MUDDY CO_2-DRIVEN BRINE FOUNTAINS AT MANGALA VALLES, MARS.

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Introduction: Mangala Valles is one of many sites on Mars probably formed by massive catastrophic release of water onto the surface [1-3]. The water was released after a dike intruded into the area from the near-by Tharsis region, causing formation of a graben, Mangala Fossa [4]. Water was forced to the surface up the graben boundary faults by topographic pressure gradients and buoyancy.

Proximal to the eastern arm of the Mangala Fossa graben two types of deposit are present. (Figure 1). The dune-like features that are found at the far eastern end of the graben (C) are proposed to be of phreatomagmatic origin [5]. We suggest that the other type of deposit, seen along the strike of the eastern arm (A and B), are mud deposits, ejected by CO_2-driven water fountains. The mechanism is similar to that seen in the Lake Nyos and Monoun (both in Cameroon) degassing events [6].

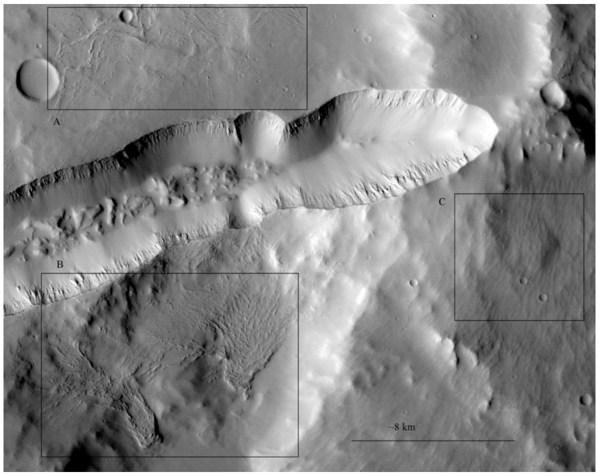

Figure 1: The two types of deposit seen around Mangala Valles. We suggest that A and B are mud deposits. The dune-like structures in C are proposed to be of phreatomagmatic origin [5].

Mechanisms: We propose that the cooling magma in the margins of the intruding dike released CO_2 into the surrounding subsurface aquifer, the gas dissolving into the salty aquifer water. When the surface was eventually broken by the dike-induced stresses, water travelled up the edge of the dike and then up the graben boundary fault. Sediment became entrained into the rising water. The pressure reduction as water approached the surface allowed CO_2 to exsolve from the water, forming a fountain at the surface [7], ejecting the water/sediment/salt mix up to 8 km from the rim of the graben [8]. The liquid water evaporated during flight (alternatively water evaporated and/or ice sublimed after landing on the surface), resulting in the mud-like deposits, which are likely to consist of a mixture of silicate solids and salts.

For the proposed CO_2-driven water fountain to be a valid explanation for the deposits, the water mass flux that can be supplied by such a mechanism needs to be equal to or greater than the mass flux that would be required to bring the sediment to the surface.

Methodology: The water mass flux f_f provided to the fountain per meter along strike of the fracture is

$$f_f = \rho_{water} U_{Fr} W_{Fr} \qquad (1)$$

where U_{Fr} is the velocity of water rising though the fracture, W_{Fr} is the width of the fracture, and ρ_{water} is the density of water, ~1000 kg m^{-3}.

The flux per metre of fracture required to carry the sediment to the surface can be related to the amount of sediment per unit volume of water, the duration of the fountain, and the volume of sediment now visible on the surface per metre along strike of the fracture. This can be expressed as

$$f_m = (\rho_m V_m) / (n t_f) \qquad (2)$$

where f_m is the water mass flux per metre of fracture required to emplace the muddy deposits, V_m is the volume of the deposits per unit metre of fracture, n is the total mass fraction of sediment and salt that can be suspended in water, t_f is the duration of the fountain, and ρ_m is the density of the "muddy" deposits.

Equation (1) does not take into account that some of the fountain material will fall back into the graben. Eq. (1) can be adapted to represent the *supplied* flux, f_s i.e. the rate of water delivered by the fountain to the surface, rather than the *total* flux, f_f, of water into the fountain. We assume that no more than ~50% of the fountain materials will land back inside the confines of the graben, depending on the angle of the fountain. For simplicity we take this percentage to be exactly 50. It follows that

$$f_s = (\rho_{water} U_{Fr} W_{Fr}) / 2 \qquad (3)$$

Thus in order for the CO_2-driven fountain to indeed be a potential source for the deposits, we require

$$[(\rho_{water} U_{Fr} W_{Fr}) / 2] > [(\rho_m V_m) / (n t_f)] \qquad (4)$$

Calculations: Leask et al. [9] estimated U_{Fr} to be ~20 m s^{-1} and W_{Fr} to be 2.3 m. On average the deposits seen around the Mangala Fossa graben extend for ~4 km from the graben edge, and a combination of shadow measurements and photoclinometry suggests that they are ~3 m thick [8]. Thus the average volume of deposit per metre along strike of fracture is V_m = ~3 m × 4 km, or ~12,000 m^3 m^{-1}. If the deposit is a porous assemblage of silicate particles alone the density may be ρ_m = ~2500 kg m^{-3}; if a significant amount of salt is present this may fill inter-grain spaces, thus increasing the density somewhat.

There is a wide range of possibilities for the total mass fraction n of material (salt plus silicates) carried by the water. Water can readily dissolve 20-30% by mass of salts that might be present on Mars (e.g. NaCl, $MgSO_4$) [10]. Water flowing on the surface may be able to transport up to 40% by volume solids and bed load and suspended load [11-13]. However, water percolating through aquifers and then stripping fines from the walls of fractures is likely to carry much less, perhaps a maximum of 10% by mass. This suggests that n may plausibly be ~0.2.

Leask et al. [9] suggested that the Mangala Fossa graben was formed in two events. We assume that the fountain occurred only during the first of these. During this event, the graben subsided ~200 m in ~2.5 hours, i.e. t_f = ~9000 seconds [9].

We now summarize the various numerical values specified above: ρ_{water} = 1000 kg m^{-3}, U_{Fr} = 20 m s^{-1}, W_{Fr} = 2.3 m, ρ_m = 2500 kg m^{-3}, V_m = 12,000 m^2, n = 0.2, t_f = 9000 s. Thus the value of the left hand side of eq. (4) is 23,000 kg m^{-1} s^{-1} and the value of the right hand side is 16,667 kg m^{-1} s^{-1}. The inequality in eq. (4) is therefore satisfied, showing that it is indeed possible to produce the observed deposits in the manner proposed.

Furthermore, by equating the two sides of eq. (4) we can find a minimum value for n_{min}, the minimum mass fraction of transported materials that will allow us to form the deposits via a CO_2-driven fountain:

$$n_{min} = [(2\ \rho_m\ V_m) / (\rho_{water}\ U_{Fr}\ W_{Fr}\ t_f)] \qquad (5)$$

Inserting the numerical values we find n_{min} = 0.145; thus at least about 15% by mass solids in the water is needed.

Conclusions: The water flux in the postulated CO_2-driven fountains is sufficient to have formed the deposits provided that the water carried ~15% by mass solids and/or salt. This finding suggests that the process can be readily explored under laboratory conditions, and we plan to do this.

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