Orientation of Calcium Sulfate Veins and Their Implications For Fluid Circulation Events at Gale Crater, Mars

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Introduction

The Curiosity rover has been observing white calcium sulfate **veins** that cross-cut sedimentary rocks at Gale Crater starting at Yellowknife Bay. They continue throughout >250m of the mudstone-dominated **Murray formation** and are also present in sandstones of the **Stimson formation**. The presence of these veins suggest a **complex fluid circulation history**; they are suggested to have formed after the lithification of the Murray and Stimson formations, representing ancient lacustrine and aeolian environments respectively. Understanding the formation of these veins can indicate a **relative timing** of subsurface fluid flow in relation to past habitable environments on Mars.

This work quantifies **vein orientations** located in the **Murray formation** of the **Bagnold Dunes area** in order to constrain possible emplacement mechanisms. If the veins were emplaced due to hydrofracturing, we expect to see definite consistent orientations. Seven sites were utilized in these analyses and were selected due to their good visibility and minimal dust coverage.

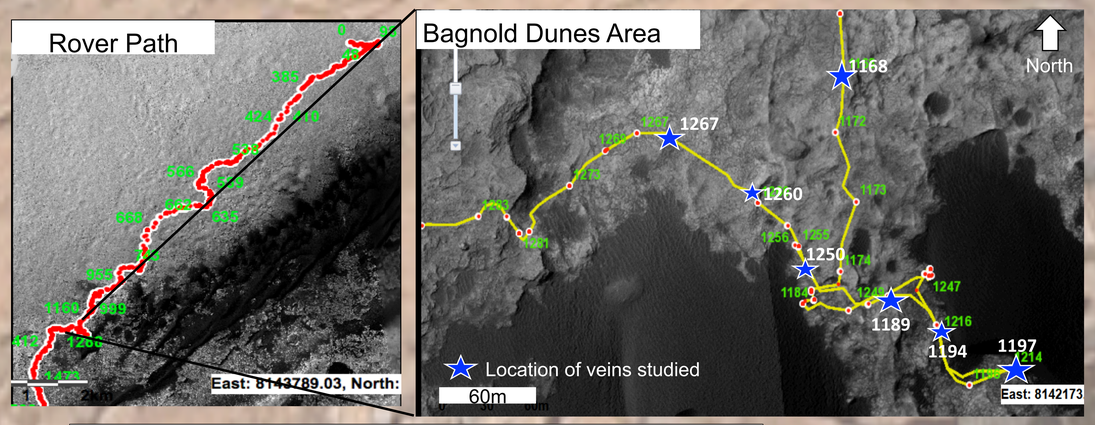

Fig. 1: Curiosity rover path on left and the Bagnold Dunes study area on right

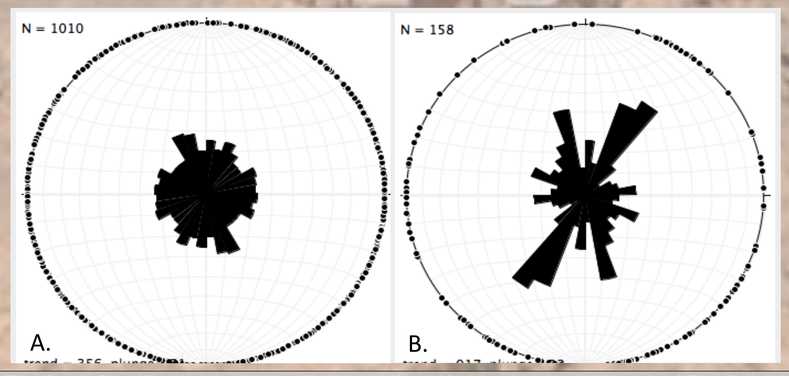

Fig. 3: (a) Combined orientations of all the veins (1010 measurements total, cf Fig. 4a). (b) Combined orientations of the widest veins (158 measurements total, cf Fig. 4b).

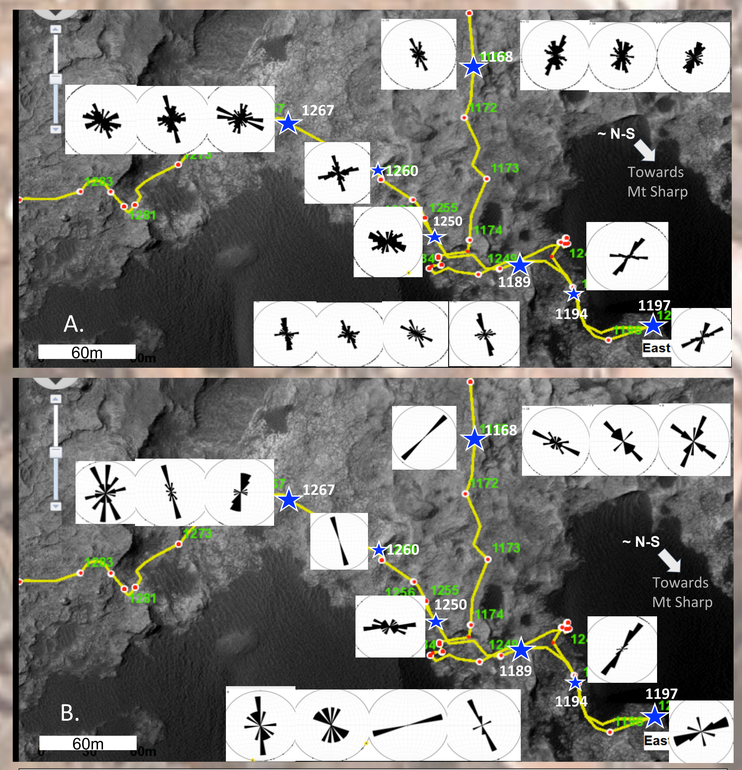

Fig 4: (a) Rose diagrams of all vein orientations depicted on an orbital image of the Bagnold Dunes area (b) Only widest vein orientations are displayed. Each diagram corresponds to a Mastcam image.

Observations and Results

- Vein orientations generally varied at individual sites and at the scale of the study as a whole
- Possible maxima of widest veins at 020° and 315° with respect to North
- Many curved veins observed across all vein widths
- Thin veins appear to be oriented perpendicular to wide veins
- Cross-cutting, offset, and branching veins of all widths observed
- Many veins have blocky, internal texture
- Fibrous veins also observed

Interpretation and Discussion

- No single orientation of the veins
- Horizontal least principal stresses (σ_3) are indicated for some of the veins
- Many vein orientations could suggest multiple generations of fractures
  - Presence of curved veins suggest at least 2 generations
- Many possible combinations of emplacement mechanisms:
  - Blocky vein textures indicate that some of the veins are from infill of pre-existing joints
  - Some intersecting geometries of fractures could be interpreted as mudcracks
  - Some vein patterns indicate faulting
  - Possible hydrofracturing, though little evidence in this study

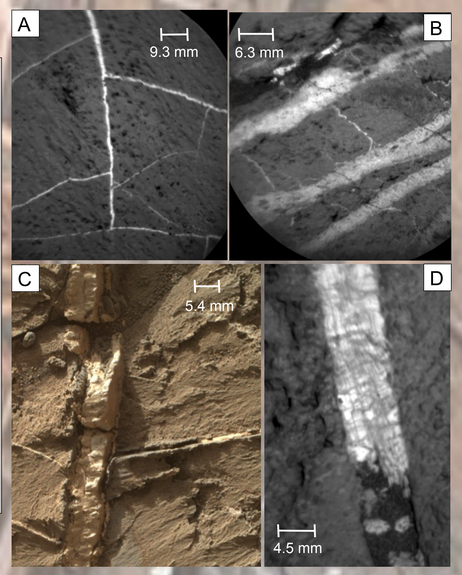

Fig 5: Examples of MAHLI and ChemCam images to illustrate vein textures and intersections between veins (a) Thin veins are oriented quasi-perpendicular to wide veins (b) Branching veins (c) Blocky internal texture (d) Fibrous vein texture

Methodology

- Each visible vein was numbered and categorized based off of its relative width:
  - The veins were logged on a 1-3 scale, 1 being thin and 3 being wide
  - They were then highlighted in colors representing their relative widths
- Each vein angle was measured with *ImageJ* and was then subtracted from the azimuth in order to find the vein's orientation with respect to North
- These orientations were plotted as rose diagrams in the program *Stereonets*
- Vein textures from ChemCam and MAHLI images were observed for fibrous and nonfibrous textures

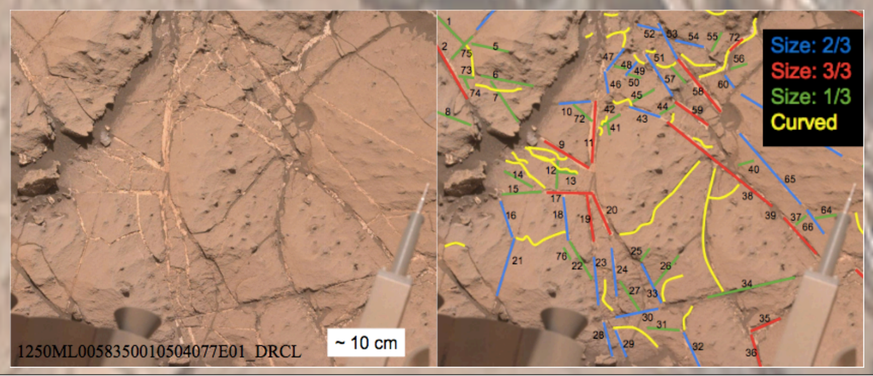

Fig. 2: Example of Mastcam image with and without annotations. Each vein measured is numbered and color coded to represent its relative width. Curved veins, in yellow, were not measured.

Acknowledgements

We are grateful to the MSL science, engineering, Mastcam, ChemCam, and MAHLI teams for enabling us to work with this data. This research was supported by the George '51 and Marjorie '44 Chandler Senior Experience Fund and the NASA MSL Mission, supported by JPL and Caltech through a subcontract with Malin Space Science Systems.

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