Overview of Secondary Phosphate Facies Observed by Chemcam in Gale Crater, Mars

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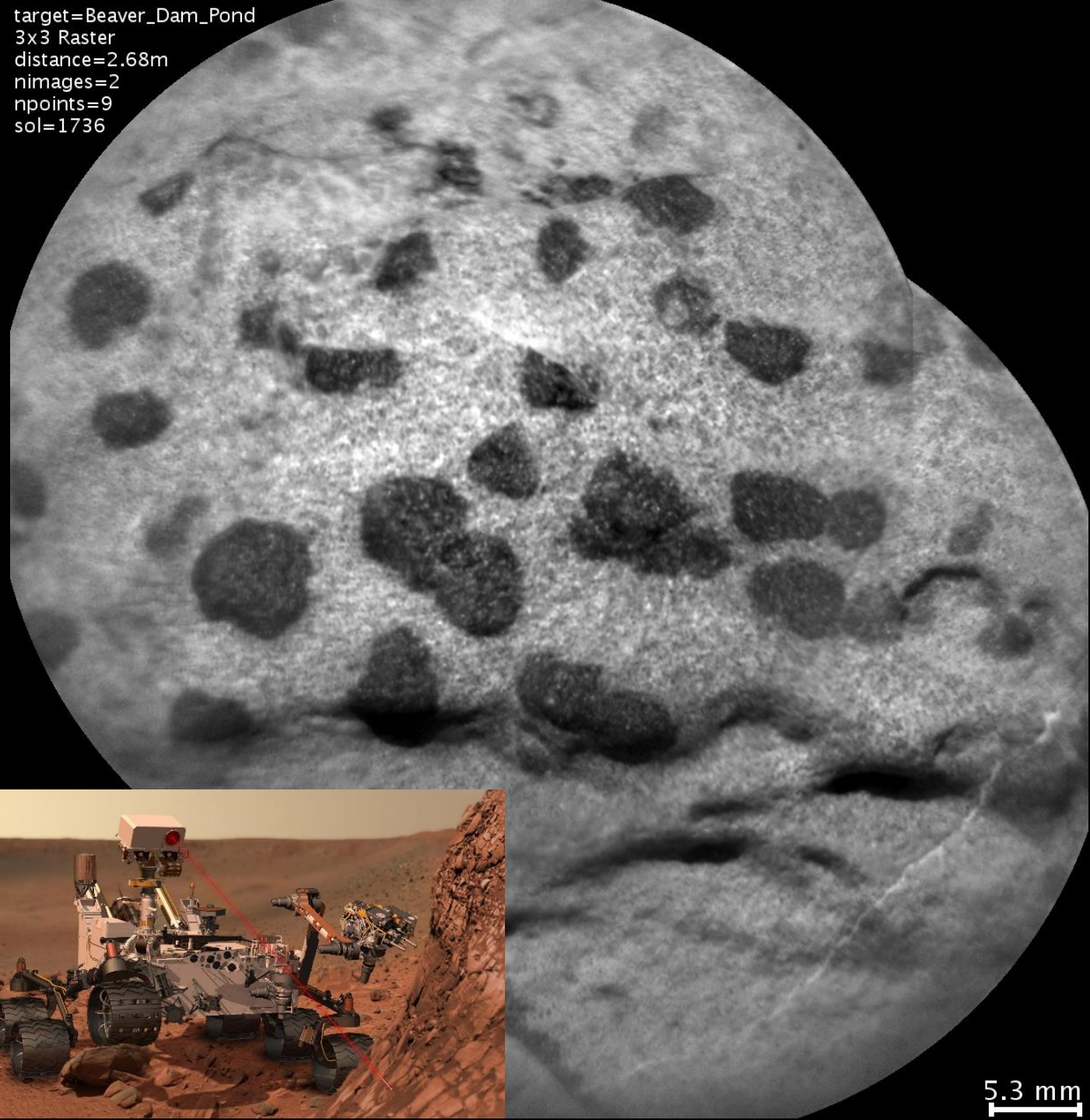
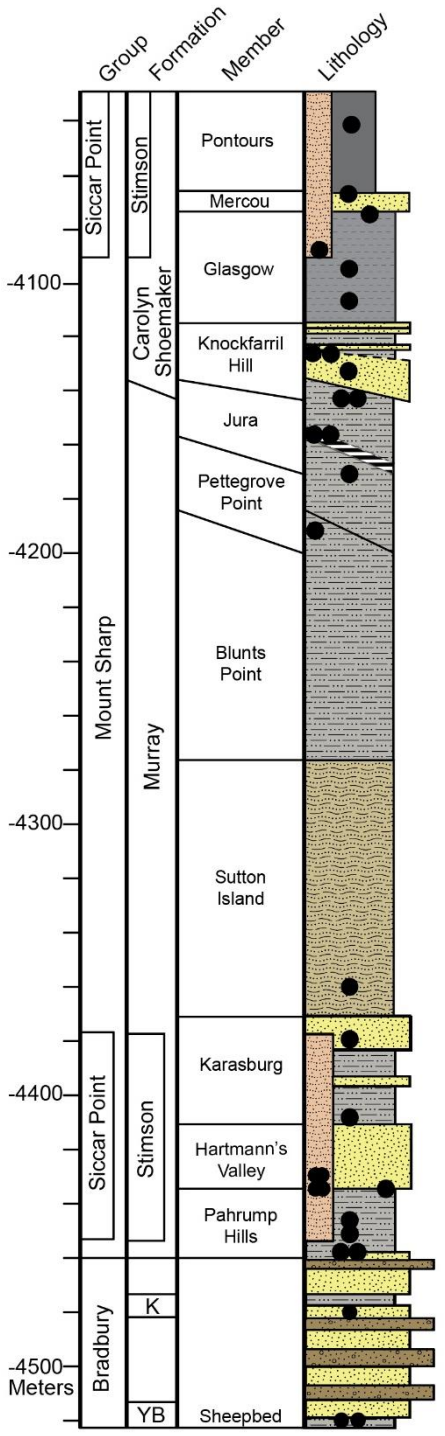


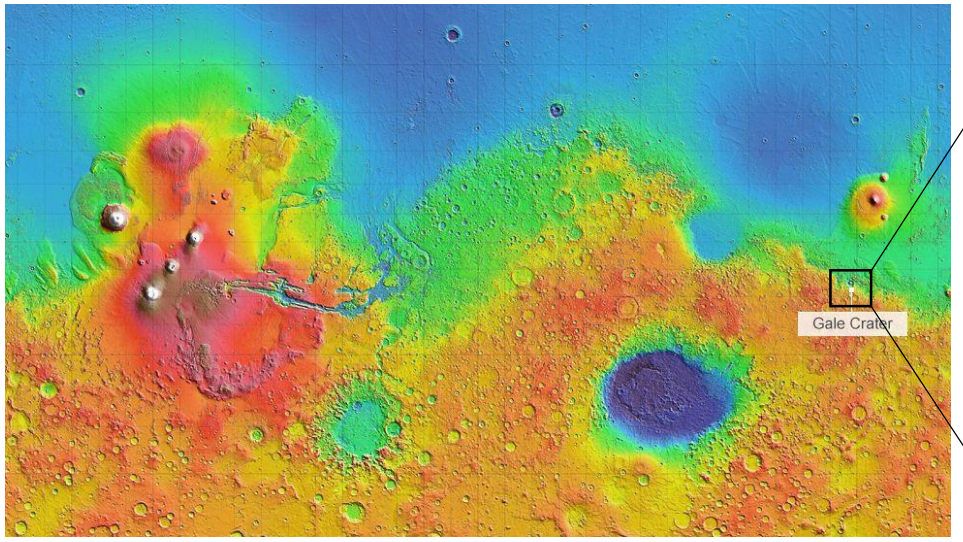
Hematite ridge and the base of Mount Sharp - sol 1516 - NASA/JPL-Caltech/MSSS/Thomas Appéré

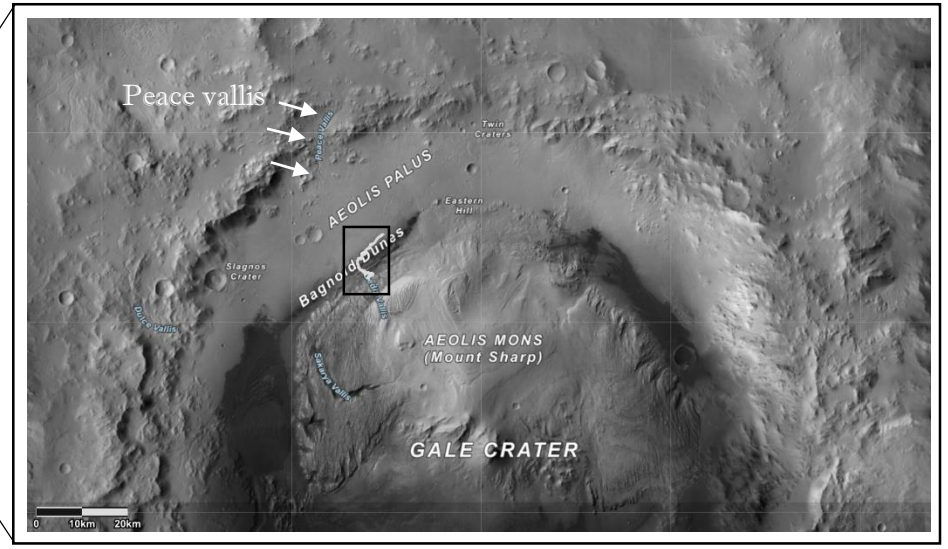
Importance of studying phosphorus on Mars:

- Phosphorus essential to the development of life on Earth
- Development of organisms limited by phosphorus supply ⇒ secondary phosphate facies often controlled by biological activity

  ⇒ Understanding the formation of phosphate minerals on Mars is interesting from an **astrobiological standpoint**, but also to understand the **phosphorus cycle in a presumably abiotic world**

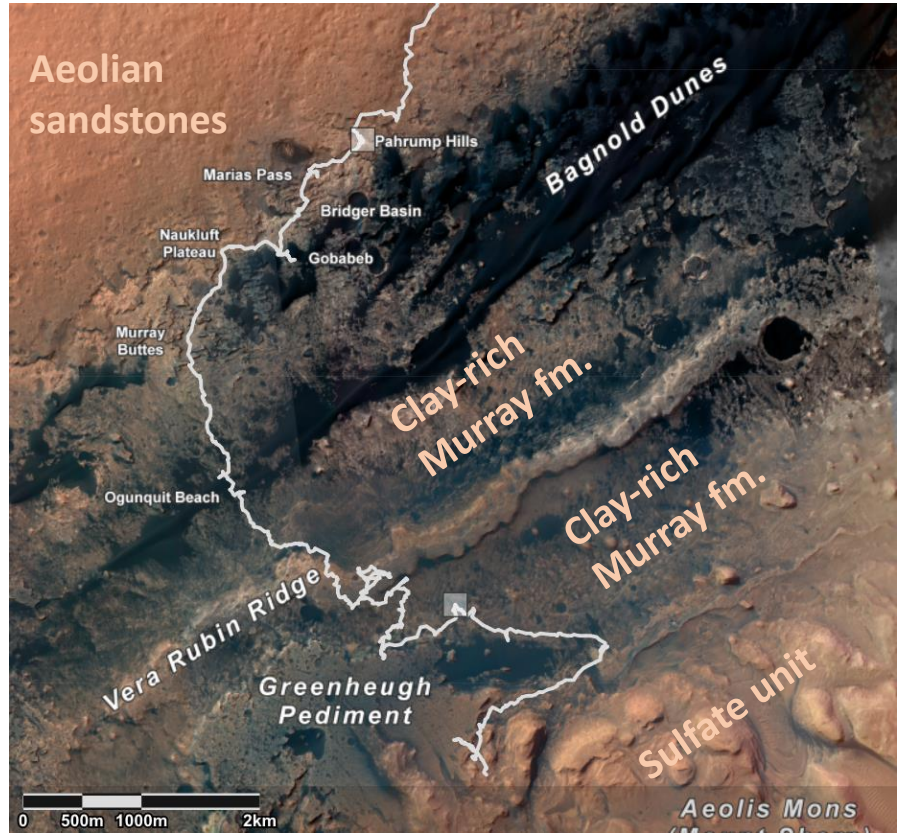




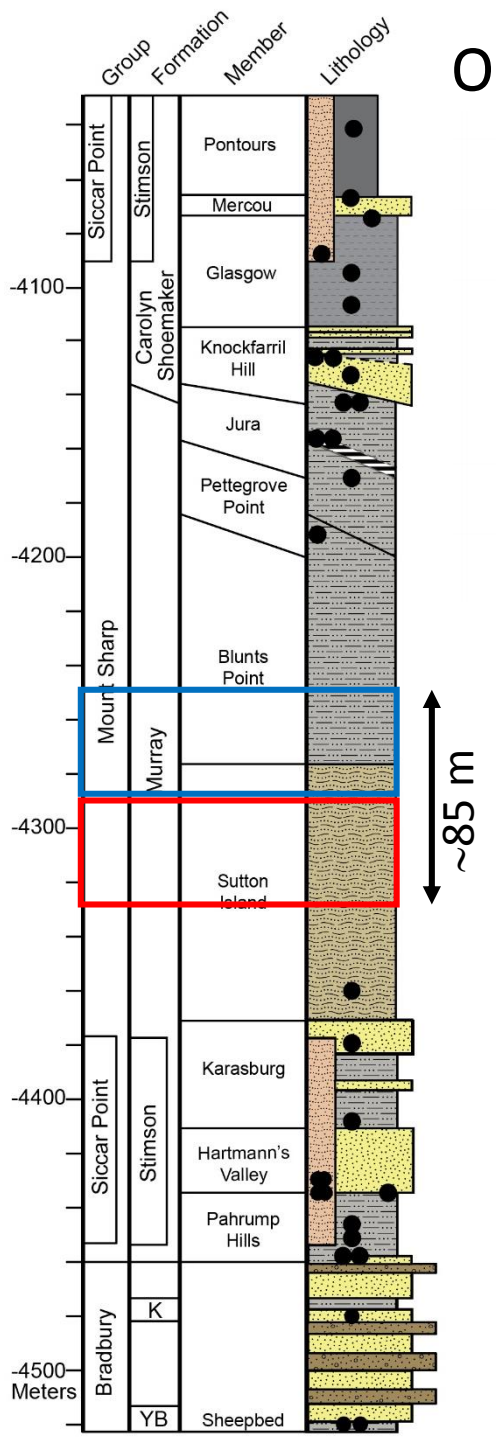


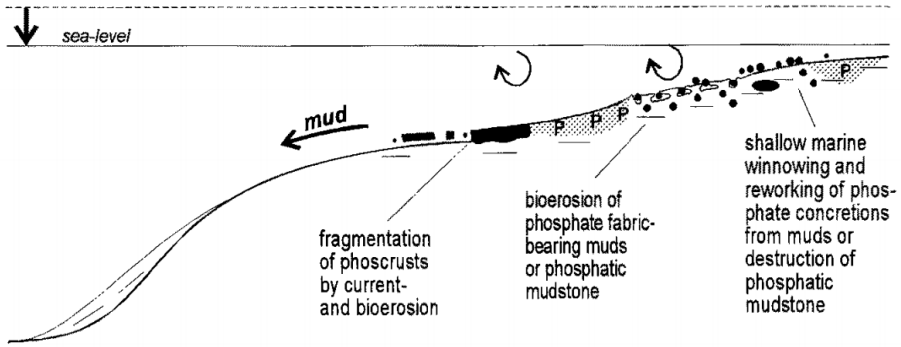
Context:

- In 10 years, Curiosity explored 28 km and ~580 m of stratigraphy in a **3.6 Gy old crater filled by an ancient lake**
- Lithology is dominated by:
  - **Conglomerates** in the Peace Vallis alluvial fan
  - **Clay-rich mudstones** in the Murray Formation (lacustrine sediments)
  - Transition towards a more **shallow lacustrine environment** in the upper section (sandstones, Mg-sulfates, halite)
  - Unconformable (younger) **overlying aeolian sandstones**
  - **Global diagenetic overprint** (mostly bassanite/gypsum veins)



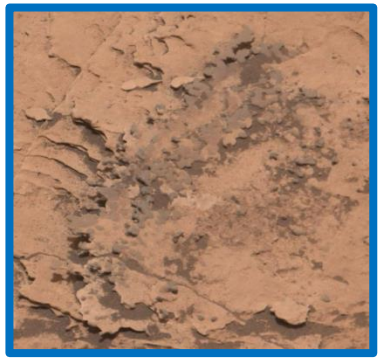
Observations of P-rich secondary facies

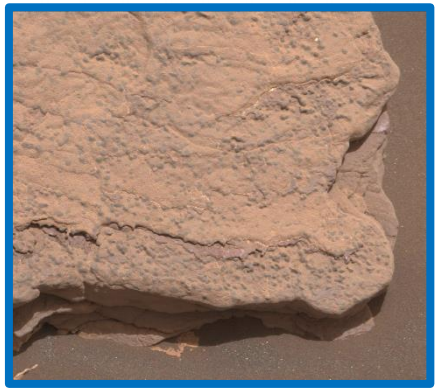


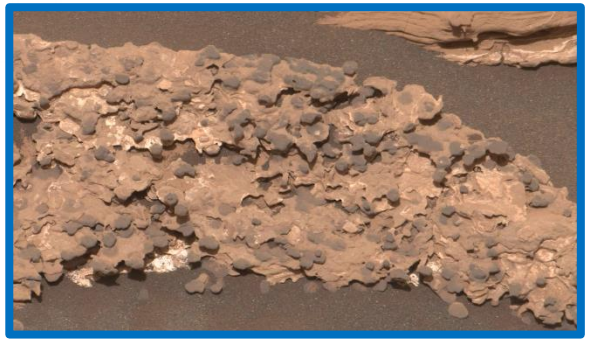


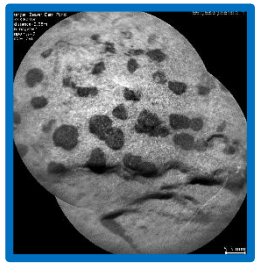
Process of phosphate grain formation (Trappe, 1998)

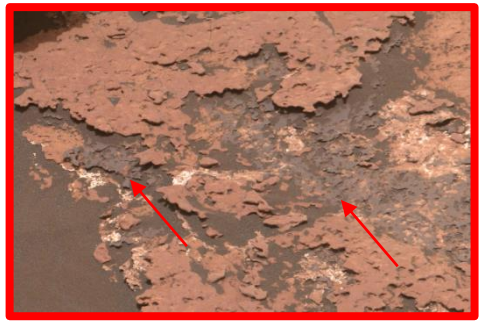
regressive stage











Dark nodules

Various sizes (a few mm to ~1 cm), dispersed along rhythmic, bedding planes; erosion-resistant; syndepositional or early-diagenetic ?

Enriched in (Mn, Mg, P, H)

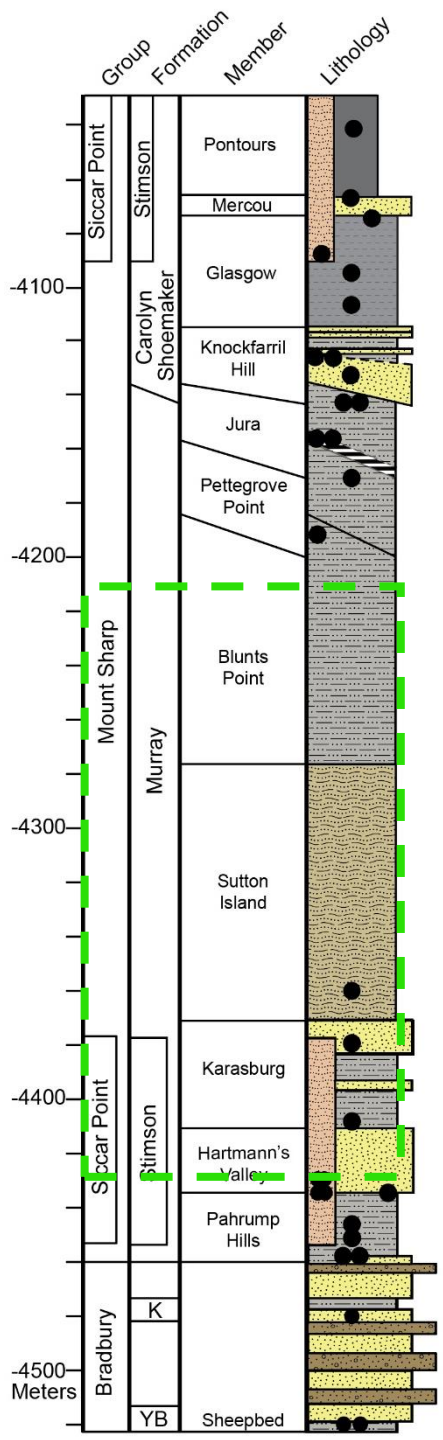
Shallower, more energetic and oxidizing near-shore environment?

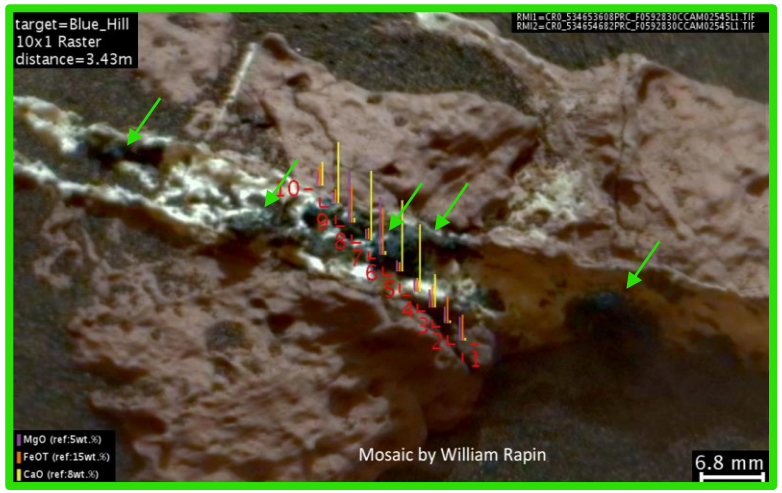
Dark laminae

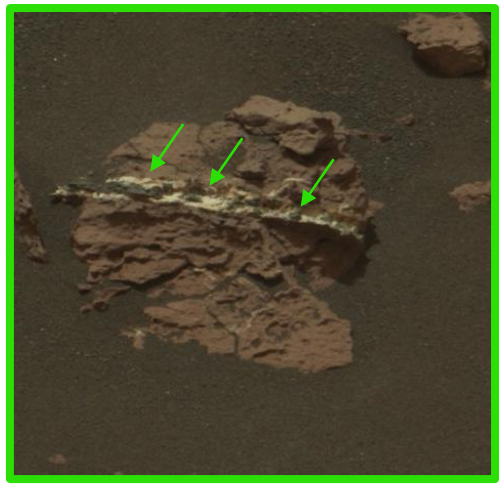
Thin parallel, subhorizontal, erosion-resistant; syndepositional or early-diagenetic ? (hardgrounds?)

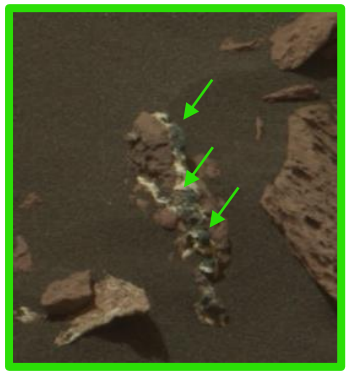
Fe-rich, Mn-poor, sporadic P enrichments

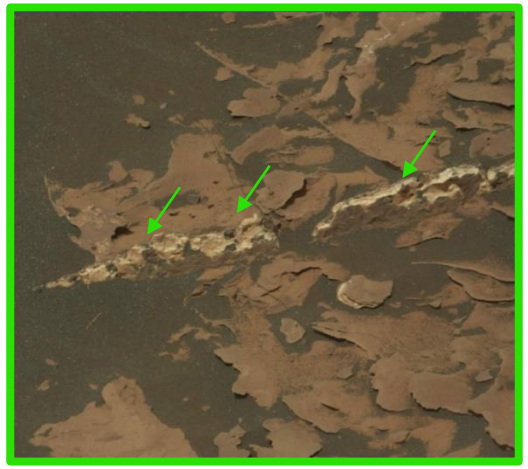
Observations of P-rich secondary facies











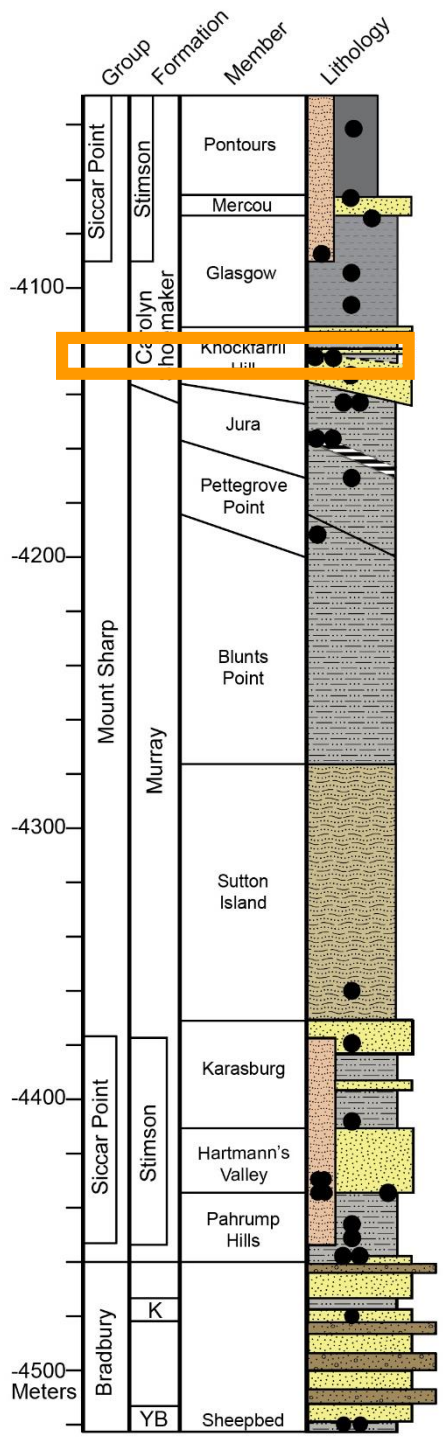
Dark inclusions

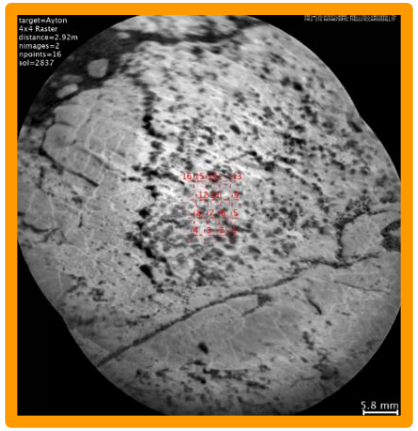
Present in diagenetic gypsum/bassanite veins over a broader stratigraphic range

⇒ **Diagenetic origin**

Strongly enriched in Fe, Mg, P, H

Observations of P-rich secondary facies

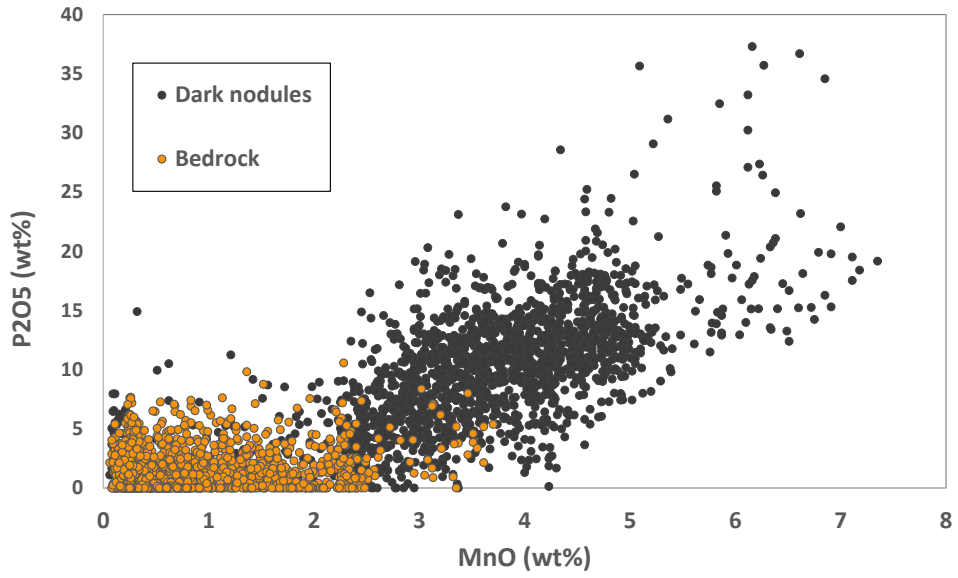




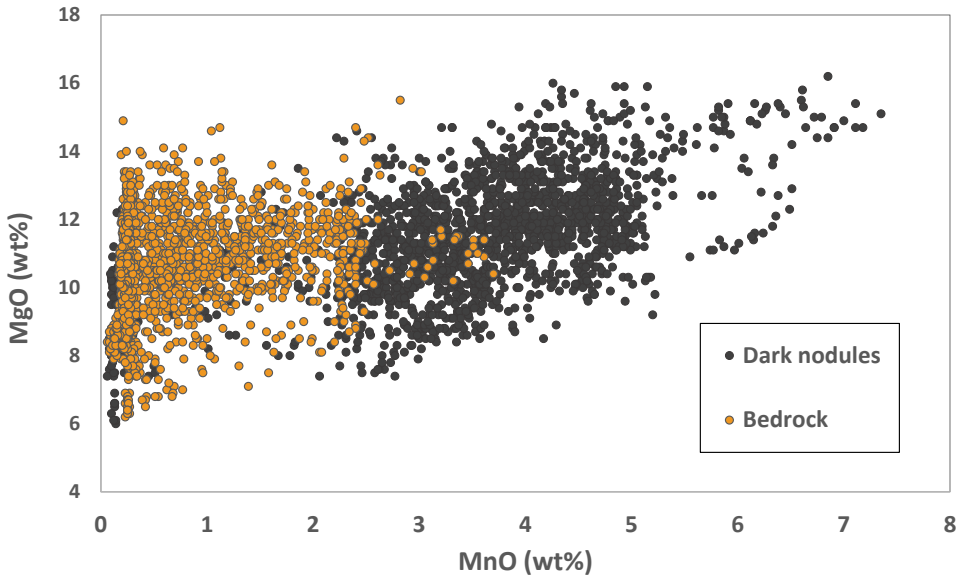
Groken drill site:

- mm-sized dark nodules in laminae, interleaved with nodule-free laminae made of mudstone
- **Chemical analysis ⇒ nodules enriched in P, Mn, Mg, H**, with molar P/Mn = 2-2.7
- **XRD analysis** ⇒ no crystalline phosphates or Mn-oxides ⇒ **P and Mn in amorphous component**
- **Evolved Gas Analysis** ⇒ **Mn as Mn^{2+}**

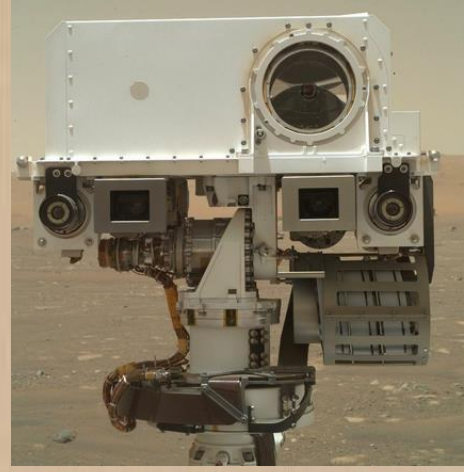
ChemCam LIBS analyses



References: Lanza et al., 2021, 2022; Treiman et al., 2021, 2022, Clark et al., 2021; this study



Summary and ongoing investigations



- Several facies observed, probably corresponding to different stages of diagenesis of the lacustrine sediments:
  - Dark laminae (syndepositional or early diagenetic)
  - Dark nodules in laminae (early diagenetic?)
  - Dark nodules in veins (diagenetic)

At water/sediment interface?

In post-lithification fractures

- The high and well-defined P/Mn and P/Fe ratios and very slow kinetics of Mn-oxides formation suggest they formed as phosphates, rather than by sorption of P to oxides

$\Rightarrow$ Amorphous (Mn,Mg) and (Fe,Mg) hydrous phosphates

- Questions under investigation:
  - What was their original composition and crystallinity?
  - Did they evolve over time with varying pH and oxidizing conditions?
  - Why do they form discrete, rare layers in the stratigraphic column?
  - Which events and environmental conditions do they trace? (e.g., P and Mn preferentially mobilized by alteration of apatite and olivine during acidic (volcanic) pulses?)