THE CASE FOR HYDROTHERMAL SEAFLOOR-TYPE DEPOSITS IN THE ERIDANIA BASIN ON MARS.

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Introduction: Eridania basin is composed of a series of connected, smaller, quasi-circular basin, which potentially originated as very ancient impacts that were resurfaced by volcanism and erosion early in Mars' history [1]. The extent of the Eridania basin was previously defined as the 1,100 m elevation contour around these sub-basins [1] (Figure 1). Irwin et al. deduced that the Eridania basin was once filled to this level because it is at this elevation that the 3-km-wide Ma'adim Vallis outflow channel originates (Figure 1), and suggested that the basin was likely filled to a lower level for some duration of time. Previous researchers noted that Noachian valley networks also terminate at an elevation of ~ 700–1,100 m [1-2], suggesting the existence of an ancient base level. If a water level existed between 700 and 1,100 m elevation, the basin topography implies that the parts of the lake would have been 1–1.5 km deep. The approximate size of such a body of water would have been ~ 1.1 × 10^6 km^2, 3 × larger than the largest landlocked lake or sea on Earth (Caspian Sea). In fact, even a conservative estimate of the volume of the Eridania sea exceeds the total volume of all other open basin lakes on Mars combined [3]. Here we synthesize previous work and provide new analyses of the mineralogy, geology, and context of the most ancient deposits in Eridania basin, which we argue formed in a deep-water hydrothermal setting [4].

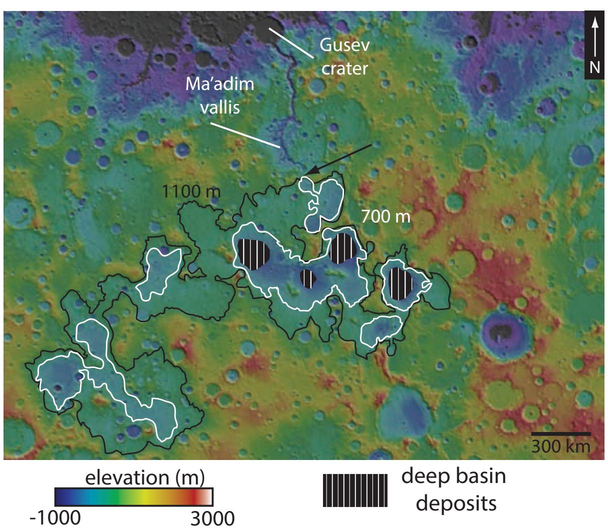

Figure 1: Eridania is located at the boundary of Terrae Cimmeria and Sirenum (180E, 30S).

Deep Basin Deposits: Unique deposits found only at the centre (deepest part) of each basin consist of fractured and dismembered blocks ~ 0.1–10 km diameter (Figure 2). While these deep basin units are in some cases formally named 'chaos' and in other cases, 'colles,' there are some clear and important geological differences among the deposits that are not reflected in the naming convention and often confused in previous work. Most importantly, the fractured blocks in the western and central parts of Eridania, as we argue in this paper, represent ancient, deep basin subaqueous units and those in the eastern parts of the basin are younger, eroded volcanics deposited subaerially.

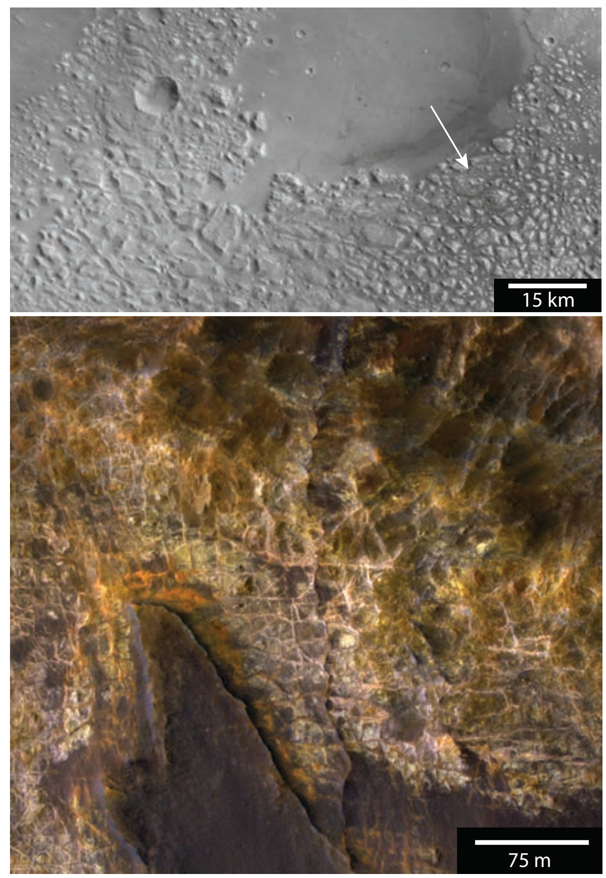

Figure 2: HRSC data show Atlantis chaos blocks (top) and HiRISE IRB false color data show mottled colors and boxwork veins within these deep basin deposits. These materials are massive (not bedded) and contain Fe and Mg-rich phyllosilicates.

Mineralogy of the deep basin deposits: CRISM spectra acquired of the deep basin deposits throughout the western and central Eridania basin contain absorptions at (λ) ~ 1.4, 1.9 and 2.3 µm indicative of the presence of Mg-rich and Fe-rich clay minerals [5-7]. In detail, the spectra show several important characteristics: a) strong 1-2 µm slope suggestive of abundant Fe^{2+}, b) absorptions at 2.30-2.305 µm indicative of Mg-substitution in Fe-rich dioctahedral clays, c) absorptions at 2.305-2.315 µm suggesting Fe-substitution in Mg-rich trioctahedral clays, d) absorptions at 1.39, 2.315, 2.43 and 2.51 µm in some deposits suggest the presence of serpentine or serpentine-smectite mixed-layered clays, e) an unusual doublet absorption at 2.32 and 2.38 suggestive of Fe-rich serpentine- or chlorite-group minerals, f) strong absorptions at 2.31 and 2.51 µm indicative of carbonate, and g) strong absorptions at 1.9 and 2.24 µm indicating the presence of hydrated silica. In addition, some deposits contain absorptions at 2.265, 2.41, 2.46 and 2.51 µm consistent with the occurrence of jarosite, which might be an indication that sulfide minerals occur with the clays, and weathering Fe-sulfate at the martian surface. Lastly, previous researchers have also identified chloride salts [8] in the area, but the chlorides uniquely occur at high elevations around the margin of the basin [4].

Summary: The deep basin deposits are unsual on Mars. The deposits are thick (>400 m), voluminous, massive (lack bedding), vein-filled, mottled, and highly altered (Figure 2). The most plausible way to produce such large volumes of massive, deep basin, deep water deposits is through seafloor volcanic-sedimentary processes focused in the basin floors where fractured, thinner crust and higher heat flow would be expected.

We conclude that thick, massive, clay-, carbonate- and likely sulphide-bearing deposits in Eridania basin formed in a deep-water hydrothermal environment on ancient Mars (>3.8 billion years ago) [4]. The clay assemblages and spectral trends observed in seafloor deposits on Earth provide a good analogue for the deep basin deposits detected remotely in Eridania [9-10]. Salts only observed at higher elevations likely represent coastal evaporative settings (Figure 3). Several lines of evidence strongly suggest that Eridania was a sustained inland sea in the late Noachian.

The deep-water environment was likely reducing based on direct evidence for Fe^{2+}-rich clay minerals and indirect evidence for Fe-sulphides. This could be an indication of stratification of an ancient sea beneath an oxidized atmosphere, chemical isolation in an ice-covered sea, or quasi-equilibrium with a reduced atmosphere. The ancient Eridania sea deposits might represent a setting analogous to Fe-rich sea environments present on the early Earth.

Implications: Ancient, deep-water hydrothermal deposits in Eridania basin represent a new category of astrobiological target on Mars. Recently, the search for habitable environments on Mars has been focused on exploration of ephemeral playa and shallow lacustrine settings. The Eridania deposits represent an ancient environment rich in chemical nutrients and energy sources. Such a deep-water environment would have been protected from harsh surface conditions and ideally suited for preservation of organic matter under reducing conditions. In fact, the earliest evidence of life on Earth seemingly corresponds to seafloor deposits of similar origin and age, although the terrestrial counterparts are metamorphosed and metasomatized [11]. Eridania seafloor deposits are not only of interest for Mars exploration, they represent a window into early Earth [12].

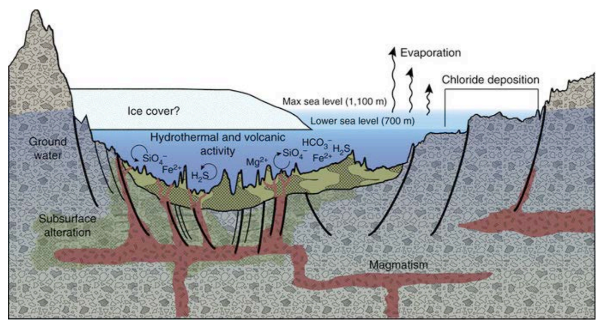

Figure 3: A schematic model showing actual topography in the Ariadnes colles area of Eridania and interpretation of the geologic context when a sea existed >3.8 Ga. Cross section is 450 km across.

References: [1] Irwin, R. P., et al. (2004), *JGR Planets* 109, E12009. [2] Hynek, B. M., et al. (2010), *JGR Planets* 115, E09008. [3] Fassett, C. I. & Head, J. W. (2008), *Icarus* 198, 37–56. [4] Michalski, J. R. et al. (2017), *Nature Comm.,* 8, 15978. [5] Noe Dobrea, E. Z., et al. (2008), *Eos Trans*., P32B03N. [6] Wendt, L., et al. (2013), *Icarus* 225, 200–215. [7] Adeli, S., et al. (2015),. J *JGR Planets* 120, 1774–1799. [8] Osterloo, M. M., et al. (2010), *JGR Planets* 115, E10012. [9] Cuadros, J. et al. (2013) *Chem. Geol*. 360–361, 142–158. [10] Michalski, J. R. et al. (2015), *EPSL* 427, 215–225. [11] Manning, C. E., et al. (2006), *Am. J. Sci.* 306, 303–366. [12] Michalski, J. R. et al. (2017), *Nature Geo*. 11, 21–26.