MODELLING OF GYPSUM AND ICE DIAPIRS IN THE MARTIAN CRUST.

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Introduction: Density inversions within sedimentary sequences provide an opportunity for underlying sediments to deform those above them and can have a significant effect on the evolution of geological structures within a planetary crust.

Rayleigh-Taylor instabilities at the interface between a low density layer and the denser rocks above may lead to the formation of diapiric upwellings. This is typically seen in sequences which contain evaporites, and these have been studied extensively on the Earth, due mainly to their association with economic concerns such as oil and gas [1].

It is likely that evaporites are present wherever water is a major component of the environment. The overwhelming evidence for liquid water at some point in martian history makes it likely that evaporites will be present in the sedimentary record of the martian subsurface [2], and these will be buoyant with respect to overlying cap rocks. Moreover, ice is likely to be a major component of the near-surface regolith, particularly at high latitudes, and this will also be buoyant with respect to overlying rocks and sediments. Both ice and mineral hydrates (epsomite, $MgSO_4.7H_2O$, meridianiite, $MgSO_4.11H_2O$, mirabilite, $Na_2SO_4.10H_2O$, and gypsum, $Ca_2SO_4.2H_2O$) are believed to be present on the basis of in situ observations by landers and rovers, and from remote neutron and gamma-ray spectroscopy [3].

In this study we have investigated how a buoyant layer overlain by a denser layer behaves over time and considered the implications for the surface geology of Mars. We have used a similar method to that employed by Beyer *et al* [4] who modelled a salt diapir (NaCl) under martian conditions. However, we have chosen to model two different cases. The first is a layer of gypsum with a basaltic overburden; gypsum has a much lower solubility than some other relevant salt hydrates and so is more likely to precipitate out of solution to form evaporite layers [5]. The second case is a layer of ice (permafrost), also with a basaltic overburden.

Methodology: We have simulated the evolution of a diapiric body within the Martian crust in order to determine the likely spatial scale of features produced at the surface, and the time-scale for ascent of the diapir to the surface. Figure 1 shows the intial set up of the model; we assume that the diapir is spherical and rises at a uniform rate through a more viscous medium [6]. We also assume that the diapiric feature has a constant volume and that the system is isothermal. We relate a scale factor R, involving the ratio of the viscosities of the buoyant and denser layers and the thickness of the buoyant layer, to the speed of ascent.

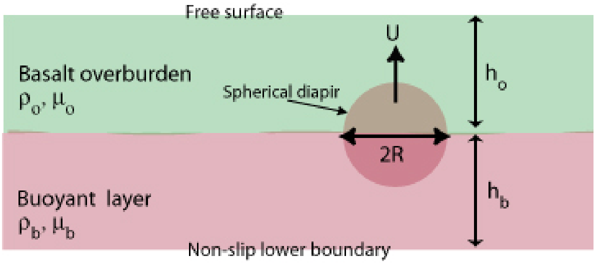

Figure 1. The initial model set up. U is the ascent speed of the diapir.

The viscosities used have been adjusted accordingly from terrestrial temperature to appropriate martian values. We have used values of $2x10^{16}$, $2x10^{19}$ and $2x10^{16}$ Pa sec. respectively for the viscosities of the ice [7], basalt [4] and gypsum [8]. The densities employed for each layer are, respectively, 917 kg m^{-3} for ice, 2700 kg m^{-3} for basalt, and 2317 kg m^{-3} for gypsum. Layer thicknesses are varied over the range 100 – 1000m for both the buoyant and overburden layers to explore the parameter space comparable to that found on Earth. Ice is stable in the martian subsurface to depths of around 4 km given a crustal geotherm of 12 K Km^{-1} [9] assuming an average surface temperature of 220 K.

Results: The scale factor of the diapirs produced by this method is related to the ratio of the viscosities and the thickness of the buoyant layer. This scale factor is representative of the size of any feature which may be produced above such a diapir. Thus we find that both a gypsum or ice buoyant layer will produce features with a similar spatial scale, typically ~ 10x the thickness of the buoyant layer regardless of the thickness of the overburden. Our model therefore yields features ranging from 1-10 km in radius. These length scales are similar to those of features in Candor Chasma, which are thought to be salt domes [4].

We are also interested in the time taken for a diapir to rise up through the overburden. Here we find that the differing density contrasts between our two scenarios, and the ratio of layer thicknesses within each scenario, are the driving forces controlling the speed of ascent. The results of the first scenario (gypsum overlain by basalt) are shown in figure 2; we find that for buoyant layer to overburden thickness ratios = 1, there are a range of ascent times from 40 – 400 Ma corresponding to thicknesses of 1000 – 100m. Whilst this may seem counterintuitive, a thicker layer has a larger scale factor (also corresponding to a larger reservoir of material from which to form the diapir). For a buoyant layer to overburden thickness ratio = 5 the time range is reduced to 7 – 14 Ma. This is significantly faster than the halite diapirs modeled by Beyer *et al* [4], where timescales of 40 – 70 Ma were reported for similar conditions.

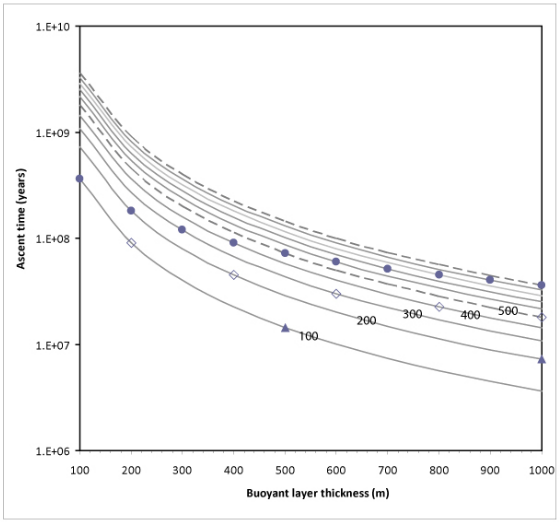

Figure 2. Ascent time as a function of buoyant layer thickness for gypsum. Each line represents a constant overburden thickness from 100–1000 m, with the 500 and 1000 m lines dashed. The points represent particular buoyant layer to overburden thickness ratios. Triangles are 5:1, diamonds 2:1 and filled circles 1:1.

In the second scenario (ice overlain by basalt) the calculated ascent times are much faster than for the gypsum – basalt case. For 1:1 layer thicknesses the diapir ascends in 8 – 80 Ma, a factor of 10x quicker than the gypsum diapir, a result of the larger density contrast between the ice and basalt. A layer thickness ratio of 5:1 yields rise times of 1.5 – 3 Ma, and a 2:1 ratio yields ascent times from 4 – 20 Ma.

Conclusions: Terrestrial salt domes have length scales of a few hundred meters to a few km and typically reach the surface in times of order 10^4-10^6 years [1]. Here we show that, under martian conditions, a gypsum or ice body of dimensions comparable to terrestrial evaporate diapirs will produce a feature with a spatial scale approximately 10x terrestrial. In the case of gypsum, the timescales involved may be similar if there is a large buoyant layer to overburden thickness ratio, but may be 1-2 orders of magnitude greater if there is not.

Mars is probably unique amongst the terrestrial planets as a place where appropriate climatic conditions occur (or have occurred in the past), to allow the development of ice diapirs. We calculate that ice diapirs can grow relatively quickly and so may have a shorter lifetime in the geological record than their salt-hydrate equivalents. How long the evidence of such features will persist in the geological record is uncertain, but it is possible that there are areas of Mars where suitable amounts of subsurface ice have existed recently enough for features to survive to the present day.

Using this model it becomes apparent that the size of the feature produced is highly dependent on the viscosity contrast between the buoyant layer and the overburden. There are a wide range of viscosities available for the materials used here. In the absence of tighter constraints on the material viscosities required to fully investigate the relation between the composition of the buoyant layer and the size of the surface feature, a range of viscosities for each material will be used to add another dimension to the parameter space investigated.

We have assumed the diapir is initiated solely by compositional rather then thermal buoyancy. Future work will address thermal buoyancy, as well as accommodating possible phase changes (including change of hydration state) in candidate materials under the appropriate martian conditions and also polymineralic diapirs, incorporating, for example, Mg- and Na-sulfate hydrates, which have densities intermediate between ice and gypsum (1400-1700 kg m^{-3}). We also intend to employ a more sophisticated linear analysis methodology, which will allow a more complete treatment of the dynamics governing the interactions of the buoyant and overburden layers.

This modeling can also be extended to the icy satellites where evaporite minerals are also likely to be present. In the case of most icy satellites, the evaporite layers are likely to form the denser overburden layers overlying less dense ice layers, although on Titan's surface it is possible that low-density organic evaporites will exist where methane-ethane lakes have dried up, these being dominated by solid acetylene and ethylene. In the outer solar system it will be important to include the phase relations of systems modelled due to the temperature ranges encountered on these satellites.

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