PINGOS, GERVIGIGARS AND MARTIAN MYSTERIES. Charles A. Wood, SN-6, NASA Johnson Space Center, Houston, TX 77058.

Viking photography has revealed numerous small crater-topped cones that have been interpreted as products of volcanic eruptions,[1,2] or alternatively, phreatic eruptions.[3] In a previous paper[1] I summarized available information on terrestrial monogenetic volcanoes that might be analogs to these small martian cones. The present note provides similar data for two other types of terrestrial cratered cones (which may also be analogs to the martian cones) for which the availability of water is a critical factor in their formation: (1) Pingos are ice-cored mounds common in terrestrial permafrost regions.[4] (2) Gervigigars (called pseudocraters in the English literature) are low energy phreatic explosion craters known only from Iceland.[5] There is a substantial literature on pingos, but no systematic quantitative data on their morphology, as is required for detailed comparison with martian cones. Thorarinsson's classic paper[5] is the major work on gervigigar; this note is based on that paper and my limited field investigations in Iceland in July, 1980.

Pingos (Ref. 4, 6, 7, 8, 9). According to McKay[6] pingos originate from "the arching of an impervious sheet of permanently frozen ground forced up by the intrusion of water under pressure." Open-system pingos are formed by the freezing of water that flows downslope within or below a permafrost layer, whereas closed-system pingos use water derived from a freezing front that advances into an unfrozen area completely surrounded by impervious material. The mounds created by the closed-system process occur on flat ground, tend to be relatively large and circular in plan, whereas open-system pingos commonly are found along valley slopes, are relatively small, and often cluster or form elongated masses. Closed-system pingos in Canada occur only in continuous permmafrost >60 m thick. Open-system pingos generally occur in discontinuous permafrost thin enough to be uplifted by the expansion of the freezing water. Rupturing of the overburden is a frequent consequence of ice expansion; sometimes tension cracks form irregular summit depressions but often a relatively uniform crater results. Some craters appear to be very much wider than others, perhaps due to thawing of the pingo's ice core and subsequent collapse of the summit. Craters are not a diagnostic feature of pingos, however, for a survey of 1380 pingos east of the Mackeenzie delta of Canada revealed that only 24% had cratered or collapsed summits.[10]

Dimensions of individual pingos are scattered throughout the literature; data collected for 37 pingos (Table 1) suggest an average basal diameter of nearly 100 m, and an average height of about 10 m. The spacing between pingos is quite variable, ranging from rare cases of isolated pingos to great concentrations. Normally open-system pingos have a higher spatial density than closed-system examples, but one of the highest known densities (15/km^2) is within the zone of continuous permafrost and thus are thought to be closed-system features.[11]

The heights of pingos are reflections of the thickness of their overburden, which typically equals 20% to 50% of the pingo height.[7] Presumably pingo basal diameter is also related to overburden (and ultimately uplift pressure of the pore ice); if so the H_{co}/W_{co} relations given in Table 1 imply that the depth to the ice layer equals 0.02 to 0.06 times the pingo diameter.

Gervigigar (Ref. 5) In Iceland an apparently unique style of water/magma interaction produces small cones and mounds commonly called pseudocraters. This name is inappropriate because the craters are real (they lack direct connection to magma sources at depth), and additionally, many pseudocraters lack craters! For these reasons the Icelandic term gervigigar, as used on Icelandic geologic maps, is preferred. Hundreds of gervigigar occur where a 2500 yr old lava flow crosses Lake Myvatn in northern Iceland. The close association of gervigigar with the young lava and the lake (and between lava flows and river valleys or sandur plains in other parts of Iceland) indicated to Thorarinsson[5] that the cones formed by explosions of steam trapped beneath the lava. Simple thermodynamic calculations by Allen[12] illustrate that more than enough energy to form the craters is available from generation of steam, however, the water (or ice) must be very close to the surface (within 1/2 the thickness of the lava flow). Allen did not investigate the relation between flow thickness and cone size, but Thorarinsson[5] noted that the largest gervigigar at Myvatn are near the center of the lake where the lava flow is thought to be the thickest. At the northern limit of the Landsbrotsholar field of gervigigar, on the southern coast of Iceland, slabs of lava have been rotated into vertical positions, but (perhaps because the flow was too thin to allow buildup of substantial steam pressure) there are no gervigigar mounds.

Gervigigar at Myvatn have large craters, but at Landsbrotsholar and Thjorsardalur (a gervigigar field stretching about 5 km along the banks of the Fossa River) they are flat-topped. Because gervigigar are quite small their dimensions cannot be readily measured on topographic maps, the data in Table 1 are based on measures of the Myvatn cones - the largest in Iceland. Gervigigar are usually highly concentrated and often overlap.

Cones on Mars (Ref. 1, 3). Dense concentrations of small cones, frequently crater-topped, have been found in various regions of Mars. These features have been interpreted both as cinder cones[1,13] and as gervigigar.[3,12,14,15] Quantitative data are presently available for only 20 cones in the Cydonia Mensae region of Mars (listed in Table 1 along with terrestrial cone comparison data), although Frey (pers. comm.) is now compiling a much larger data set. In terms of the information in Table 1, terrestrial cinder cones appear to have the greatest similarity to the Cydonia cones. The martian cones, however, were formed in a gravitational field only 40% as stong as the Earth's, thus ballistic cone-forming processes (gervigigar and cinder cones) would yield cones about 2-1/2 times wider than equal energy terrestrial eruptions. Similarly, pingos would also probably be larger because martian overburden could be 2-1/2 times thicker (for the same weight) than on Earth. In order to maintain the terrestrial W_{cr}/W_{co} ratio, however, martian gervigigar and cinder cones must have had (a) larger volumes or (b) smaller ejection velocities. Based on crude height data, I

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previously estimated that the volume of the median size Cydonia cones is roughly 25% of the volume of median diameter terrestrial cinder cones. Thus the only way to account for the equality of terrestrial and martian W_{cr}/W_{co} values, interpreting the Cydonia cones as cinder cones, is to postulate low energy eruptions on Mars. If, on the other hand, the Cydonia features are martian gervigigar, their estimated volumes are roughly 500 times greater than typical for Icelandic gervigigar. This abstract was accepted for publication in the abstract volume of the 3rd Coll. on Planetary Water, Oct. 1980, but was inadvertently omitted. I thank Herb Frey for critical discussions.

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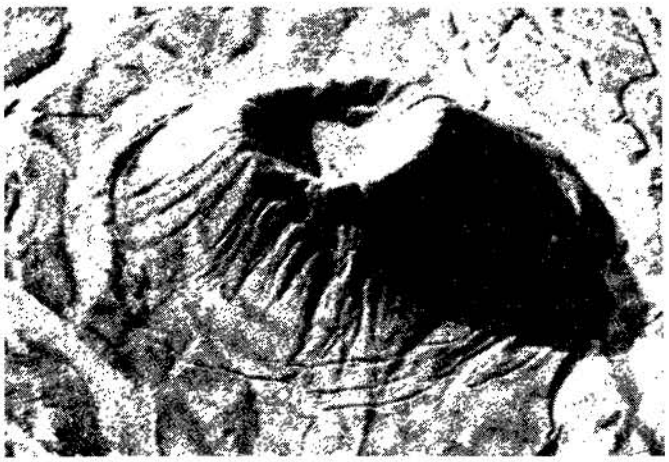

TABLE 1: AVERAGE DIMENSIONS OF SMALL CONES

Cone Type	W_{co}(m)	W_{cr}/W_{co}	H_{co}/W_{co}	SD[19]
Pingo [9 10 11 16]	30/90/600 (n=37)	0.40/0.60/0.80 (n=8)	0.02/0.12/0.33 (n=36)	0.06/34
Gervigigar [5 17 19]	3/80/500 (n=42)	0.32/0.40/0.52 (n=22)	0.06/0.10/0.20 (n=14)	50/200
Cinder Cone [1 18]	250/800/2000 (n=910)	0.40 (n= 83)	0.18 (n=83)	0.03/0.5
Cydonia[1 3] (Mars)[19]	400/800/1500 (n=20)	0.33/0.41/0.51 (n=20)	?	0.1/0.5

W_{co} = cone basal diameter; W_{cr} = crater diameter; H_{co} = cone height (range, mean and sample size-n- given for columns 2-4. SD = cone spatial density, representative values in cones/km^2.

Right: 30 m high pingo in central East Greenland, with shallow lake from ablation of interior ice; from Muller, 1959.

Below: Part of the Thjorsardalur gervigigar field in southern Iceland. The prominent cone on the left is 10-15 m high; the low cone in the right foreground has a very shallow saucer but craters are rare to absent.

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