GEOPHYSICAL METHODS TO DETECT GROUND ICE PRODUCED BY RECENT FLUID FLOWS ON MARS. N. M. Coleman, Member of the American Geophysical Union and the Health Physics Society (252 Johnston Lane, Mercersburg, PA 17236, nmc@nrc.gov).

**Introduction:** Geologically recent fluid flows have eroded gullies in steep slopes at the surface of Mars [1]. Ancient gullies have not yet been seen, perhaps because steep slopes on Mars are highly susceptible to physical erosion and backwearing. Nearly all of the flows occurred where liquid water is unstable at the surface throughout the Martian year [2]. This suggests that the fluids are brines, and if so, they present unique opportunities to directly sample ice derived from Martian groundwater and any extant life it may contain. Aquifers provide suitable refuges for the long-term survival of life that may have evolved early in Martian history [3]. Possible evidence of life in Martian meteorites [4] is an incentive for this search. As experiments on Earth have shown, spore-forming bacteria 250 million yrs old can be isolated and grown [5]. If brines have been released, deep drilling through rock may no longer be needed to recover groundwater samples. The flows formed gullies along steep slopes of depressions at mid to high latitudes where temperatures allow water ice to be stable near the surface [6]. The released water should have quickly refrozen at the base of the steep slopes below the outflow points. Current rover technology can be adapted to detect shallow ground ice in the floors of depressions where the groundwater outflows would have collected, infiltrated, and frozen. A test of this model would be the detection of shallow ground ice and evaporites at the infiltration sites. These sites are promising targets for sample return missions, but large target areas are needed to accommodate the uncertainty ellipses in landing zones. Sites like this can be surveyed by Mars Odyssey, which will study the mineralogy and abundance of H in surface layers. Other useful sites to study from orbit include landslides in the Valles Marineris, which have exposed the interiors of ancient aquifers, and the lowest points in Hellas, where groundwater-fed lakes may have existed for long periods.

Various ideas seek to explain the groundwater outbreaks, including the melting of ground ice by heat from igneous intrusions, meteorite impacts, or tectonic movements [7, 8]. Given that average annual surface temperatures are < 220°K, the fluids must be either brines or CO₂ as a liquid or gas [9]. Models that invoke release of CO₂ may be viable because theoretical studies [10] suggest that the Martian cryosphere is ~2-6 km thick. However, Table 1 (using eq. 2 of [10]) shows that a eutectic NaCl brine (freezing point ~252 K) could exist at shallow depths in places where ice-free layers of low thermal conductivity exist at the surface (dry soils and some vesicular basalts can have thermal conductivities <0.2 W/mK [10]). These layers may consist of eolian deposits and impact ejecta. Under these circumstances brines could interact strongly with the atmosphere, consistent with a recent isotopic study [11].

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Over eons, Martian groundwater has almost certainly evolved to a strong brine, considering long residence times, rapid rates of surface evaporation, and atmospheric loss of volatiles. The brine composition will vary spatially as a function of physical conditions, solute species and strength, and the types of stable and metastable salts in contact with the fluids. Viscous cold brines would reside in high-permeability zones (basalt flow-top breccias or impact ejecta) which would permit them to slowly migrate under small pressure, concentration, and thermal gradients. Lateral migration toward outcrops is favored because permeability in layered strata tends to be larger horizontally than vertically.

**Geophysical Methods:** Geophysical methods can readily assess the presence and abundance of shallow ground ice. Electrical methods could also be used, but this report focuses on nuclear techniques, especially neutron methods, because they are highly sensitive to the presence of H as a surrogate for liquid or frozen water, or water chemically bound in clays and other minerals. The key to evaluate the abundance of ground ice is to simultaneously map the subsurface bulk density and relative H abundance along continuous rover transects. Density data cannot be obtained from orbit—a lander or rover is needed. The methods described below are extensively used in exploration for groundwater, hydrocarbons, and nondestructive materials testing.

**Neutron methods.** Neutron detectors were used on Lunar Prospector and are onboard the 2001 Mars Odyssey mission. Neutron logging is commonly used on Earth to evaluate the water-filled porosity in a rock
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formation adjacent to a borehole, or to evaluate the volumetric content of moisture in unsaturated zones. Fast neutrons emitted by an active source pass through the surrounding media and are slowed (thermalized) to varying degrees by collisions with atomic nuclei. Hydrogen is especially effective. In colliding with a H nucleus, a neutron loses, on average, 63% of its energy compared to 12% lost colliding with an O nucleus [13].

Different types of neutron logs are made by counting scattered neutrons at various energy levels. Measurements of epithermal neutrons (0.1 to 100 eV) provide the highest % of response due to H and are least affected by other elements that are also good moderators (e.g., B and Cl) [13]. Neutron methods are so sensitive to the presence of water that they can be used to study infiltration and volumetric moisture content in unsaturated rocks and sediments in desert regions [14]. Variations in water content of a few % can be discerned. An excellent detector for thermal neutrons in the presence of a gamma field is the BF₃ detector [15]. It is a gas-filled detector that uses B-10 enriched to ~96% for increased sensitivity. B-10 has a very high cross section (σ = 3840 barns) for thermal neutrons. These neutrons interact with and are absorbed by B-10, which then emits charged particles (alphas and lithium ions) which are easily detected [16]. Various shields can be used with a BF₃ counter to absorb thermal neutrons and detect higher-energy neutrons in the epithermal range. Detecting both thermal and epithermal neutrons helps to determine whether moderators such as Cl are abundant in the target in addition to H. He-3 counters (σ = 5330 barns) are also used for neutron detection, but gamma ray discrimination is more difficult than for equivalent BF₃ tubes [16]. Various neutron sources could be used. Cf-252 spontaneously fissions and has a high emission rate of 2.3E6 neutrons per second per microgram Cf-252 [15]. The average value of the neutron energy distribution is 2.3 MeV. Hybrid sources produce neutrons by bombarding Be with alpha particles. Ra-Be sources produce average neutron energies of 5 MeV with a yield of 1.7E7 neutrons per sec per Ci [15]. This hybrid is also a strong gamma source, which can help assess the density of surficial materials.

**Gamma density logging.** The density of near-surface materials can be estimated by logging the formation response to a gamma source. Gamma rays interact with rock or soil mainly by Compton scattering. The intensity of the scattered gamma rays is an exponential function of the density of the target materials [13]. This gives a more complete picture of subsurface conditions when used with neutron methods. Density data can only be obtained using a lander or rover.

**Discussion:** Nuclear methods provide efficient and reliable ways to detect shallow ground ice, and have the advantage that the sources require no power and the detectors need little power to operate. The depth of penetration of the methods discussed depends on underground properties and the intensity of the nuclear sources. Modest penetration of <2 m will suffice because the goal is to locate rich deposits of near-surface ground ice derived from recent groundwater flows. This would guide future missions to collect samples for in situ analysis or Earth return. The most promising areas would have the strongest epithermal neutron scatter combined with bulk density variations consistent with interstitial ice. A strong Cl signature may also be present. The more distance a rover can cover, and the longer it survives, the greater the chance of finding shallow ice. To ensure long life for a rover, power and heat can be obtained from radioisotope thermoelectric generators (RTGs) and heater units. RTGs continue to power deep space probes decades after launch. Sagan Memorial Station (Mars Pathfinder) might still be active if it had Viking-era power sources to warm it through the frigid Martian nights.

**Conclusions:** Geologically recent fluid outbreaks on Mars present unique opportunities to recover possible extant life. Current rover technology can be adapted to use nuclear sources and detectors to locate shallow ground ice for sample return missions. As experiments on Earth have shown, 250-million-year-old microbes can be isolated and grown [5]. The recovery and return of Martian life constitutes a “Holy Grail” of planetary exploration. A possible path to that prize is in sight.

**References:**