NUMERICAL MODELING OF HYDROTHERMAL SYSTEMS ON MARTIAN VOLCANOES: PRELIMINARY RESULTS. V.C. Gulick[1], M.S. Marley[2], V.R. Baker[1], 1) Lunar and Planetary Lab, Univ. of Arizona, Tucson, AZ 85721; 2) NASA-Ames Research Center, MS 245-3, Moffett Field, CA 94035.

We are continuing our investigation of martian hydrothermal systems and the formation of small valleys on Mars. Fluvial valleys have formed on geologic features (*e.g.*, volcanoes, impact craters) and in regions (*e.g.*,intercrater plains) which would have developed vigorous hydrothermal systems [1]. Because the degree and nature of valley development in these regions appears to correlate with the lifetimes of the associated hydrothermal systems [2] and because numerous fluvial landforms on Mars (*e.g.*, outflow channels) imply a subsurface water source [3], martian fluvial valleys might also have formed from an endogenically derived hydrologic cycle [4]). Here we present preliminary results of our numerical modeling effort of hydrothermal systems associated with volcano formation.

To model such hydrothermal systems, we consider a cylindrical igneous intrusion of height 4 km intruded 2 km beneath the martian surface. The model extends to a distance, R, 20 times the radius of the intrusion, r_I. The intrusion is surrounded by a homogeneous, water- saturated medium having a permeability of 10 darcies and a porosity of 0.25. The intrusion is emplaced at time $t = 0$. Temperature and heat flow boundary conditions at the perimeter of the intrusion are derived from conductive cooling calculations [5]. Ground water is held at hydrostatic pressure along a permeable boundary at $r = R$. The surface is also permeable. Initial ground-water temperature is 0° C. The finite element, density-dependent ground-water flow simulation model SUTRA (**S**aturated-**U**nsaturated **Tra**nsport)[6] is then employed to model numerically the resulting ground-water flow and energy transport. SUTRA employs a simple linear expression for the temperature dependence of fluid density. Instead, we have modified the program to use the complete equation of state of water as implemented by Johnson [7]. When the 1100° C magma (typical temperature for basaltic magmas) is first intruded, the intrusion/country rock boundary temperature is 550° C [5]. This temperature remains above 275° C for 16,000 years for a 1 km radius intrusion. Cooling times for other sizes are proportional to the square of the intrusion radius. After the intrusion boundary cools below ~275° C, the vigor of the hydrothermal circulation begins to decline. Although circulation continues for several additional 10^4 to 10^5 years, this abstract considers only the early vigorous phase, when peak surface discharges are obtained.

The modeled intrusion heats the surrounding ground water which is then driven upwards by buoyancy forces. We assume that any impermeable upper boundary, such as a permafrost layer, is removed by the initial hydrothermal circulation. The upward moving water is then free to reach the surface. Since an infinite subsurface reservoir is assumed, water lost from the system is replenished by flow across the permeable boundary at $r = R$. The physical state of water reaching the surface depends on the atmospheric pressure. If the modern Mars conditions are assumed, then much of the water would reach the surface as steam. However, if more earth-like surface pressures are assumed, then liquid water outflow would dominate. Average temperature of the discharged water is ~100° C.

Hydrothermal circulation develops relatively early in the model and peak surface discharges are reached within several hundred years. The results of our modeling indicate that only fluid very near the thermal anomaly actually reaches the surface. Thus the surficial fluxes are confined to an annular region within several hundred meters of r_I. A 30 km^3 intrusion produces a discharge of 1×10^4 kg sec^{-1}(10 m^3 sec^{-1}). Discharges are proportional to the volume of the intrusion: a 100 km^3 intrusion produces 3×10^4 kg sec^{-1} of water.

The greatest subsurface influence on the surficial discharges is the assumed permeability of the country rock. Our models reproduce the established linear relation [8] between discharge and permeability. Permeabilities of permeable basalt fall in the range 10 - 1000 darcies; permeability of the martian megaregolith has been estimated at 3000 darcies [9]. Since the above results were obtained for a permeability of 10 darcies, actual discharges may be up to two orders of magnitude greater.

Large intrusions produce thermal anomalies which persist for long periods of time. They are thus very efficient at cycling subsurface water to the surface. Over the modeled timescale for example, a 30 km^3 intrusion will introduce 10^{13} m^3 of water to the surface in 36000 years, compared to 10^{14} m^3 over 144000 years for 100 km^3 intrusion.

We further note that the hydrothermal system modeled is highly idealized. Terrestrial volcanic intrusions are seldom confined to the central magma chamber. Rather additional magma often intrudes as dikes and sills farther away from the magma chamber [2]. Such subsidiary intrusions can greatly extend the area of hydrothermal activity. The fate of near surface water has not been addressed in this model. We expect that some of this water would eventually intersect the surface at seeps and springs furthur down the flank of the volcanoes. Thus discharge regions are unlikely to be as localized as presented here. Absolute discharge, however, would be expected to remain roughly constant.

To facilitate comparison of the hydrothermal discharges with rainfall over terrestrial volcanoes, we calculate equivalent depths. These are the yearly discharges divided by the area of the small discharge region. Because both discharge and discharge area vary with intrusion size, most equivalent depths do not vary a great deal over the size range studied. Typical hydrothermal equivalent depths range from 200 to 700 m $year^{-1}$. By comparison, average rainfall on the Hawaiian volcanoes is about 2 m per year on the windward (wet) flanks and about 0.2 m per year on the leeward (dry) facing slopes, although over much larger areas. The windward flanks of these volcanoes are characterized by extensive runoff and sapping valley development. Leeward side valleys are generally less well developed. Valleys on the windward face of Mauna Kea are similar to those on the north flank of Alba Patera. While the variation of rainfall with time is not well known for the Hawaiian islands, valleys have formed on surfaces as young as 10^5 years. Thus these hydrothermal fluxes, if delivering significant fractions of liquid water, should be sufficient to produce valley formation, given appropriate surfaces [2].

Hydrothermal circulation clearly provides an important source of surficial and subsurface water flow. Based on our preliminary results, discharges and volumes of water seem adequate for the development of fluvial valleys. As we explore a greater variety of intrusion geometries and subsurface physical properties, we expect to provide a more definitive look at the role of hydrothermal systems in the paleohydrology of Mars.

References: [1] Gulick, V.C. *et al.,* 1988, *LPSC* **XIX**, 441–442. [2] Gulick, V.C. and Baker, V.R., 1989, *LPSC* **XX**, 364– 370. [3] Baker, V.R., 1982, *Channels of Mars*(Austin: Univ. of Texas Press). [4] Baker *et al.,* in press, Mars Conference 1989 book chapter (Univ. of Arizona Press). [5] Jaeger, J.S., 1968, in *Basalts* (eds. H.H. Hess and A. Poldervaart), 503–536. [6] Voss, C.I., 1984, U.S. Geol. Surv. Report 84–4369. [7] Johnson, J.W. 1987, Ph.D. thesis (Univ. of Arizona). [8] Norton, D. 1984 *Ann. Rev. Earth and Planet. Sci.* **12**, 155–178. [9]Carr, M.H. 1979, *JGR* **84**, 2995–3007.