbon dioxide-ice and a permafrost layer, 1-6 km thick, is suspected to exist at the planet's surface (Rossbacher and Judson, 1981; Clifford, 1993).

2. Terrestrial Subglacial Volcanism

2.1. Formation of Terrestrial Tuyas

Three main units comprise tuyas on Earth: 1) pillow lavas, 2) hyaloclastite deposits, and 3) subaerial flows. This section details each of the phases individually.

2.1.1. Pillow lavas. Effusion of basaltic lava from the vent will melt the overlying ice both overhead and laterally into liquid water and begin the formation of a subice cavity (Figure 1-A) (Allen, 1979). The melt water quenches the lava into pillows (Allen, 1979). Density decrease from melting of ice in the cavity forms a small air pocket at the top, decreasing the heat transfer efficiency at the top, allowing for the walls of the cavity to melt faster (Hoskuldsson and Sparks, 1997).

2.1.2. Hyaloclastite deposit. Pressure decrease from melting of the overlying glacier allows for gases in the lava to exsolve (Chapman and Tanaka, 2001). As lava continues to quench and volatiles exsolve, explosive eruptions occur, fragmenting the solidified lava. Debris deposits of the fragmented glass, palagonatized tuff, and pillow breccia covers the pillow lavas (e.g. Allen, 1979; Smellie, 2000) (Figure 1-A).

2.1.3. Subaerial flows. The lava eventually melts through the overlying ice and erupts above the water level of the glacial lake (Chapman et al., 2000) (Figure 1-B). The subaerial flows form a flat capping layer over the hyaloclastite deposits. Subsequent eruptions may form flows, cones, and craters on the cap layer (Allen, 1979).

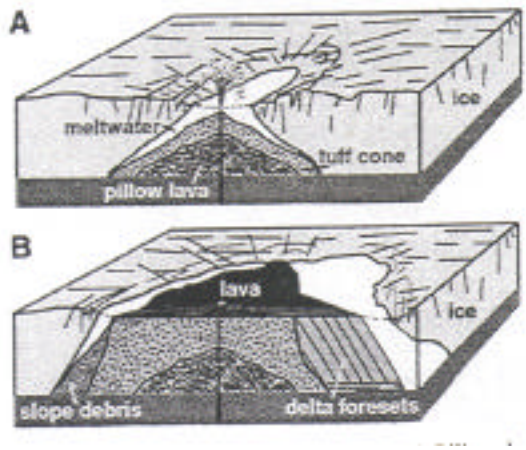

Figure 1. Schematic view of the formation of a tuya. A) Development of pillow lavas and tuff cone. B) Subaerial flows form cap rock on hyaloclastite deposit. From Chapman and Tanaka (2001).

2.2. General Morphology of Terrestrial Tuyas

Table mountain is a geomorphic term describing flat topped mountain, without implying origin. A tuya is a table mountain of volcanic origin. The morphology of the tuyas consists of steep flanks ~ 34º and a relatively planar top (Allen, 1979). The flanks may show modification by erosion, glaciers, gravitational slope failure, or jökulhlaups (e.g. Chapman et al., 2000; Chapman and Tanaka, 2001). Icelandic table mountains are 200 – 1000 m high and <10 km wide (Thorarinsson, 1967). Examples of terrestrial tuyas include Herdubreid and Hrútfell, 1,682 m and 1,390 m tall respectively (Figure 2) (Gudmundson, 1996).

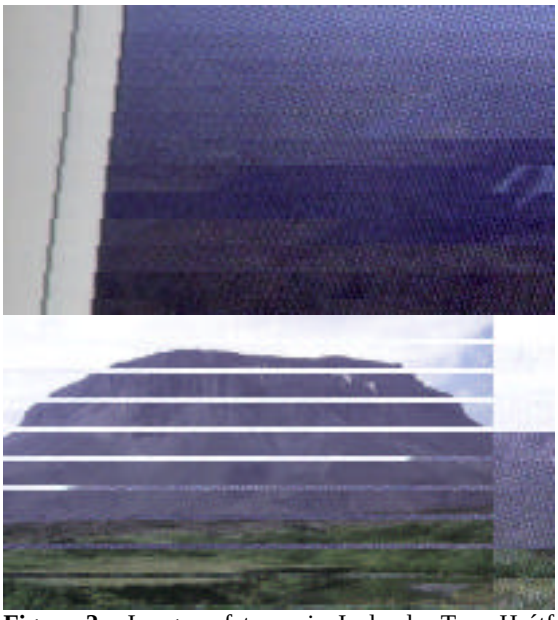

Figure 2. Images of tuyas in Iceland. Top: Hrútfell (height: 1390 m). Bottom: Herdubreid (height: 1682 m). From Gudmundsson (1996).

3. Martian Subice Volcanic Landforms?

3.1. Martian table mountains – tuyas?

Allen (1979) has identified several landforms on Mars that resemble volcanic table mountains but has only listed 8 of them. The landforms are located in the northern hemisphere both near and far from major volcanic regions (Figure 3). The landforms range in relief from 100 – 1000 m and length:width dimensions from 1 x 0.8 km – 16 x 16 km (Allen, 1979). Please note that Allen (1979) did not consider landforms < 1 km and > 20 km in his study to keep within size constraints of terrestrial tuyas and the interpreted table mountains (tuyas) showed possible eruption features (e.g. cones, capping flows, and craters) to distinguish them from other mesas.

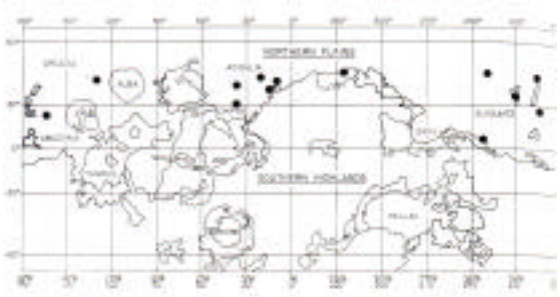

Figure 3. Location of possible tuyas and moberg ridges in the Northern Plains, Mars. From Allen, 1979.

3.1.1 Viking Frame 26A28. A tuya in Acidalia Planitia (Figure 4), identified by Allen (1979), of the more striking analogs for Martian tuyas. A steep sided, flat cap rock, overlies a lower plateau that forms a terrace of approximately equal width around the cap rock. The lower plateau measures 7x5 km and the estimated height of the feature is 470 m (Allen, 1979). Several pitted features are adjacent to the scarp of the lower plateau. Topographic analysis of these features would reveal if they are cones or craters. If the landforms reveal a cone or dome morphology similar to terrestrial analogs, then the possibility of volcanic activity in the area and the interpretation that the table mountain is of volcanic origin would be strengthened.

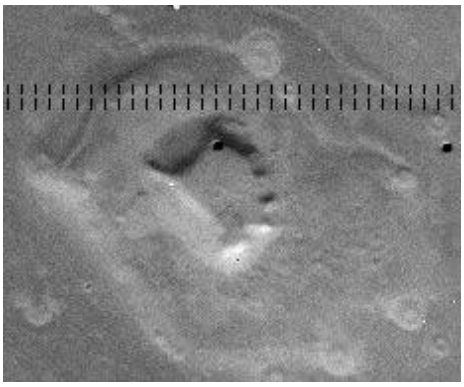

Figure 4. Viking Frame 26A28. Martian tuya identified by Allen, 1979. The landform is located at 45° N 22° in the Acidalia Planitia. The main plateau is 7 x 5 km and is 470 m high.

Two other tuyas listed by Allen (1979) in the Acidalia Planitia and Chryse Planitia exhibit a flat cap rock overlying a lower plateau that forms a equal width terrace around cap layer and (Figure 5). The geomorphic trend of a flat cap rock overlying a lower, terrace-like plateau is also observed in other landforms adjacent to the interpreted Martain tuyas. This author feels the frequency, dimensions, and parallel shape to the cap rocks of the geomorphic feature is significant enough to warrant further study into the origin of this feature.

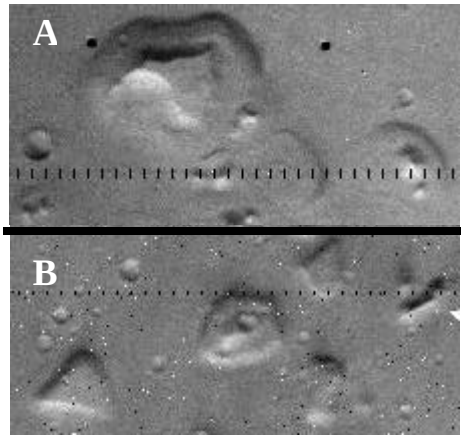

Figure 5. Two Martian tuyas, that exhibit the lower, terrace plateau. A) Tuya is 4 x 4 km, 300 m high. B) 1 x 0.8 km and it is 100 m high.

3.1.2 Viking Frame 545A14. The tuya in the Elysium Region (Figure 6) does not exhibit a lower terrace plateau like the tuyas in Chryse and Acidalia Planitia. This tuya is 12 x 7 km and 970 m high (Allen, 1979). A high resolution Mars Orbiter Camera image (Figure 7) shows features strikingly similar to Hrútfell (Figure 2), including steep flanks, glacial-like valleys, and sharp edged corners. A distinguishable unit exhibiting a branching, flow-like pattern on the illuminated flank adjacent to the craterform edge is interpreted by this author to be lava flows (Figure 6). The Martian tuya is proximal to the Elysium volcanic region, increasing the likelihood that a volcanic eruption in that area could occur if the area was once under ice.

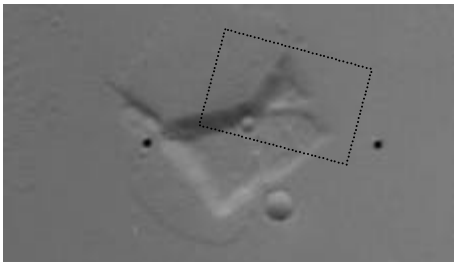

Figure 6. Viking Frame 545A14. A tuya located at 26° N 193° in the Elysium Planitia. The structure is 12 x 7 km and is 970 m high. Area imaged in Figure 7 is outlined.

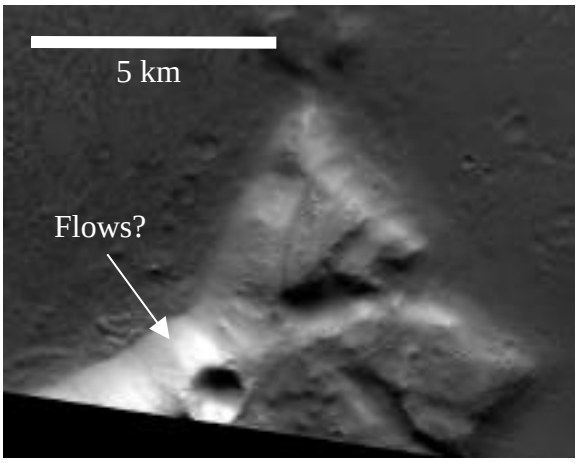

Figure 7. Orbiter Camera image SP240504. This is a close up of part of the tuya in Viking Frame 545A14 in the Elysium Planitia.

3.2. Tuya be or not tuya be, that is the question. Further analysis of the Martian tuyas could produce substantial evidence arguing against a volcanic origin for the table mountains. In this event, the data would show that local volcanism has not occurred in the areas, but does not rule out the past occurrence of glaciers or ice sheets in the area. Subice volcanic structures may be: 1) eroded away, 2) non-existent, 3) modified beyond recognition, or 4) exhibit a morphology not observed on Earth.

4. Glaciation on Mars

Several authors (e.g. Baker et al., 1991; Kargel and Strom, 1992; and Kargel et al., 1995) have cited geomorphic evidence for past glaciation on Mars, aside from tuya features. A unique, surface texture, termed thumbprint terrain, has been the leading evidence for a glacial landscape on Mars. The terrain occurs in several regional locations on Mars, and notably for this paper, including Acidalia and Chryse Planitia. Thumbprint terrain is named so because the landscape of large, parallel, en echelon ridges resembles large fingerprints (Kargel et al., 1995). Several hypotheses for the formation of these ridges involving ice have been proposed. The ridges have been interpreted to be glacial moraines (e.g. Scott and Underwood, 1991), while other structures resemble eskers, kames, and melt water channels (Kargel et al. 1995). Baker et al. (1991) propose a large ocean was temporarily present in the northern hemisphere on Mars, versus glaciers. Kargel and Strom (1992) suggest the presence of thumbprint terrain in the Northern Plains indicates the coexistence of both sea and ice sheets on Mars in the northern hemisphere, versus only an ocean or glaciers.

Interpretation of tuyas on Mars holds great implications for climate history. The tuyas serve as markers for the location of local ice sheets. The heights of the tuyas serve as minimum estimates for the local thickness of the glaciers (Allen, 1979). Relative ages from crater counts of the regional area of the tuya locations can constrain the minimum age of when the glaciers receded.

5. Summary

Interpretation of the origin of landforms plays an important role in determining the volcanic and climatic history of Mars. Several table mountains, interpreted to be tuyas, are located in the Northern Plains of Mars. A positive indication that these are subice volcanic features would indicate local volcanism away from large volcanic regions as well as the past presence of local ice sheets. The structures need to be researched in more detail with Mars Global Surveyor data confirm the possibility that these are subice volcanic landforms.

References

Allen, C. C., Volcano-ice interactions on Mars: *J. Geophys. Res.*, 84, 8048-8059, 1979.

Baker, V. R., R. G. Strom, V. C. Gulick, J. S. Kargel, G. Komatsu, and V. S. Kale, Ancient oceans, ice sheets and the hydrological cycle on Mars: Nature, 352, 589-594, 1991.

Chapman, M. G., C. C. Allen, M. T. Gudmundsson, V. C. Gulick, S. P. Jakobsson, B. K. Lucchitta, I. P. Skilling, and R. B. Waitt, Volcanism and ice interactions on Earth and Mars: *in* Gregg, T. K. P., and J. Zimbelman, eds., *Environmental Effects on Volcanic Eruptions: From Deep Oceans to Deep Space*, 39-74, Kluwar Academic/Plenum Pulishers, New York, 2000.

Chapman, M. G., and K. L. Tanaka, Interior trough deposits on Mars: Subice volcanoes?: *J. Geophys. Res*., 106, 10087-10100, 2001.
Clifford, S. M., A model for the hydrologic and climatic behavior on Mars. *J. Geophys. Res*., 98, 10973-11016, 1993.
Gudmundsson, A. T., Volcanoes in Iceland: 10,000 years of volcanic history: Vaka-Helgafell, Reykjavik, 136, 1996.
Hoskuldsson, A., and R. S. J. Sparks, Thermodynamics and fluid dynamics of effusive subglacial eruptions: *Bull. Volc*., 59, 219-230, 1997.
Kargel, J. S., V. R. Baker, J. E. Beget, J. F. Lockwood, T. L. Pewe, J. S. Shaw, and R. G. Strom, Evidence of ancient continental galciation in the Martian northern plains: *J. Geophys. Res*., 100, 5351-5368, 195.
Kargel, J. S., and R. G. Strom, Ancient glaciation on Mars: *Geology*, 20, 3-7, 1992.
Rossbacher, L. A., and S. Judson, Ground ice on Mars: Inventory, distribution and resulting landforms, *Icarus*, 45, 25-38, 1981.
Scott, D. H., and J. R. Underwood, Jr., Mottled terrain: A continuing Martian enigma, *Proc. Lunar Planet. Sci. Conf. 21st*, 627-634, 1991.
Smellie, J. L., Subglacial eruptions: *in* Sigurdsson, H., Houghton, B. F., McNutt, S. R., Rymer, H., and Stix, J. eds., 2000, *Encyclopedia of Volcanoes*, San Diego, CA, Academic Press, 403-418, 2000.
Thorarinsson, S., Some problems of volcanism in Iceland: *Geol. Rundsch*., 57, 1-20, 1967.

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