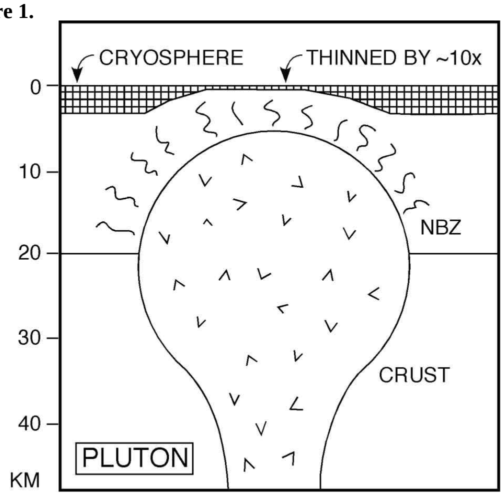
MARS: GEOLOGIC SETTING OF MAGMA/H_2O INTERACTIONS: J. W. Head[1] and L. Wilson[1,2], [1]Dept. Geol. Sci, Brown Univ., Providence, RI 02912 USA, [2]Environmental Sci. Dept., Lancaster University, Lancaster LA1 4YQ, UK, james_head@brown.edu.

Introduction and Background: The interaction of rising magma with surface ice, ground ice and ground water is known to be an important class of processes on Mars [1-8]. In order to continue to quantify these relationships and understand their influence on the Martian geologic record, we outline here several plausible examples of these processes and provide quantitative assessments of their effects [see also 2,4,7]. In a separate contribution we outlined the general environments in which these types of interactions occur on Mars [5].

Plutons: These represent large magma bodies rising diapirically into the crust and lithosphere (Figure 1) and involve the advective transfer of heat to the intrusion zone and the conduction of heat into adjacent regions. In this example, a 30 km diameter pluton intruded to a typical neutral buoyancy zone (NBZ) depth of about 20 km [2] would have its top at ~6 km depth, below the base of the cryosphere. Effects: The advective heat transfer will initially increase heat flow through conduction to the surroundings, which will decrease cryosphere thickness by a factor of ~10. Unless resupplied, the pluton will cool significantly in only a few tens of millions of years. Post-emplacement evolution of the pluton (e.g., differentiation) may result in emergence of evolved melts above the NBZ. Cryosphere thickness is critical and this particular example will differ depending on variations in cryosphere thickness in space and time. Such an intrusion could melt the base of thick ice-rich deposits, such as those at the poles of Mars, but a significantly shallower or larger pluton is required to completely melt the cryosphere under current conditions. Shallower and larger plutons might characterize the major volcanic edifices seen on Mars, such as those at Tharsis and Elysium. Plutons are excellent candidates for the production of hydrothermal systems [4]. Heating of the groundwater and melting of the base of the cryosphere could significantly alter local and regional equipotential surfaces and hydrostatic relationships. In their simplest form (Figure 1), plutons are most important for regional effects on heat flow.

Figure 1.



Dikes: In contrast to the rather equidimensional nature of plutons, dikes represent the vertical and lateral emplacement of magma-filled cracks, often all the way to the surface to produce eruptions. Dikes thus provide much more efficient heat transfer to the cryosphere. In addition, dike intrusion to shallow depths can create a near-surface stress field, resulting in faulting of the overlying rocks, breaching of the cryosphere, and the opportunity for water under hydrostatic head to reach the surface through the cryosphere, potentially resulting in large-scale release of groundwater. A candidate for such a situation is Mangala Valles (Figure 2) [8]. In this case, graben extending radially from Tharsis are interpreted to be the surface manifestation of a dike propagated laterally from magma reservoirs at Tharsis [9,10]. The dikes penetrate into a region of Noachian upland cratered terrain on the northern slopes of the southern uplands, where groundwater is interpreted to be confined by a cryospheric seal. As the top of the dike intrudes into the cryosphere, local melting, combined with the near-surface stress field associated with dike emplacement, breaks the cryospheric seal, causing release of the groundwater under regional hydrostatic pressure, and formation of the outflow channels of Mangala Valles.

Figure 2a.

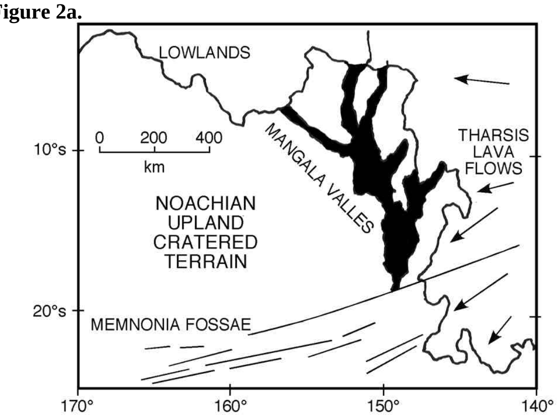
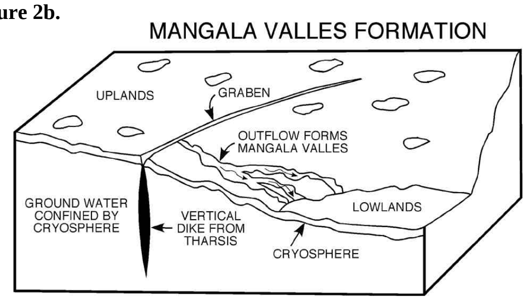


Figure 2b.



In addition, ground water and melted ground ice can be incorporated into the magma to produce explosive eruptions and widening of the vent system [2], such as the types of eruptions that are thought to be responsible for the many of the paterae on Mars [8,11]. In a variation on this theme, an environment may exist in which both effusive volcanic and lahar-like eruptions will occur. An example of such a situation where these two types of deposits exist is the Elysium region [12] (Figure 3a). Recent work using new altimetry data has shown that the lava flows are erupted from topographically higher vents, while lahar-like flows [13] are erupted from vents in a restricted range of lower elevations [14]. One interpretation of this relationship (Figure 3b) is that dikes emplaced laterally from reservoirs below Elysium propagate to the surface and penetrate the cryosphere to cause eruptions. At high elevations, effusive and explosive eruptions occur, while at low elevations, breaching of the cryospheric seal releases groundwater under hydrostatic head, which mixes with volcanic ash and other products to form lahars [14]. In summary, the consequences of dike emplacement is that they provide much more efficient heat transfer to the cryosphere than plutons. They can interact with hydrosphere and cryosphere, break artesian seals, and produce major water outflows, lahars, and explosive eruptions. Dikes will also cause direct melting of ice out to several dike widths solely by conduction; if convection occurs, the lateral influence can increase several fold. Dikes are extremely important for lateral transport of heat, fracturing of the cryosphere, water release, and local heat generation in the vicinity of the dike, which can also set up local hydrothermal circulation systems. But because the geometry of dikes is orthogonal to the cryosphere, the melting efficiency is focused at the top of the dike. Obviously, greater efficiency for cryospheric melting is found in sills, where the geometry of the heat source is more parallel to the cryosphere.

Figure 3a.

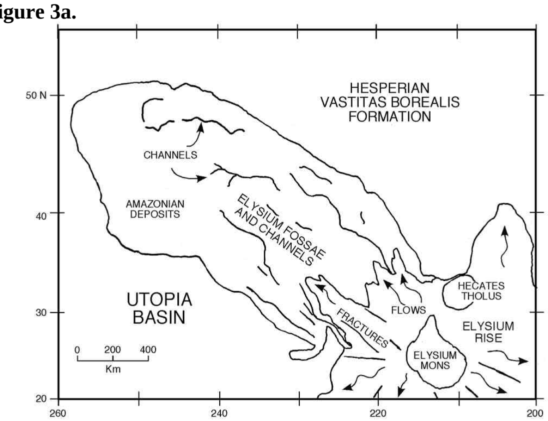
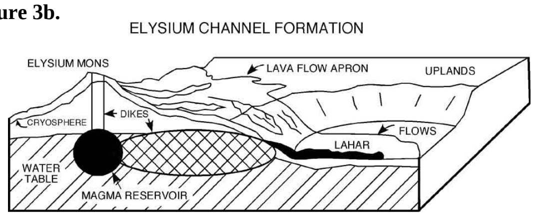


Figure 3b.



Sills: Sill geometry is best for delivery of heat to shallow crustal levels and thus sills are extremely efficient in melting near-surface ice and releasing groundwater [2,7,15]. In addition, the presence of a low-density cryosphere can enhance density contrasts in the shallow crust and favor the intrusion of sills. Sill intrusion provides plausible models for several outflow channels. For example, consider the intrusion of a sill about 150-200 km in diameter, 100 meters thick, and emplaced at the base of a hydrous cryosphere (Figure 4a). Heat is lost primarily from the top and upward, not downward. Heat from the sill surface (surface T is ~1000K) is initially conducted into the surrounding ground ice; when this melts, heat is convected across to the receding ice surface. After about eight years, the sill is chilled to the middle and 250 meters of ice is melted from the top. Loss of the rest of the heat from the sill would produce about a 500 meter vertical column of ice melted over 150-200 km diameter sill, for a total of ~104 km^3 of water. The consequences are that sill intrusion can plausibly produce surface uplift, significant melting, collapse, chaos formation, and outflow channel formation (Figure 4b). Sill intrusion provides plausible models for several outflow channels, and may explain why some outbursts appear to be one-time events. If some of the water drains out, the heat transfer capacity is seriously influenced, and heat may then be simply deposited into the surroundings or lost inefficiently.

Figure 4a.

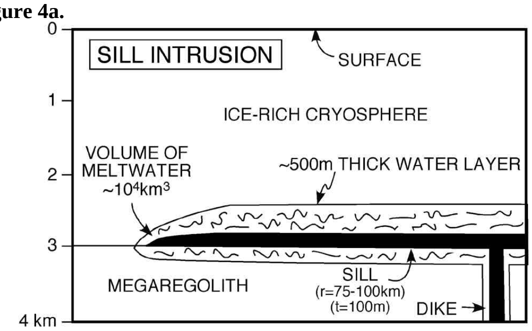
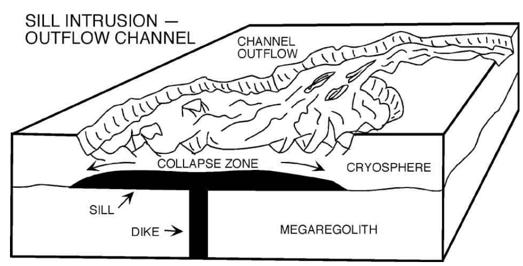


Figure 4b.



Summary and Conclusions: These examples indicate that the geometry of intrusion (pluton, dike, sill) is very important for the nature and magnitude of consequences of magma and H_2O interactions. Similarly, the presence, nature, and geometry of the cryosphere and groundwater are crucial factors, about which little exact information is known. What is clear from the geological record is that magma/H_2O interactions have been extremely important in the history of Mars. New insights into the geometry of interactions and their consequences, and basic physical models, can help to decipher this record. Clearly, Mars is an important laboratory for the study of magma/H_2O interactions.

References: 1) M. Chapman et al., *Environmental Effects on Volcanic Eruptions*, Kluwar, 39, 2000; 2) L. Wilson and J. Head, *RG*, 32, 221, 1994; 3) C. Allen, *JGR*, 80, 8048, 1979; 4) V. Gulick, *JGR*, 103, 19365, 1998; 5) J. Head and L. Wilson, *LPSC 32*, this volume, 2001; 6) P. Mouginis-Mark, *Icarus*, 64, 265, 1985; 7) S. Squyres et al., *Icarus*, 70, 385, 1987; 8) H. Masursky et al., *NASA TM 88383*, 459, 1986; 9) L. Wilson and J. Head, *LPSC 31*, #1371, 2000; 10) L. Wilson and J. Head, *LPSC 32*, #1153, 2001; 11) D. Crown and R. Greeley, *JGR*, 98, 3431, 1993; R. Greeley and D. Crown, *JGR*, 95, 7133, 1990; 12) K. Tanaka et al., *USGS Map I-2147*, 1992; 13) E. Christiansen, *Geology*, 17, 203, 1989; 14) P. Russell and J. Head, *LPSC 32*, #1040, 2001; 15) E.D. Scott. and L. Wilson. *JGR, 104*, 27,079, 1999.