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Early Noachian rocks in megabreccia deposits on Mars

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Abstract

Megabreccia consists of randomly oriented angular to subrounded blocks, many larger than 1 m diameter, and forms suddenly in energetic environments such as impact events [1]. Megaregolith is a related term for unconsolidated material resulting from heavy bombardment, but megabreccia may be indurated bedrock. We have identified megabreccia in more than 100 locations on Mars to date from HiRISE images, generally in the form of indurated bedrock [2-5]. It is commonly found in the central uplifts of large craters in or near Noachian (>3.8 Ga) terrains (Figure 1), near the rims of large basins such as Isidis, and in deep exposures such as the floor of Uzboi Valles and in parts of Valles Marineris. Megabreccia is typically identified in well-exposed bedrock outcrops, in particular from the diversity of colours and textures indicating diverse lithologies. CRISM has identified hydrated minerals such as clays in many of these locations, especially in the matrix but also in many blocks. Unaltered mafic minerals are also common in the blocks. These may be among the very oldest rocks exposed on the surface of Mars, with brecciation occurring during the time of heavy bombardment and many clasts from still older bedrock. In some cases megabreccia with relatively small (1-5 m) clasts probably formed by post-Noachian cratering, particularly when found in the pitted and ponded material filling the crater floors, which may be analogous to suevite [6, 7]. But the indurated megabreccia exposures with large (>10 m) blocks and diverse lithologies are found in locations consistent with deep bedrock, such as the central uplifts of large craters. A 100-km diameter crater is expected to cause ~10 km of structural uplift in the central structure. Crater central uplifts bring up relatively intact stratigraphy, so we interpret the jumbled megabreccia as pre-existing deposits from older impacts. We speculate that there may be a global (but likely discontinuous) crustal layer of megabreccia cemented by melt and hydrothermal alteration.

Life on Earth probably began during the period of heavy bombardment, and perhaps before the late heavy bombardment of ~3.9 Ga [8]. The oldest rocks known on Earth crystallized at ~4 Ga, but are heavily metamorphosed and interpretations about the environment of early Earth are controversial [e.g., 9]. In contrast, the oldest known rock from Mars (ALH84001) crystallized at ~4.5 Ga [10]. Hence, Mars may preserve a much better record of the environmental effects of early differentiation and heavy bombardment into a water-rich crust.

Out of the four current candidate Mars Science Laboratory (MSL) landing sites [11], Holden crater would provide the best access to Noachian megabreccia, which is exposed in terrace blocks in Holden and in Uzboi Valles within the breeched rim/terrace area [2, 5]. Megabreccia from Holden ejecta is also present at the Eberswalde crater landing site, but would be more disturbed (including the matrix) than that on the floor of Holden crater. There is a small exposure of megabreccia in the deepest canyon into the layered mound in Gale crater, perhaps accessible in an extended mission of MSL if it lands at that site. The region around the Mawrth Vallis candidate landing site appears devoid of megabreccia, although it is present in the central uplifts of large craters within a few hundred km.

There is considerable interest in studying Early Noachian (>4 Ga) Mars, perhaps by MSL,

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ExoMars or a later rover, to search for prebiotic chemistry, the earliest traces of life, and to better understand the history and interactions of Mars' early differentiation, loss of core convection driving a magnetosphere, heavy bombardment, possible true polar wander, and atmospheric change. A significant challenge is to identify where to best access Early Noachian rocks. We suggest that the megabreccia deposits that are located in places where deep crustal exposures are expected based on the regional geology, mark what are most likely the oldest exposures. Studying undisturbed Early Noachian strata might be ideal, but may prove extremely difficult to locate at the surface. Most likely the oldest strata were both exposed and disturbed by large impact events. Exposures deep in Valles Marineris could be the most promising locations to search for intact ancient strata, but would be very challenging landing sites. The northern rim region of Hellas basin is another candidate for undisturbed Late Noachian strata, but the elevation may be too high for landing. We suggest that the best near-term approach would be to visit a megabreccia deposit that provides access to a diverse suite of ancient rocks. Some depositional geologic context is available from evaluation of the regional setting and from large blocks, some of which are clearly layered or banded. In some locations such as the Nili Fossae region there are layered but unbrecciated strata overlying the megabreccia, and these strata may still be of Noachian age. The mineral assemblages in unaltered blocks near Nili Fossae are distinct from typical Hesperian lavas [12, 13] and may be fragments primary crust.

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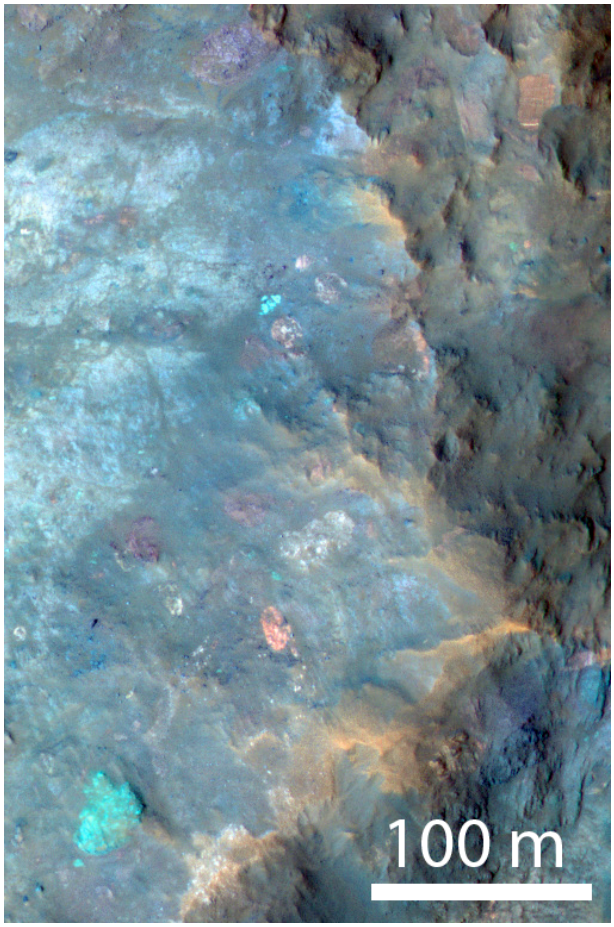

Figure 1. Megabreccia in the central uplift of a 25-km crater on the rim of a 300-km crater in the Noachian highlands. HiRISE ESP_013092_1630