Surveying Clay Mineral Diversity in the Murray Formation, Gale Crater, Mars

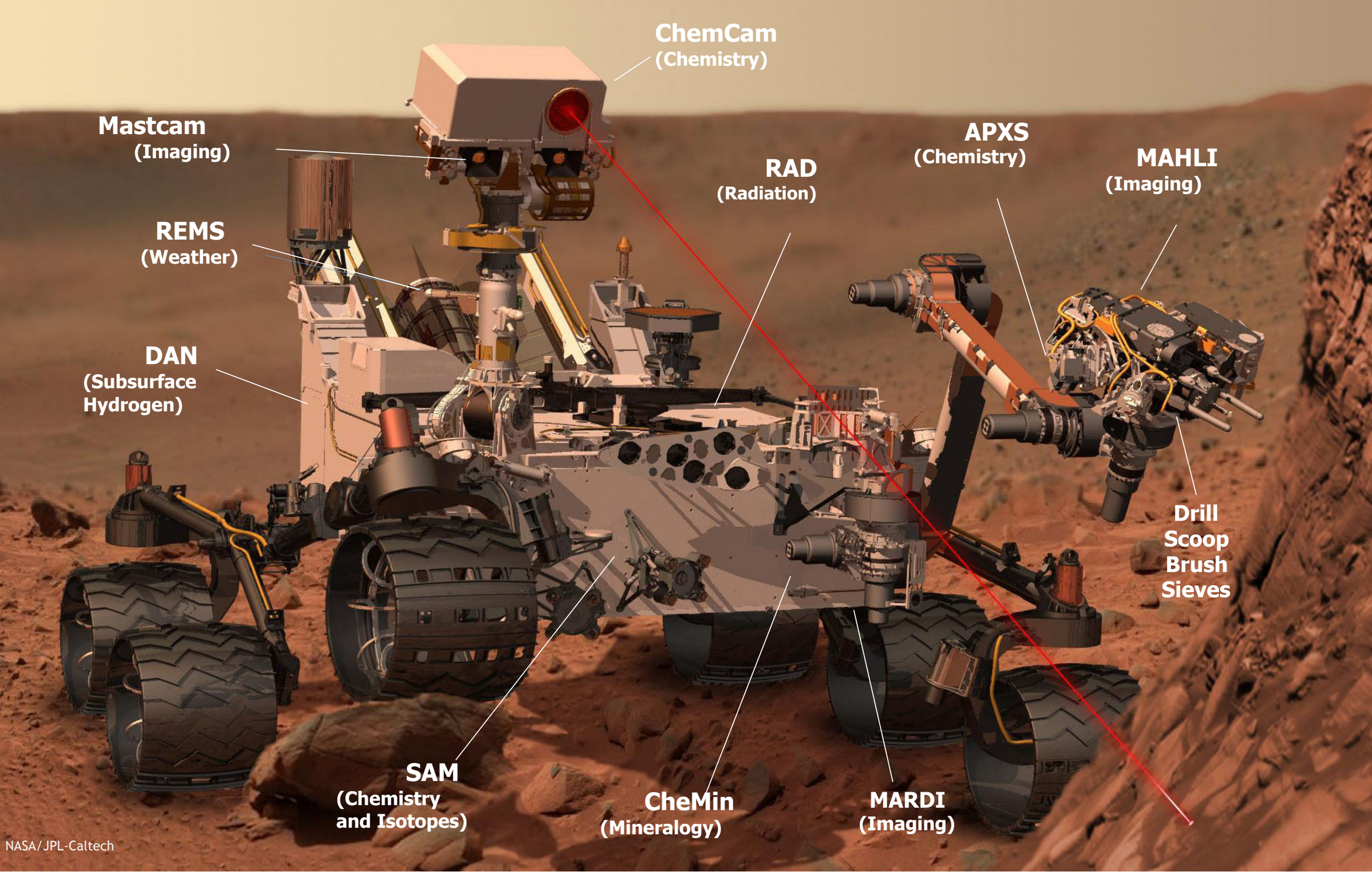
T.F. Bristow*, D.F. Blake, D.T. Vaniman, S.J. Chipera, E.B. Rampe, J.P. Grotzinger, A.C. McAdam, D.W. Ming, S.M. Morrison, A.S. Yen, R.V. Morris, R.T. Downs, A.H. Treiman, C.N. Achilles, P. Craig, D.J. Des Marais, J.M. Moorokian, J.A. Crisp, R.M Hazen.

*Exobiology Branch, NASA Ames Research Center

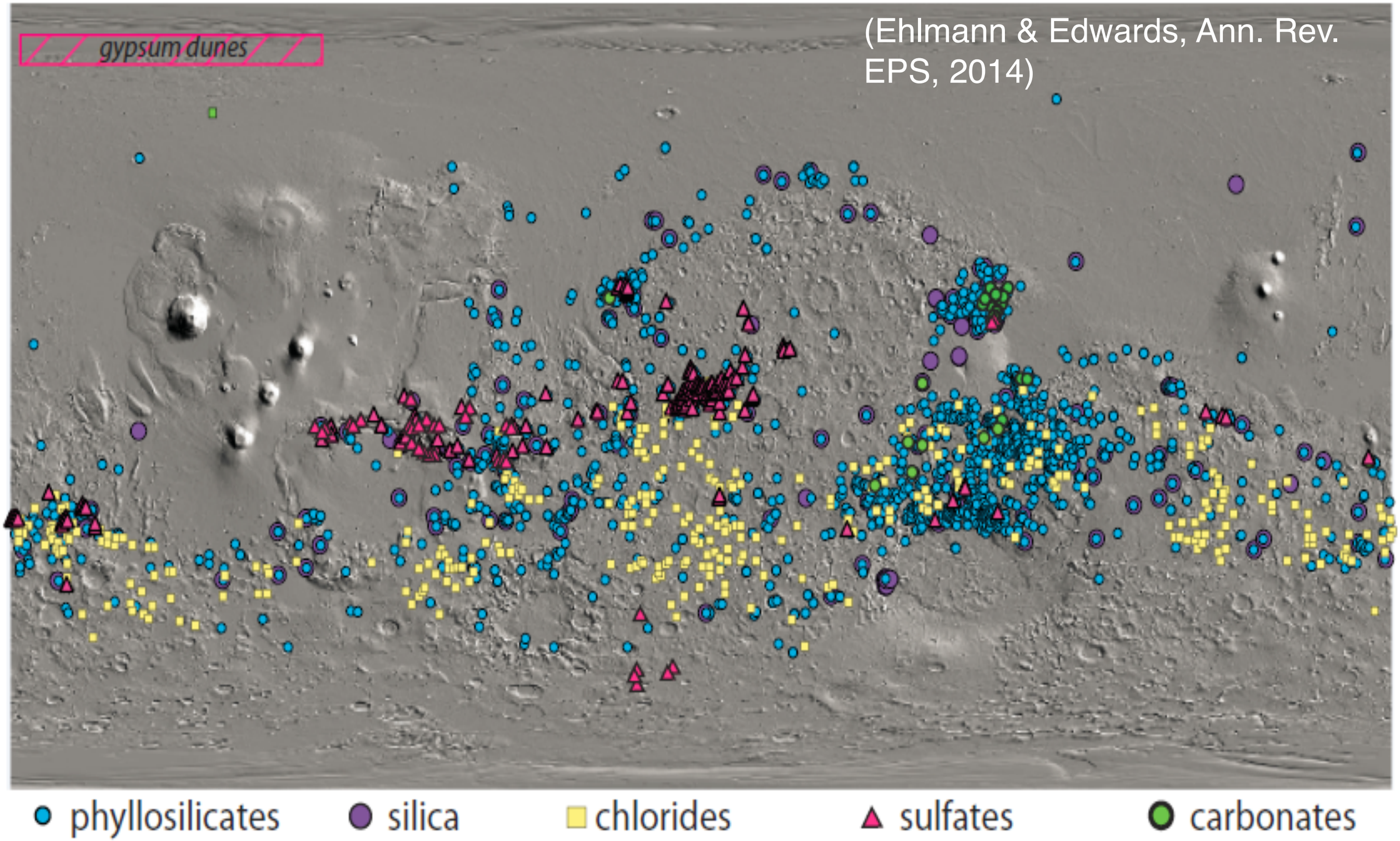
Curiosity's primary scientific goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present.

- Landed in August 2012
- How have investigations of clay minerals at Gale Crater help Mars Science Laboratory Rover *Curiosity* meet it's goals.

NASA/JPL-Caltech/MSSS

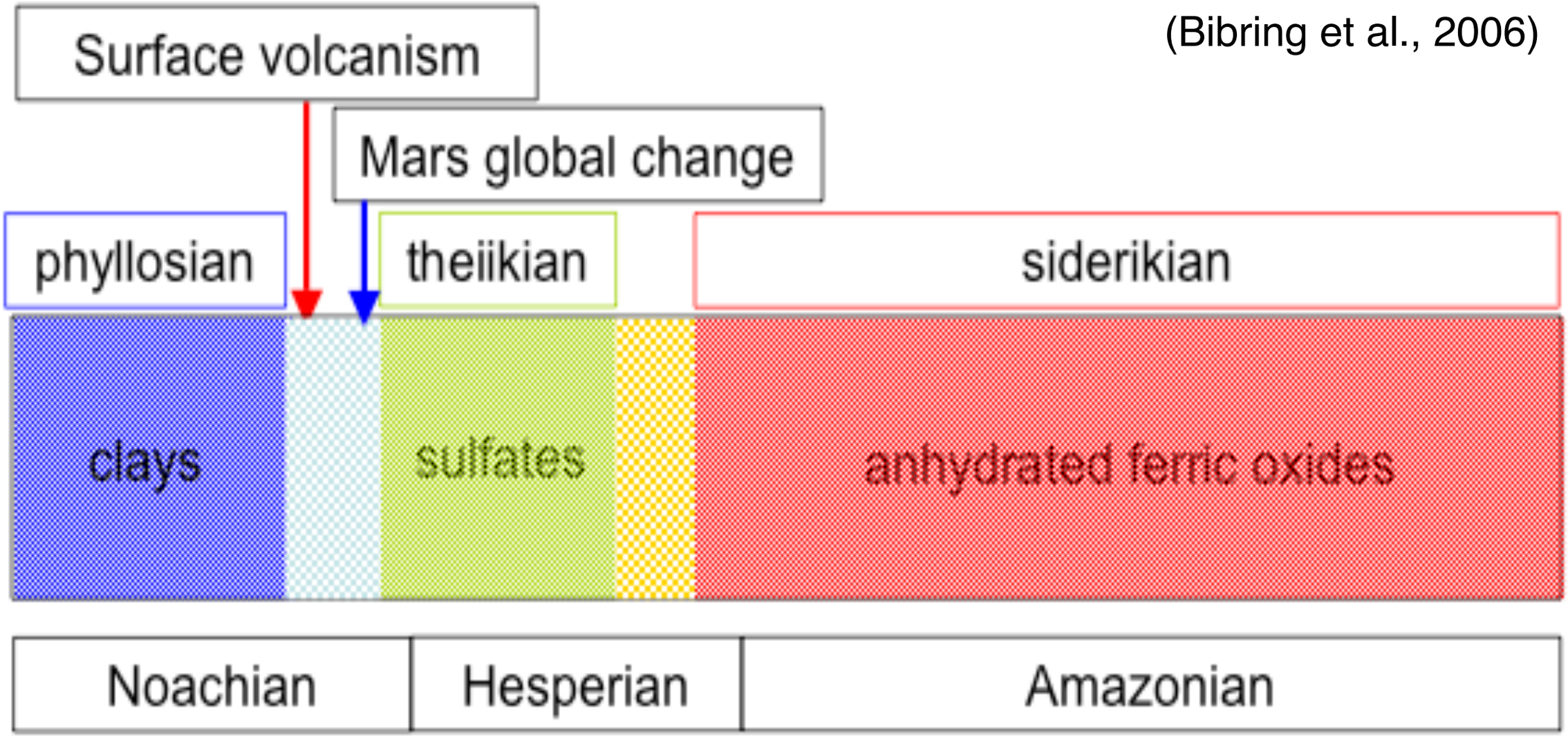


Curiosity's Science Payload

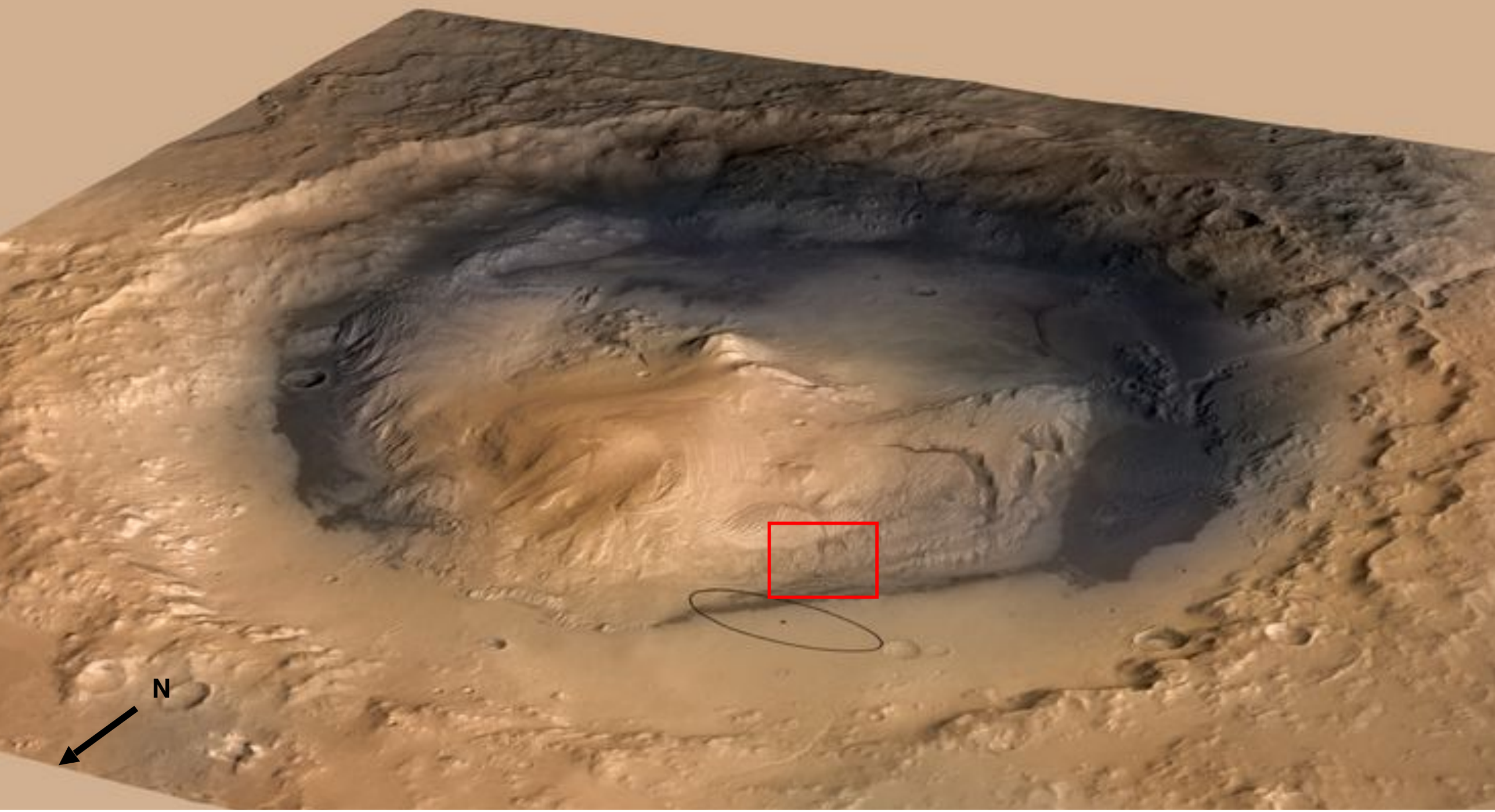


Distribution of aqueous minerals on Mars

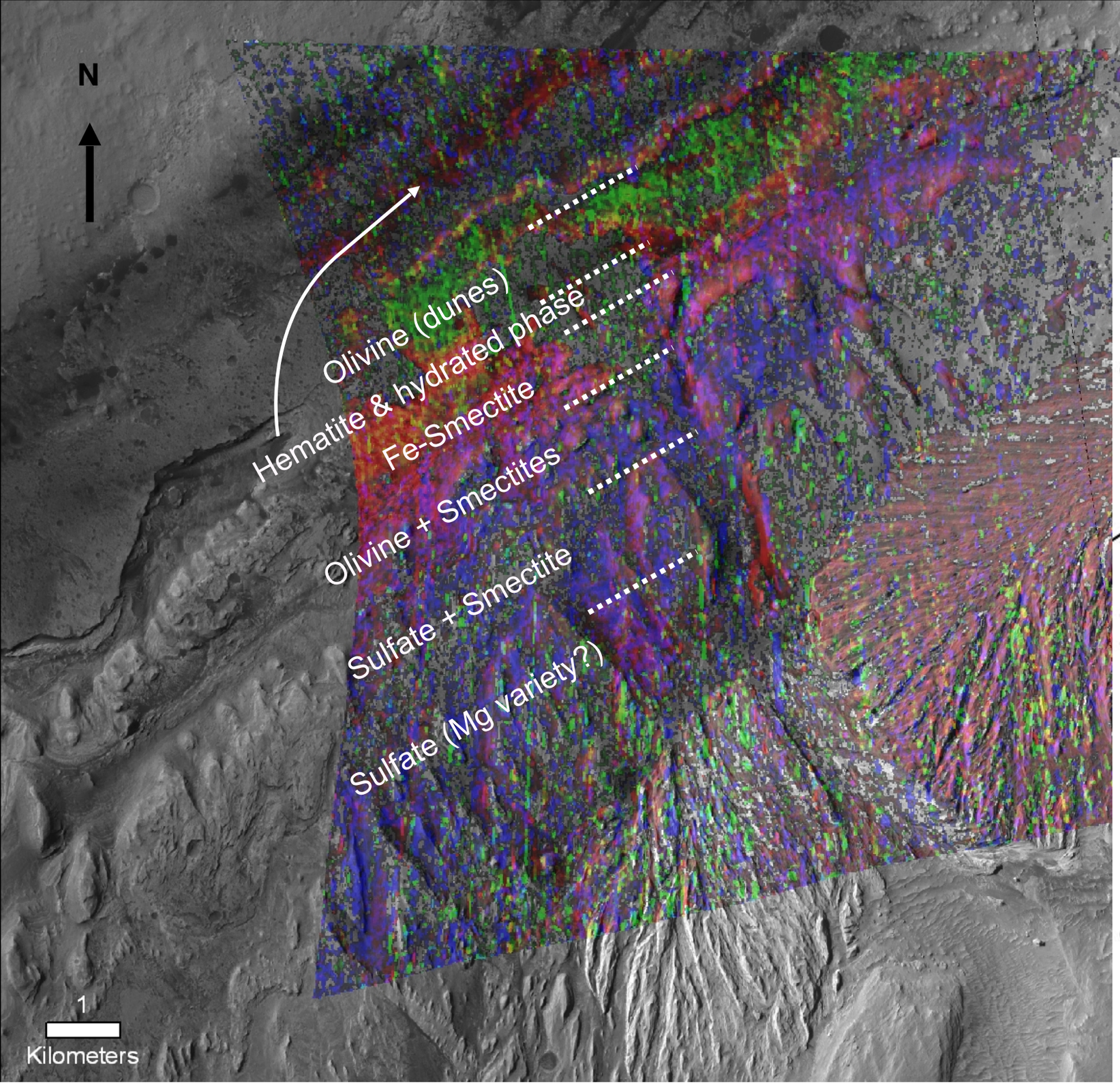
(Bibring et al., 2006)

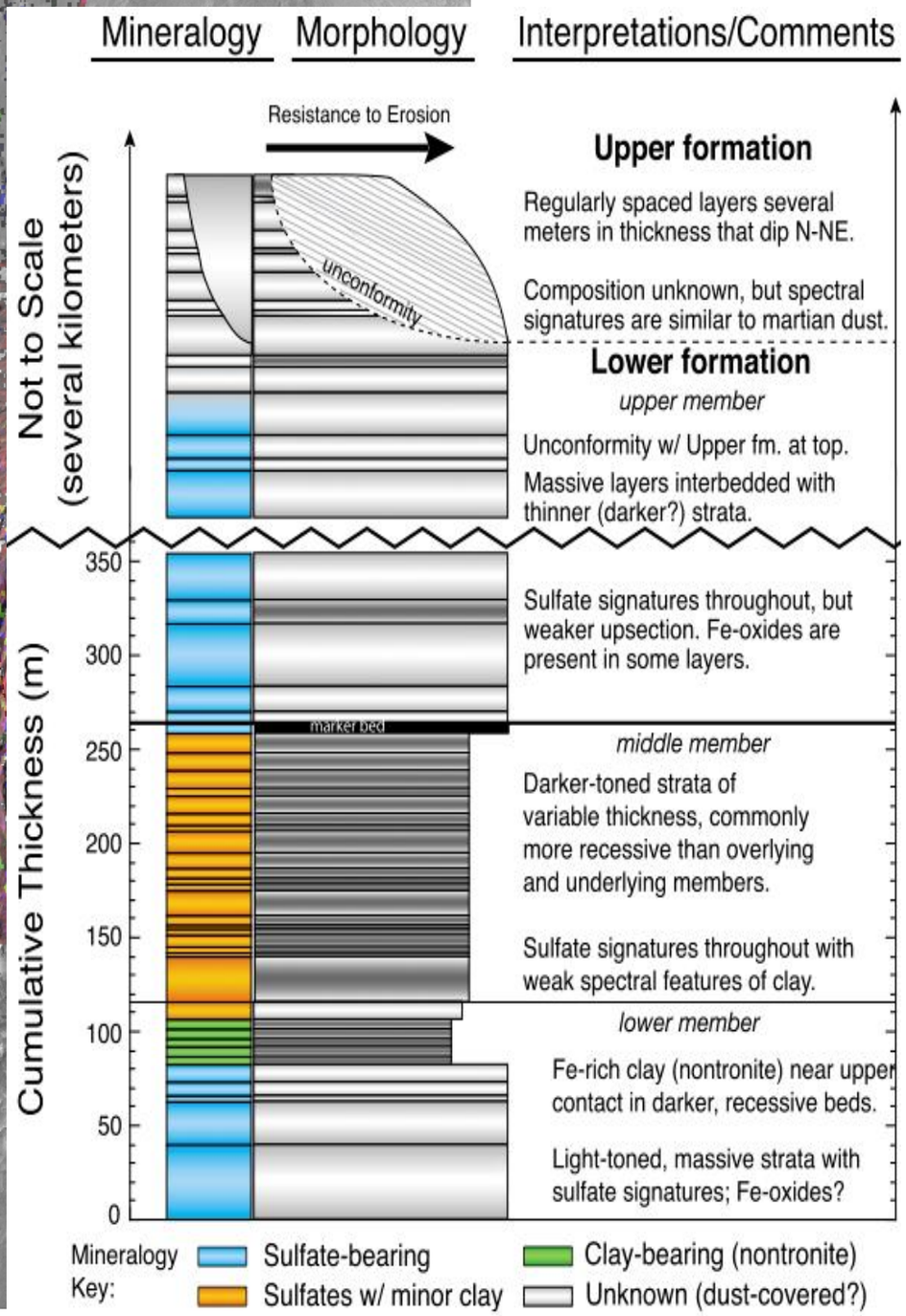


Temporal evolution of aqueous minerals on Mars



150-km Gale Crater contains a 5-km high mound of stratified rock. Orbital spectroscopy data indicate strata in the lower section of the mound contain clay minerals overlain by sulfate-bearing deposits, suggesting that they may have recorded environmental changes over time.

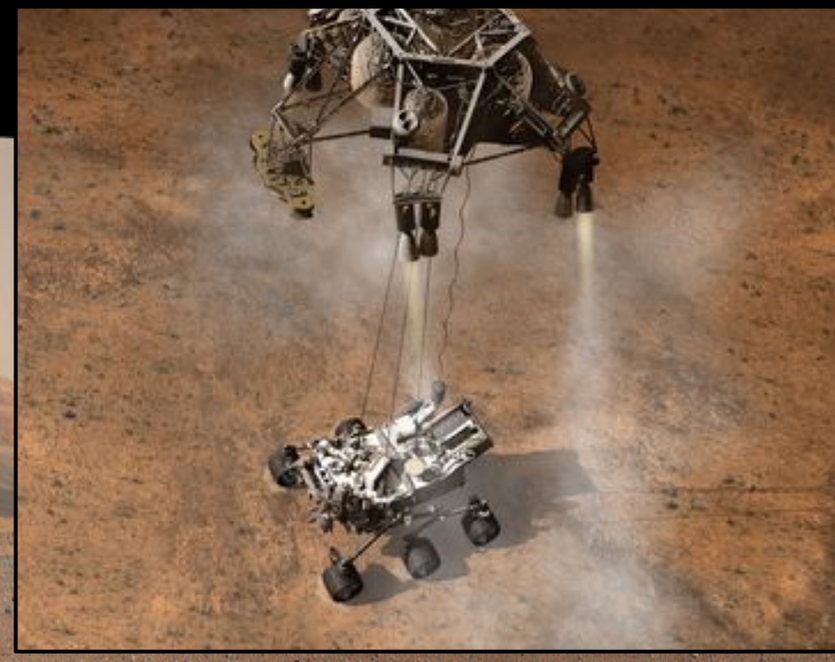




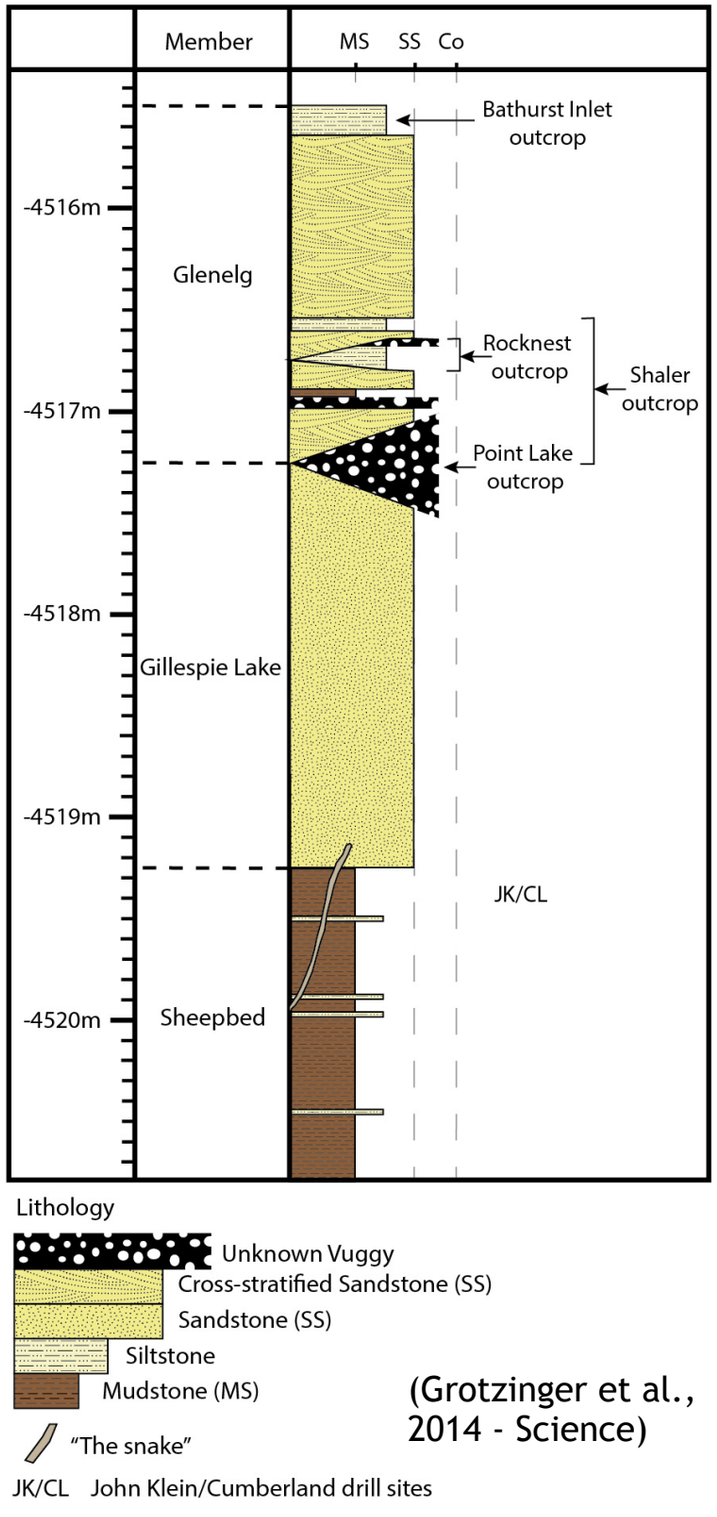
(Milliken et al., 2010)

Orbital survey of lower mound mineralogy

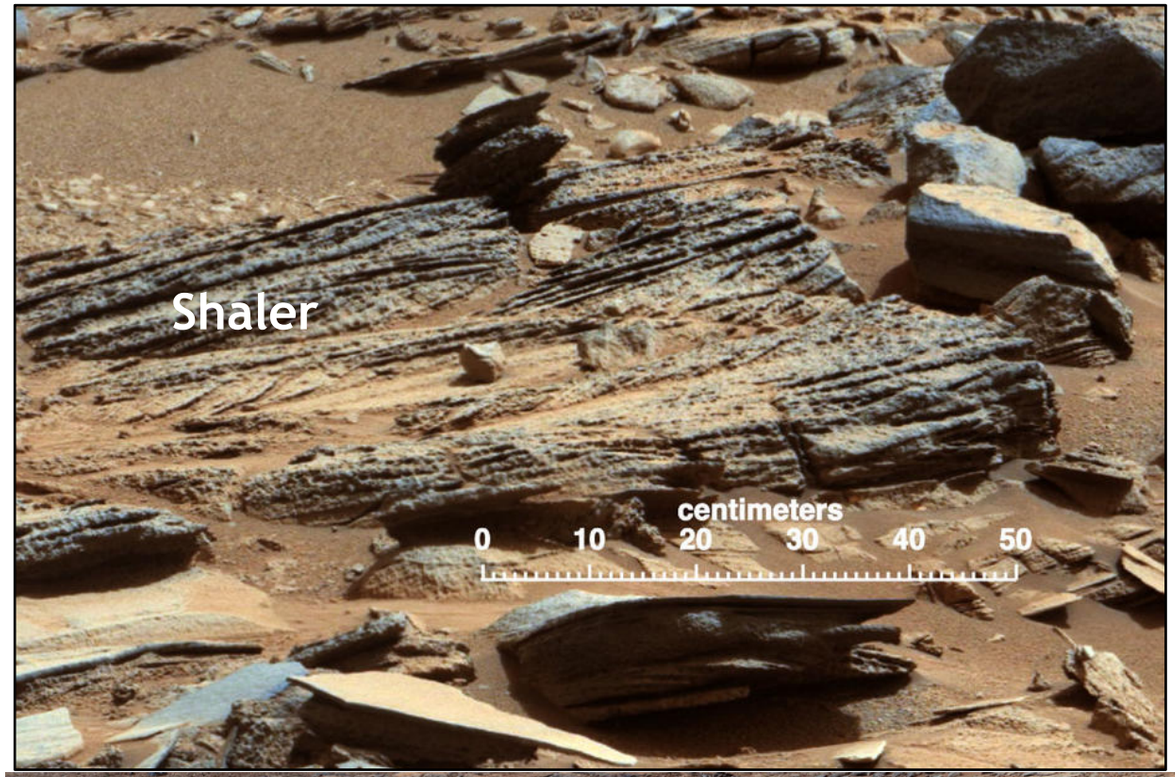
MSL at Gale Crater



NASA/JPL-Caltech/MSSS



(Grotzinger et al., 2014 - Science)



- Siliciclastic, mudstones, siltstones and sandstones of basaltic bulk composition.
- Facies analysis indicate a fluvio-lacustrine origin.

Stratigraphy of Yellowknife Formation

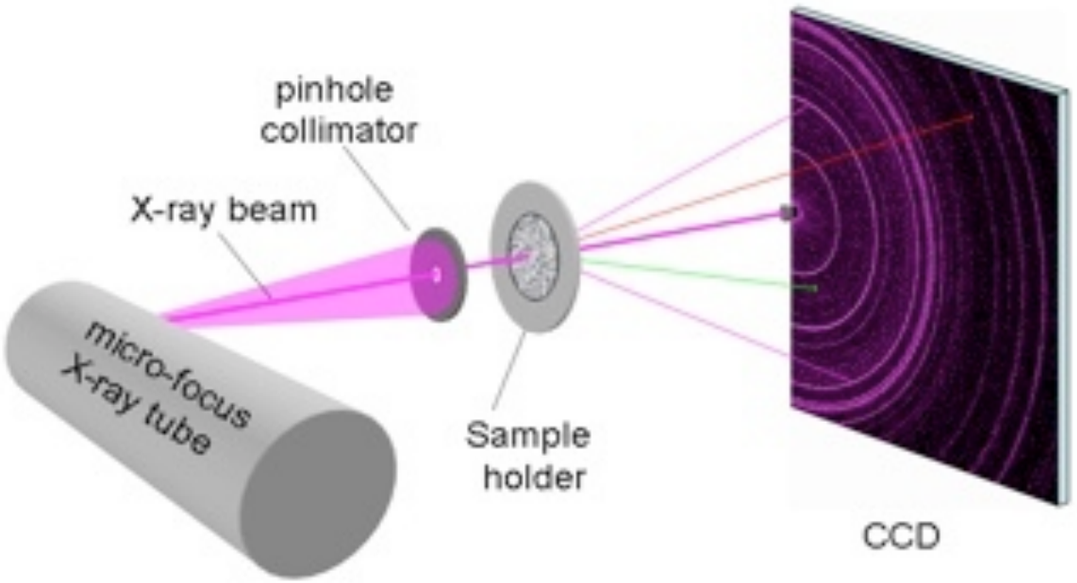
NASA/JPL-Caltech/LANL/CNES/IRAP/IAS/LPGN

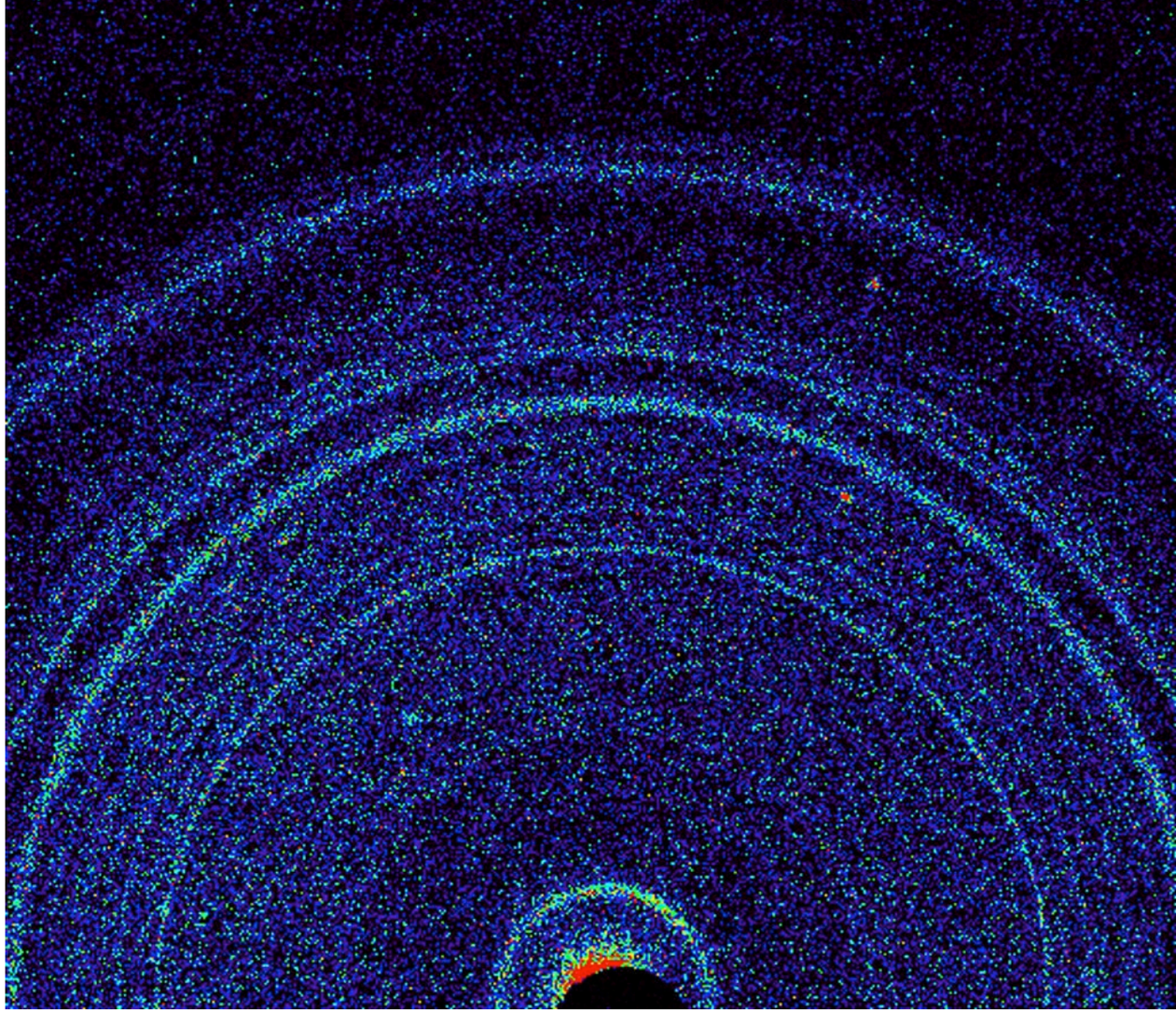
NASA/JPL-Caltech/MSSS

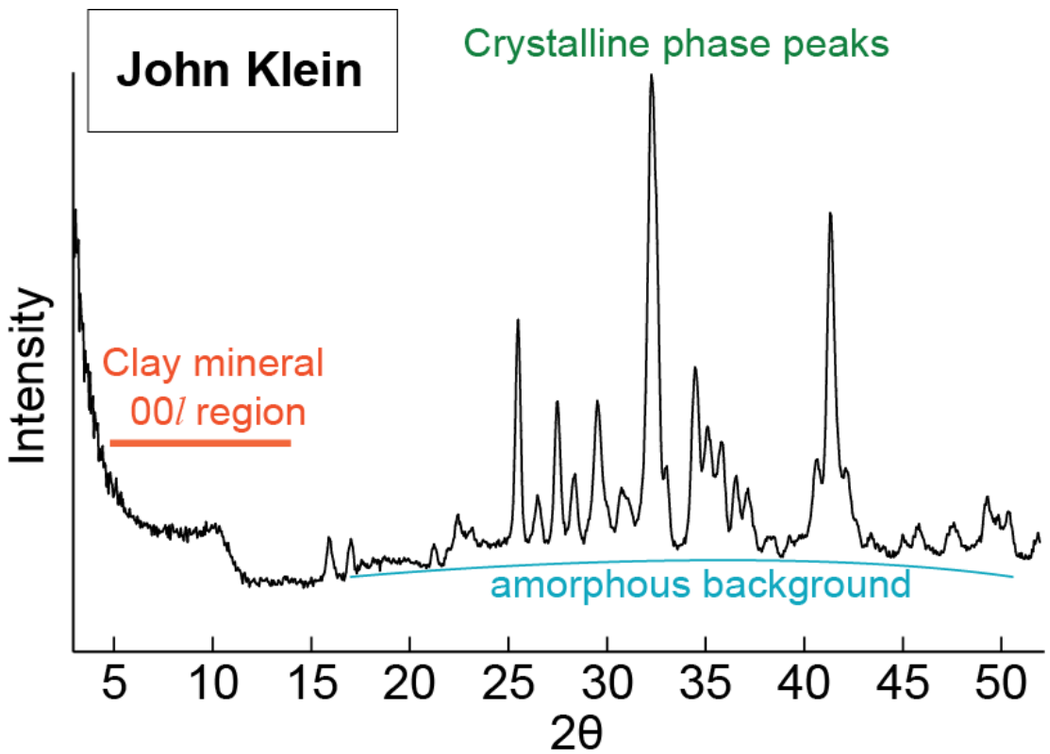
NASA/JPL-Caltech/MSSS

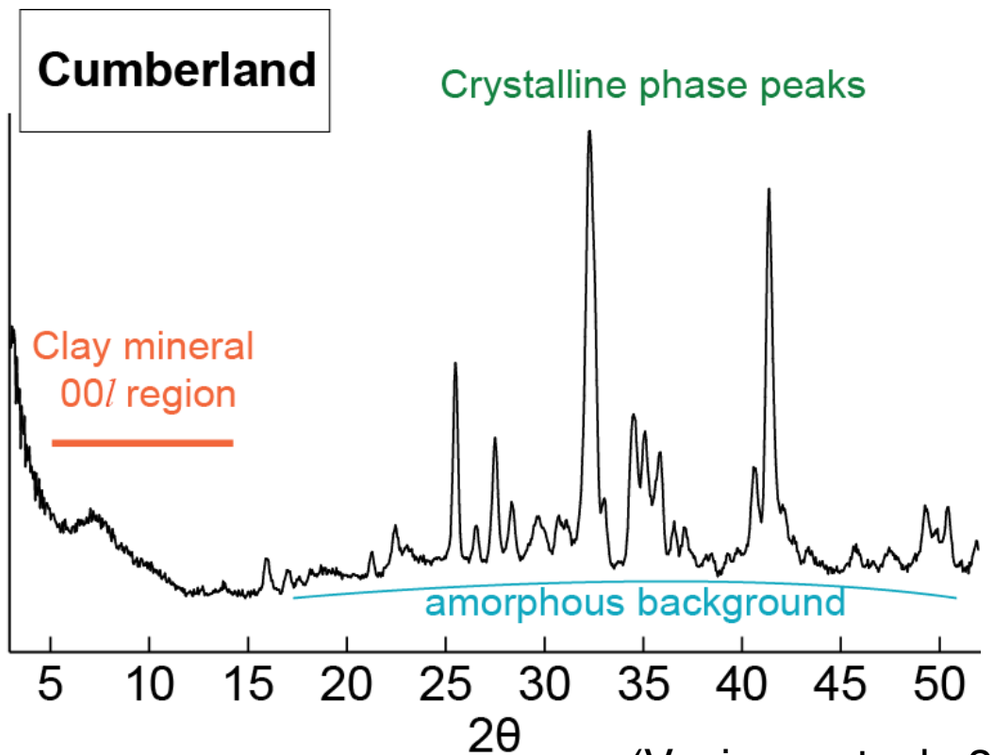
Curiosity's 1.6-cm diam. drill bit, drill and test holes, and scoop full of acquired sample

CheMin XRD









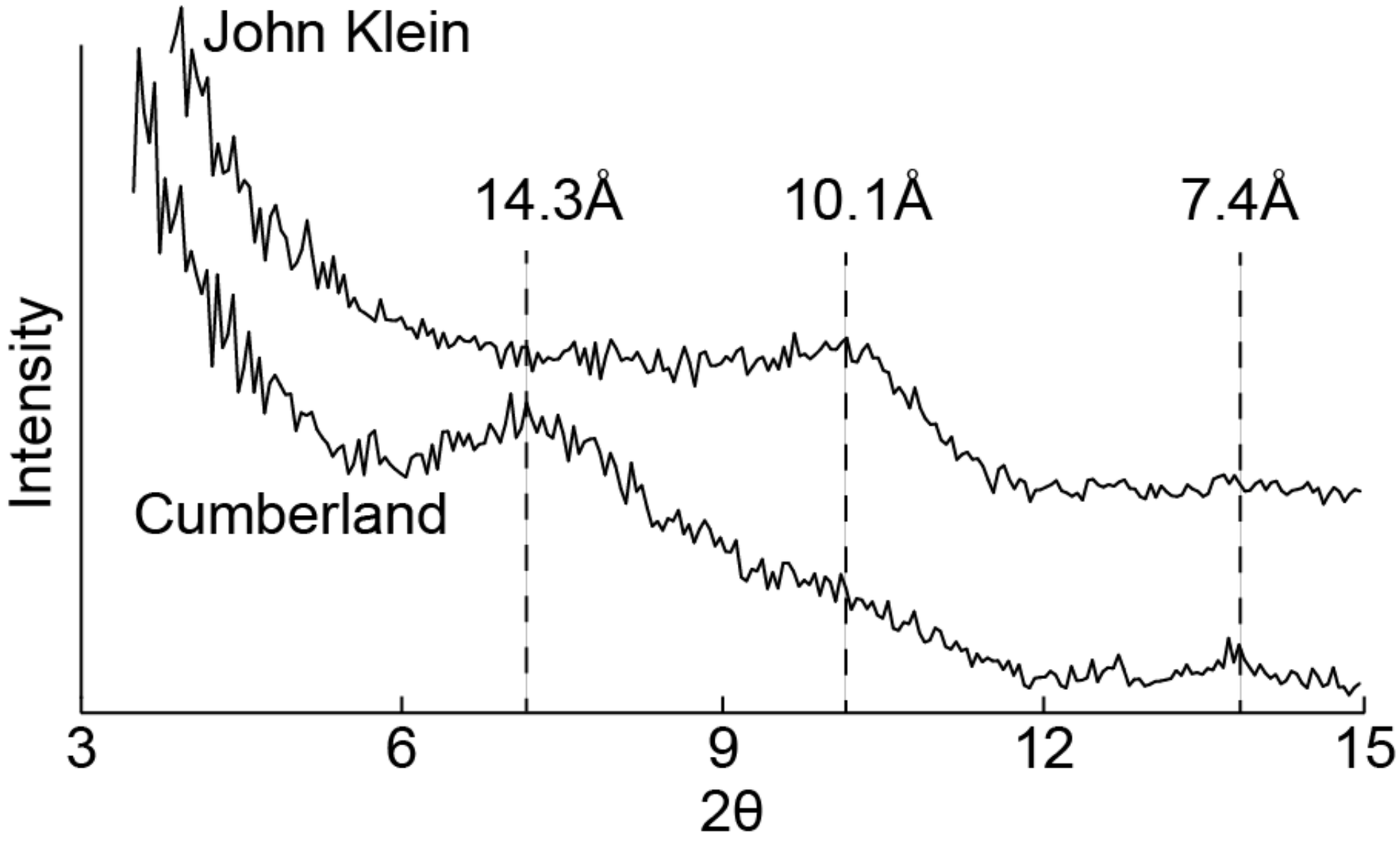
(Vaniman et al., 2014 – Science)

Phase	John Klein (wt%)	Cumberland (wt%)
plagioclase	24	24
olivine	3	1
pyroxene	14	17
magnetite	4	5
akaganeite	1	2
clay minerals	24	19
amorphous	30	33

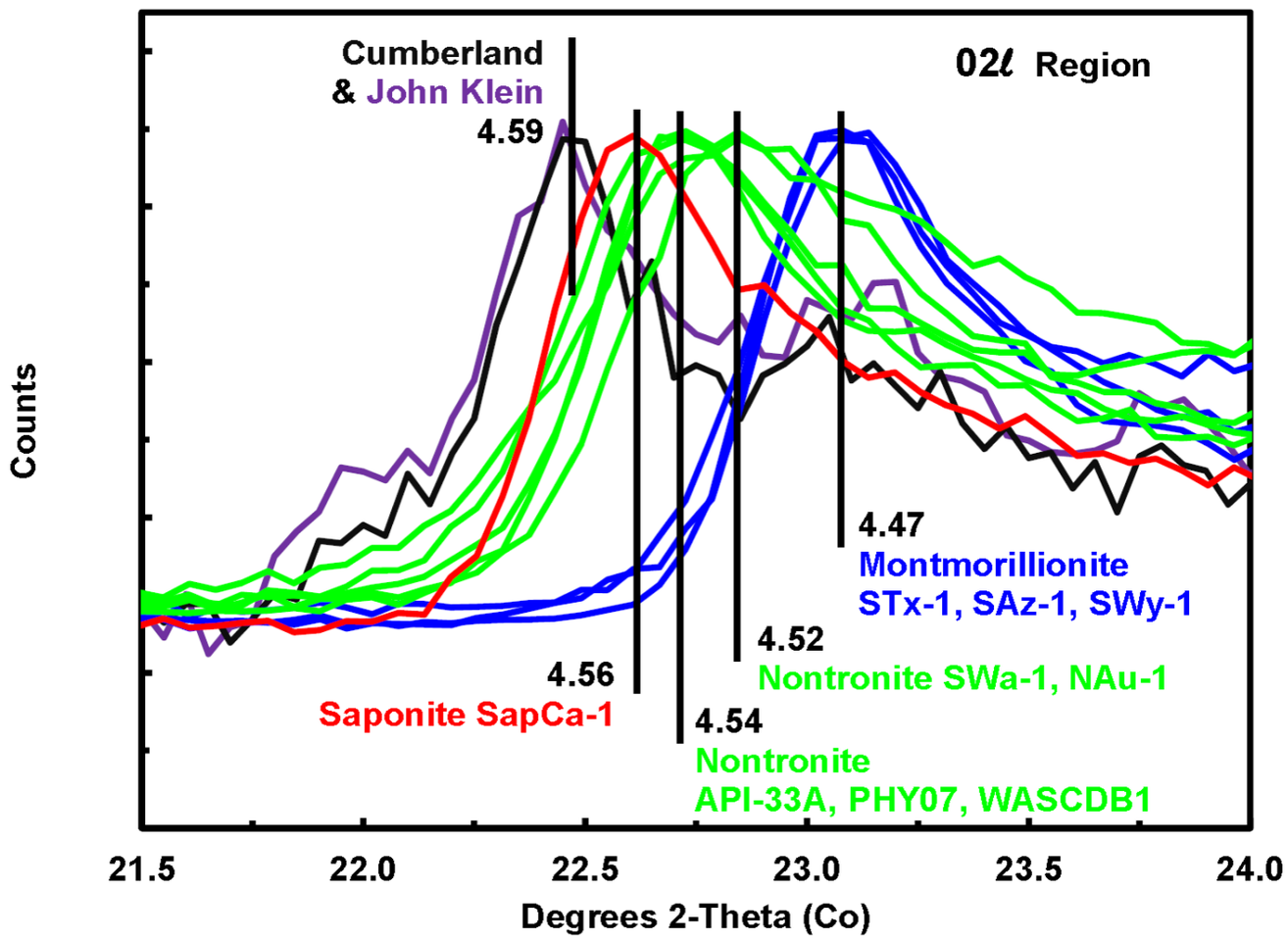
(Vaniman et al., 2014 - Science)

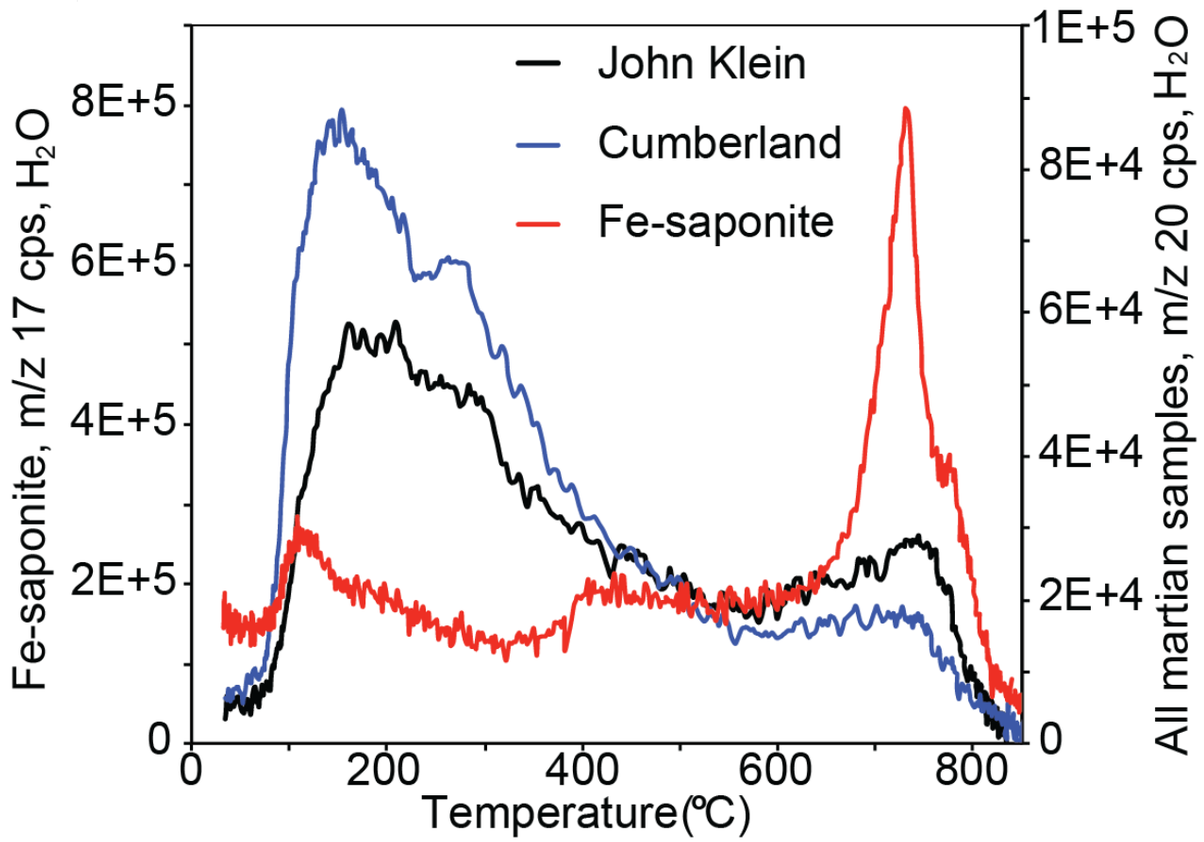
- Olivine content lower than regional average of 11 wt% (Rogers and Christiensen, 2007 – JGR).
- Magnetite content higher than “Adirondack class” basalts measured by Spirit (McSween et al., 2008 – JGR).

Clay Mineralogy



- Position of 00*l* peaks and absence of strong peak at ~7Å indicate 2:1 type phyllosilicate.
- Limited K content of the clay mineral fraction and absence of other diagnostic peaks for illite indicate the presence of a smectite.
- Smectite permits variable interlayer spacing and 00*l* peak position.





Comparison of 02*l* data from Sheepbed with XRD patterns from clay mineral standards run on CheMin.

SAM evolved gas analysis – consistent with quantity and type of smectite identified by CheMin.

- 02*l* reflection used to indicate type and number of cations in the octahedral sheet. 060 out of range.
- Sheepbed clay mineral identified as a Fe-rich saponite.

Origin of smectite

- Bulk chemistry of mudstone close to average martian basalt (i.e catchment composition)
- Simple clay mineral assemblage.
- Lower levels of olivine than expected.
- High magnetite abundances for a lacustrine mudstone.

In situ clay mineral formation:

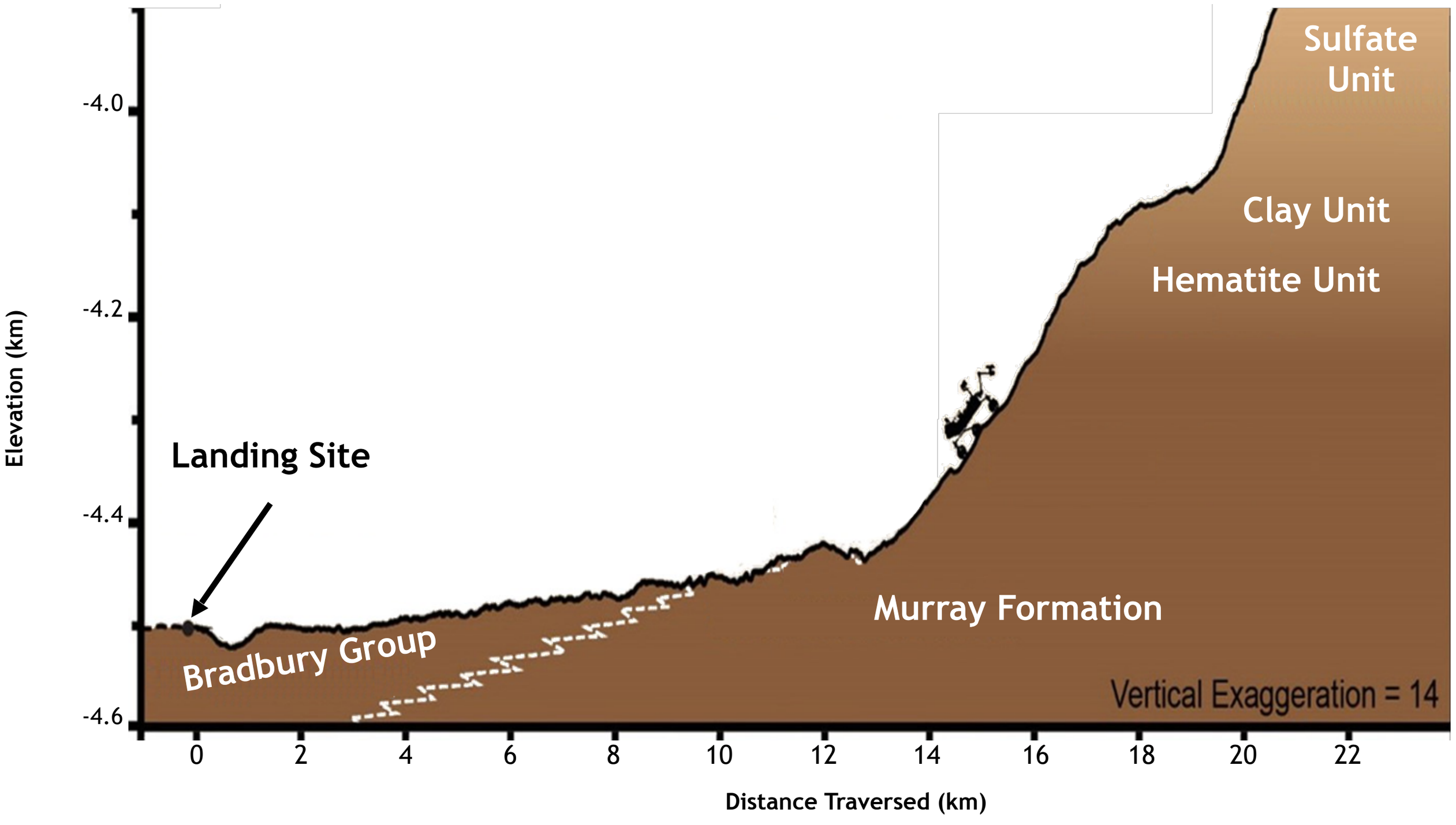
Fe-forsterite + Amorphous material → Saponite + Magnetite

Key indicator of ancient habitability.

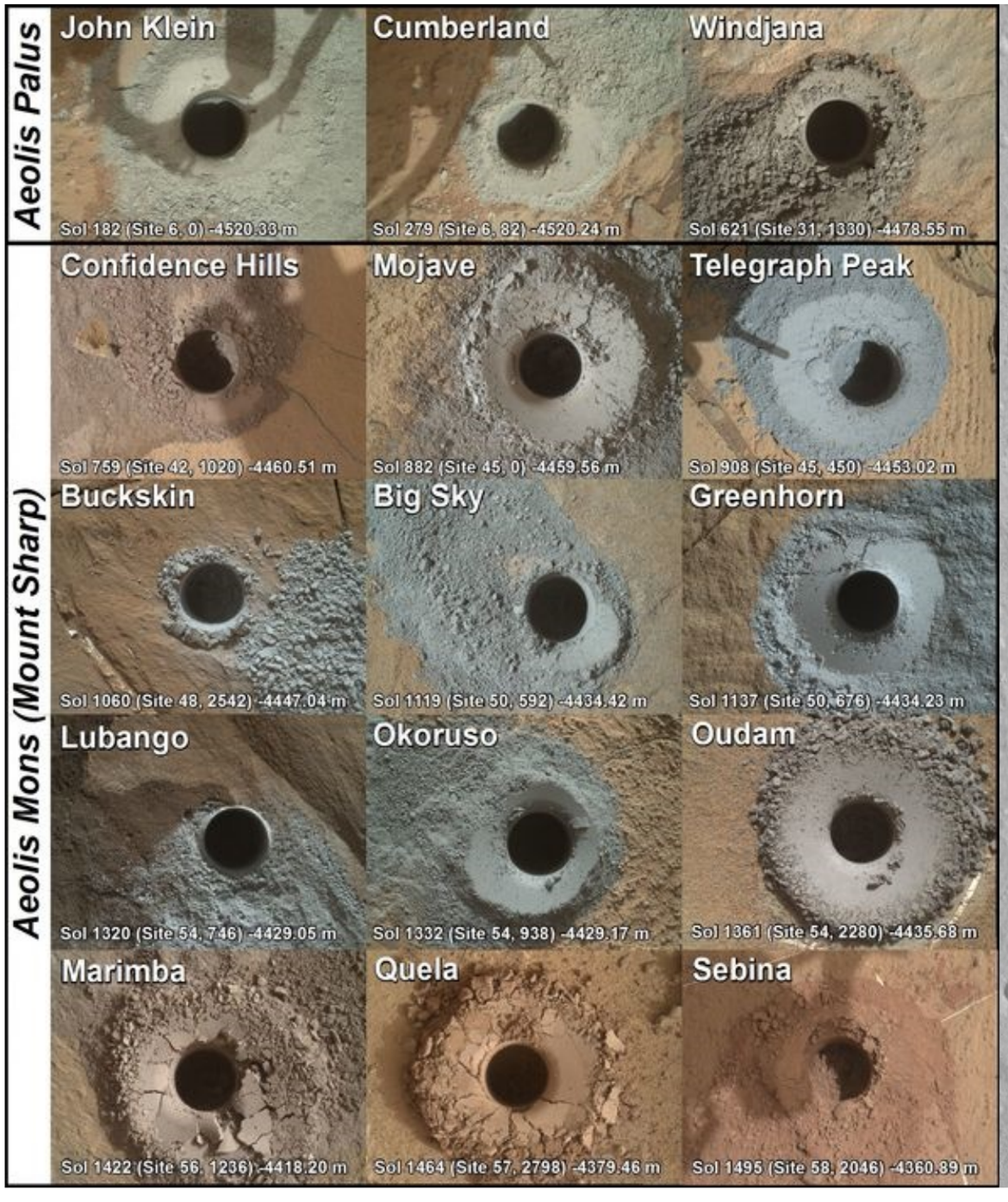
- Implies prolonged aqueous alteration at circum-neutral pH.
- Change in redox state of Fe provided a potential source of energy.

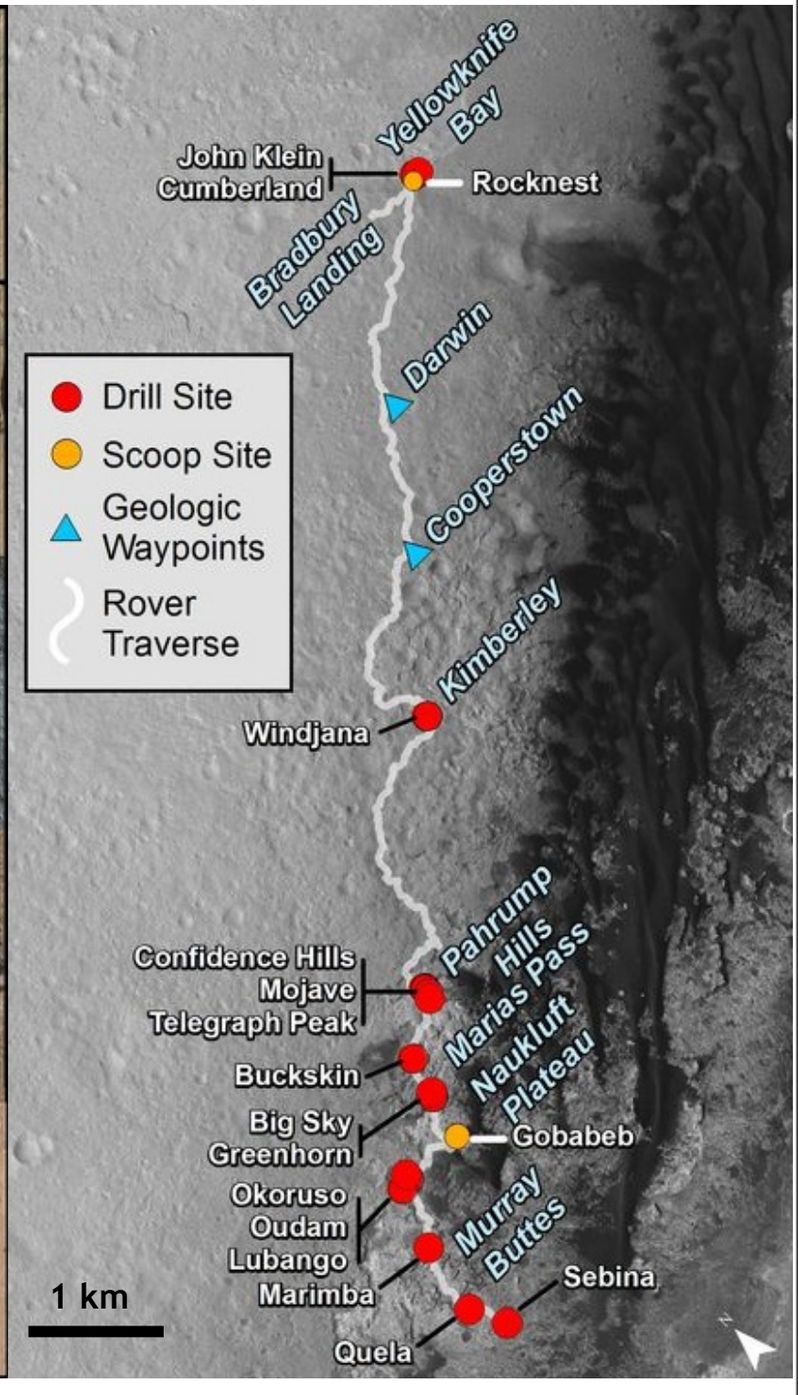
(Vaniman et al., 2014; McLennan et al., 2014; Grotzinger et al., 2014; Bristow et al., 2015)

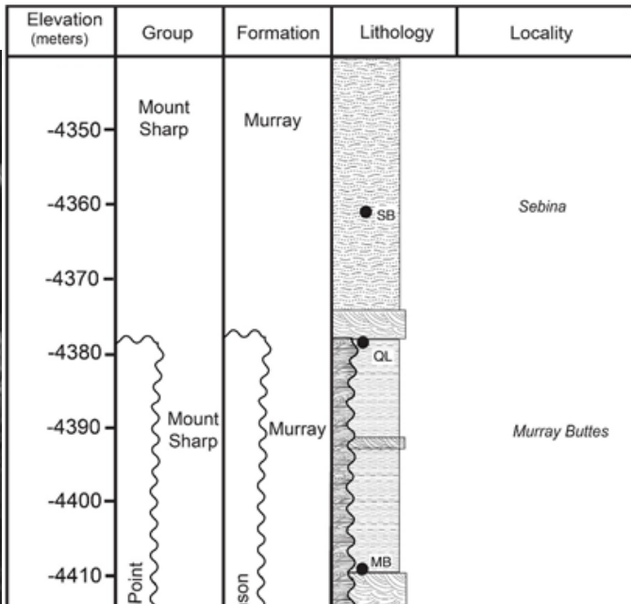
Gale Crater Stratigraphy

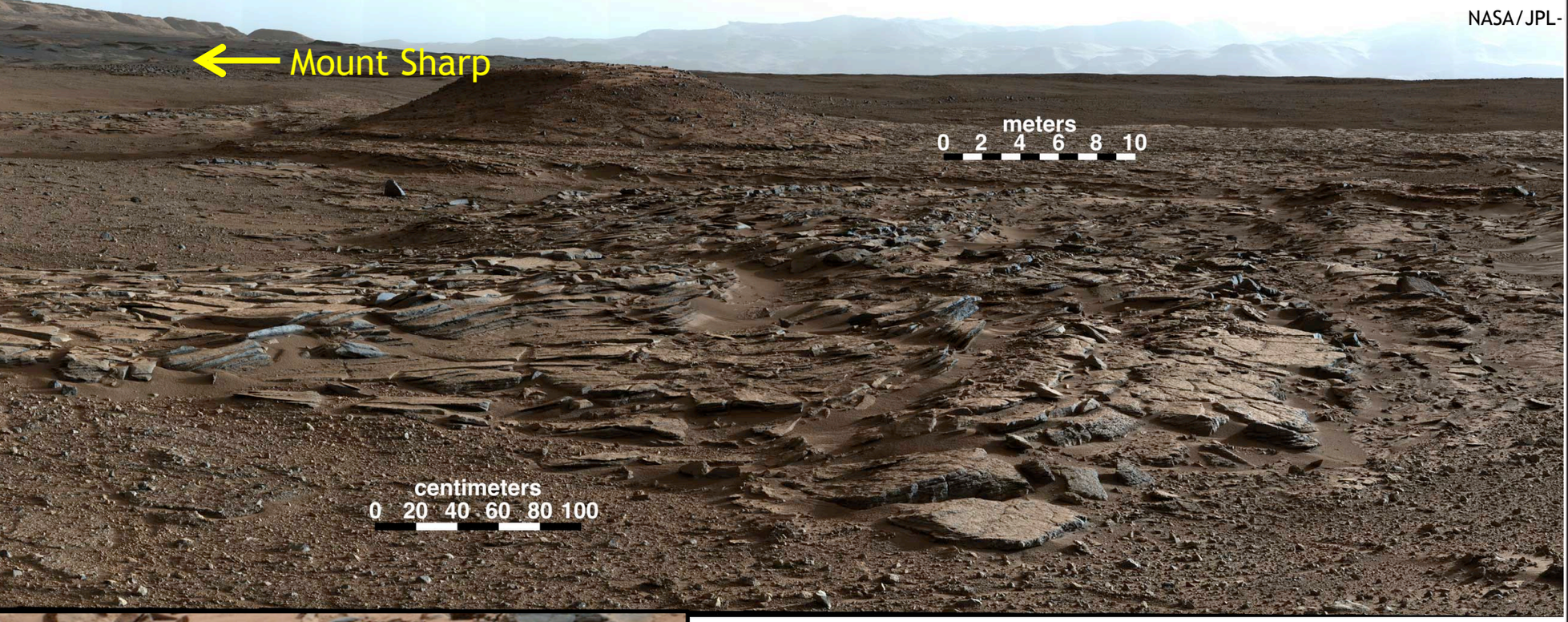


Drill and Scoop Sample Sites

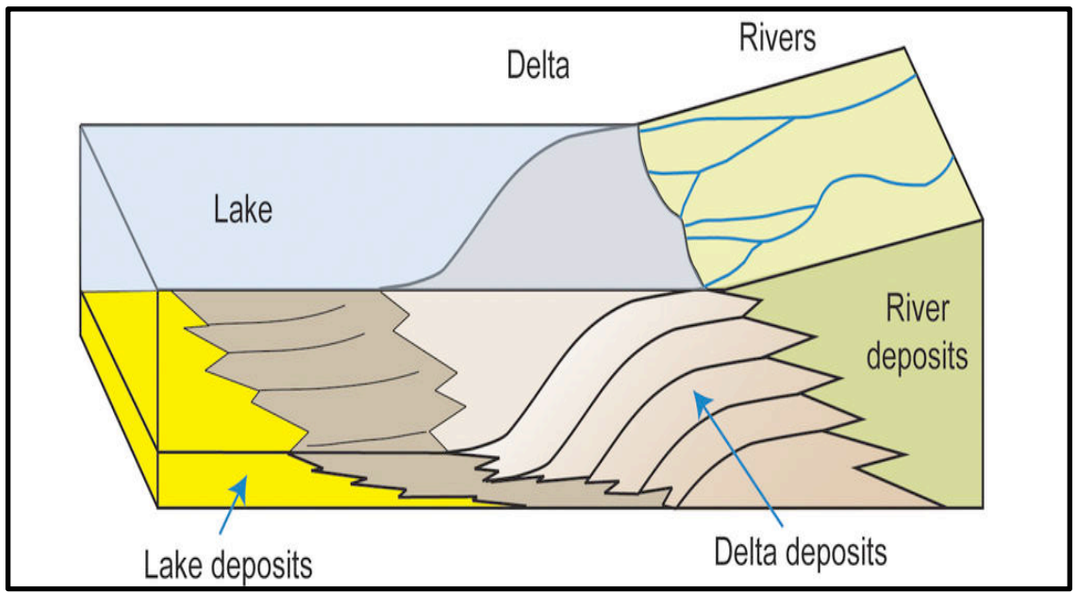


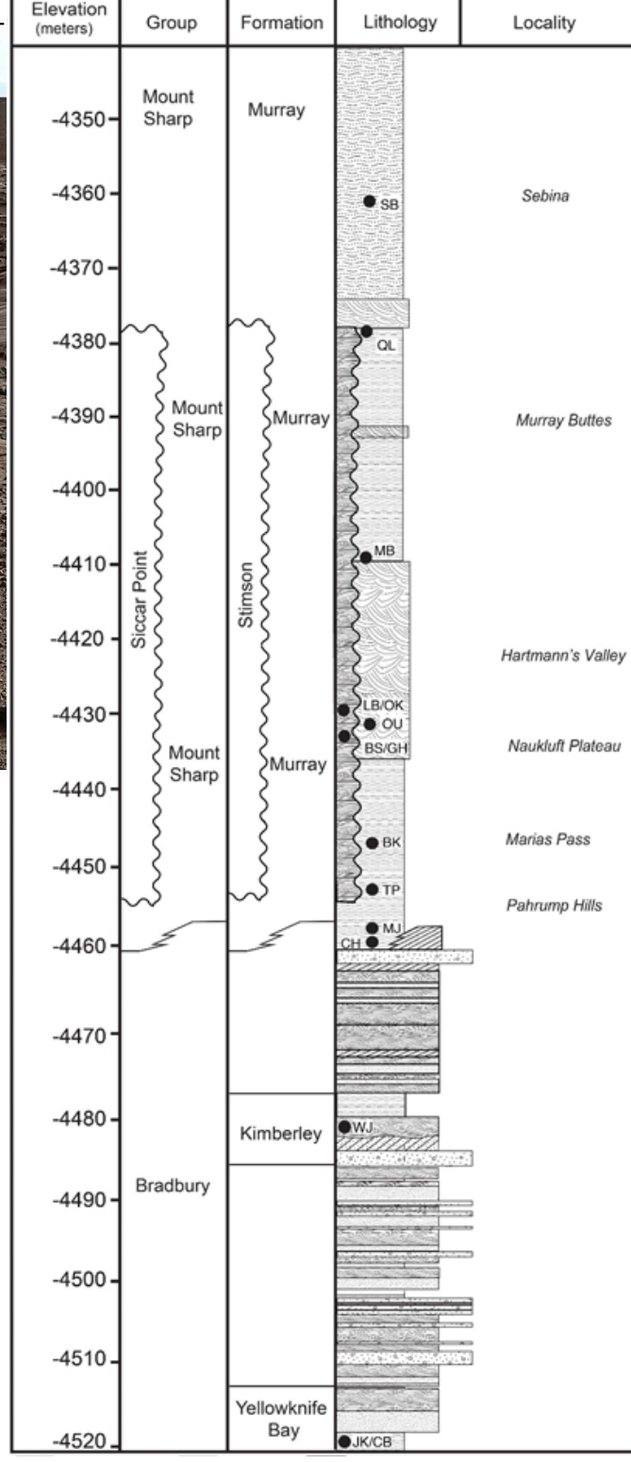






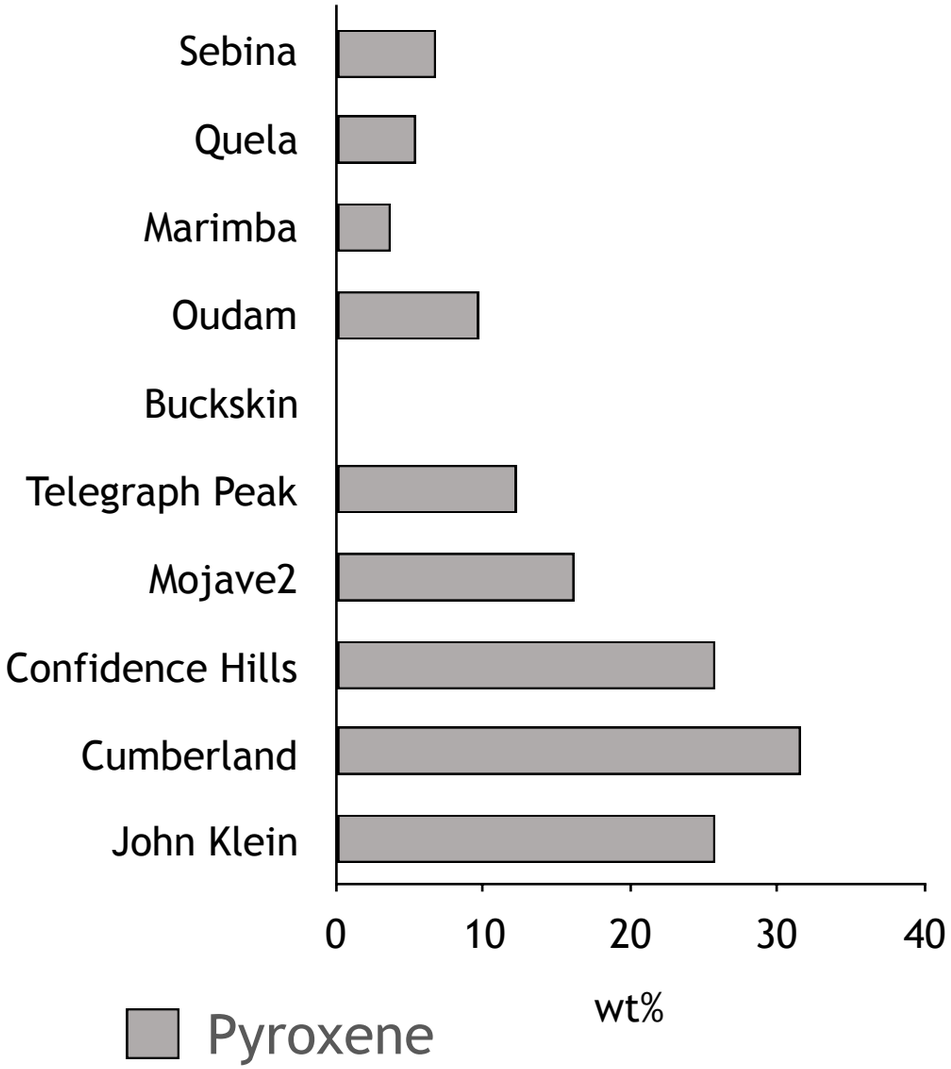
NASA/JPL-

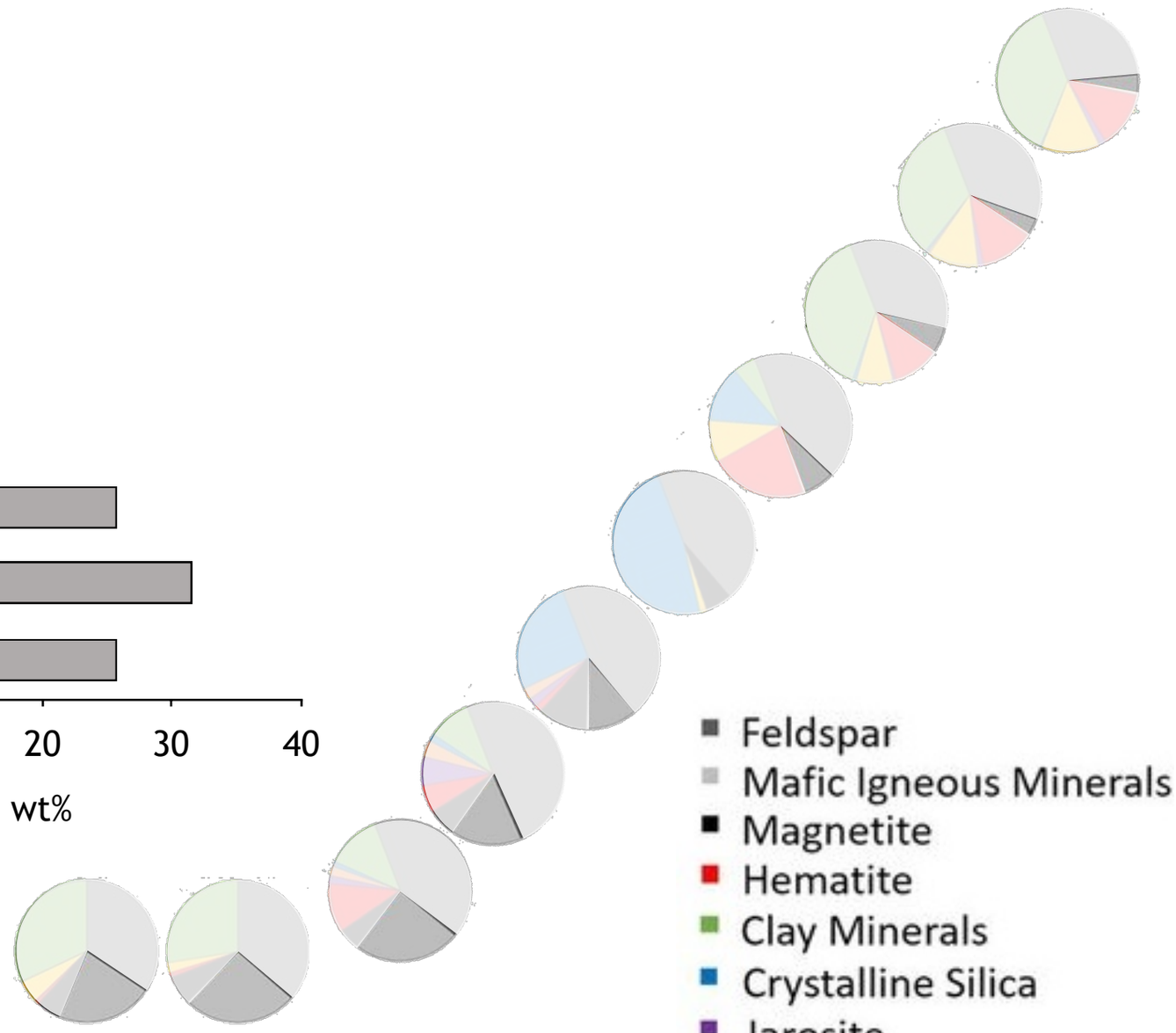


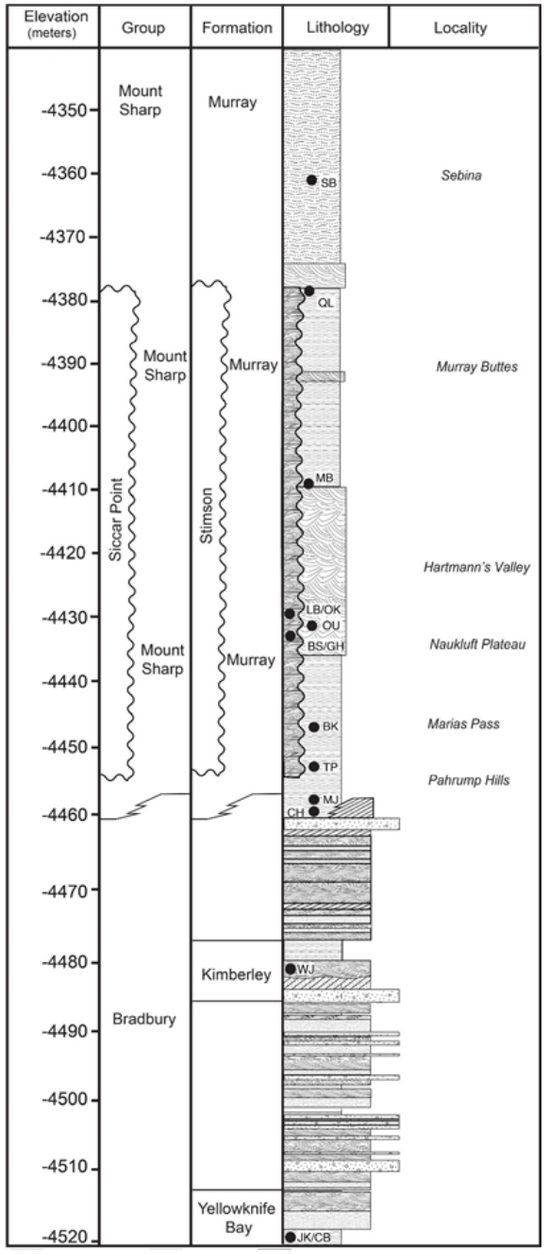


Exploring ~3.5 Ga sedimentary rocks at Gale

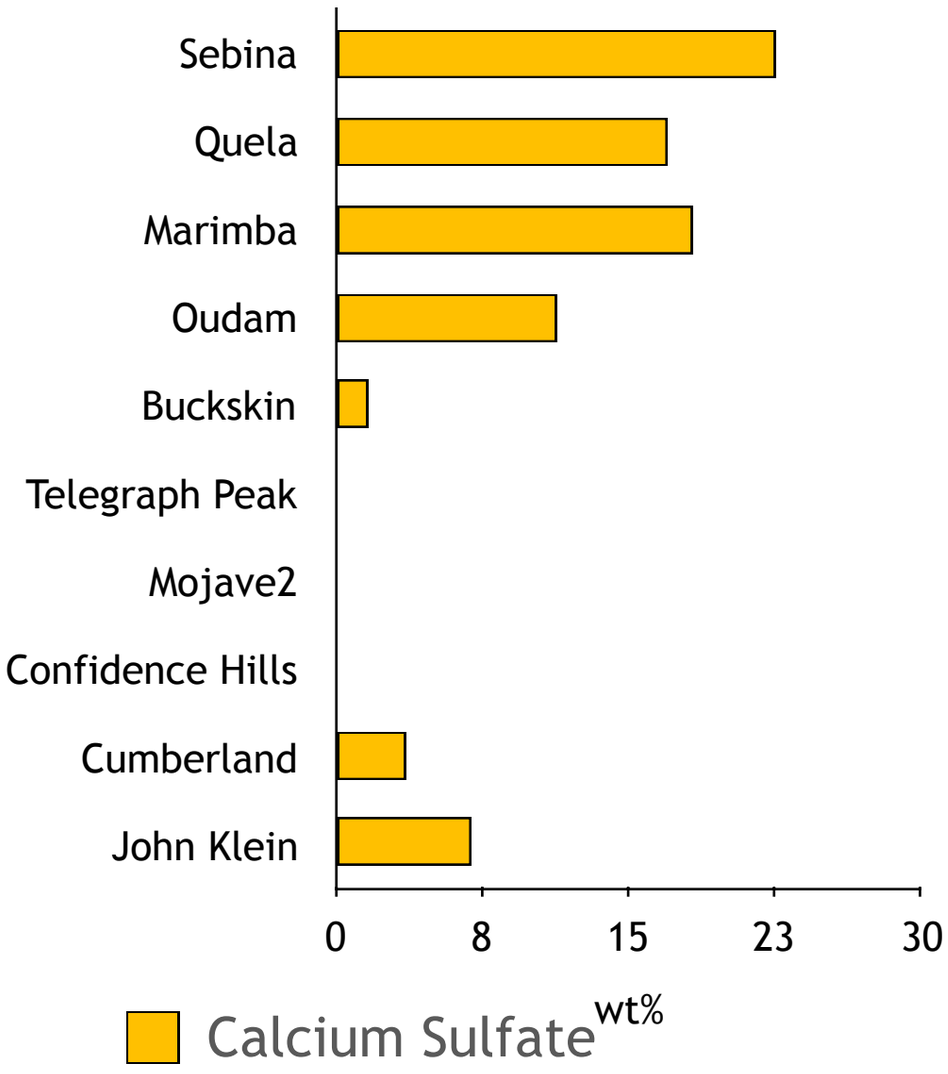
Mudstone Mineralogy – Pyroxene

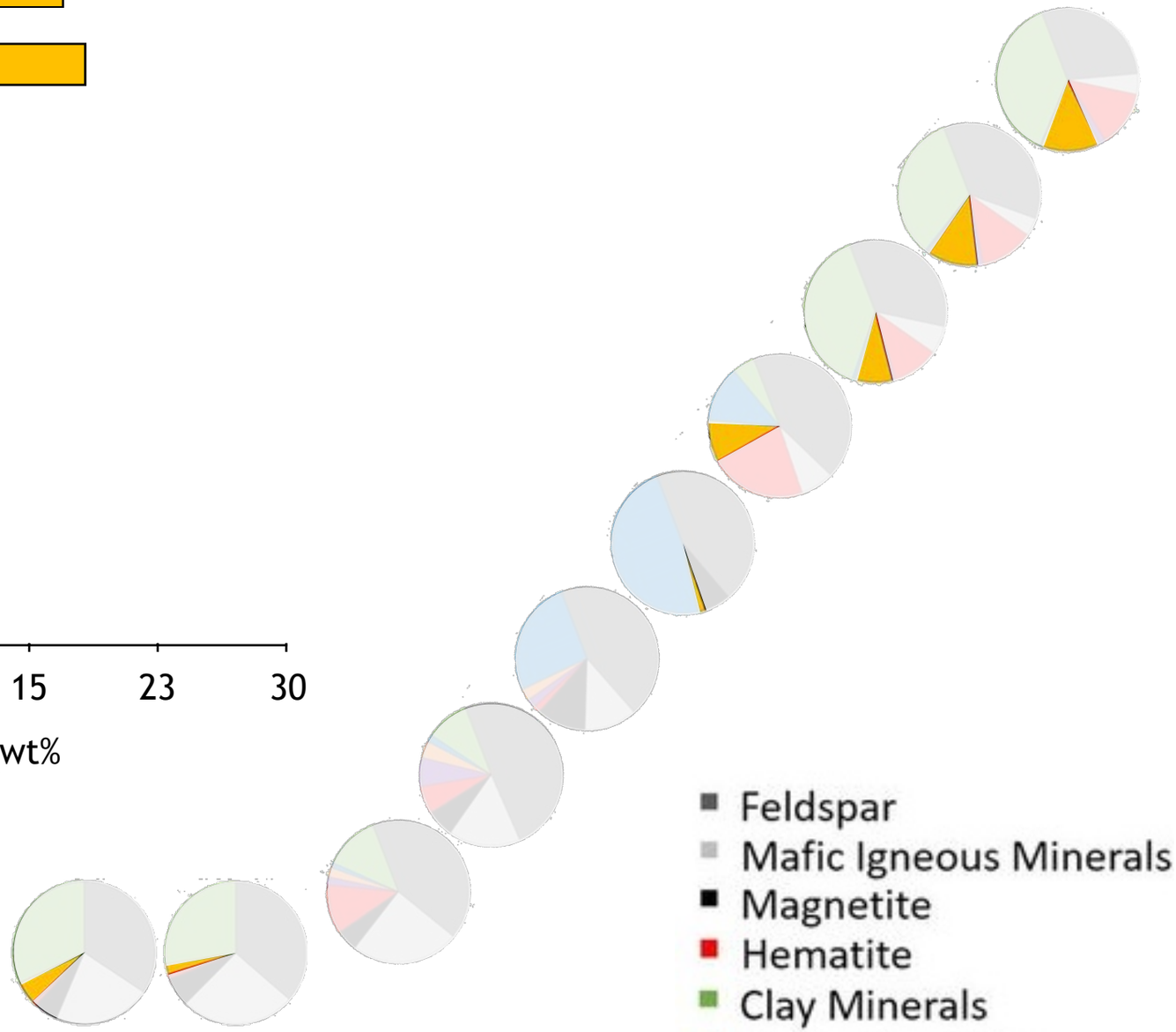


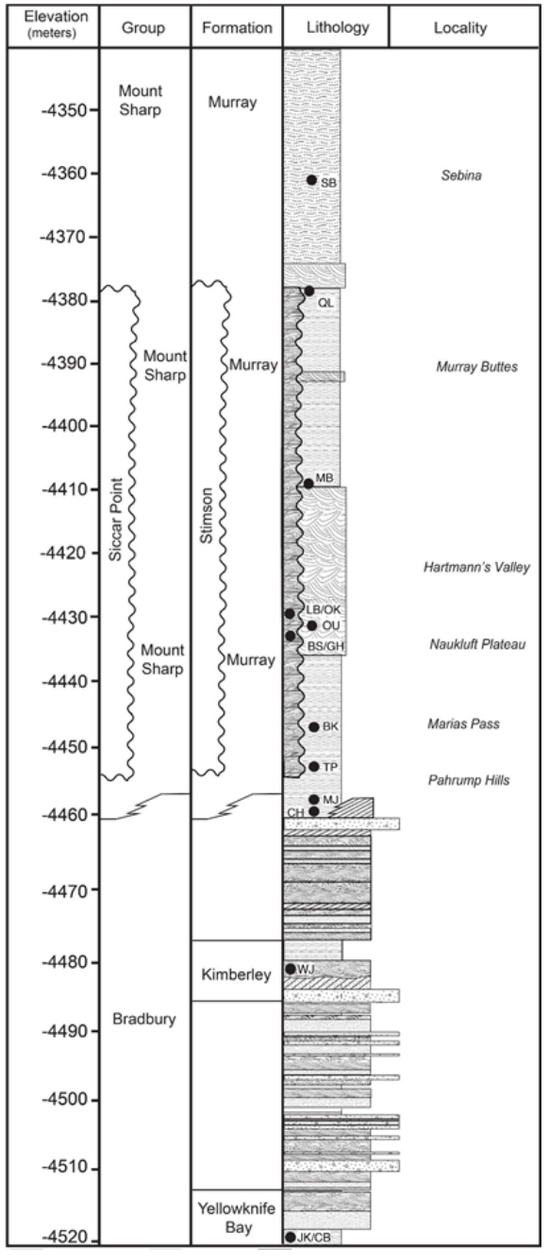




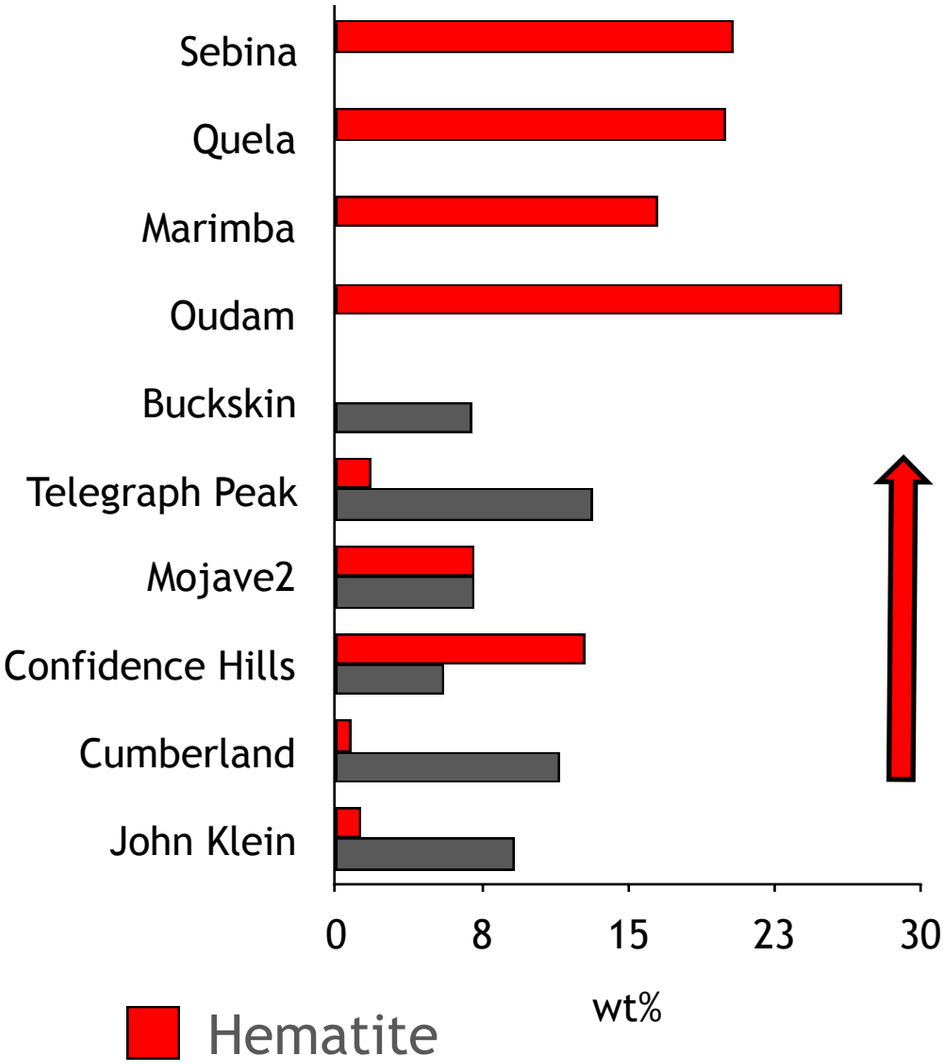
Mudstone Mineralogy – Calcium Sulfates



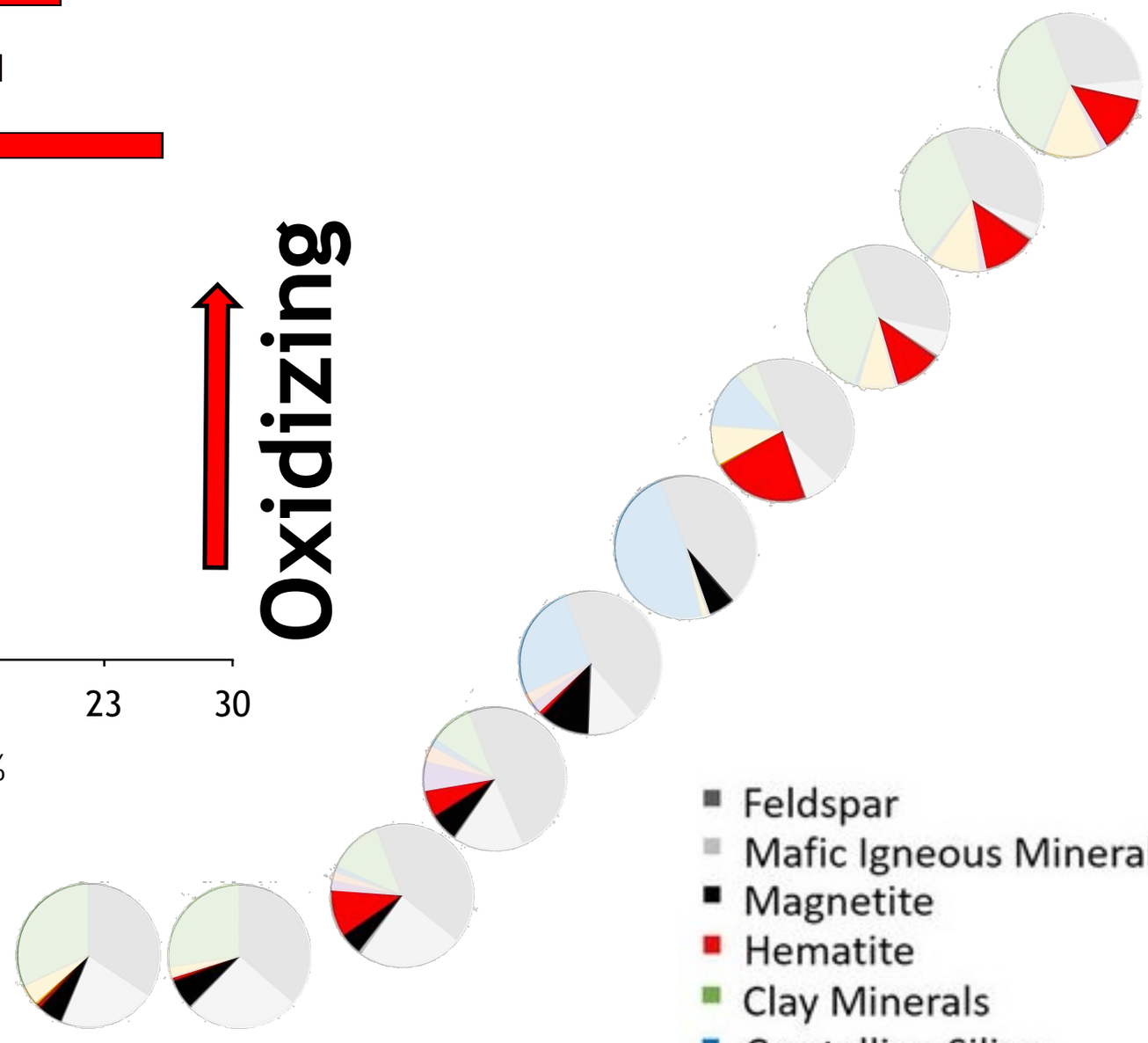


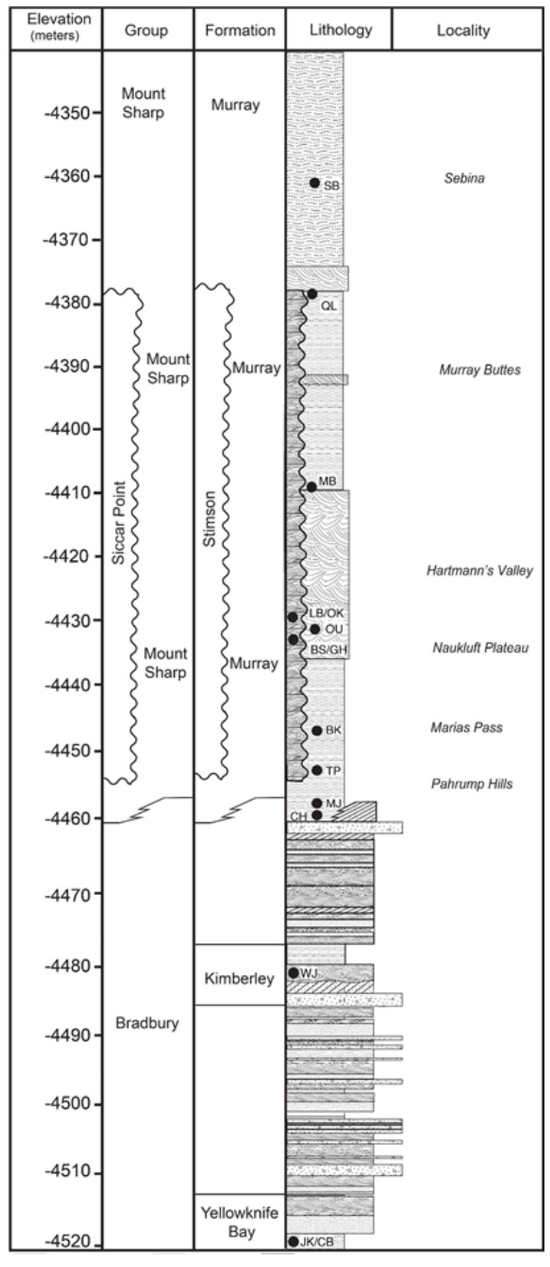


Mudstone Mineralogy – Fe Oxides

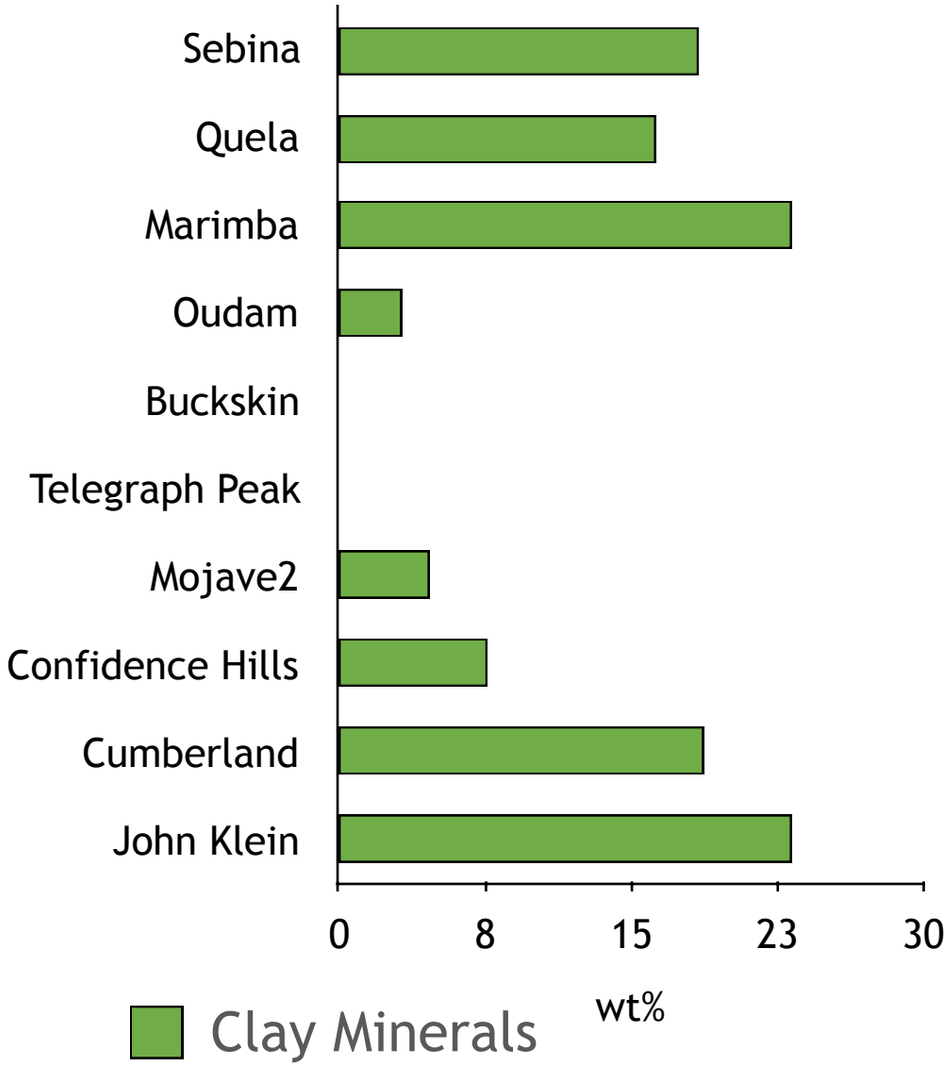


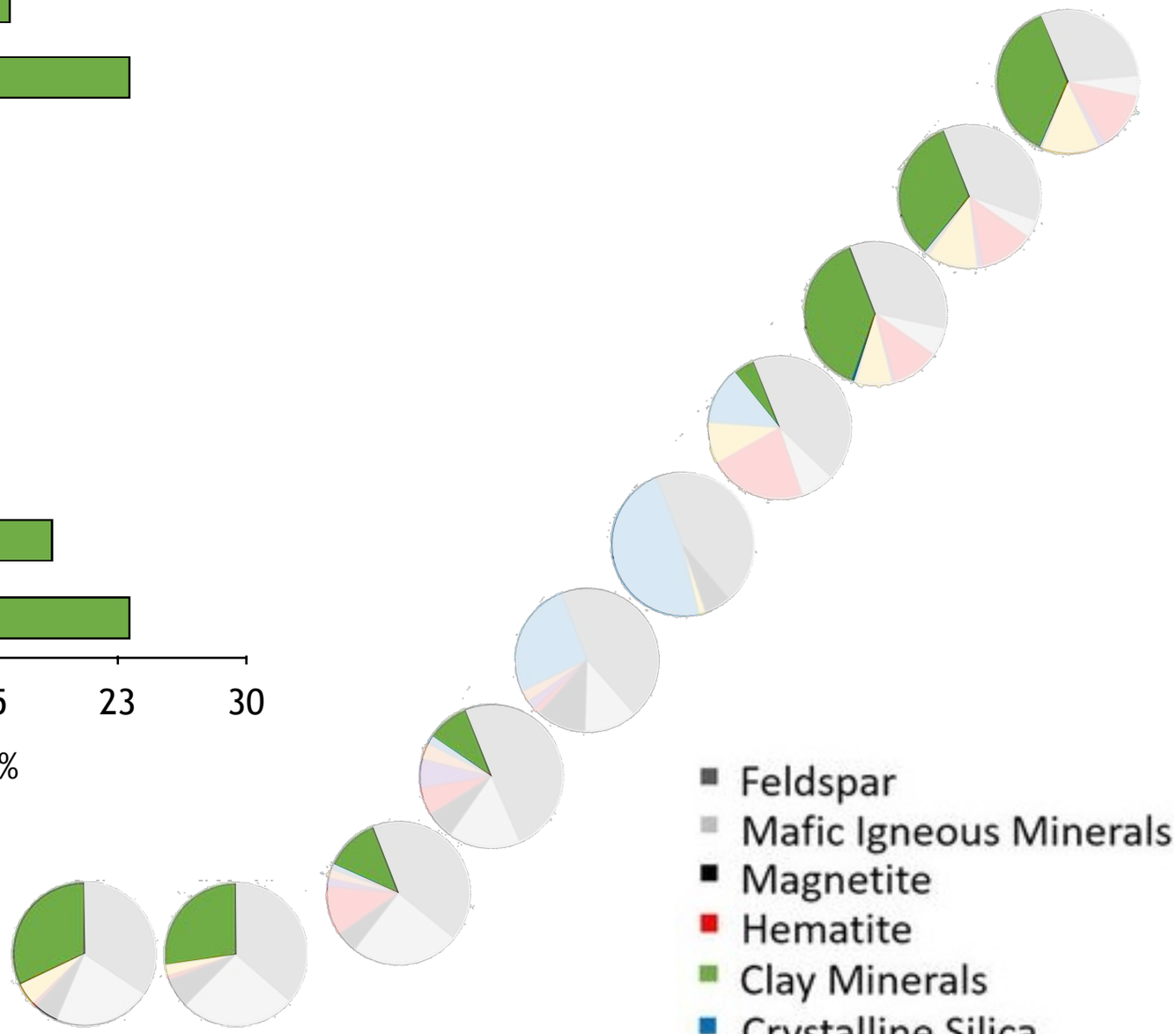
Oxidizing

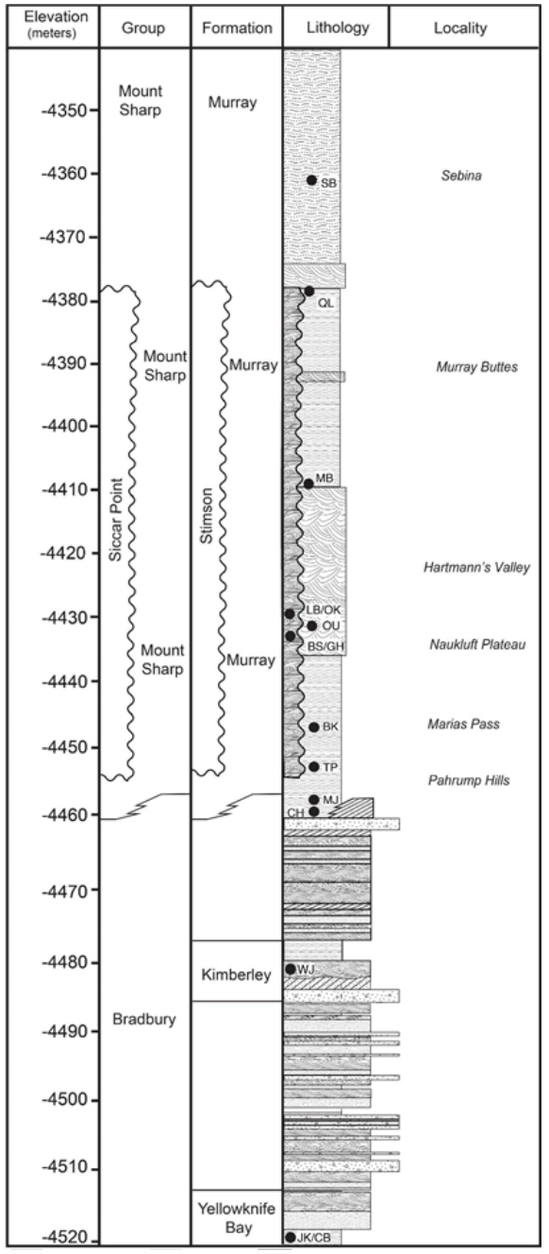




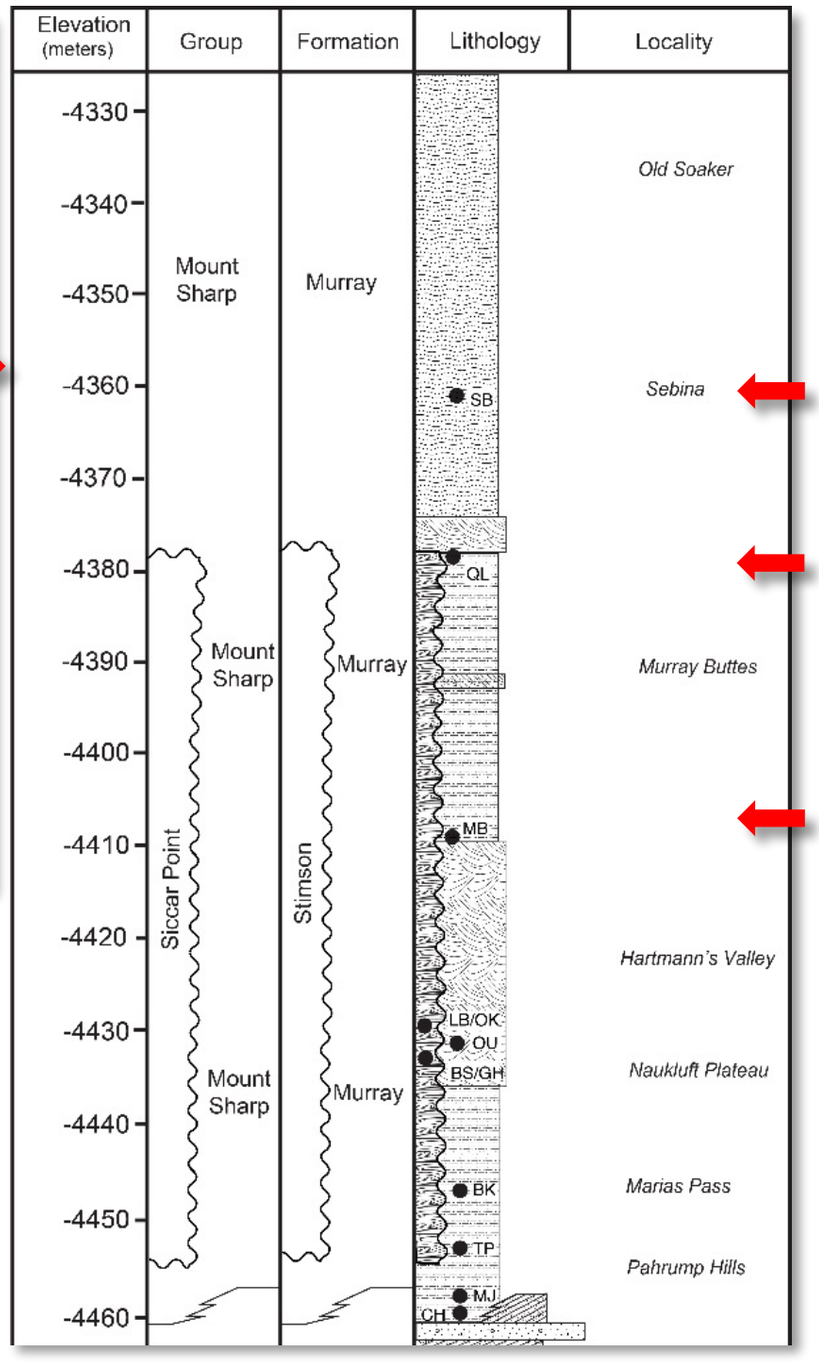
Mudstone Clay Mineral Content



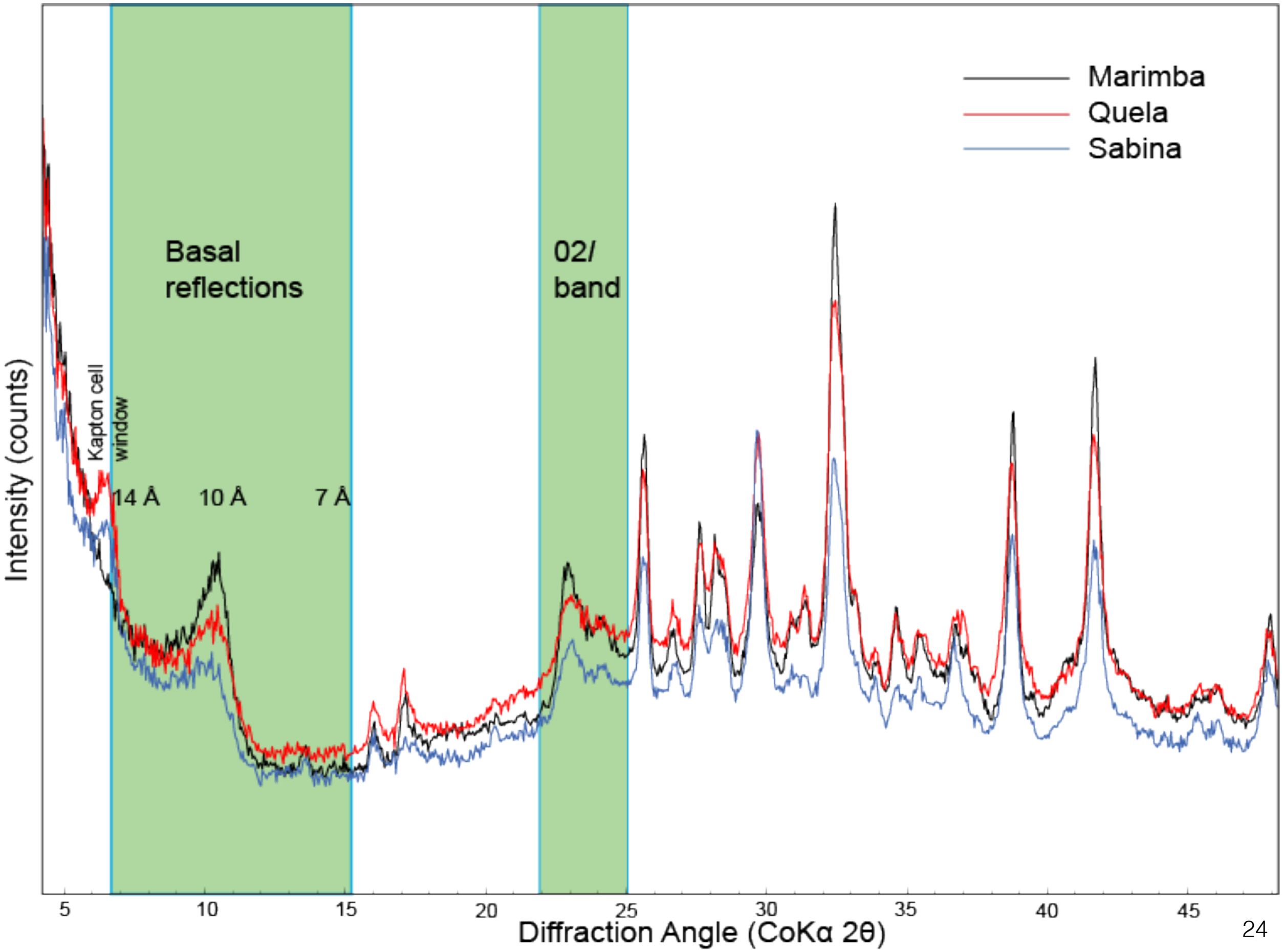




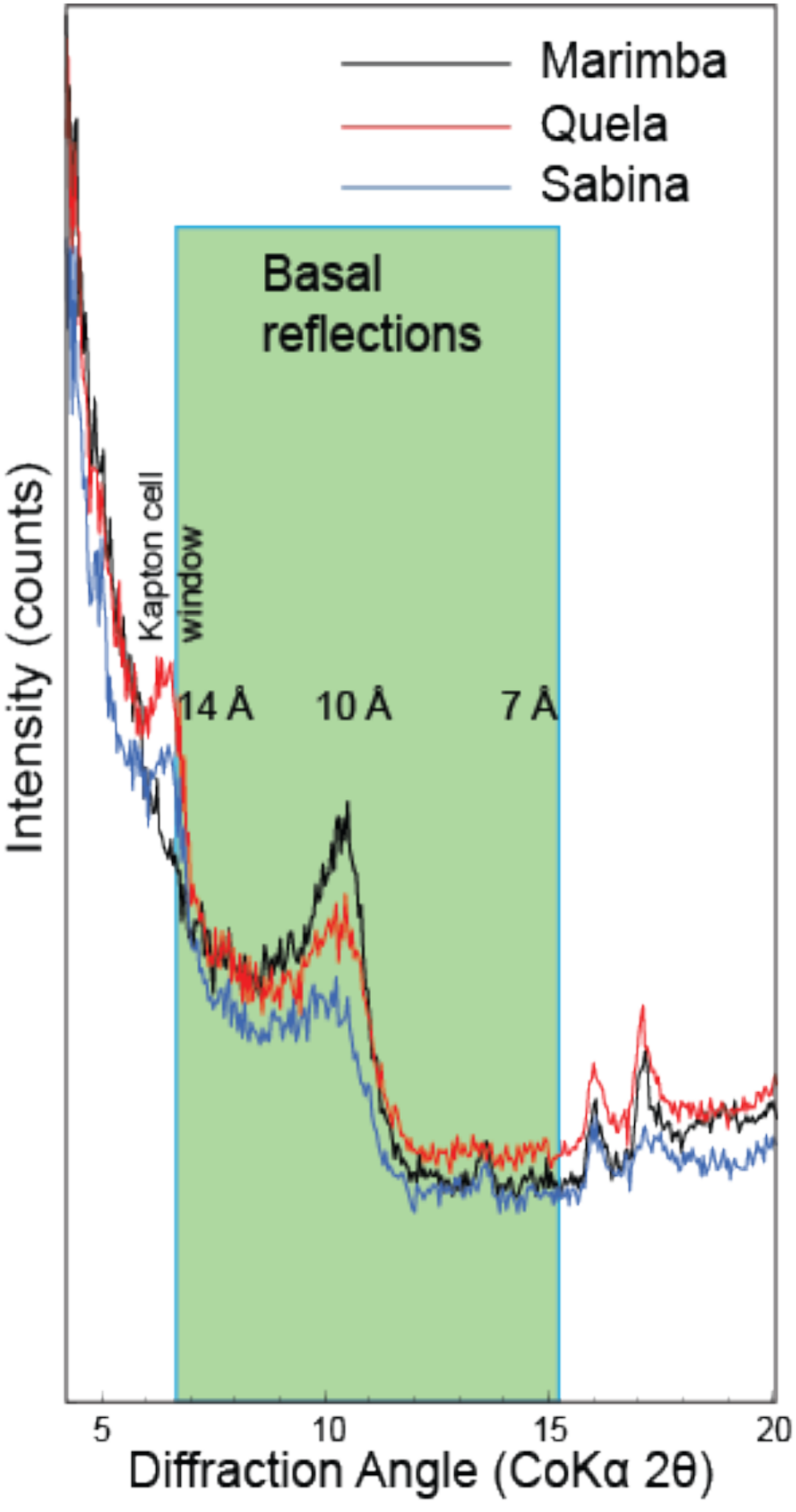
Sample Context: Marimba, Quela and Sabina

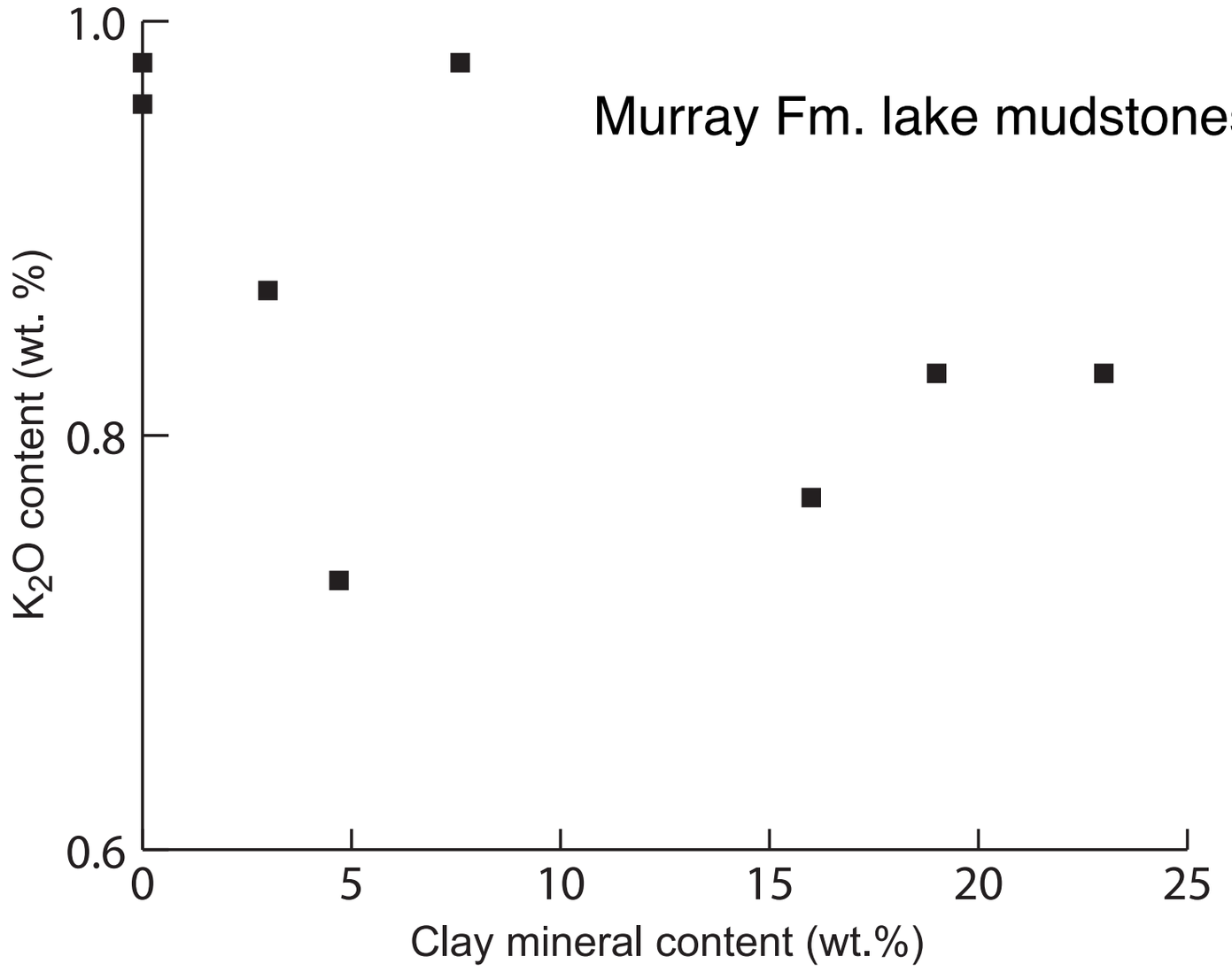


- Marimba and Quela come from laminated lacustrine mudstones.
- Sabina from an overlying package of heterolithic mudstone-sandstone representing lake environment subject to periodic desiccation.

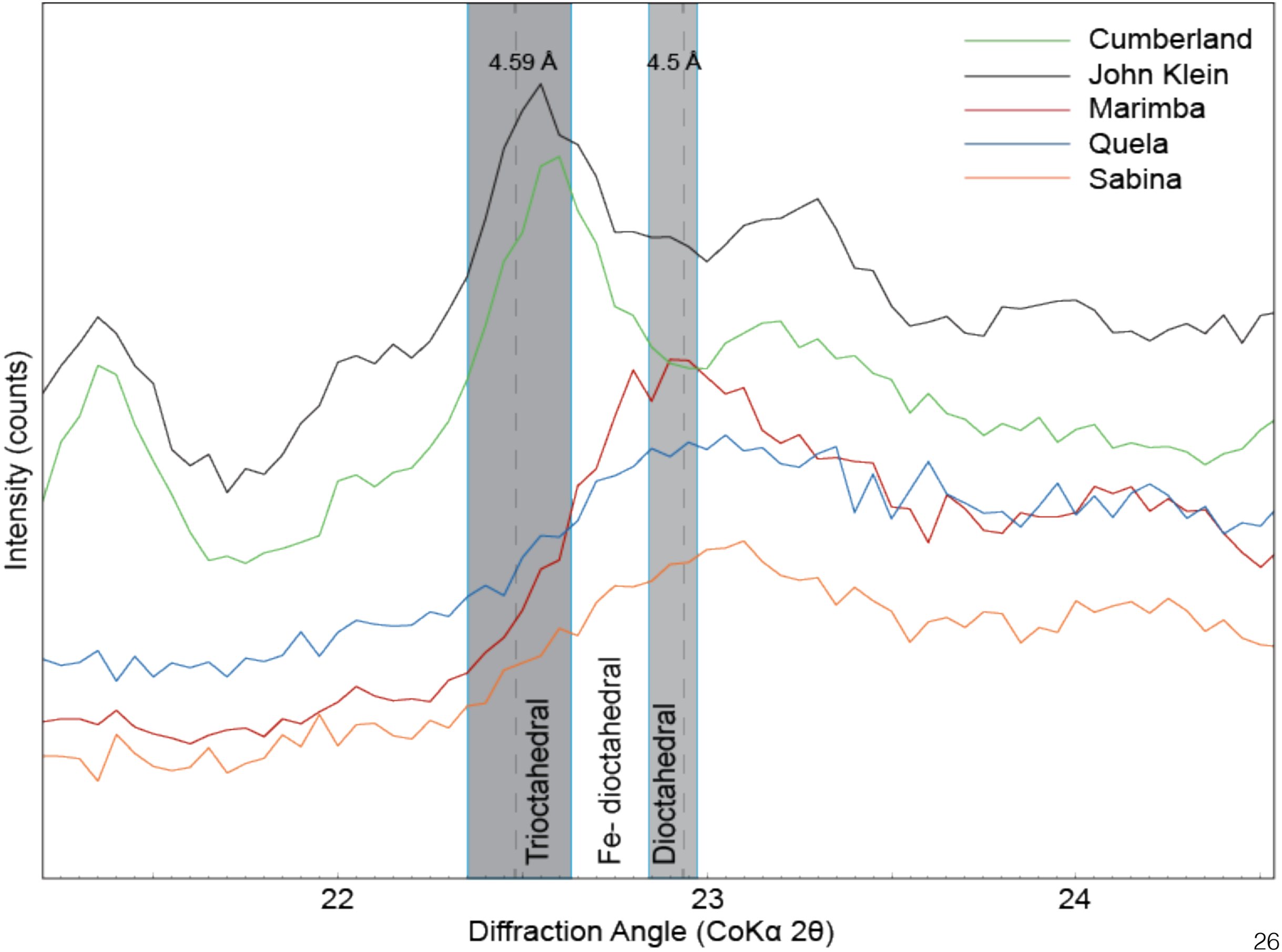

Marimba
Quela
Sabina
Basal reflections
02/ band
Kapton cell window
14 Å
10 Å
7 Å
Intensity (counts)
5
10
15
20
25
30
35
40
45
Diffraction Angle (CoKα 2θ)

Basal Reflection



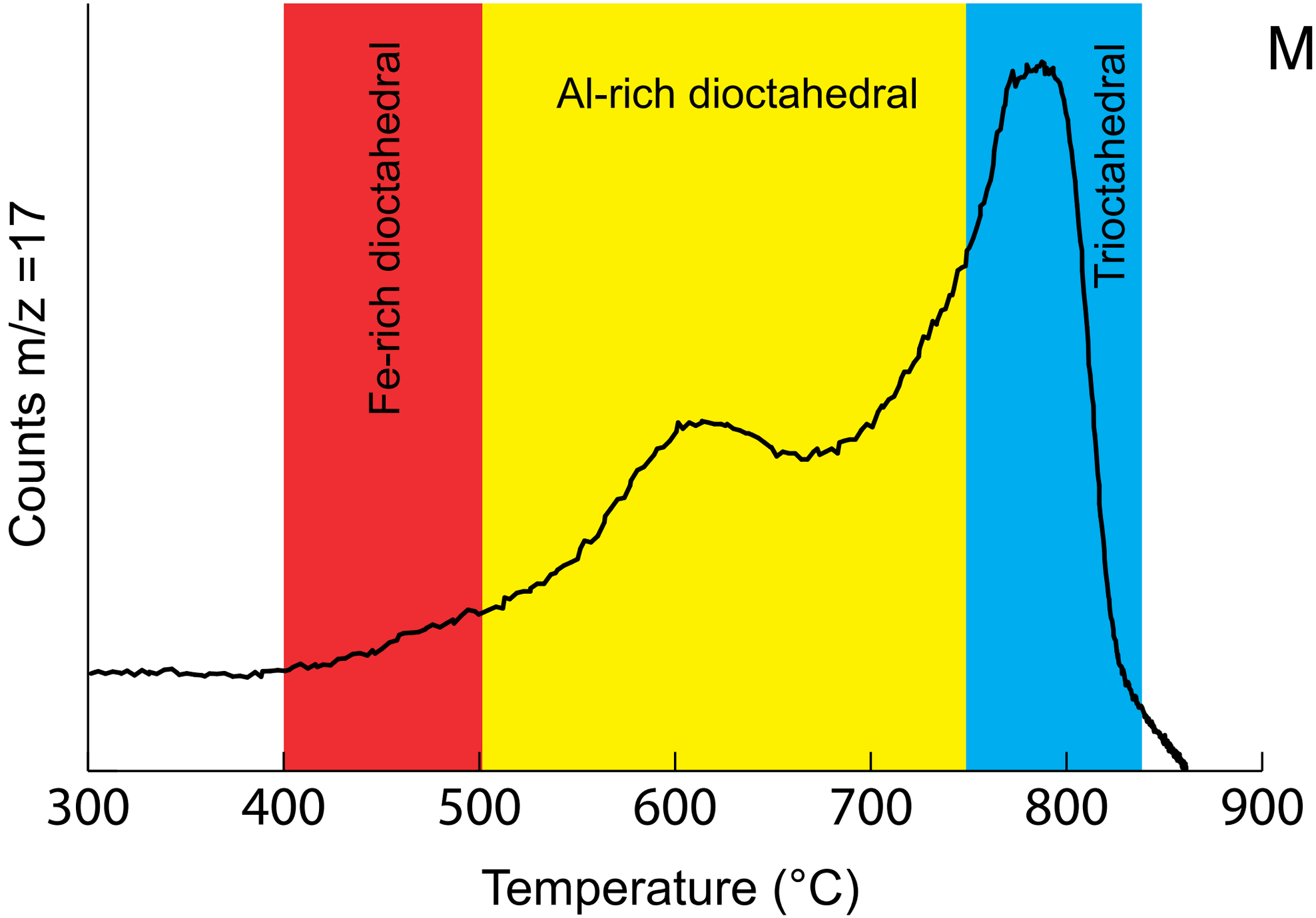


- No indications that clay minerals influence bulk K_2O content of samples.
- Collapsed smectites are main clay mineral phase in Upper Murray samples.

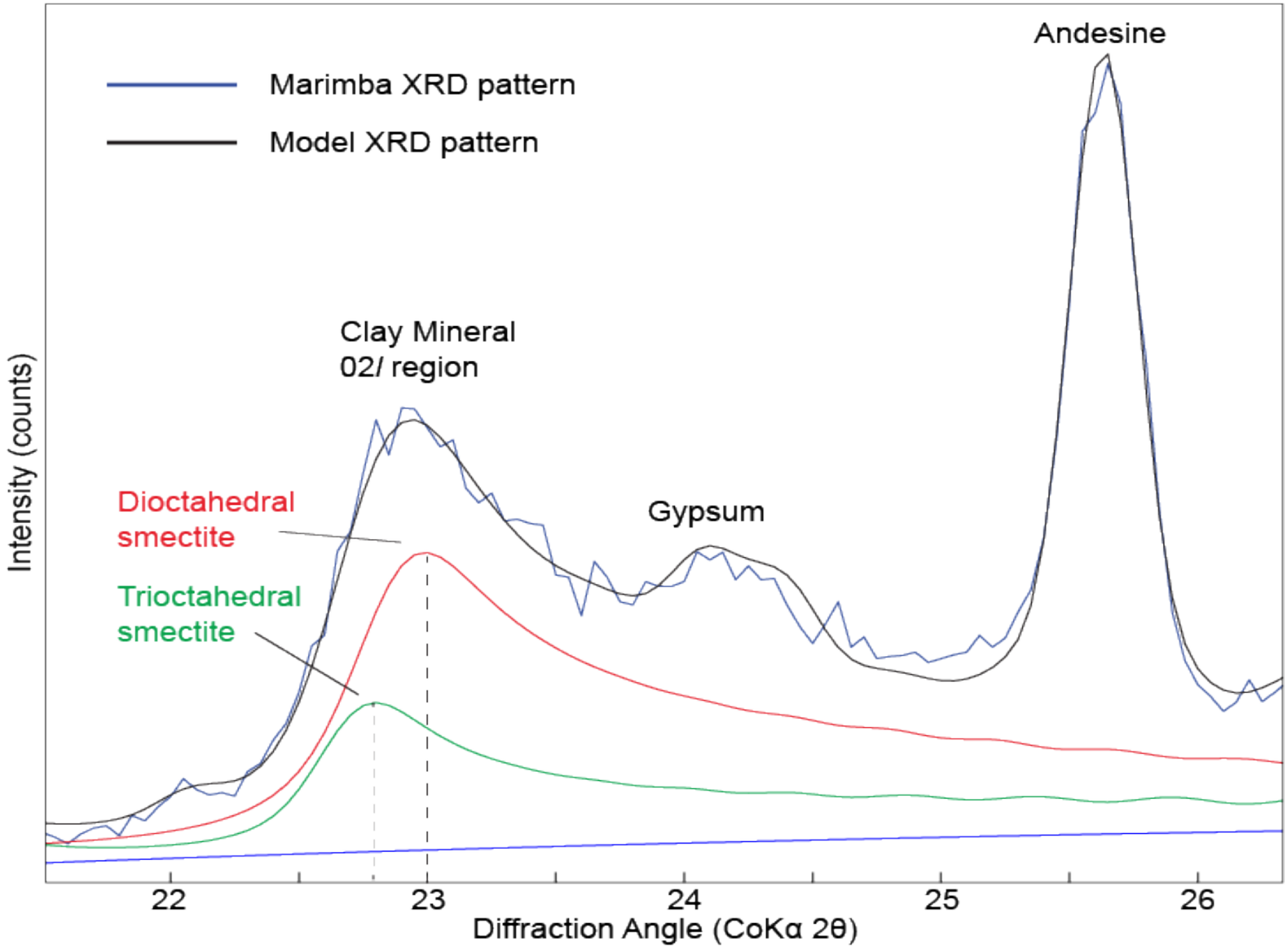

Cumberland
John Klein
Marimba
Quela
Sabina
4.59 Å
4.5 Å
Trioctahedral
Fe- dioctahedral
Dioctahedral
Intensity (counts)
22
23
24
Diffraction Angle (CoKα 2θ)

SAM EGA – Clay Mineral Dehydroxylation

Marimba



Reconciling SAM and CheMin Data

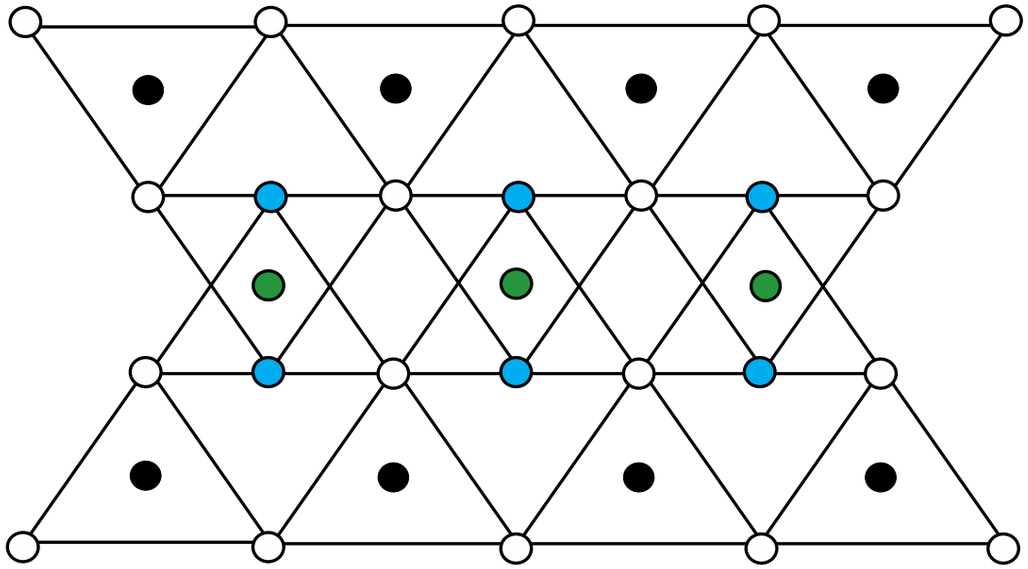


BGMN fits including dioctahedral and trioctahedral smectite structures

- Marimba, Quela and Sebina contain both Al-rich dioctahedral + trioctahedral smectites.
- Dioctahedral clay minerals not observed before with XRD at Gale.

Factors favoring formation of dioctahedral smectite

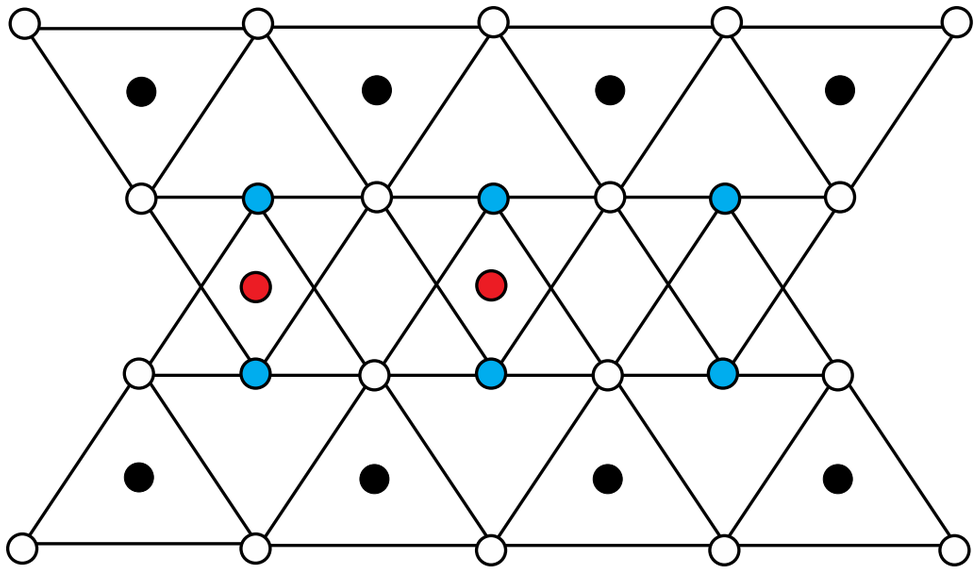
YellowKnife Bay



Trioctahedral
2:1 phyllosilicate

● Mg^{2+}, Fe^{2+}

Upper Murray Formation



Dioctahedral
2:1 phyllosilicate

● Al^{3+}, Fe^{3+}

Oxidation + elemental mobilization, pH drop

→

Loss of Mg^{2+}, Si – relative enrichment of Al^{3+} and Fe^{3+}

Implications

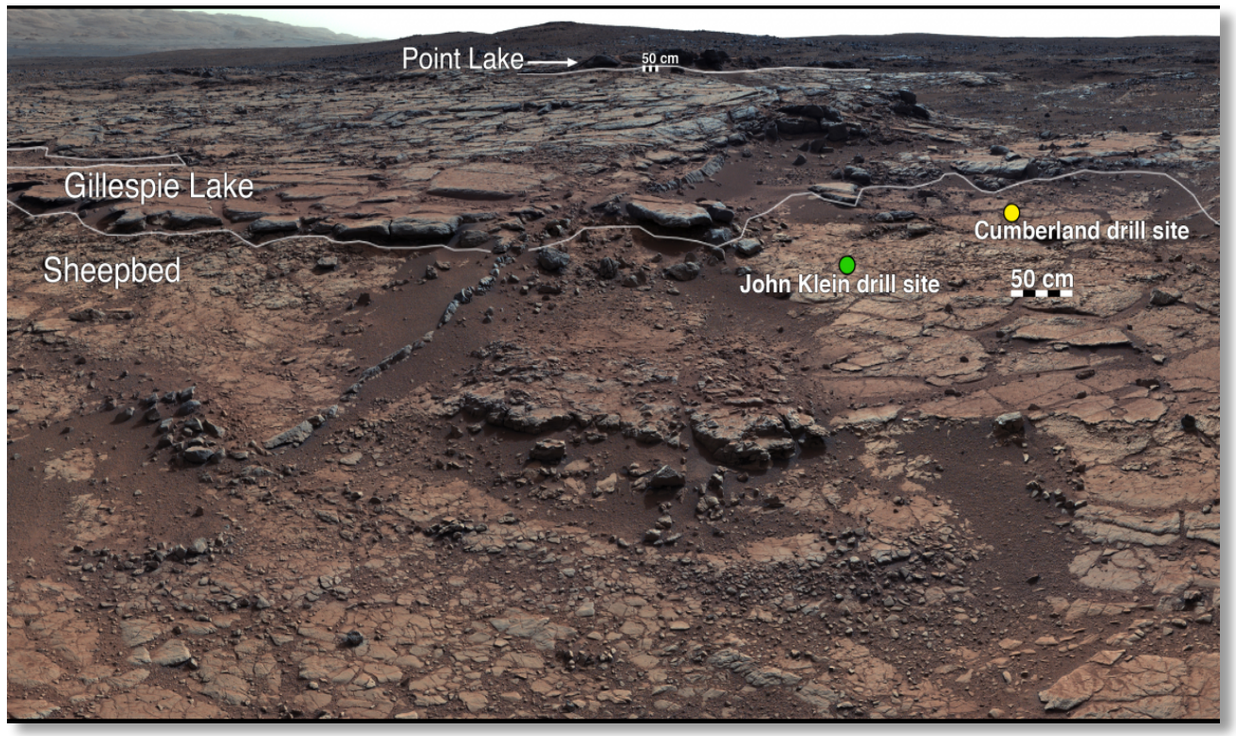
Change in clay mineralogy correspond with changes in other mineralogical and sedimentary indicators:

- More advanced aqueous alteration and element mobility - reduced abundance of pyroxene.
- Oxidizing conditions - hematite main Fe-oxide.
- Desiccating/evaporative conditions – increased Ca-sulfates, mudcracks.

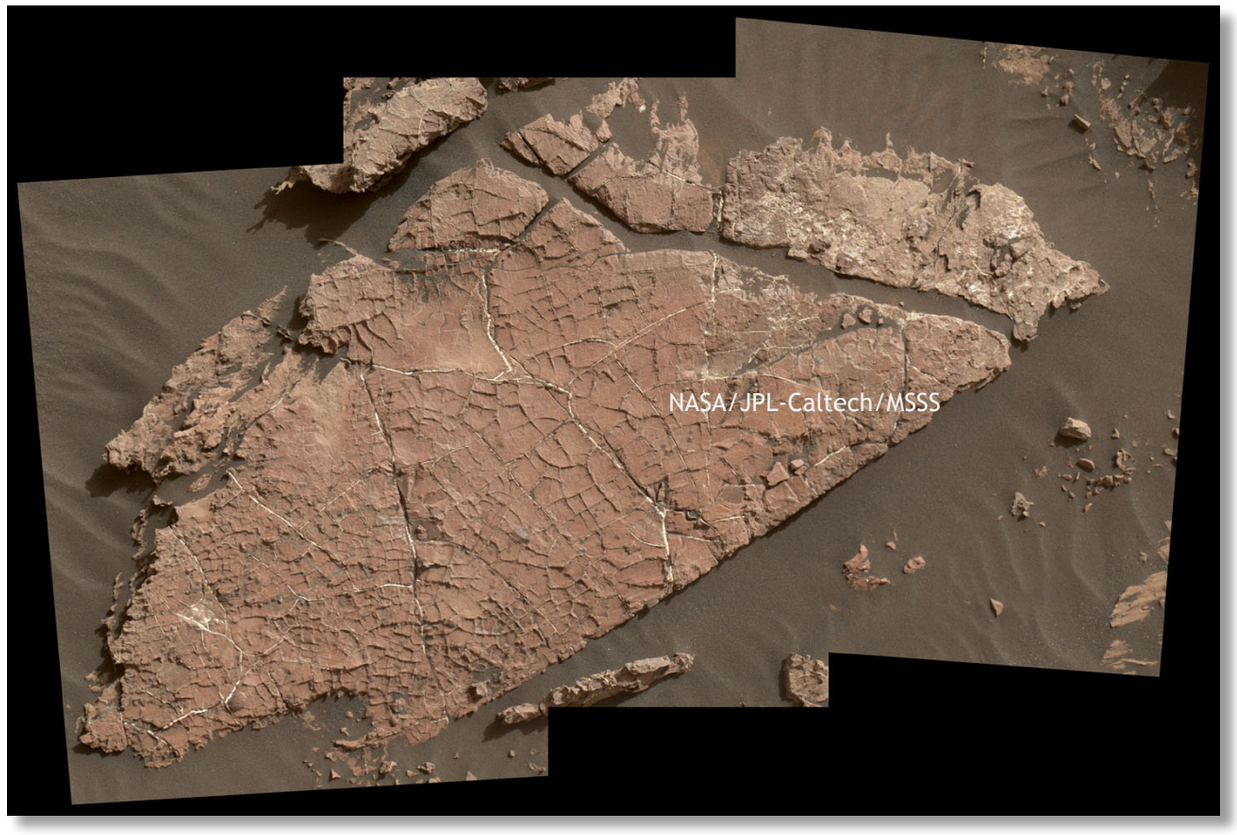
Clay minerals are a product of near-surface processes.

Implications

Broadens the spectrum of mineralogical facies documented by MSL:



Yellowknife Bay



Upper Murray

Does Upper Murray mineralogy/sedimentology reflect a change regional/global change in conditions, or is MSL simply sampling a different sedimentary facies?