RESULTS FROM THE ICE AND CLIMATE EVOLUTION SCIENCE ANALYSIS GROUP (ICE-SAG).

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Charter: In October 2018, the Executive Committee of the Mars Exploration Program Analysis Group (MEPAG) chartered the formation of the Ice and Climate Evolution Science Analysis Group (ICE-SAG) to identify what might be done in the decade 2023–2032 to achieve compelling science objectives related to the recent and ongoing evolution of Martian volatiles and climate. This activity is a part of community preparations leading up to the next NASA Planetary Science Decadal Survey, as the Executive Committee explores approaches to answering the fundamental science questions in the MEPAG Goals Document [1]. A recent update to that document incorporated changes focused on polar science and the ongoing evolution of volatiles and climate on Mars [2].

ICE-SAG is tasked with identifying:

- Compelling science objectives that could be addressed in the decade 2023–2032, with traceability to the recently updated MEPAG science Goals (Life, Climate, Geology).
- Measurements required to address these objectives and proof-of-concept techniques needed to make such measurements, and/or the technology investments needed to develop the required techniques to a sufficient level of maturity.
- Mission approaches—including orbiters, landers, drillers, rovers, networks—that could make the measurements required to address the compelling science objectives.

These tasks include (1) indicating which measurements (traced to mission concepts) are needed before others and which are needed concurrently, (2) identifying major technical challenges, (3) sorting the various mission scenarios via analogy and comparison into the following mission classes: Small Spacecraft, Discovery, New Frontiers, Flagship, and (4) prioritizing the New Frontiers and Flagship class missions for costing and technical evaluation by NASA for consideration in the 2023-2032 Planetary Decadal Survey.

Our presentation will summarize ICE-SAG results and give an overview of our process and considerations. Additionally, we will outline any next steps of relevance for the community.

Motivation: Orbital and *in situ* surface exploration have revealed a complex system of Martian ices:

- Permanent polar caps with icy layered terrains, which are thought to contain records of the Martian climate over the geologically recent past, but whose apparent age and internal layering differ dramatically between north and south poles.
- Enough carbon dioxide ice sequestered in the south polar cap that, if sublimed, would more than double the present atmospheric mass [3].
- Widespread ice in the uppermost meter or two of the ground extending from the poles to the mid-latitudes, where some small impactors have exposed shallow ice closer to the tropics [4].
- Massive ice in the form of debris-covered glaciers in numerous mid-latitude locations [5].
- Possible shallow equatorial ice [6], [7].
- Evidence that seasonal carbon dioxide frost may be a major surface erosive agent at mid-to-high latitudes on the planet within the present climate [8], [9], [10].

Hypotheses for the formation of these deposits, together with adjacent landforms, point to effects of transport, deposition, and sublimation of volatiles, dust, and other refractory materials over seasonal, interannual, and ultimately much longer timescales, i.e., those of the Martian astronomical cycles (variations in obliquity and in the eccentricity and phasing of the orbit) (Figure 1). The preservation state and layering in these reservoirs can reveal important clues about climate evolution on Mars.

Much remains to be learned in testing these hypotheses and ensuring that critical processes are fully identified and quantified. For example, we do not yet know if either of the polar caps are undergoing net accumulation or ablation, or how to interpret the different observations of layered deposits that are seen as records of “recent” past climates and climate shifts. Quantification of the transport and placement of Martian volatiles is needed to understand volatile processes and reservoir distribution on Mars through geologically recent history. Surface, subsurface, and atmospheric conditions also constrain the frost distribution and frost-related processes. Layers may record accumulation and climate for up to 100 Ma or more. Together, all of these factors create icy and rocky landforms that we aim to interpret as records of past climates.

Finally, we note that the variables important to questions of Martian ice and climate are interconnected with other areas of Mars science, and disentangling the critical variables will be difficult. The importance of understanding ice on Mars is paramount, as it is a key to climate change, human exploration plans, and even considerations of habitability on Mars.

The ICE-SAG team and process: The team (see author list) consists of Mars scientists whose areas of expertise include observations of frozen water and carbon dioxide in their many forms and locations, studies of atmospheric conditions and cycles, laboratory experiments and numerical modeling of regolith–atmosphere water exchange and frost- and ice-related processes, terrestrial analog field studies, and models of how shifting orbital parameters influence the formation and abundance of ice on Mars. Team members come from a range of institutions and career levels.

To supplement the expertise within the SAG, subject matter experts also have been invited to present on specific science questions and technologies, including drilling methods for accessing the subsurface through ice and regolith, analogous studies of terrestrial climate, and the potential Martian isotopic record.

SAG members have primarily interacted via telecons, supplemented by a face-to-face meeting being held at the Planetary Science Institute Headquarters in Tucson, Arizona in mid-January of 2019.

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* Documents available at https://mepag.jpl.nasa.gov/.

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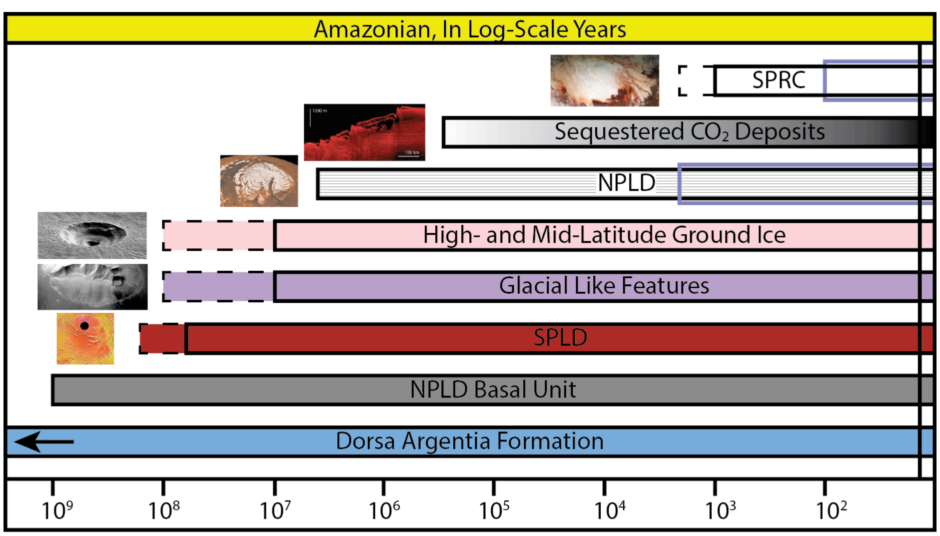

Figure 1. *Schematic showing ages of known Martian volatile-rich deposits and thus the periods of climates (and climate shifts) that may be recorded in each. SPRC is the south polar residual cap. SPLD and NPLD are the north and south polar layered deposits. Purple lines represent estimated surface ages of SPRC and NPLD. Vertical black line at right represents start of spacecraft observations (Mariner 4, 1965). Modified from figure by I. Smith [11].*