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## **Wet to Dry Depositional Environments Recorded in the Clay-Sulfate Transition Region in Gale Crater, Mars: Overview and Stratigraphic Context for Curiosity's Exploration Campaign**

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**WET TO DRY DEPOSITIONAL ENVIRONMENTS RECORDED IN THE CLAY-SULFATE TRANSITION REGION IN GALE CRATER, MARS: OVERVIEW AND STRATIGRAPHIC CONTEXT FOR CURIOSITY'S EXPLORATION CAMPAIGN.** L. A. Edgar<sup>1</sup>, J. Grotzinger<sup>2</sup>, C. Fedo<sup>3</sup>, M. Meyer<sup>4</sup>, W. Rapin<sup>5</sup>, W. Dietrich<sup>6</sup>, A. Bryk<sup>6</sup>, S. Gupta<sup>7</sup>, A. Roberts<sup>7</sup>, S. Banham<sup>7</sup>, J. Reahl<sup>2</sup>, C. Seeger<sup>2</sup>, D. Rubin<sup>8</sup>, G. Caravaca<sup>5</sup>, E. Rampe<sup>9</sup>, K. Lewis<sup>10</sup>, K. Stack<sup>11</sup>, R. Milliken<sup>4</sup>, J. Schieber<sup>12</sup>, A. Cowart<sup>13</sup>, J. Davis<sup>7</sup>, E. Kite<sup>14</sup>, L. Thompson<sup>15</sup>, C. O'Connell-Cooper<sup>15</sup>, J. Berger<sup>9</sup>, J. Frydenvang<sup>16</sup>, <sup>11</sup>A. Vasavada, <sup>11</sup>A. Fraeman. <sup>1</sup>USGS Astrogeology Science Center, Flagstaff, AZ, <sup>2</sup>Caltech, <sup>3</sup>U. Tennessee, <sup>4</sup>Brown U., <sup>5</sup>IRAP- CNRS, U. Toulouse, <sup>6</sup>U.C. Berkeley, <sup>7</sup>Imperial College London, <sup>8</sup>U.C. Santa Cruz, <sup>9</sup>NASA JSC, <sup>10</sup>Johns Hopkins U., <sup>11</sup>NASA JPL, <sup>12</sup>U. Indiana, <sup>13</sup>Planetary Science Institute, <sup>14</sup>U. Chicago, <sup>15</sup>U. New Brunswick, <sup>16</sup>U. Copenhagen.

**Introduction:** One of the key factors in selecting Gale crater as the landing site for the Mars Science Laboratory (MSL) mission was the ability to observe environmental transitions recorded in Aeolis Mons (informally known as Mt. Sharp). Orbital observations had revealed a vertical succession from strata that have abundant clay minerals to strata containing Mg sulfates [1], hypothesized to be tied to a shift from wetter to drier conditions. More recently, the Decadal Survey identified this question as central to Mars exploration: Did habitability persist through dramatic changes in the ancient climate? This work focuses on addressing the environments in which the clay-bearing and sulfate-bearing units were deposited, and what that implies about the evolution of the Martian climate. Here we provide an overview of Curiosity's exploration campaign through the clay-sulfate transition region and into the Mg sulfate-bearing unit (~Sols 3081-3755, elevation from -4072 m to -3850 m, investigated by the MSL science team from April 2021 to February 2023), and provide a summary of the sedimentological and stratigraphic context for the region.

**Geologic Setting:** For much of the mission, Curiosity has explored strata that were deposited in ancient aqueous environments, including fluvial [2], deltaic [3], and lacustrine [4-8] paleoenvironments. Prior to arrival at the clay-sulfate transition region, Curiosity investigated the Glen Torridon region, which showed evidence for lacustrine mudstones and fluvial cross-bedded sandstones, consistent with a lake margin depositional environment [8]. Directly below the strata summarized in this work, Curiosity explored a prominent outcrop of the Carolyn Shoemaker formation known as the Mercou member, which is interpreted to record ancient river bars in alluvial and shoreline environments [9]. Prior to arrival at the clay-sulfate transition, Curiosity conducted long distance imaging of the area, which predicted the presence of alternating eolian and subaqueous deposition [10], which could be tested as the rover investigated the area in situ.

**Exploration of the clay-sulfate transition and development of a stratigraphic column:** Curiosity's exploration campaign through the clay-sulfate transition

focused on sedimentological and geochemical analyses to investigate changes in depositional and diagenetic environments. Sedimentological interpretations were primarily based on data from Mastcam, Navcam, MAHLI, and the ChemCam Remote Micro Imager (RMI). Facies were identified based on sedimentary structures, texture, and grain size (where possible).

Through the course of the traverse, the MSL team identified one new stratigraphic formation and five new stratigraphic members (**Fig. 1**). As described below, a new formation was defined based on lithic characteristics that were distinct from the underlying strata. Members were identified on the basis of characteristics that were distinguishable from other parts of the formation, to recognize particular parts of a heterogeneous formation. Drill targets were selected to sample each distinct stratigraphic member.

**Sedimentology of the clay-sulfate transition:** Here we define 5 distinct stratigraphic members of the clay-sulfate transition region and into the Mg sulfate bearing unit.

*Pontours member.* The Pontours member represents the uppermost strata of the Carolyn Shoemaker formation. It is defined by palimpsest planar lamination in light-toned bedrock, crosscut by abundant veins and nodules (see [11-12] for more details of diagenetic features). This heavy diagenetic overprinting obscures observation of grain size, but the outcrop character is similar to underlying mudstones. It is interpreted to have formed in a marginal lake environment.

*Dunnideer member.* This member is also heavily diagenetically overprinted but is defined by the appearance of meter-scale cross-stratified sandstone. The Dunnideer member is expressed as more resistant outcrop compared to underlying strata, as seen in both rover and orbital observations. It is interpreted to record eolian deposition and defines the base of the Mirador formation.

*Port Logan member.* The Port Logan member is defined as a cross-stratified sandstone, which experienced a lesser degree of diagenetic overprinting. Bedsets range in thickness from decimeter to multiple

meters, representing the preservation of well-developed eolian dunes.

**Contigo member.** This member records continued deposition of cross-stratified sandstones and is defined by the occurrence of lenses of thinly bedded, locally ripple cross-laminated sandstones [13]. Lenses are laterally continuous over tens of meters. The bedset thickness thins towards the top of this member. The Contigo member is interpreted to represent an eolian dune field punctuated by periods of shallow interdune lacustrine deposition.

**Catrimani member.** This member represents a change to predominantly planar stratification. Due to a high degree of diagenetic overprint, grain size is indeterminate. It is interpreted to record an eolian sandsheet environment, possibly due to intersection with the water table limiting the ability to form dunes.

**Amapari member.** The Amapari member is a laterally continuous dark-toned interval that was first identified based on orbital geologic mapping [1], known informally as the Marker Band. It is defined by two distinct facies: a symmetrical-rippled facies overlain by a thickly laminated facies, both of which are interpreted to have formed in a shallow lake [13–16].

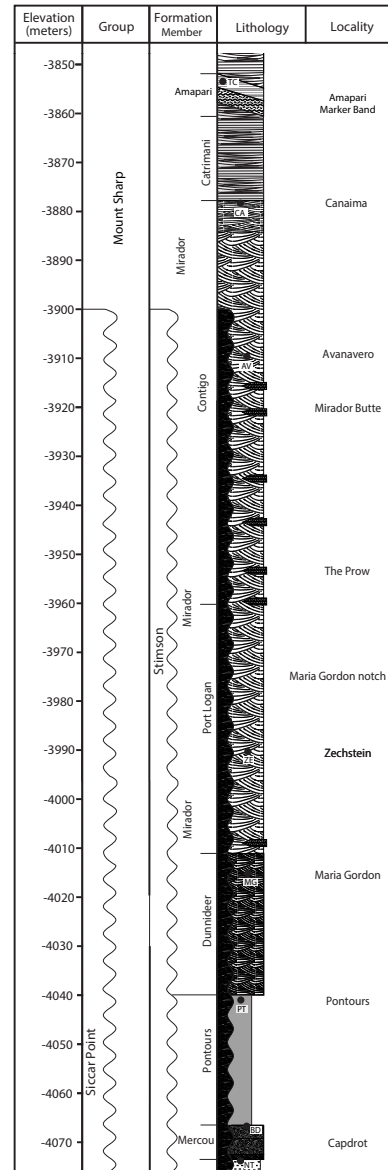
Strata above the Amapari member show a return to eolian deposition, as described elsewhere [17–18]. Mineralogy of the clay-sulfate transition region is described by [19], notably recording a decrease in phyllosilicates coincident with the appearance of cross-bedding at the start of the Mirador formation.

**Summary:** The clay-sulfate transition region records a variety of sedimentary environments, including eolian, fluvial, and lacustrine processes. The Mirador formation is dominated by eolian deposition, with intermittent wet episodes. Lenses of wave-rippled sandstone within the Contigo member and the well-developed wave ripples and thickly laminated facies of the Amapari member indicate that water was still available, but in limited and variable quantities. Wave-rippled facies indicate shallow water depths and the influence of wind, which point to ice-free conditions during their formation. While the Mirador formation generally records drier conditions than strata previously explored by the Curiosity rover, habitable conditions may still have been present, in limited duration.

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**Figure 1.** Stratigraphic column representing a log of the lithologies encountered along the rover's traverse through the clay-sulfate transition region, recording a change from lake margin facies to dominantly eolian deposition, with intermittent wet intervals. Degree of shading represents diagenetic overprint. Black circles correspond to drill holes.