SCIENCE ENABLED BY AERIAL EXPLORERS: ADDRESSING OUTSTANDING QUESTIONS IN THE MARTIAN GEOLOGICAL RECORD.

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Introduction: Mars is the only place in our solar system with a rock record that preserves the first billion years of evolution of an Earth-like world. Studying this period will enable us to better understand the factors that drive the divergent evolutionary paths of small rocky planets [1]. Exploring this well-preserved record of major geological evolution can solve key questions in planetary science today [2]:

(i) How do core dynamos form and evolve?

(ii) What processes form early planetary crusts?

(iii) What are early drivers of climate evolution?

Despite their importance, Mars' most ancient terrains have never been explored in situ. This is due in part to the fact that many are found in the Martian highlands, which have elevations that are inaccessible by traditional entry, descent, and landing systems (EDL). Others are too steep or rough to be explored with existing rovers (e.g., walls of Valles Marineris).

The success of the Ingenuity Mars helicopter sets the stage for a potential future standalone Mars Science Helicopter (MSH) that could explore ancient outcrops at high elevations or in steep terrains. Current MSH concept designs allow up to ~5 kg of science payload and traverses of several kilometers per flight [3].

An EDL strategy called Mid-Air Helicopter Delivery (MAHD) is used to deliver MSH to the Martian surface. In MAHD, the rotorcraft transitions from the stowed configuration inside the aeroshell during atmospheric descent to stable controlled flight before landing. This eliminates the need to carry a large dedicated lander and provides volume for larger rotors in the aeroshell, hence more scientific payload. The lower entry mass enables landing at higher elevation than other EDL approaches [4]. An additional major advantage is the ability to have large landing ellipses with dangerous terrain as the helicopter can autonomously navigate a safe airfield to land on within the ellipse. Finally MAHD reduces EDL system complexity, mass and importantly cost. Details of MAHD are discussed in [4].

Goals and associated measurements: A MSH could perform landed and in-flight observations on geological units in tandem (Fig. 1) using four instruments capable of fitting within the payload mass limit: a magnetometer, a context camera, a chemistry instrument such as a micro-laser induced breakdown spectroscopy (LIBS) or X-ray fluorescence (XRF), and an imaging spectrometer for mineralogy. Combined, data from these instruments could collect key measurements required to address all three goals:

Goal 1: Paleomagnetism. Establishing the time history of the strength and direction of Mars' now-extinct global magnetic field is critical to understanding the thermal evolution of Mars to the escape of Mars' atmosphere and its long-term habitability. In coarse-scale orbital data, strong crustal fields are mostly found in highland terrains, e.g., Cimmera-Sirenum block [5] (Fig. 2). There are currently limited data on the remanent magnetic field that would help constrain the evolution of the dynamo and correlate it with processes of crustal formation and climatic evolution recorded in sedimentary sequences. Acquiring the first in situ stratigraphic analysis of the remanent magnetic field on temporally-constrained Noachian outcrops would constrain the lifetime of the early dynamo. Furthermore, in situ measurements of bedrock could yield the first constraints on the field's paleodirection, which in turn could constrain the history of reversals and possibly even tectonic events. Required measurements include crustal field strength and direction coordinated with imagery and mineralogy [15].

Goal 2: Magmatism/tectonism. The degree of crustal differentiation and the question of early crustal recycling on Mars has not been settled, yet this topic is

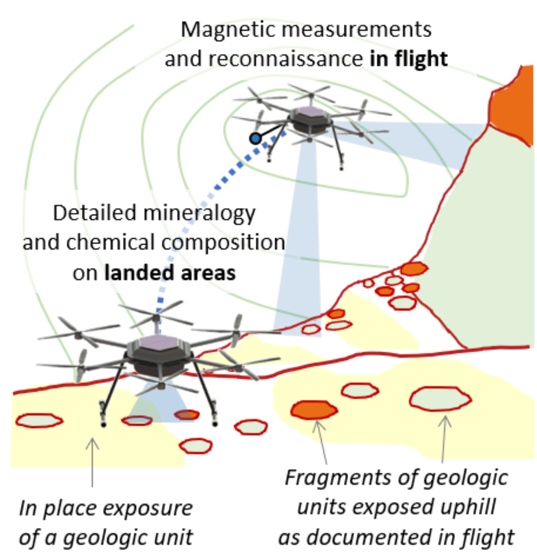

Figure 1: Geological investigation using coupled landed and in-flight observations.

fundamental for understanding the early Mars system. Magmas drive the flux of volatiles from the interior, and are therefore a major contributor to climatic evolution. *In situ* data on the lithology of key Noachian crustal components (Fig. 2) are now needed to test models for the origin of the global crustal dichotomy and processes that formed the early crust. With evidence for feldspathic and silica-rich magmatic rocks in the southern hemisphere [6–8], it is possible that a significant fraction of the crust forming the southern highlands has a more evolved composition resembling the magmatic series of the Archean proto-continental crust. Such models add to the collective lines of evidence towards major shifts in our understanding of early Mars history and need to be tested *in situ*. Required measurements include high resolution images of rock textures, chemistry and mineralogy.

Goal 3: Paleoenvironment. Sedimentary outcrops [11] and sequences of secondary minerals [16] found in Noachian and Hesperian terrains record changing aqueous conditions, atmospheric redox state, and climates on throughout Mars' history. Exploring these outcrops *in situ* will advance our knowledge on early paleoenvironments. Integrating these results with goals 1 and 2 will help understand how evolutionary processes, such as volcanic degassing and loss of Mars' atmosphere to space, drove the nature and persistence of habitable environment on Mars. Required measurements include high resolution compositional, textural, and stratigraphic mapping of key areas.

Conclusions: The key advantage of helicopters is that they can cover 100+ km over a mission lifetime and to traverse steep and rough terrains. MSH coupled with MAHD will be transformative over current flagship rover designs because it will enable *in situ* access at regional scales, at reduced cost, and will bridge the gap between orbital maps and detailed *in situ* analyses.

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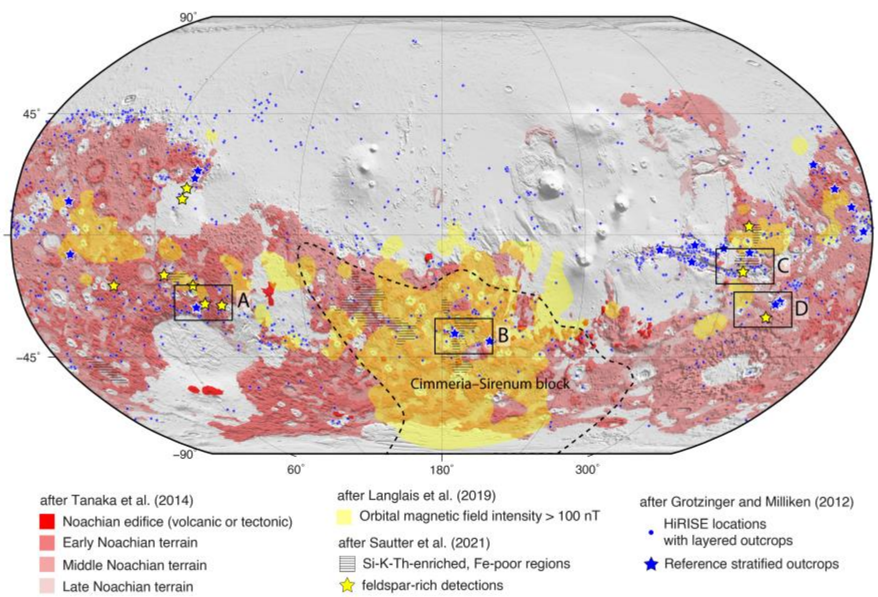

Figure 2: MSH provides decisive advantages to investigate the record of : paleomagnetism (in yellow area of crustal magnetic field >100 nT based on orbital measurements by MGS and MAVEN [12]), crust formation (Noachian aged-terrains [13], evolved igneous compositions [14], outline of Cimmeria-Sirenum block [5]) and paleoenvironments (stratified deposits observed in HiRISE data [11]). Regions of interest combining all objectives include northern Hellas (A), Eridania basin (B), Valles Marineris (C) and Holden crater (D).