TERRESTRIAL ANALOGS OF MARTIAN ICE CAVES. Norbert Schorghofer, Planetary Science Institute, Honolulu, HI & Tucson, AZ, USA (norbert@psi.edu).

Introduction: The quality of a field analogue depends on the aspect one seeks to study, but generically the following properties are sought for a terrestrial cave that serves as an analog to a martian cave: 1) hosted in volcanic rock, 2) temperatures continually below the melting point of ice (permafrost) or otherwise devoid of liquid water, and 3) little biological alteration or contamination.

Martian caves [1] are situated at depths below the influence of seasonal ground temperature variations and above the depths where geothermal heat becomes dominant. Mean annual surface temperatures on Mars range roughly from 230K to 160K. Hence, phase transitions are by sublimation and ice deposits in martian caves are expected to be in the form of (atmogenic) hoarfrost [2].

Caves provide access to the subsurface and are well-known for their ability to preserve the past. On Mars, ice caves (rock-hosted caves with perennial ice deposits) are of particular interest [2,3], because they may have preserved a record of the planet's climate history; they could potentially have preserved stratified (time-resolved) records of biosignatures, and they may serve as water sources.

Database: A database of terrestrial ice caves and volcanic caves has been compiled [4], based on hundreds of sources, including [5] and [6]. Currently it includes 521 caves with perennial ice and 1,597 lava tubes. The database format (CaveXML) is designed to also include extraterrestrial caves, but few have been added so far.

CaveXML: An XML-based interchange format for speleological data has been discussed as early as 2001, but the first implementation was only written in 2020 [4]. CaveXML is a new format and can be extended with additional XML namespaces. Uniform data exchange formats facilitate sharing of speleological data. The aforementioned database is the first to use CaveXML, but has also been linked with the Karstlink ontology. The Karstlink project [7] interconnects various speleological databases.

Some notable potential terrestrial analogs: The database systematically contains entries for host rock (e.g., limestone, basalt), cave type (e.g., lava tunnel, tectonic cave), and contents (e.g., permanent ice), along with the bibliographic references the information is based on.

Volcanic ice caves. The database contains 30 records of lava tubes with permanent ice. These include well-known caves such as Grotta del Gelo in Sicily (Italy), Fuji Ice Cave (Japan), and Crystal Cave (Lava Beds National Monument, USA). Volcanic ice caves are also found in China, Iceland, and Hawaii.

Caves with hoarfrost. The database currently contains 38 records that mention hoarfrost or sublimation crystals, although it is rarely documented whether perennial or merely seasonal. Large ice crystals or massive hoar deposits have been reported from Kungur Ice Cave (Russia), Crystal Cave (California), Jochloch (Switzerland), Crystal Kingdom Cave (Greenland), and others. Hoarfrost is also found in glacial caves in Canada and Antarctica.

High-altitude. The highest-lying known ice caves are Putnikov Cave (Tajikistan, ~4,600m a.s.l), Dena Ice Cave (Iran, 3,895m a.s.l.), and Amarnath Cave (India, 3,888m a.s.l). The highest-lying documented volcanic ice cave is Mauna Loa Ice Cave in Hawaii, where microbes have been identified in a secondary mineral deposit [8]. On Mt. Kilimanjaro, short lava tubes (with no ice reported) are found up to 5,250m a.s.l.

Permafrost ice caves. All martian rock-hosted caves lie in permanently frozen ground (permafrost). Numerous caves are known in permafrost regions on Earth [5]. Permafrost often prevents liquid water from entering a cave, but ice deposits can be atmogenic. Jochloch is an example of a permafrost cave with hoarfrost. Dry (ice-free) permafrost is common on Mars, but rare on Earth. No terrestrial cave hosted by dry permafrost was found in the literature.

Understudied and unstudied aspects: Studies of the time evolution of spelean hoarfrost deposits that never melt would inform models that predict the physical properties, isotopic composition, and thickness of spelean hoarfrost on Mars. In the context of searching for biomarkers in spelean ice, a relevant process is the inclusion of dust in the hoarfrost. A terrestrial analogue may be the pink (dust-bearing) hoarfrost in Crystal Cave [9].

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