IN SITU INSTRUMENT OPPORTUNITIES

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What is an "in situ instrument"?

- I prefer the more utilitarian distinction between *planetary surface instruments* and orbital or deep space instruments
- *Sensor* suggests a transducer, while *instrument* is a means to perform an experiment, including sample handling.
- In addition to chemistry (inorganic and organic), biology, mineralogy, also have physical properties (size, shape, density, hardness, thermal conductivity, etc.) and atmospheric sciences

What is in the roadmap: Table 1 (SIOSS challenges)

- Instruments
  - Integrated/miniaturized sensor suites
- Sampling
  - Subsurface sampling to >1m, cores to 10 cm
  - Preservation of sample biological and chemical integrity
  - Temperature control of frozen samples
  - Unconsolidated material handling in microgravity
- Long term
  - Nothing 2017-2022
  - Extreme environment technologies (vacuum, microgravity, radioactive, high/low temperature, high pressure, caustic…

What is in the roadmap: Table 5 (Planetary Science needs)

- Mini spectrometer, filters, coatings
- Pulsed lasers (Raman, LIBS) and tunable CW (NIR/IR)
- Gas and elemental composition, APXS, IR, gamma, Raman, XRD, neutron…
- Geochronology
- Biological sensing
- Sample handling
- High power, extreme environments

What is in the roadmap: Table 8 (Sensor technology)

- Particles, fields, waves
- Sample Handling
  - Acquisition (subsurface and cores)
  - Transfer and delivery
  - Cryogenic & sealing (preserve volatiles, control and monitor cross-contamination
- Chemistry and Mineralogy (beyond APXS)
  - Wet chemistry (measure dry weight, dissolved ions to ppm)
  - Elemental composition (LIBS, XRF) with spatial resolution
  - Mineralogy (Raman, XRD, IR/UV) with spatial resolution
  - Microscopy (SEM, hyperspectral)
- Organics and biology
  - Ppb detection (requires contamination control)
  - Mass range and resolution (<0.1 amu!)
  - Biomarker detection
- Planetary protection

In-situ surface physical, chemical, & biological sensors

QUESTIONS TO PANELISTS

Top *sensor* challenges (not in roadmap are yellow)

- Imaging with chemical identification, microscopic to macroscopic
- *In situ* geochronology
- *In situ* biomarker detection
- Ultra-high resolution mass spectroscopy (resolve isobars)
- Lower degree of difficulty:
  - Atmospheric instruments
  - Physical property instruments
  - Geophysics (seismometry, heat flow)
  - Terrestrial in situ instruments

Top *system* challenges (not in roadmap are yellow)

- MSR curation (in situ)
  - Need to avoid alteration as well as loss of volatiles and cross-contamination. Requires thermal control
- Excavation technologies (rock, soil, ice)
- Extreme environments (Venus, Titan)
- Power technologies
  - kW and mW power sources
  - Non-solar, non-nuclear (e.g. wind, thermal, chemical)
- Planetary Protection and Contamination Control
  - Full-spacecraft sterilization

High Priority Sensor Technology Areas (non-biological)

- Liquid phase analysis
  - Wet chemistry
  - Lab-on-a-chip
  - Ice/water analysis
- Mass spectroscopy
  - Isobar-resolving (>100K resolving power)
  - Laser ablation mass spectroscopy
  - Geochronology
- Chemical microscopy
  - SEM/EDX
  - Small spot scanning XRF
  - Spectroscopic imaging
  - Chromophor microscopy

Lower priority sensor technology areas (non-biological)

- Sounding
  - Lidar and scanning lidar
  - LIBS and Raman
  - Neutrons and gammas
  - Acoustics
  - Seismometry
  - GPR
  - NMR
  - Remote thermal properties
- Other
  - Physical properties
  - Atmospheres
  - XRD
  - Electric and magnetic fields

Alignment with NASA capabilities, role, competitiveness

- All sensor and system technologies listed above could be well addressed by NASA with appropriate levels of R&A funding, except possibly:
  - Extreme environment operation (large investment, opportunity for cost-sharing)
  - Full-spacecraft sterilization

Game changing technologies (near tipping point is yellow)

- Ability to do things relegated to sample return, e.g.
  - In situ geochronology
  - Advanced life detection
  - Micro-analysis
- Non-nuclear power sources (e.g. thermal, chemical)
- Extreme environment operation (esp. Venus)
- New architectures:
  - Extreme surface mobility
  - Broadened access to deep space (flying instruments)
  - Ability to collect and store massive amounts of data and samples with high autonomy, uploading “apps” for data mining and analysis.
  - Fleets of miniature payloads

For discussion

- Time horizons for insertion
- Payoffs, risk, technical barriers and chance of success

Example:

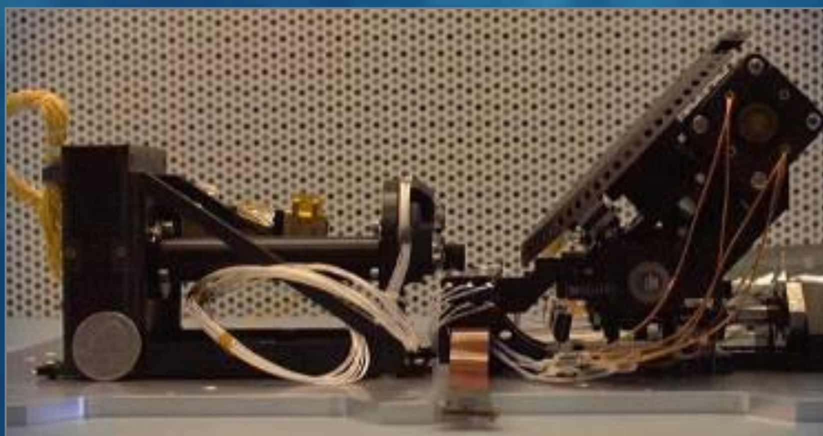
CHEMICAL MICROSCOPY

Big Questions

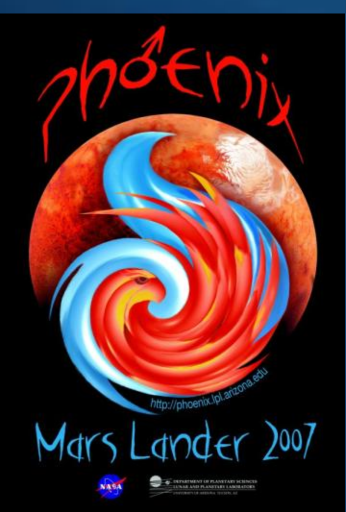
1. What is the relationship between the airborne dust, surface soil, and the present-day rock mineralogy, on Mars in general and at particular sites?
2. What weathering and alteration processes are occurring presently? What is the contribution of aqueously altered material to the soil?
3. What does the microstructure of soil tell us about the spatial extent and time scale of water activity?
4. How local or global is the material observed in the regolith? What is the spatial distribution? What is the capacity for transportation of sediment, and how might it have changed with time?
5. What are the dynamics of the upper meter or two of regolith? What is the exposure age of the surface? The exposure history of the subsurface?

The Microscopy, Electrochemistry, and Conductivity Analyzer (MECA)

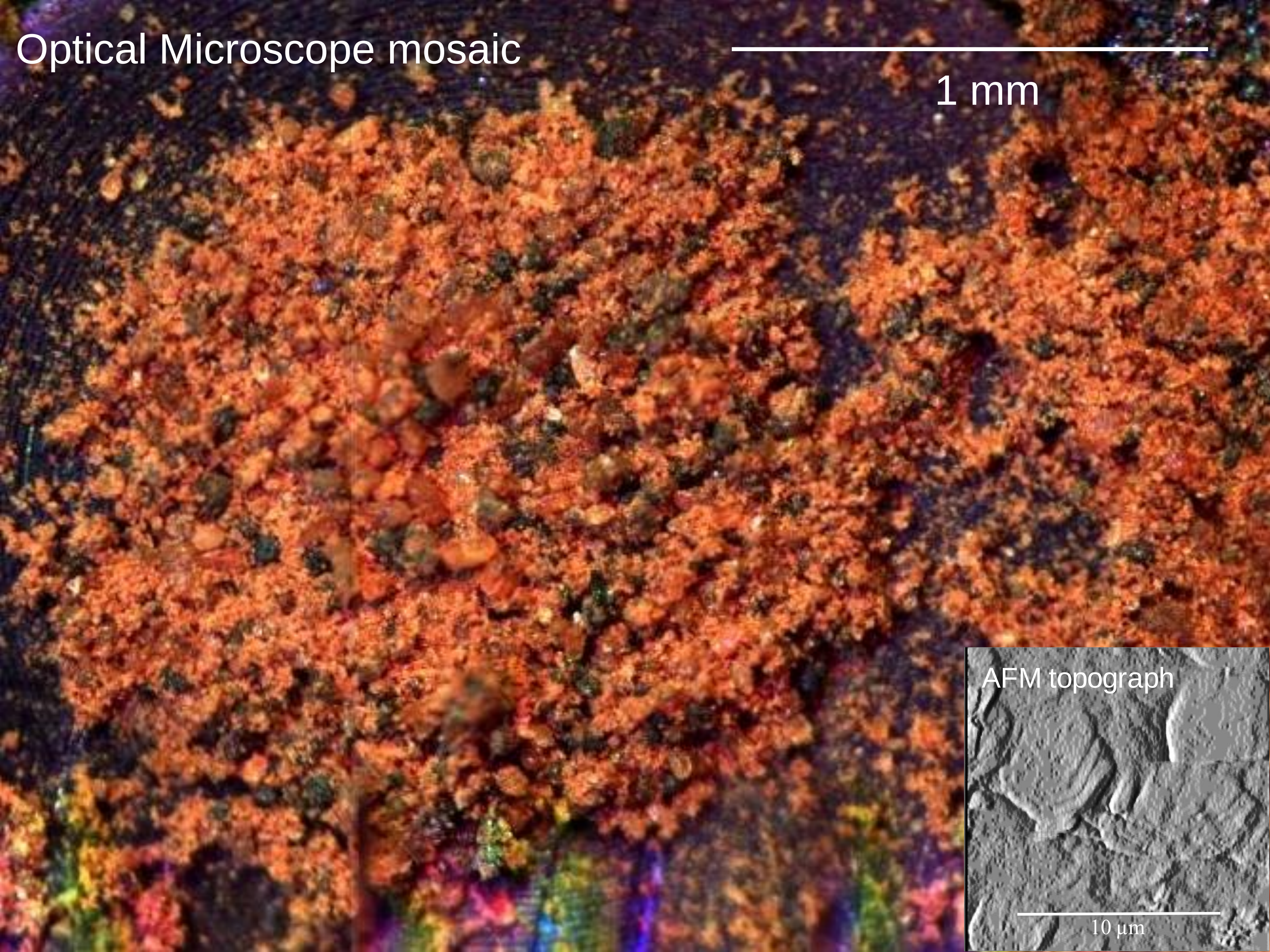
Originally the Mars Environmental Compatibility Assessment for the 2001 Mars Surveyor Lander



30 cm

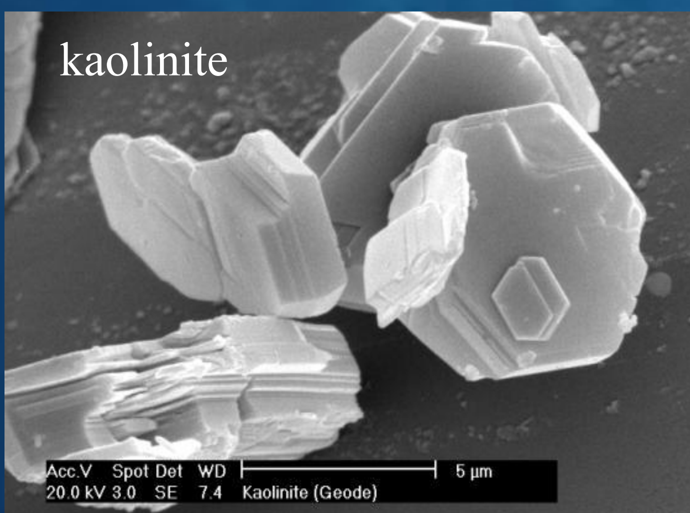


12 cm

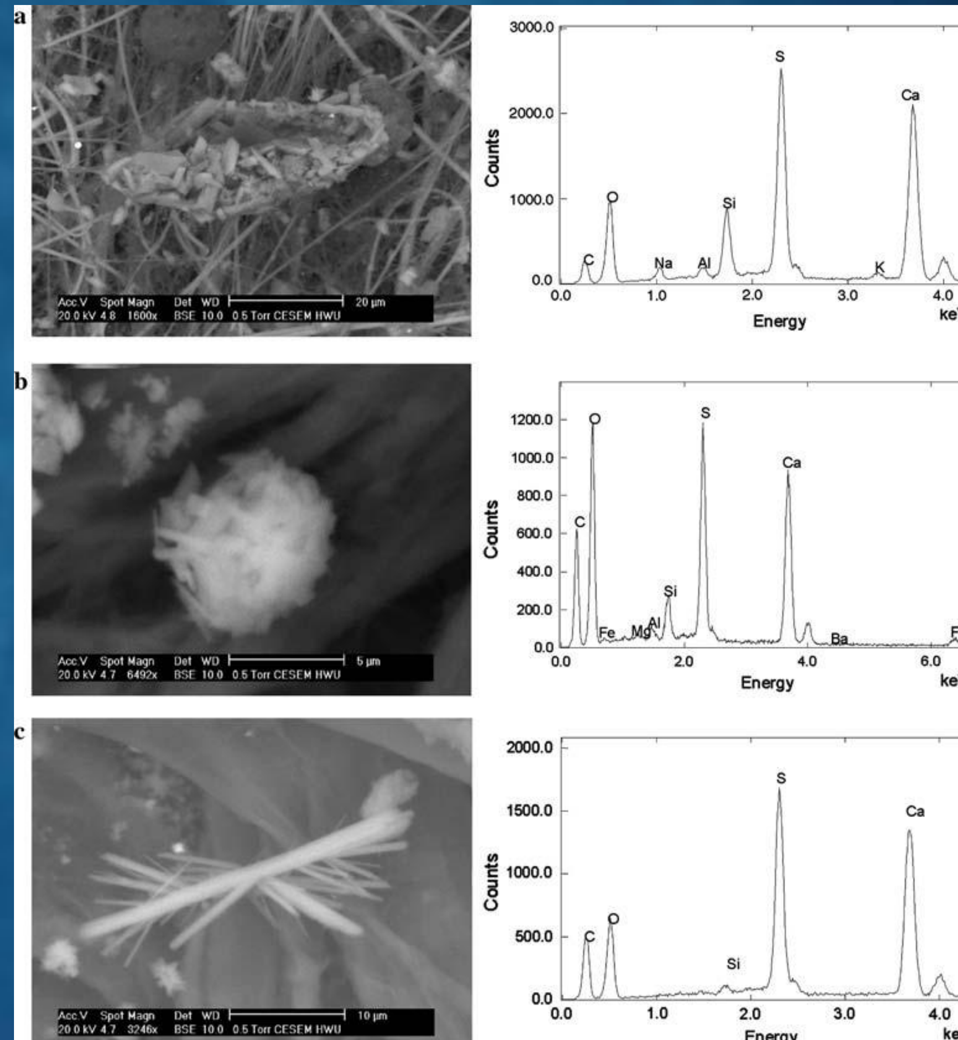

Optical Microscope mosaic
1 mm
AFM topograph
10 μm

Suggested Approach to Surface Investigation

- Microanalysis
- Diversity
- Subsurface access
- Sample Return



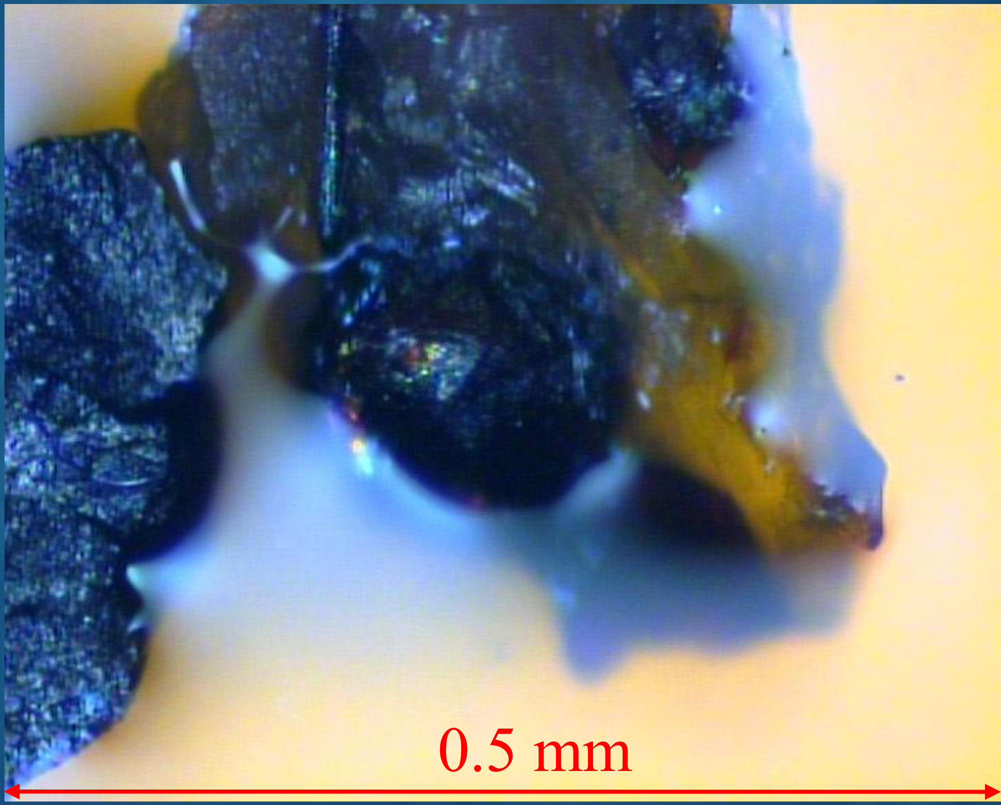
SEM image Courtesy M. Velbel



ESEM/EDX of Calcium sulfate airborne particles (Iordanidis et al., Environ Geochem Health 30, p. 391, 2008)

Wet chemical microscopy

- Microscope slides coated with dehydration-resistant chromophors
- Blue indicates pH in the example at right

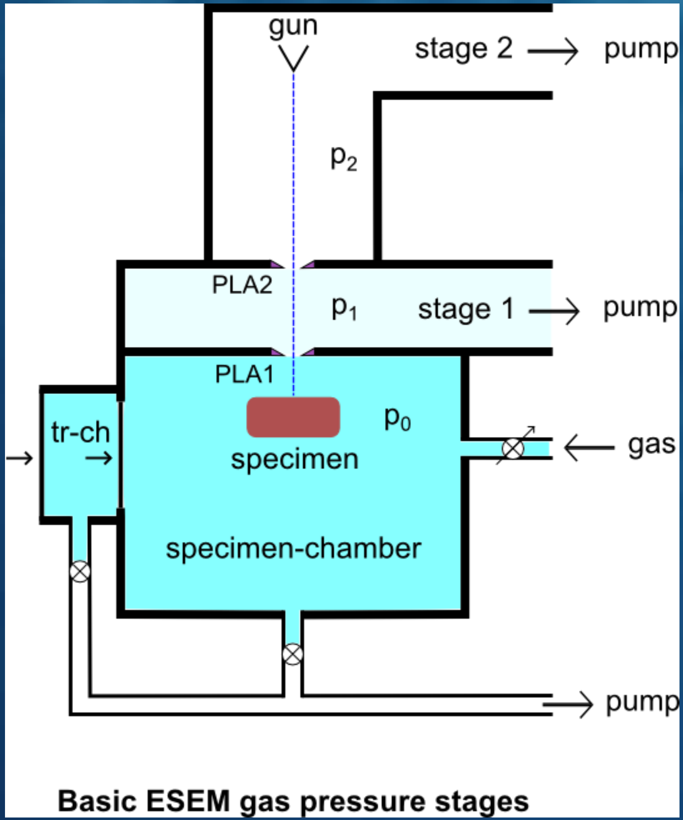


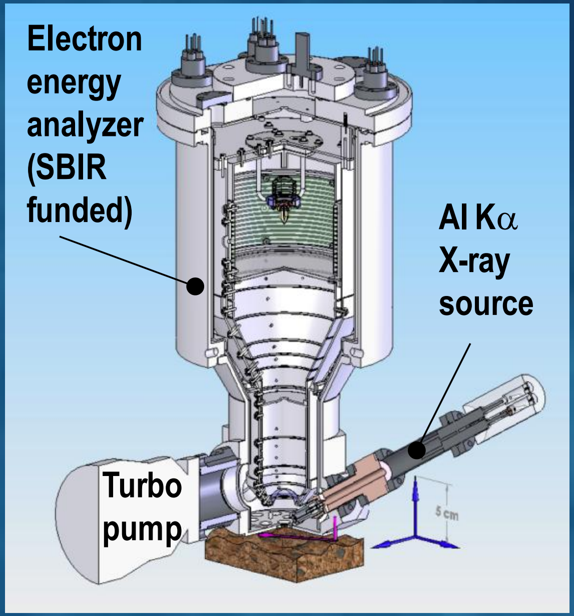
Technology roadmap

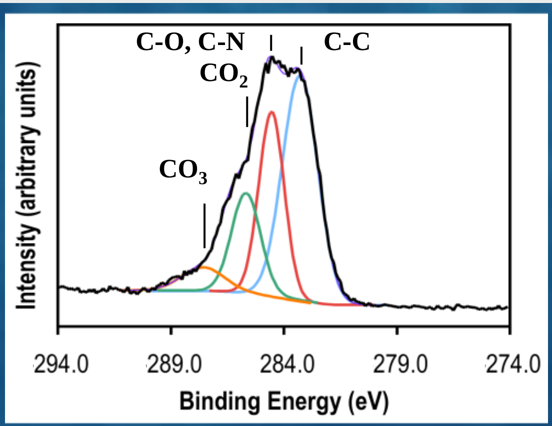
- Extend microscopy to ESEM
- Add EDX for compositional microanalysis
- Add electron diffraction for structural analysis
- Perform contextual macro-analysis
  - Optical and near-IR (e.g. μ-OMEGA), possibly with stains
  - Mineralogy with Raman, Mossbauer, XRD
  - Surface chemistry with XPS, AES, SIMS
  - Surface texture with BET (done by Viking)

Technology examples

Microimaging with ESEM already uses Mars-like pressure for charge control and sample preservation. Technology is compact (diagram from Wikipedia, gun from FEI website)







XPS probes near-surface region, including atmospheric species interacting with the surface (courtesy P. Grunthaner)

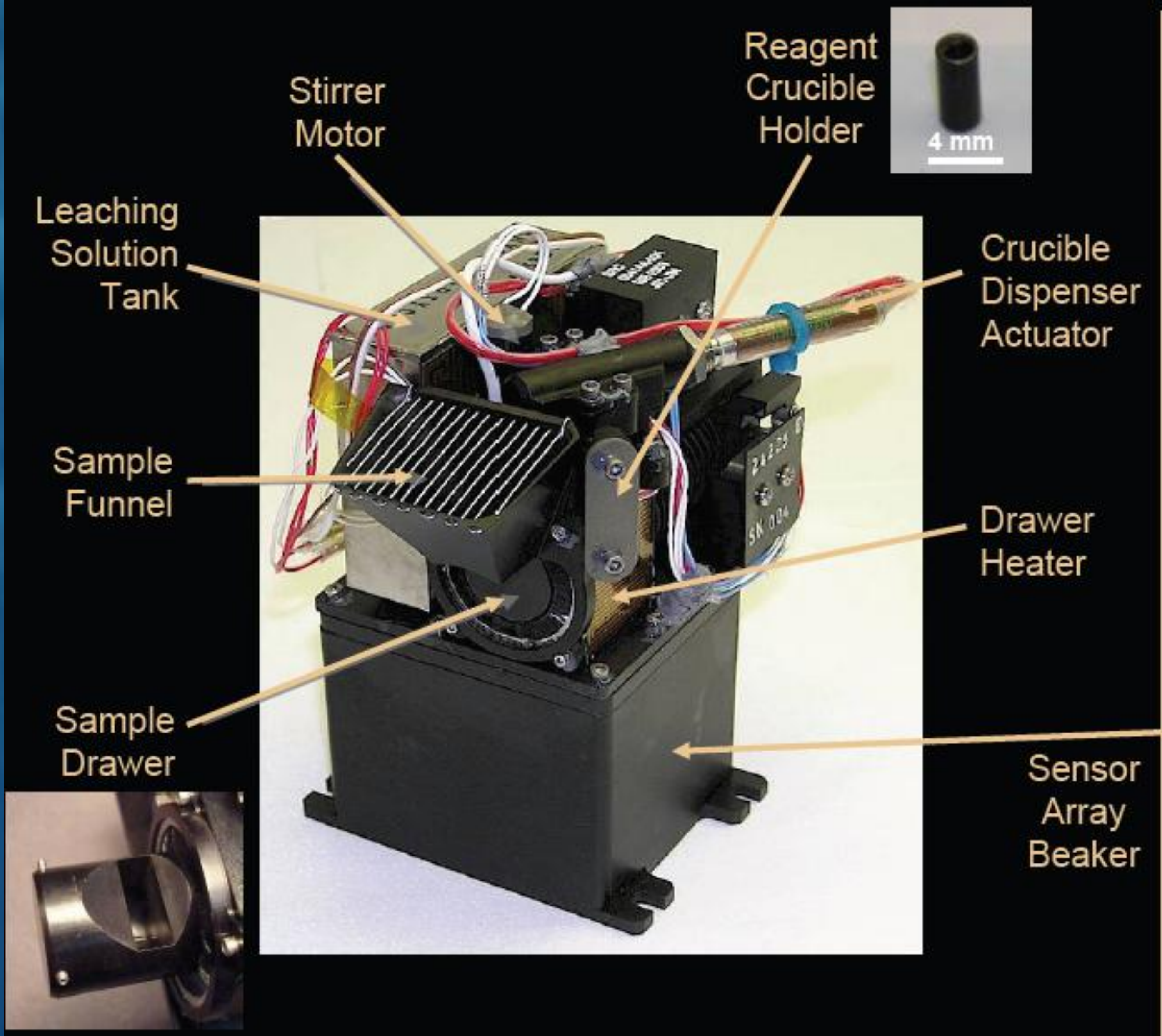
Example:

SOLUBLE CHEMISTRY

How to do *in situ* chemistry

- Detection of volatiles
  - Examples
    - Mass Spectroscopy and calorimetry via pyrolysis (TEGA)
    - GC/MS via pyrolysis (Viking MS, SAM)
    - GC/MS via humidification (Viking biology, SAM)
  - Characteristics
    - High energy, often only see dissociated fragments
    - Wall and gas phase reactions can be a problem
    - Only see volatile species
- Aqueous analysis
  - Examples
    - Electrochemical sensing (MECA WCL)
    - *Chromatography, electropheresis, colorimetry, etc. (in development)*
  - Characteristics
    - Very low energy
    - Only see solubles
    - Can't associate cations with anions
    - Limited species can be seen, but large dynamic range
    - Reactions can occur in solution

The Wet Chemistry Lab (1 of 4)



K^+, Na^+

Mg^{2+}, Ca^{2+}, Ba^{2+}

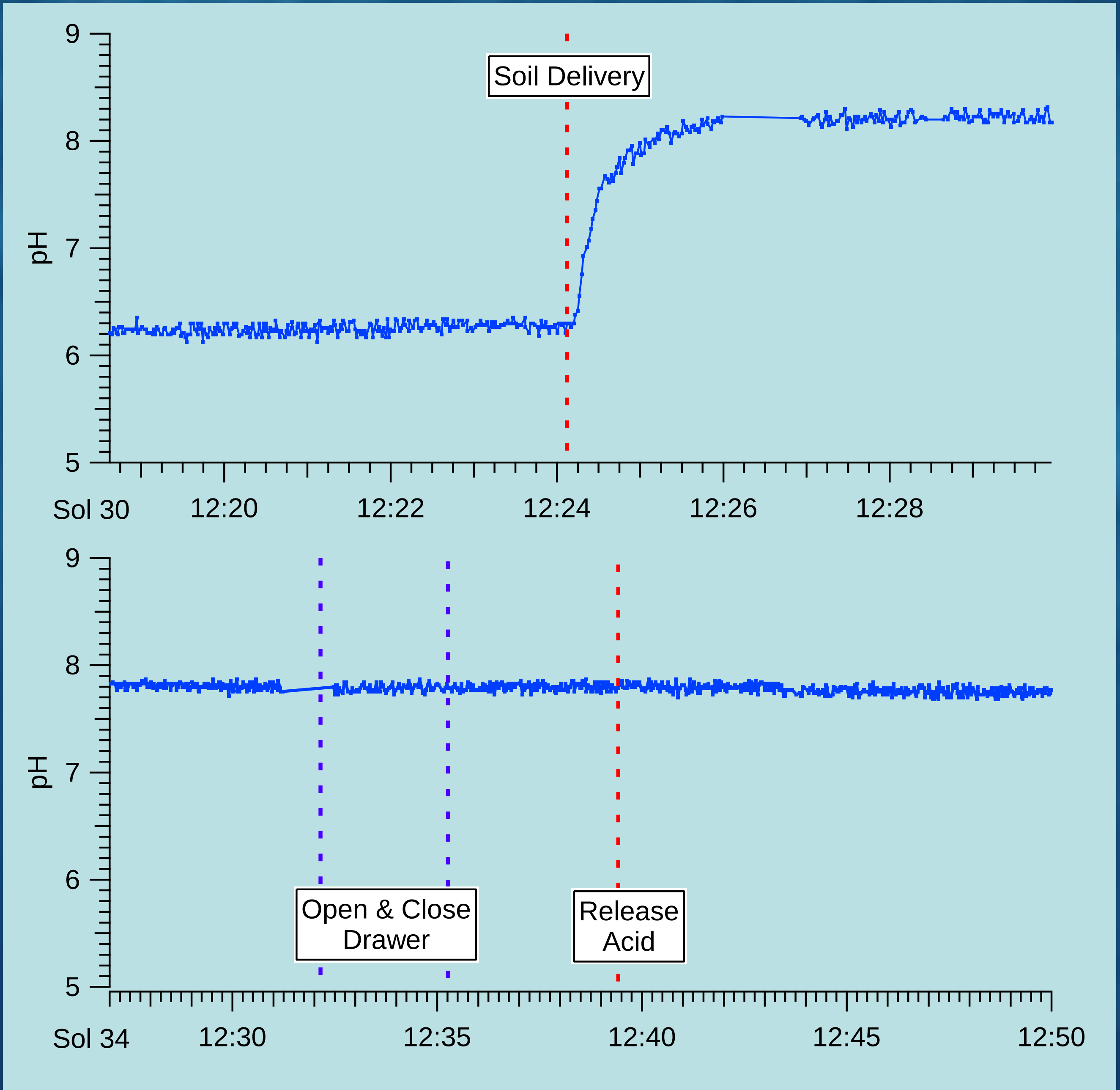
Cl^-, Br^-, I^-

NO_3^-/ClO_4^-

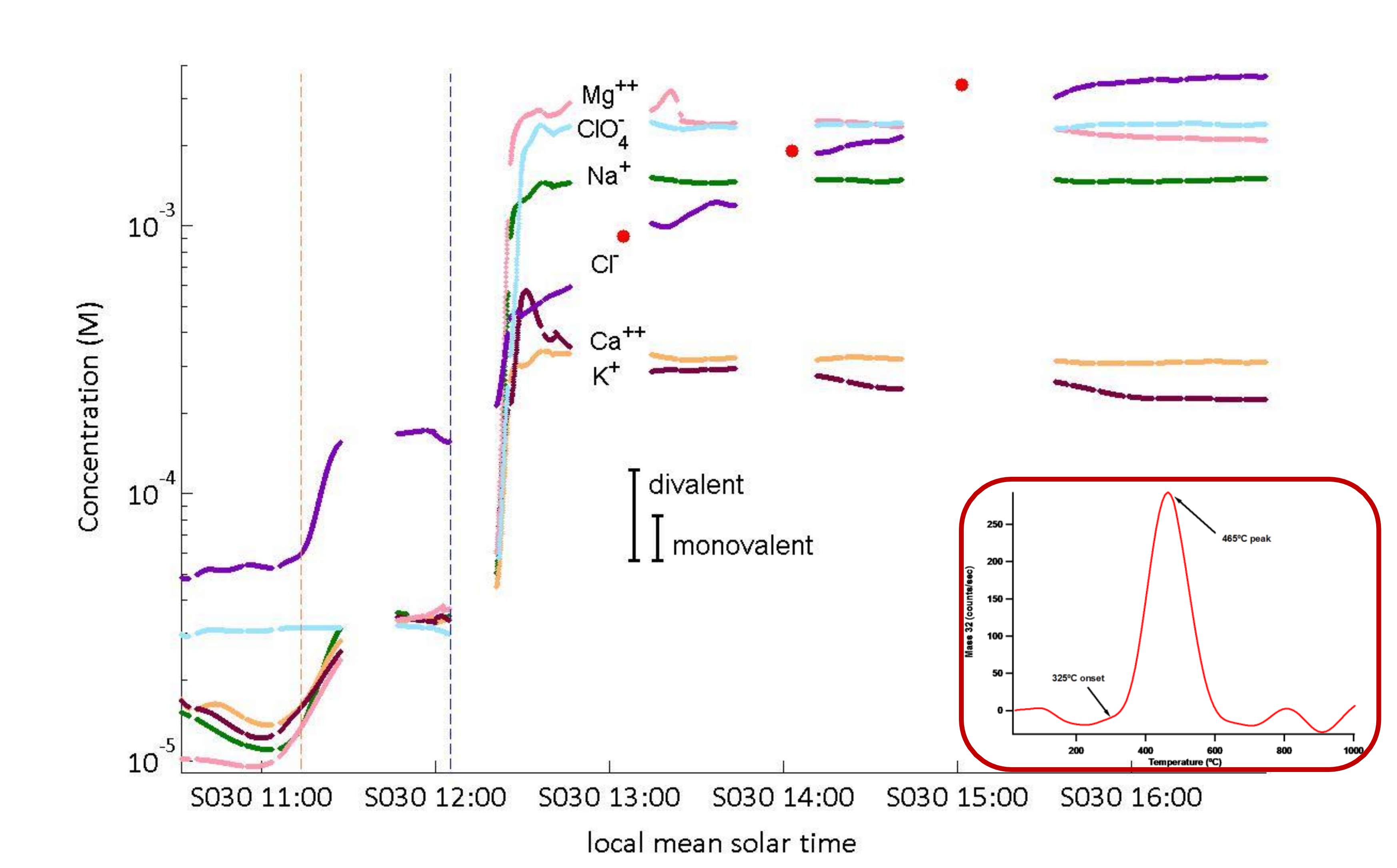
CV, CP

pH, Eh, cond., T

pH Measurement

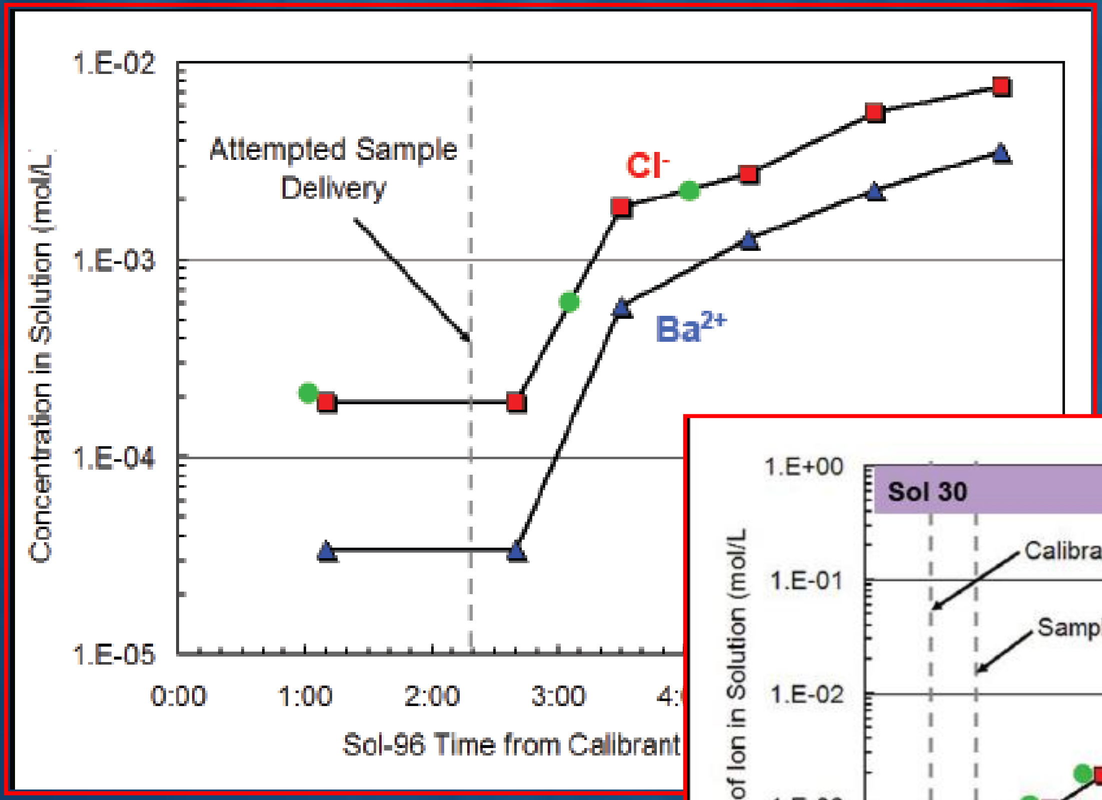


Dissolved ions (after re-calibration)

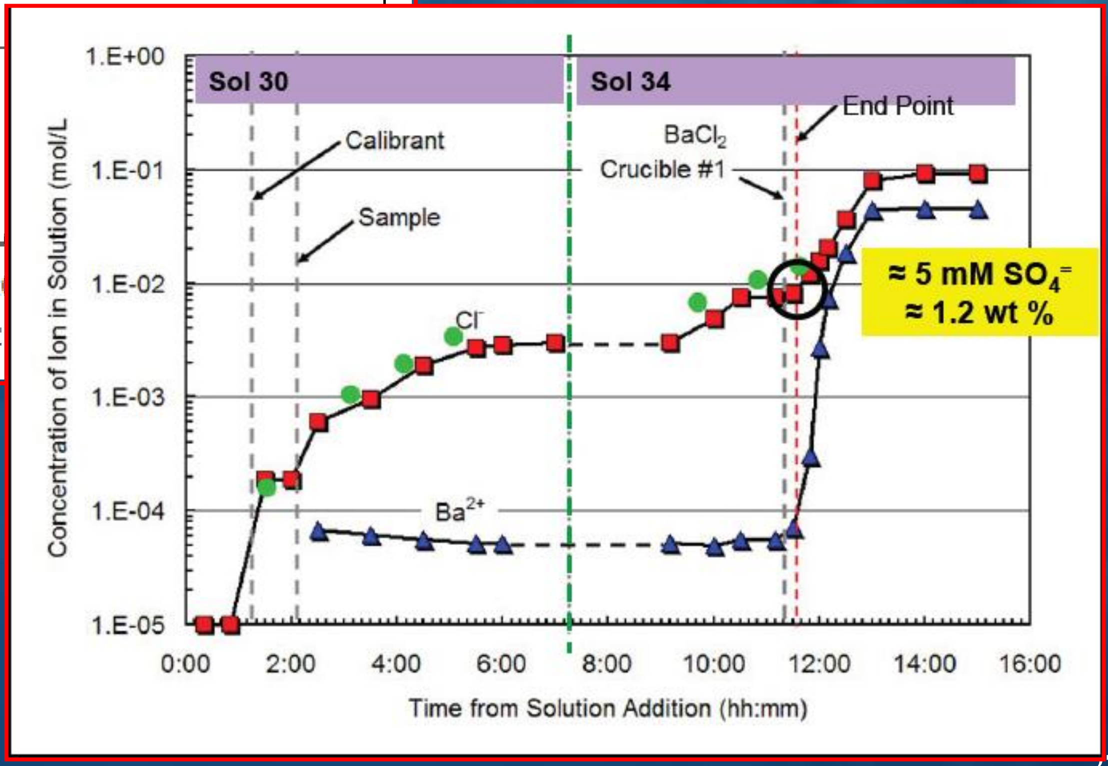


Sulfate titration

"Blank" (Note: Cl^- leak from $BaCl_2$ observed)

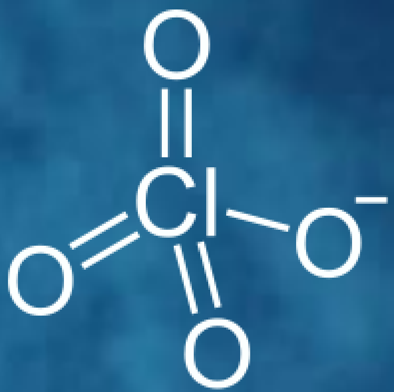


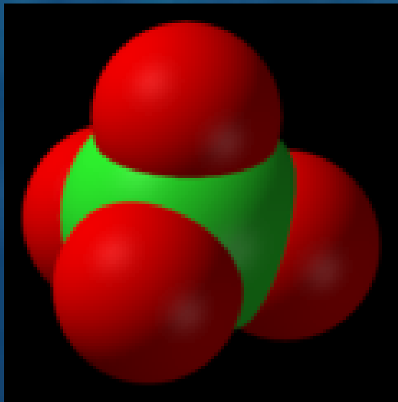
Sample



Research implications of perchlorate-rich soil

- **Geochemistry and geology:**
  - Good: Stable brines allow some chemistry and fluvial processes
  - Bad: Uniform distribution suggests soil has been dry for a long time
- **The search for life:**
  - Good: Microbes use it for energy
  - Bad: It's a desiccant (drying agent)
  - Contra-indicative: On Earth, microbes reduce perchlorate to chloride
  - Bad: Where there is perchlorate, there is likely chlorate, chlorite, hypochlorite…
  - Confounding? Perchlorate combusts organics in experiments such as Viking, TEGA, SAM.
- **Human exploration**
  - Good? Easily extracted for power or O_2 source
  - Bad? Modest (reversible) toxic hazard





Implications for instrument and mission development

- In situ instrument strategy: Wet or dry analysis?
  - Dry analysis needs heat, burns perchlorate
    - →Invest in Lab-on-a-chip, liquid chromatography, etc.
  - Pyrolytic approach burns organics
    - →Invest in alternative organic detection such as Urey
- Sample return strategy
  - Long-term curation on surface exposes samples to thermal cycles that have been shown to cause significant secondary alteration *even without brines*, which exacerbate problem
  - Brine and oxidant formation could destroy organics and other biomarkers
  - →Possibly severe constraints on surface curation methods
- ESMD interest as *in situ* resource, possible hazard