

MINERALOGICAL EXAMINATION OF THE BOXWORK UNIT (ALTADENA MEMBER), GALE CRATER, MARS BY THE CHEMIN X-RAY DIFFRACTOMETER.

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Introduction: The Mars Science Laboratory *Curiosity* rover landed in Gale crater in 2012 with the goal of exploring the past habitability of Mars. In 2014, *Curiosity* began driving up Mount Sharp, the central mound of the crater, to assess the implications for past habitability of the increasingly younger sediments in this central mound. On Sol 4534 (May 8, 2025), *Curiosity* entered an area of prominent ridges (meter-scale) and hollows termed the “boxwork unit” (Figure 1). Orbital observations of the boxwork unit led to hypotheses that the ridges represent fracture zones cemented during aqueous alteration to become more resistant to Mars’ aeolian erosion than the intervening hollows [1, 2].

Curiosity’s campaign to understand the boxwork unit has included analyses by nearly all of its instruments, including diffraction (XRD) measurements by the CheMin instrument of material from three drillholes: a ‘background’ sample collected just after entering the boxwork unit, Altadena (AD); a bedrock sample in a hollow, Valle de la Luna (VL); and a sample of typical ridge material, Nevado Sajama, (NS) (Figure 1).

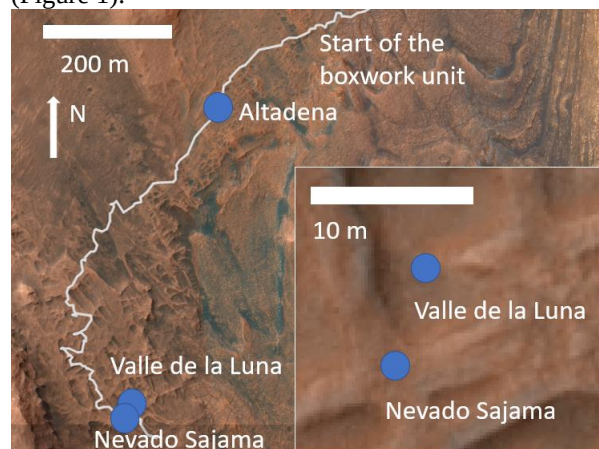


Figure 1. Map showing the start of the boxwork unit and the three drill sites where CheMin analyzed bedrock. Inset is a finer scale map showing locations of Valle de la Luna (VL) and Nevado Sajama (NS).

CheMin analyses: Quantitative mineral abundances and abundances of X-ray amorphous materials were determined in AD, VL, and NS using XRD by the CheMin instrument [3]. Calculations of the

chemical composition of the X-ray amorphous material are currently in progress [4]. To determine mineral abundances and unit-cell parameters of well-crystalline minerals, 1-dimensional XRD patterns are analyzed by Rietveld refinement using the JADE software (Materials Data, Inc.). For abundances of phyllosilicates and X-ray amorphous materials, XRD patterns are analyzed within FULLPAT [5]. Preliminary results are shown in Figure 2.

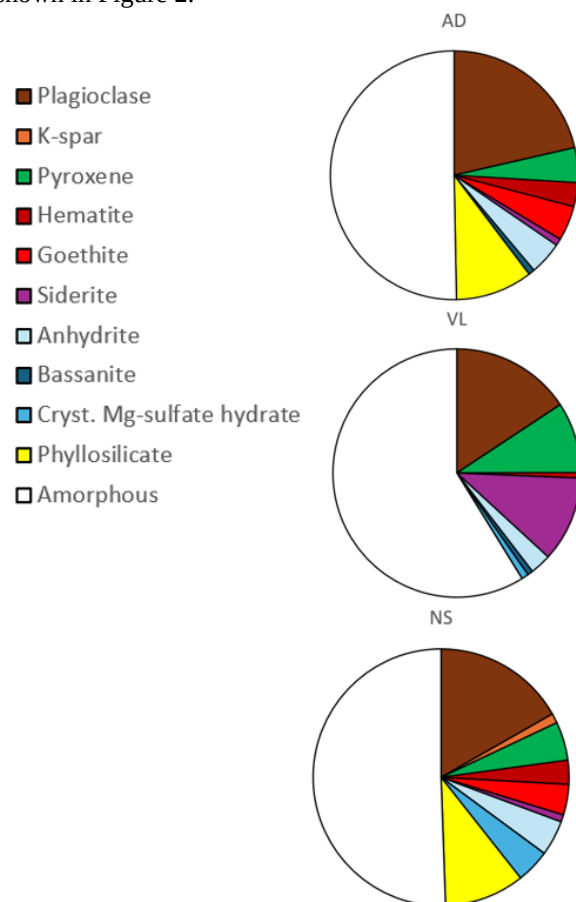


Figure 2. Pie charts, summing to 100%, of abundances of mineral and X-ray amorphous components in Altadena (AD), Valle de la Luna (VL), and Nevado Sajama (NS).

Comparisons among samples. All three samples consist of ~50% X-ray amorphous material and ~20% plagioclase (Figure 2). Compared to AD and NS, the

hollows sample VL contains: abundant siderite; nearly no ferric oxy(hydr)oxide (hematite, goethite); nearly no anhydrite; no phyllosilicates; and considerably more pyroxene.

Implications of mineralogy for formation of the boxwork unit: The ridges of the boxwork unit could represent fracture zones that were cemented by fluid flowing through them, thus making the fracture zones and surroundings more resistant to erosion [1, 2]. *In situ* observations emphasize: the small topographic differences between the ridges and the hollows and the relatively large changes in elevation among the ridges [6]; the ridge and hollow morphology and diagenetic textures [7]; and the presence of the nodules [8]. However, chemical analyses by the APXS and ChemCam instruments show small and non-systematic differences in composition between ridges and hollows [9].

CheMin analyses of the boxwork unit samples yield insight into their potential formation mechanisms. The number of moles of iron in the siderite in VL is approximately equal to the number of moles of iron in the goethite and hematite combined in AD and NS. This indicates changes in oxidation state between the siderite-containing and iron oxy(hydr)oxide-containing materials, consistent with formation of the goethite and hematite from siderite (see [10, 11]). The presence of both goethite and hematite can constrain the pH and temperature of alteration of AD and NS, as proposed for the rocks in the clay-sulfate transition [12].

If AD, VL, and NS formed from a similar parent material (which seems likely because their bulk compositions are similar [9]), the lower abundances of pyroxene in AD and NS could indicate greater aqueous alteration; pyroxene would be expected to dissolve more rapidly under more acidic conditions, i.e. pHs of ~3-6.5 [13]. This suggests that the clay minerals in AD and NS could have formed by aqueous alteration of original pyroxenes which is consistent with the volumes of the pyroxene and clay minerals measured by CheMin.

Although the higher abundances of clay minerals in AD and NS (samples not from hollows) could make the ridges less resistant to erosion, the presence of the iron oxy(hydr)oxides could make them more resistant to erosion. For example, the presence of iron oxy(hydr)oxides in Vera Rubin ridge is interpreted to lead to enhanced resistance to erosion, although in Vera Rubin ridge no goethite was observed and hematite ranged from 2.9% (Rock Hall) to 14.7% (Stoer) [14].

Conclusions and future work: The *Curiosity* rover continues to explore the boxwork structure in the Altadena member, with an additional drill site and Chemin measurement planned, as well as investigations of the contact between the Altadena unit and the

Layered Sulfate unit. These additional measurements and modeling will help to interpret and build upon the observations of the Altadena unit. This evidence of aqueous alteration and therefore potentially habitable environments in younger sediments as *Curiosity* continues to ascend Mt. Sharp suggests that the period of martian habitability may have extended for much longer periods of time.

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References: [1] Siebach, K.L. and J.P. Grotzinger, (2014) *Journal of Geophysical Research: Planets*, 119 189-198. [2] Siebach, K.L. et al., 2026, this conference. [3] Blake, D., et al., (2012) *Space Science Reviews*, 170 341-399. [4] Simpson, S.L., et al., (in preparation). [5] Chipera, S. and D. Bish, (2013) *Advances in Materials Physics and Chemistry*, 3 47-53. [6] Dietrich, W.E., et al., 2026, this conference. [7] Seeger, C.H., et al., 2026, this conference. [8] Willcocks, F.M. et al., 2026, this conference. [9] O'Connell-Cooper, C. et al., 2026, this conference. [10] Hausrath, E.M. and A.A. Olsen, (2013) *American Mineralogist*, 98 897-906. [11] Tutolo, B.M., et al., (2025) *Science*, 388 292-297. [12] Rampe, E.B., (in final preparation). [13] Hausrath, E.M., et al., (2008) *Geology*, 36 67-70. [14] Rampe, E.B., et al., (2020) *Journal of Geophysical Research: Planets*, 125 e2019JE006306.