THE AMAPARI MARKER BAND, GALE CRATER, MARS: METAL ENRICHMENTS AND POTENTIAL MECHANISMS OF FORMATION.

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Introduction: The Amapari Marker Band (AMB) is a unique resistant feature in the sulfate-rich Mirador formation (Mf), and is a feature that spans Mt Sharp, the central sedimentary mound within Gale crater, Mars [1]. From orbital observations, the AMB appears darker and retains craters, exhibits a high-Ca pyroxene signature, and varies in thickness [1]. The AMB was initially interpreted as a volcanic or more indurated sulfate deposit [1–2]. NASA *Curiosity* rover data has shown the AMB is a chemically and sedimentologically unique feature in the stratigraphy and only a thin interval in the Mount Sharp group (MSg) sequence [3–10]. The sedimentary textures and chemistry of the units above (Chenapau member) and below (Catrimani and Contigo members) the AMB are very similar but differ in mineralogy (Mg-sulfate in Catrimani [11] and siderite+Mg-sulfate in Chenapau [12]).

Methods: *Curiosity* crossed through the AMB twice (Fig 1). Four drills were attempted on the ripple unit before a successful drill at 'Tapo Caparo' at the top of the laminated unit. We use indices of alteration (Chemical index of alteration, CIA; Mafic index of alteration, MIA; Index of Laterization, IOL) corrected for Na, Ca, and Mg salts to track alteration in the AMB [13].

Results: The AMB in this region is composed of layers of thinly laminated resistant material (lowest to highest): ripple unit (5–25 cm thick), nodular laminated unit, and laminated unit (30–60 cm thick; Fig 2 [10]). Just below the AMB, two ChemCam targets of the bedrock reveal a high frequency of sulfate veins. Western strata materials have MSg-like laminated textures. Chenapau member is similar to other Mf cross-stratified sandstones.

ChemCam observed an abrupt change in chemistry at the AMB, where the ~17.5 wt% FeO_T in Catrimani member targets increases to ~27 wt% FeO_T in the AMB ripple unit. Many points are highly enriched in MnO up to ~6 wt%, and a positive FeO_T and MnO trend is observed. CaO in the bedrock increases, and MgO decreases compared to Catrimani member targets. Sulfur decreases to average Gale in the AMB. Within some points, ChemCam observes an increase in Zn, and Cl, as does APXS [8]; e.g., the Coimin nodular target has elevated Fe, Mn, Zn, and Cu in the same two observation points. The second crossing ripple unit targets are similar to the first, but the Cl content decreases to typical Gale values.

Within the Western strata, FeO_T and MnO decrease to MSg-like compositions, while CaO remains elevated.

MgO increases but remains much lower than the Mg-sulfate rich material of Catrimani [9]. The Marker Band top layers have similar composition to the Western strata.
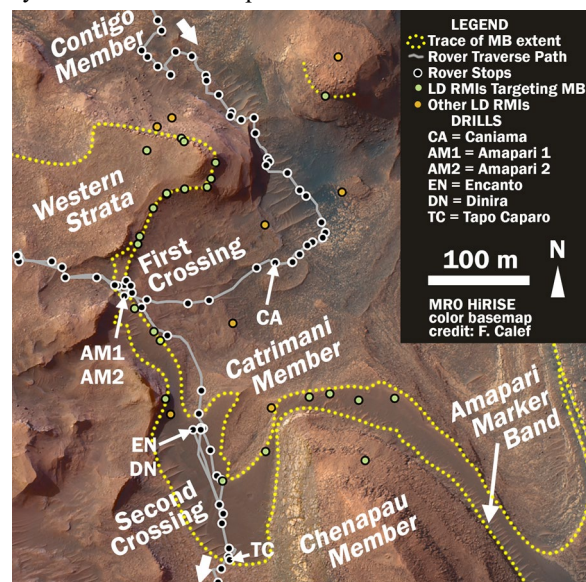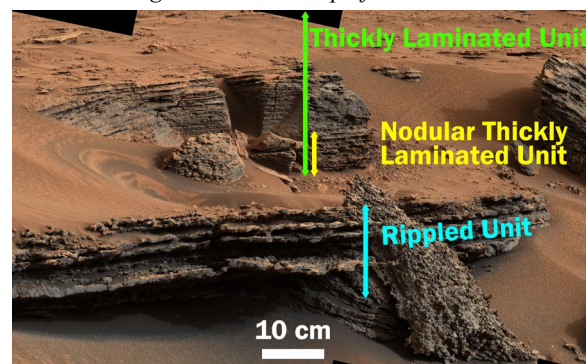

Fig 1: Overview map of the AMB.

Fig 2: AMB layers observed at the first crossing with units labeled. Image credit: NASA-JPL/MSSS.

The FeO_T, MnO, and ZnO content of the laminated unit is much less than in the ripple unit. Notably the nodules still retain high FeO_T and ZnO in some cases but have very low MnO content [9].

ChemCam targets and APXS data on the drill tailings [8] show that the CIA of all units in the AMB is low, except in Tapo Caparo which is slightly elevated. The oxidized

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MIA and IOL is elevated in ripple unit targets and drill tailings, which decreases in the laminated and Tapo Caparo targets. There are clear oxidation and laterization trends in the AMB data (Fig 3).

Discussion: The ripple unit has been interpreted as having formed in a shallow lake environment exposed to the atmosphere [10]. The overlying thickly laminated unit implies that the shallow lake at this location became deeper over time [10].

The high FeO_T, MnO, and ZnO enrichments are unique compared to previous Gale crater results and changes to these elements occur over very thin horizons in the AMB [9]. Thin bedding of redox sensitive elements is common on Earth near redox fronts [e.g. 14]. However, Zn is not a redox sensitive element, and only occurs in ferromanganese materials with a strong correlation with Mn due to Mn oxide scavenging of Zn [e.g., 15]. Zn requires a shift to higher pH to precipitate from a fluid.

Hence, the working hypothesis based on the oxidative and laterization trends (Fig 3), with Zn enrichments is to consider three formation scenarios AMB metal enrichments that could incorporate both redox and pH fronts: ferromanganese concretions, laterites, and ironstones. Ferromanganese concretions can form subaerially or subaqueously in thin beds on Earth due to redox cycling in the subsurface, but Zn enrichments only occur with high Mn oxide as well [e.g., 14]. AMB nodules have high Fe and Zn, with Mn in the ripple unit and with depleted Mn in the nodules, so we can likely rule out ferromanganese concretions as a formation scenario. Basalt-derived laterites on Earth can have very high Fe, moderately enriched Zn, and Mn oxide enrichments over thin oxidized horizons [e.g., 13,16]. The relatively low IOL for the AMB implies it is weakly laterized (Fig 3B). However, this implication does not hold up against the minor element trends between FeO_T and e.g., TiO_2; low TiO_2 in the AMB could imply an extreme level of laterization [9]. In these situations, Al and Ti are mobile and Zn trapped in refractory Ti phases will enter solution [16]. Thus, the AMB is not fully compatible with a laterization model. Lastly, ironstones form by upwelling warm fluids that cross a chemical front and coat grains with phases including hematite, chamosite, and siderite and can preserve textures, including wave ripples [14].

Conclusions: The stratigraphy of Contigo and Catrimani members suggests that a shallow water table rose throughout the section [10]. This water would have a high concentration of sulfate to produce the crystalline sulfates observed just prior to the AMB. If this groundwater was slightly acidic and moderately reducing, it would have been able to transport Fe, Mn, and Zn [9]. While the laterization scenario and others cannot be fully ruled out at the AMB, we hypothesize in one scenario akin to ironstone formations. An upwelling groundwater encountered a chemical front at the ripple unit in the AMB to promote Fe, Mn, and Zn precipitation at higher pH and perhaps higher oxidation, and coated grains, cementing the ripple unit [9]. If Mn concentration is low relative to Fe and Zn, in the presence of CO_2 at a chemical front deep within a stratified lake, nodules that are enriched in Fe and Zn, but not Mn, could form the nodular laminated unit [9]. Chemically stratified lakes are locations where microbial communities thrive on Earth [e.g., 17], and thus this lake may have been a habitable environment.

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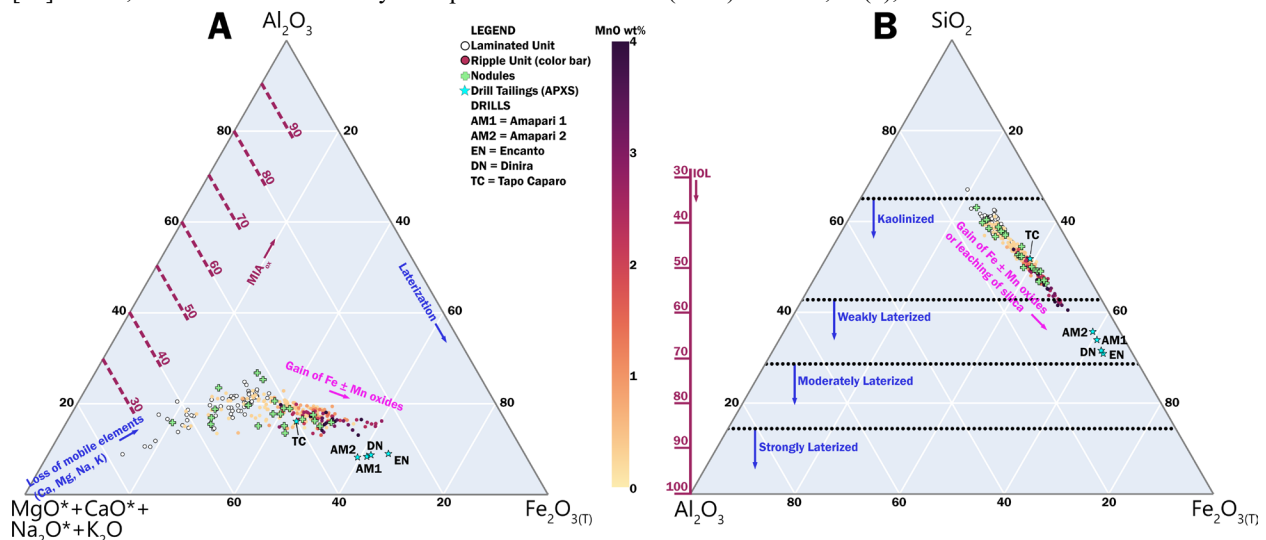

*Fig 3: A) Oxidation and B) laterization trends in AMB materials. *Oxides corrected for salts.*