Gangotri mission concept on the glacial key to the Amazonian climate of Mars.

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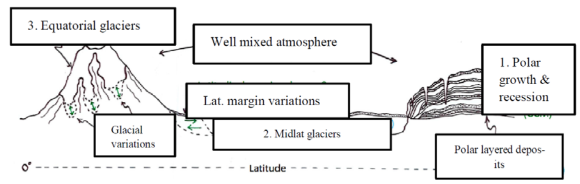
Motivation and overview. The wealth of geologic information bound in martian ice, including climate cycles, potential biomarkers, atmospheric particulates, and sources of H_2O that may drive alteration within the critical zone (CZ: zone of interaction between the atmosphere and the porous upper crust) has long been recognized. Much progress has been made in the last decade, including polar ice sheets [e.g., 1] and midlatitudinal ice [e.g., 2, 3, 4].

Despite recent advances, outstanding questions remain at the forefront of exploration [cf. 5]. Martian midlatitudes provide a notable opportunity to explore these in the evolution of ice beyond the poles [Fig 1], as emphasized in the NASA 2023-2032 decadal survey's general mission outline [6]. Such glaciers are ablating as evident from both scarp activity and collapsed boulder fields [2]. Accordingly, our mission concept—aptly eponymous with the large and fast-receding Himalayan glacier, Gangotri—would investigate the geologic origins of midlatitudinal martian glaciers. Gangotri would help to characterize Amazonian climate evolution via a hybrid thermo-mechanical drill called RedWater [7] for deep and possibly multiple englacial sampling. Gangotri would use regolith compositional measurements to analyze ice-regolith interaction, and stable isotope measurements to characterize fundamental exchange processes of major ice reservoirs. Meanwhile, geophysical observations would cross-calibrate composition with some sensitivity to the presence of brines or meltwater.

Aims and rationale: Advancing Gangotri's [8] concept maturity level to mission-proposal readiness will support one human exploration and two broad science outcomes. The science outcomes are: (1) determining climate-driven processes of mid-latitudinal glaciers as a key H_2O reservoir of Mars while specifically testing the hypothesis that, instead of groundwater [9], englacial weathering of sediment produced Mars's globally widespread sulfate sedimentary rocks [10]; and (2) determining the habitability and biomarker preservation potential [11] of glaciations during the Amazonian geologic eon. The human exploration outcome is to characterize glacial ice and associated soils as a resource [12] particularly for crop plants [13].

Mission Concept Summary. Here we present the mission architecture as a reference in relation to the Gangotri Science Traceability Matrix (STM archived online). Assessing the tradespace of what may be achievable at lower cost levels is desirable and our preliminary instrument tradespace lowers costs without undermining the science and human exploration goals enumerated in STM. Gangotri's spacecraft architecture is archived online).

Fig 1. Schematic of the latest H_2O reservoir model for Mars by Vos et al. [14], testable by characterizing deuterium to hydrogen (D/H) isotopic ratio in midlatitudinal glaciers (2nd of the three reservoirs). Possible layering within midlatitudinal glaciers [2] increases the likelihood of an isotopically variable counterpart to Reservoir 1.



Summary of science payload by [8]. The Rover is a mobile-to-stationary platform for the payload to identify the optimal drill site and develop environmental and geologic context. Mobility ensures enhanced insight into lateral variations in fundamental properties of the ice sheet, especially stable isotopes.

The deck-mounted Sample Analysis at Mars (SAM) [15] would primarily sample variations in the D/H ratio in glacial ice delivered from drilling, along with opportunistic measurements of atmospheric D/H for reference. With six gas chromatograph (GC) columns, and the capability to use these in tandem with a mass spectrometer for gas chromatograph mass spectroscopy, the SAM instrument suite can search for organic compounds, complementing the drill-mounted payload [16].

The arm-mounted Gamma-Ray and Neutron Spectrometer (GRNS) subsystem would provide rapid detection of water ice and bulk geochemistry within a meter of the surface to identify target drilling sites. The GRNS is baselined as one module of the EPICS instrument [17], a low-resource combined GRNS that incorporates elpasolite scintillator material and silicon photomultipliers (SiPMs). Notably, SiPMs require only tens of volts bias, simplifying the design and reducing the possibility of high-voltage breakdowns in landed environments.

The wheel-mounted acoustic seismometer array consists of low-mass (9 g each) piezo-ceramic seismic sensors and pulsers integrated into the rover wheels to ensure best ground coupling. Piezo-ceramics can also generate controlled low-energy signals (only micrometers displacement). Over a rover transect, active pulsing measurements can provide continuous subsurface maps (~meter depth) of mechanical properties to predict and confirm observations from other payload instruments, particularly GRNS, searching for buried ice as well as the presence of brines or fluids [18].

Deck-mounted MEDA uses mission heritage [19]. MEDA sensors will be on the mast, deck, front, and interior of the rover's body, consisting of five air temperature sensors; radiation and dust sensor; relative humidity sensor; thermal infrared sensor; wind sensors; instrument controller; and pressure sensor.

The RedWater Drill (Fig 2) is the core of science operations for englacial characterization [7]. A key development need is incorporating a sample preparation-delivery system to the deck-mounted SAM. RedWater uses traditional coiled tubing drilling approach with a bottom hole assembly consisting of a motor and drill bit, to be augmented with thermal ablation. Englacial observations will use the three drill-mounted instruments: dust logger, UV fluorometer, and UV microscope.

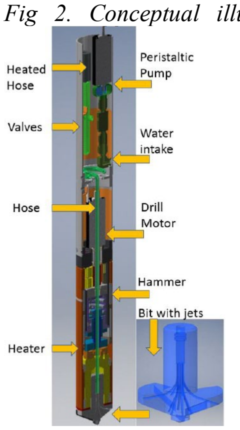


Fig 2. Conceptual illustration of the RedWater hybrid thermo-mechanical drill, to be modified for Gangotri. Our design would include downhole instruments.

We identify four tradespace priority levels. Level 1 satisfies the mission goals, while each additional level enhances the degree of interpretation and hypothesis testing (STM): (1A) drill integrated UV fluorometer for biomarker detection; (1B) Drill deployment and sample preparation and delivery system; (1C) SAM minimal adaptation (STM) for englacial D/H isotopic ratio data; (1D) Navigation Cameras, based on M2020 EECAM, to visually identify optimal glacial drilling site; and (1E) MEDA system to provide continuous temperature, pressure, humidity and wind velocity measurements for comprehensive atmospheric process insight over a martian year for refining current global circulation models on ice stability and exchange with the atmosphere.

Level 2 enhances site selection and increases englacial isotopic insight: (2A) Arm Imager for high-resolution images of the surface to guide drill deployment; (2B) minimal GRNS module to characterize depth to ground ice; (2C) mast mounted cameras to map the terrain based on MSL's MastCam; and (2D) SAM without GC for detailed englacial D/H.

Level 3 provides contextual composition, maximizes englacial information, and offers complementary borehole characterization: (3A) drill integrated dust logger and microscope to identify englacial dust-ash layers and siliciclastic chemical weathering processes; (3B) Full GRNS module to characterize bulk chemistry at decimeter depths; and (3C) MiniTES-analog/Raman incorporated into the rover mast for mineralogical differences between dust of global provenance and local soils, along with D/H isotopic ratio data, and biomarkers.

Level 4 provides reconnoitering and environmental characterization: (4A) Mars Helicopter Scout (MHS) to identify distally hazardous terrain, map geology with nadir and stereoscopic imaging; and (4B) acoustic seismometer system supplementing GRNS-based characterization of regolith stratification.

Technology development needs: Thermo-mechanical drilling through englacial heterogeneities (e.g., siliciclastic lags), and minimizing RedWater's thermal flux effects on sample isotopes; sample preparation and delivery from borehole to deck-mounted SAM; embedding fluorometer, dust logger, and microscope in RedWater; piezoelectric acoustic seismometer design and integration in rover wheels; adapting MHS for geologic mapping and hazard characterization.

Relevance to other target bodies. Martian englacial sampling will yield tools for interrogating ice-rich environments throughout the solar system, especially of icy bodies like Europa. In turn, that would curtail risk and cost for future missions to Europa by using Mars as the steppingstone towards the Ocean Worlds Exploration Program mandated by the US 2016 Congressional Bill.

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