

MINERALOGY OF MARS ANALOG EXPLORATION TARGETS IN THE TODILTO FORMATION.

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Introduction: The Todilto Formation is a mid-Jurassic carbonate-sulfate evaporite sequence in NW New Mexico and SW Colorado [1,2,3]. Despite great extent ($>150,000 \text{ km}^2$), the Todilto is thin ($<37 \text{ m}$) and in general mineralogically simple, with basal limestone and upper carbonate plus Ca-sulfate (gypsum in outcrop, anhydrite where buried beneath the Colorado Plateau). The Todilto was emplaced by rapid marine flooding of the underlying Entrada Formation dune field [4]. Comparable flood events on Mars may account for some Ca-sulfate deposits seen from orbit [5].

Todilto Mineralogy: The basal limestone is laminated calcite with minor gypsum, kaolinite, and detrital quartz; thin bituminous laminae may occur along fissile partings (Figure 1). The overlying evaporite grades to a “chicken wire” fabric of gypsum nodules separated by septae of calcite and rarer dolomite.



Figure 1: Laminated basal Todilto; fine-grained calcite with detrital quartz (clear grains). Minor gypsum and kaolinite are associated with dark, bituminous bands.

Todilto outcrops are essentially calcite plus gypsum, but they locally include many other minerals. In the Grants uranium district uraninite is syngenetic in the basal limestone, along with ~26 other authigenic minerals [2,6] and including the type locality of santafeite, a Mn-vanadate [7]). The basal carbonate often has Fe-oxide and oxyhydroxide pseudomorphs after pyrite, an organically mediated sulfide that formed beneath microbial mats in Todilto playas [2]. Biological components were not trivial; where the Todilto is deeply buried, oil has migrated into underlying Entrada sandstone to form commercially productive deposits [8]. Even in weathered outcrops total organic carbon (TOC) in laminated Todilto carbonate may be ~1%, likely derived from algae and bacteria [1].

In general, unique mineralogy and high TOC are associated with carbonates and not with the gypsum. However, Fe-rich gypsiferous bodies can occur within

contorted laminar calcite below the carbonate-sulfate transition (Figure 2). The dm-scale Fe-rich bodies preserve some pyrite, albeit mostly replaced by goethite pseudomorphs. The Fe-rich bodies do not preserve bituminous matter but the pyrite, out of equilibrium in its present association, is a vestige of microbial reducing environments.

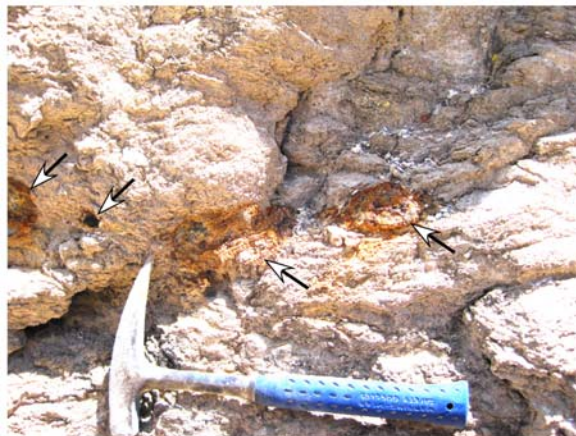


Figure 2: Fe-rich inclusions (arrows) in upper contorted, laminated carbonate facies of the Todilto Formation.

Exploration Targets: The simple composition of the Todilto is generally monotonous; in such a setting it is likely that exploration would zero in on features such as the basal layers or Fe-rich bodies shown here. The draw to these is in part because they simply stand out in imaging and in part because they represent contact or interface assemblages where initial low-salinity deposition or redox boundaries were present. Similar features might be encountered on Mars, although oxidation at the martian surface could destroy both bitumen and pyrite [9]. Nevertheless, Mössbauer data indicate a range of oxidation and suggest preservation of Fe-sulfide [10]; detection of bitumen or pyrite in evaporite sediments could provide pointers to past life.

References: [1] Kirkland D.W. et al. (1995) *NM Bur. Mines and Min. Res.*, Bull. 147. [2] Armstrong A.K. (1995) *NM Bur. Mines and Min. Res.*, Bull. 153. [3] Vaniman D.T. et al. (2007) *LPS XXXVIII*, Abstract #1404. [4] Ahmed Benan C.A. and Kocurek G. (2000) *Sedimentology*, 47, 1069-1080. [5] Gendrin A. et al. (2005) *Science*, 307, 1587-1590. [6] Granger H.C. (1963) *NM Bur. Mines and Min. Res.*, Memoir 15. [7] Sun M.-S. and Weber R.H. (1958) *Am. Min.*, 43, 677-687. [8] Ross L.M. (1980) *Oil & Gas Jour.*, Nov. 3, 102-110. [9] Davila A.F. et al. (2008) *EPSL*, 272, 456-463. [10] Morris R.V. et al. (2008) *JGR*, 113, E12S42, doi: 10.1029/2008JE003201.