EVIDENCE FROM HYDROGEN ISOTOPES IN METEORITES FOR A MARTIAN PERMAFROST. T. Usui[1,2], C. M. O'D. Alexander[3], J. Wang[3], J. I. Simon[4], and J. H. Jones[5], [1]Dept. of Earth & Planet. Sci., Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro, Tokyo 152-8551, Japan (tomohirousui@geo.titech.ac.jp), [2]Lunar Planetary Institute, USRA, Houston, TX 77058, USA, [3]Dept. of Terrestrial Magnetism, Carnegie Institute of Washington, Washington, DC 20015-1305, USA [4]Center for Isotope Cosmochemistry and Geochronology, ARES NASA Johnson Space Center, Houston, TX 77058, USA, [5]ARES, NASA Johnson Space Center, TX 77058, USA.

Introduction: Fluvial landforms on Mars suggest that it was once warm enough to maintain persistent liquid water on its surface [e.g., 1]. The transition to the present cold and dry Mars is closely linked to the history of surface water, yet the evolution of surficial water is poorly constrained.

We have investigated the evolution of surface water/ice and its interaction with the atmosphere by measurements of hydrogen isotope ratios (D/H: deuterium/hydrogen) of martian meteorites [2, 3]. Hydrogen is a major component of water (H_2O) and its isotopes fractionate significantly during hydrological cycling between the atmosphere, surface waters, ground ice, and polar cap ice. Based on *in situ* ion microprobe analyses of three geochemically different shergottites, we reported that there is a water/ice reservoir with an intermediate D/H ratio (δD = 1,000–2500 ‰) on Mars [2]. Here we present the possibility that this water/ice reservoir represents a ground-ice/permafrost that has existed relatively intact over geologic time.

Origin and History of the intermediate-δD water reservoir: Two distinct martian water reservoirs have been previously proposed (Fig. 1a). One is primordial water that is retained in the mantle and has a D/H ratio similar to that of planetary building blocks (i.e., chondrites) [e.g., 2, 4]. The other is near-surface water that is isotopically fractionated because it has exchanged with the atmosphere (previously called the exchangeable reservoir) [e.g., 5]. Such fractionated D/H ratios of atmospheric (4950 ± 1,080 ‰) and near-surface (5880 ± 60 ‰) waters have been recently reported by the *Curiosity* rover at Gale crater near the equatorial region (5.4°S) [6].

Our new data [2] obtained from low-contamination ion microprobe analyses require the existence of a water reservoir with an intermediate D/H composition that has exchanged with a diverse set of martian samples. This intermediate reservoir (δD: 1,000–2500 ‰) cannot be the mantle source of any of the SNC martian meteorites (SNC: shergottite, nakhlite, chassignite) as they exhibit δD values of ≤275 ‰ [3, 4, 7, 8]. An "unidentified reservoir", such as ancient, hydrous lower crust [9], may have preserved such intermediate δD water. However, such a hidden reservoir deep in the interior is not consistent with the fact that the intermediate δD signature is found only in matrix glass phases (impact melts and quenched groundmass glass) that formed near the surface. We are also doubtful that either polar ice or regolith ice is the source of the intermediate δD reservoir because they will have exchanged with the high-δD atmospheric water over geologic time (~10^9 year); e.g., even the polar ices that dominate the current surface water inventory are estimated to have a lifetime of only ~10^6 year [10].

We propose that the water reservoir with the intermediate δD value represents a massive ground-ice/permafrost layer (Fig. 1b). The ice reservoir must be of sufficient size because it has not completely exchange (i.e., has not reached isotopic equilibrium) with the atmosphere. Theoretical investigations suggest that a global H_2O-ice reservoir with a thickness of >30 m can preserve a δD value of <2000 ‰ over a geological extended period of time (~3×10^9 year) [11]. The existence of such a massive ground ice reservoir has been recently proposed based on subsurface radar sounder observations (Fig. 1c, d). Mouginot et al. [12] reports that the northern plains surrounded by putative Hesperian shorelines have lower dielectric constants than that of typical volcanic materials at depth of 60-80 m, and propose that the northern plains are filled with massive ice deposits interbedded with layers of sediment and volcanic materials.

The total inventory of "observable" current surface water is estimated to be ~3×10^6 km^3, which is more than one order magnitude smaller than the estimated volume of ancient surface water that is thought to have covered the northern lowlands (~2×10^7 km^3 to 2×10^8 km^3) [13]. A major issue with respect to paleo-oceans and -lakes is where all the water went. Carr and Head [13, 14] argue that losses of sublimated water to space (~7×10^6 km^3), as well as the know water sinks such as polar layered terrain, are insufficient to account for the missing water. They suggest that the remaining water must be sequestered elsewhere on the surface or in the ground. Our meteorite results strongly supports the latter, i.e., that the missing water exists as massive ground-ice/permafrost layers beneath the northern plains.

A simple mass balance calculation indicates that ~400 m of pure-H_2O ground ice beneath the northern plains (~1/3 of Mars surface) is equivalent to the volume of a putative Hesperian ocean (~2×10^7 km^3). The probability of such a massive ground ice reservoir is supported by theoretical investigations that suggest that deep (up to ~20 km) ice-rich permafrost layer has potentially survived under the martian hydraulic and thermal conditions [15]. Our meteorite study supports the hypothesis [e.g., 12, 15] that a deeply buried cryosphere in the northern plains could account for a large part of the initial water budget of Mars.

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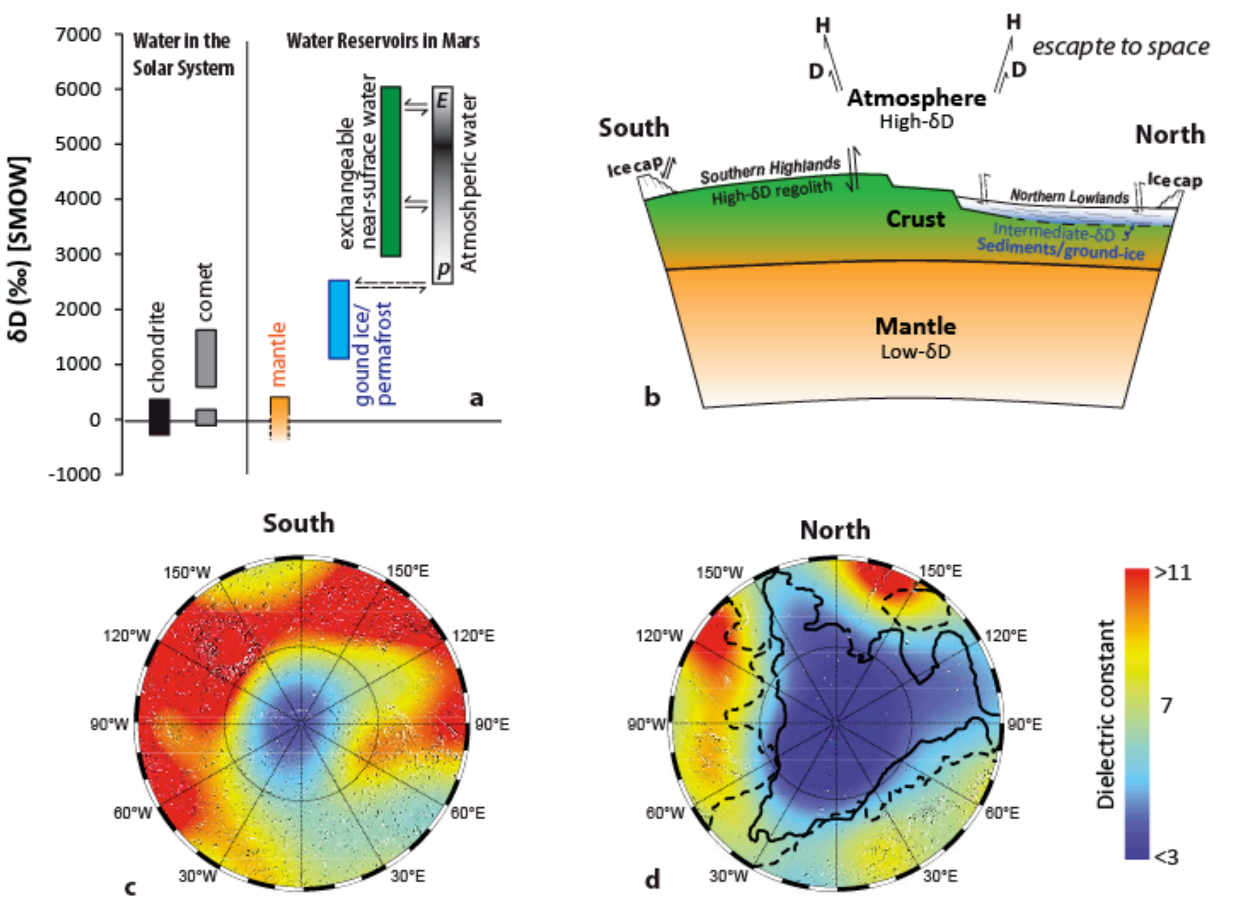

Figure 1: (a) Hydrogen isotopic compositions of water in the Solar System and martian water reservoirs. δD ranges of carbonaceous chondrites, comets, martian mantle (275 ‰), crustal water (3000-5880 ‰) and the atmosphere (2500-6000 ‰) are from [3, 5, 6, 16]. The intermediate δD reservoir (ground-ice/permafrost) is obtained from our new ion probe analyses [2]. (b) Schematic cross section illustrating locations of the martian water reservoirs. Interaction between the ground-ice/permafrost and the atmosphere is expected to be limited. (c, d) Dielectric maps of the southern and northern hemispheres of Mars obtained from the Mars Express's subsurface radar sounder modified after ([12]). A mapped area with a lower dielectric constant (shown as "cooler color") is interpreted to contain less dense materials and/or higher water-ice amounts. Dashed and full lines in (d) indicate putative paleo-shorelines, Arabia and Deuteronilus, respectively.