EPSC Abstracts
Vol. 13, EPSC-DPS2019-445-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Organic matter preservation potential at the ExoMars 2020 landing site: a preliminary assessment

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Abstract

We investigate the mineralogy and associated aqueous alteration settings for the ExoMars 2020 landing sites, specifically the Noachian clay sediments and paleosols, so as to assess their potential for sequestering organic matter on geologic timescales. Their suitability for the ExoMars rover science goals is discussed pending additional feedback from the geo/exo-biology communities.

1. Introduction

The ExoMars rover mission will study the rock record of early Mars in search for organic matter and possible bio-signatures [1]. Of critical importance for the science return are the properties of the landing site chosen for the mission. After a long selection process, Oxia Planum has been selected as the nominal site, with Mawrth Vallis as backup [2]. We present the large-scale environments that have been inferred from orbit, e.g. soils and clay-rich sediments, with a special focus on the organic matter retention and preservation potential of these formations.

Both Oxia Planum and Mawrth Vallis straddle the margin of the Chryse Planitia basin, at the planet's crustal dichotomy boundary. Both have been ascertained to constitute records of ancient environments (at least Late Noachian > 3.8 Gya, probably older) in which hydrous clay minerals and other secondary phases formed and/or were deposited. Both sites are likely part of a large smectite clay-rich expanse of several 1000s of km, suggesting a regional, if not a global alteration process in a water environment at/near the surface [3]. This 100s of meters thick clay unit is layered (at the meter scale, at least), suggesting these may be clay-bearing sediments. The finer details remain elusive: what was the parent material? Was the clay material transported or formed in-situ during/after deposition? For how long or how recurrently did this sedimentary process take place?

2. Mineralogy

A primary driver for the site selection process was the presence of hydrous minerals (hydrated/hydroxilated species formed through water-rock interactions), indicating past water-bearing environments. Clay minerals are also known to trap/store organic matter and likely played an active role for the emergence of life on Earth. While the nature of the rock cannot be determined, high (10s %) abundances of clay and other hydrous minerals have been found at both sites [4]. Oxia Planum exhibits mostly homogenous clay mineralogy throughout the landing ellipse (over 100 km wide) which is representative of the bulk of the clay mineralogy elsewhere at Mars as inferred from orbit. Some mineral variability is found at the meter scale in some places within the landing ellipse, in particular towards its easternmost edge where a delta-fan has been reported [5]. In contrast, Mawrth Vallis exhibits a high diversity of hydrous minerals including smectite clays, kaolins, sulfate salts, hydrated silica, allophane, and hydroxides, all accessible within the ellipse [6].

3. Geologic setting

While they likely share, at least partly, the same alteration history, striking differences exist between the sites. Mawrth Vallis presents compelling evidence for past pedogenesis [7]: the vertical zonation of the upper 10s of meters is consistent with soil horizons having developed atop a diverse sedimentary record. This paleosol unit exhibits the most mineral diversity with clays, oxides, salts and clay precursors [8]. By contrast, there is scant evidence for top-down weathering at Oxia Planum, which is thought to mainly comprise a sedimentary unit. There, subtle variations in the sedimentary clay unit may hint at some diversity in the depositional environments or of limited post-depositional alteration, but to a lesser extent than at Mawrth Vallis.

Regional scale post-sedimentary ponding at Oxia Planum is attested by the presence of deltaic deposits rich in hydrated silica [5]. Mawrth Vallis did also experience late-stage but localized ponding as the clay units are incised and topographic lows appear to have allowed pools of water to exist there, and in some cases led to the precipitation of salts.

The clay mineralogy of the sedimentary stack also differs: while Oxia Planum exhibits intermediate Fe-Mg, 2:1 di-tri smectitic/mica phyllosilicates such as vermiculite and some hematite, Mawrth Vallis mostly displays Fe^{3+} 2:1 nontronite smectites, with some strata containing smectitic micas and Fe^{2+}-rich smectites. These differences may result from subtle differences in geochemical conditions, although a preservation/exhumation bias cannot be excluded at this stage. Whether these sediments were deposited subaerially or subaqueously for any or both sites cannot be ascertained confidently from orbit.

4. Organic carbon potential

The likelihood that these sites may have been habitable or that they have efficiently concentrated, retained and preserved organic matter still remains to be thoroughly assessed. What is certain however is that their geologic and mineral distinctiveness translates into a dissimilar likelihood of finding organic matter and bio-signatures [9]. This should be the main science driver for the site selection process of ExoMars 2020.

On Earth, clay-rich marine & deltaic sediments (black shales prominently) are able to retain several wt% of organic carbon over geologic timescales [9-13]. Soils are also recognized as being able to retain similar amounts of organic carbon, but long term storage and preservation is less constrained. Paleosol with organic matter are known to exist however and their exobiological potential is being investigated [e.g. 9,14]. Soils additionally have an inheritance capability wherein remnants of the older unit (sediments) are incorporated into some soil horizons and may therefore also be accessible to a rover.

For both environments (except in deep marine sediments), because most of this carbon consists in biodegraded remains of land biota and soil microorganisms, similar values should not be expected on Mars. Concurrently, biodegradation (if it existed) was likely limited on Mars, whereas it is a major source of loss of organic carbon in terrestrial soils. Burial-induced degradation in sediments was also likely more limited at Mars which does not have any plate tectonics.

Regardless of the intrinsic preservation potential of each type of aqueous setting, the accessibility by the rover must be taken into account: the full temporality offered by the thick sedimentary stack will not be accessible by a rover with a limited range and traversability within stratigraphic windows. Some deposits such as the siliceous deltaic sediments of Oxia Planum may not be accessible either.

Altogether, these uncertainties highlight the crucial need for additional feedback from the geobiology and exobiology communities.

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