INTRODUCTION: Since August 2011, Mars Exploration Rover Opportunity has been investigating the geology of western rim segments of 22 km diameter, Noachian-aged, degraded [1, 2], Endeavour Crater. She is currently located almost halfway down the back-wasted crater wall in Perseverance Valley, between Capes Tribulation and Byron [3] (Fig. 1).

A unique lithology, the Matijevic formation that crops out in a small region on the inboard side of Cape York (Fig. 1), has been shown to be pre-Endeavour bedrock [4, 5]. The Matijevic formation is directly overlain by polymict breccias of the Shoemaker formation [5, 6]. We have interpreted a lower subunit of the Shoemaker formation on Cape Tribulation as distal ejecta from one or more pre-Endeavour craters [7]. Sulfate-sandstones of the Burns formation post-date Endeavour Crater [5]. The pre-Endeavour bedrock and associated alteration styles are discussed herein.

ENDEAVOUR CRATER: The pre-Endeavour bedrock core of the Endeavour Crater is represented by the Matijevic formation, which is light-toned, planar outcrops with discontinuous, erosionally resistant dark veneers [4, 5]. The rocks are fine grained, with subrounded particles ≤0.3 mm in size, and they contain 1-4 mm-sized spherules in varying proportions. Apparent bedding in some outcrops is expressed as mm- to cm-scale planar laminations. Fine-grained clastic rocks can form by impact, explosive volcanic, aeolian, or fluvial/lacustrine processes; the limited exposures do not allow us to distinguish among these possibilities [5].

Endeavour rim rocks are basaltic-composition polymict breccias (Shoemaker formation) composed of 1-10 cm-sized, erosion-resistant clasts in a fine-grained matrix. Two texturally distinct breccias are present: a clast-poor unit with typically smaller clasts; a clast-rich unit with generally coarser clasts [8]. Clast-poor breccias form planar, eroded outcrops, while the clast-rich breccias are more resistant, forming ridge crests on Capes York and Tribulation. The walls of Marathon Valley document stratigraphic relationships between the two units: clast-rich breccias form the upper unit; clast-poor breccias occupy the valley floor [3].

Polymict breccias outside the tectonic rim of Ries Crater (equivalent to Opportunity’s location) show no systematic vertical grain size variation in the deposit [9]. Polymict ejecta within the outer rim of Mistastin Crater are similarly poorly sorted [10]. Stratigraphic relationships between the lower and upper Shoemaker units do not match expectations for single-impact ejecta. Mean clast size and abundance decrease with radial distance outward in Ries and Meteor Crater ejecta, and in impact experiments [9, 11]. The stratigraphy in Marathon Valley is consistent with a lower unit of distal ejecta from one or more older craters overlain by proximal ejecta from Endeavour Crater.

Noachian alteration: Several alteration episodes of Noachian to Early Hesperian age affected the Endeavour rim [4-6, 14, 15]. The oldest is Si-Al-rich vein formation in the Matijevic formation [15]. Silica-Al+Ge-rich veins occur as curvilinear red zones cutting the lower Shoemaker formation in the Marathon Valley region [16, 17]. A linear array of Si-Al-rich
pitted rocks occupy a fracture system in Perseverance Valley within an area of lower Shoemaker rocks [3, 18]. Based on our interpretation of the lower Shoemaker, all occurrences of crosscutting Si-Al-rich veins are in pre-Endeavour rocks [7], implying this alteration style was restricted to the Noachian bedrock.

Endeavour rim rocks are basaltic in composition and overlap the Martian basalt field (Fig. 2). The “purple rocks” represent a fine-grained, homogeneous lithology of uncertain origin found scattered at several locations. They might be evolved igneous compositions, or an altered composition formed under low water/rock, acidic conditions (blue arrows; cf., [19]).

The three lithologies that crosscut outcrops show evidence for compositional modification by alteration. The Lihir/Espérance veins that cut the Matijevic formation show the effects of alteration under higher water/rock conditions; two abraded targets plot nearest the field for terrestrial montmorillonites (Fig. 2). We interpreted the Lihir/Espérance veins to have formed as a mixture of montmorillonite and silica produced by moderate-temperature alteration of bedrock by circumneutral to mildly alkaline fluids [14]. The calculated end-member vein composition [14] plots within the montmorillonite field. Rocks from red zones show modest evidence for alteration; they are enriched in Al and Si, and sometimes Ge, compared to host bedrock [16]. One of the Perseverance Valley pitted rocks is similar to the purple rocks, while others express compositional evidence for alteration.

The second oldest alteration event on Endeavour rim is low-water/rock alteration along the unconformity between the Matijevic and Shoemaker formations, forming veneers on the former. Ferric smectites are inferred to occur in these veneers [4], which post-date the Si-Al-rich veins [15]. Ferric smectites occur within the lower Shoemaker rocks of Marathon Valley [20], but their temporal relationship with the red zones has not been established. Thus, ferric smectites are associated with the pre-Endeavour bedrock. In the walls of Iazu Crater, ~25 km south of Endeavour, ferric smectites are observed in Noachian-aged basaltic-composition rocks underlying layered sulfates of the Burns formation [20], lending support to a Noachian age for ferric smectite alteration.

Key findings: Clast-poor, fine-grained breccias of the lower Shoemaker formation are identified as a pre-Endeavour lithology, expanding the extent of Noachian bedrock, and providing ground-truth for the orbitally-defined Noachian subdued crater unit. The oldest identified alteration event is formation of, Si-Al=Ge-rich veins by circumneutral to mildly alkaline hydro-

![Figure 2](image-url)  
**Figure 2.** Alteration diagrams for Si-Al-rich crosscutting veins in pre-Endeavour bedrock.