Why Mars Sample Return is of Increasingly Compelling Interest to the International Mars Exploration Community

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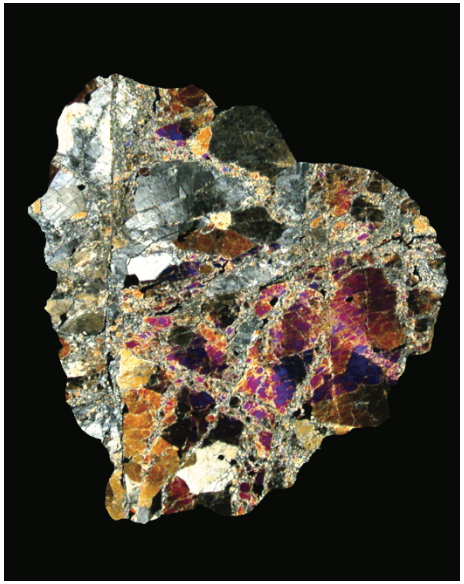
1. Martian Meteorites

- The number of martian meteorites has now grown to over 100!
- Mars has joined the Moon and Vesta as the best characterized solar system bodies (other than Earth), in part because we have samples of them to study in the laboratory, for example:
  - Mars has a chondritic bulk composition and it is volatile depleted.
  - Mars has a unique oxygen isotopic fingerprint
  - Martian crust consists mostly of basaltic lavas and their fractionation products

Valuable, but we have learned their limits.

ALH 84001



From McSween et al. (2018)

Meteorite Studies: Limitations

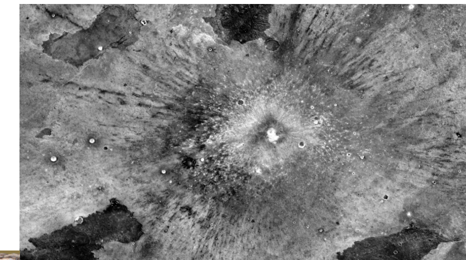
Limited Sampling of Rock Types

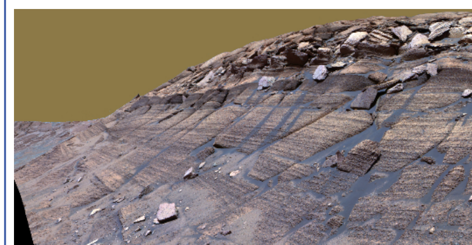
- Fluvial, lacustrine, evaporative, aeolian, granular, hydrothermal, or pyroclastic materials have NOT been sampled as meteorites
- Some of these are the most likely to contain organic matter and/or biomarkers

NWA 7034 regolith breccia-the lone sedimentary meteorite

Lack of Geological Context

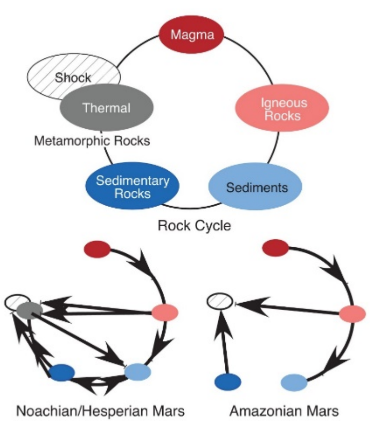
- No source craters have been confidently identified





- Cannot be used to underpin planetary chronology

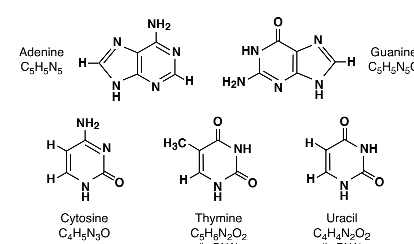
Biased Sampling of Rock Ages



- Igneous rocks from the first half of martian history are virtually unsampled
- Igneous rocks represent the starting point for all other rock types in the martian rock cycle and are key to differentiation and the original crustal composition.

Alteration via ejection process

- Some scientific investigations depend on analyzing samples that have not been strongly heated (volatiles, organics, some mineralogy)



Amino Acids

Sulfates with varying H_2O

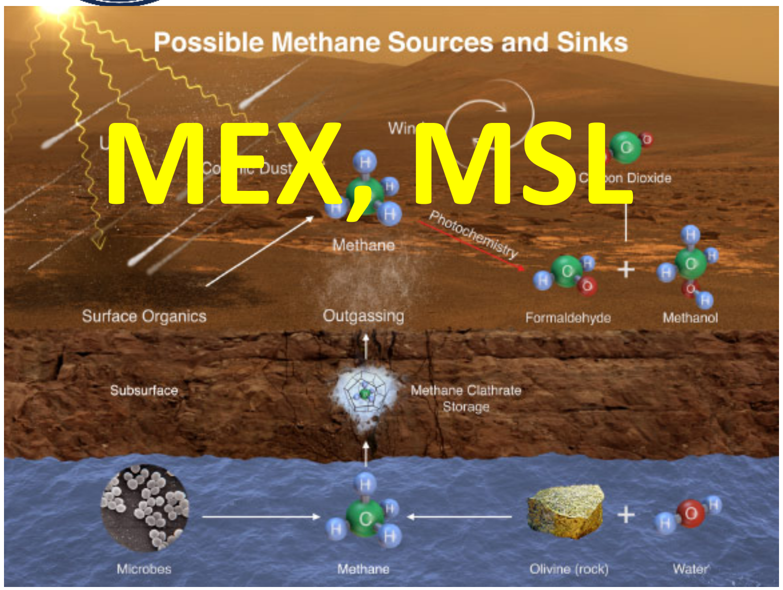
From McSween et al. (2018)

2. Mission Results

- Fabulous **new discoveries** have been obtained by the in-situ & orbital) exploration program. These results have emphasized the additional value that would come from analyzing Mars samples using the **greater spatial resolution** and great **diversity of instrumentation** available in terrestrial laboratories.

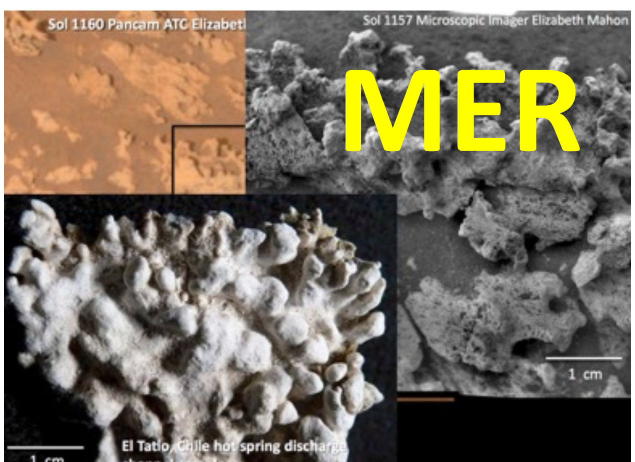
Results have raised important new hypotheses that cannot be fully tested without samples.

Mission Results – Habitable Environments



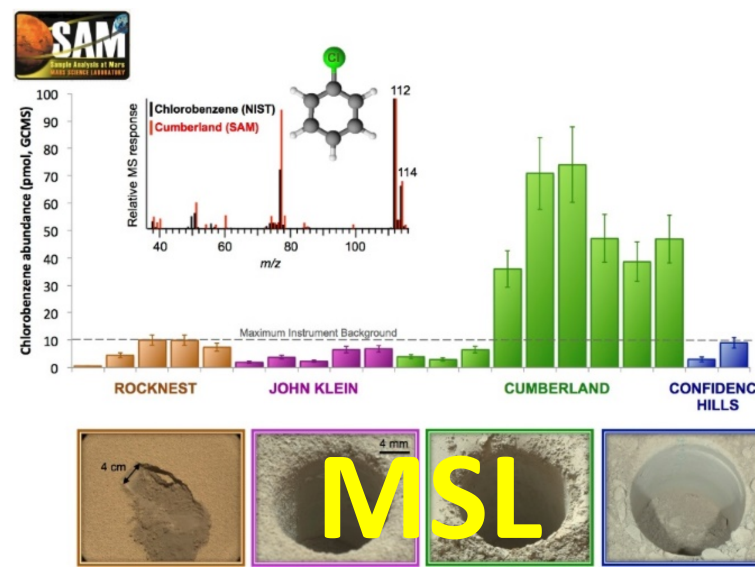
"Mars is episodically producing methane from an additional unknown source"

A habitable fluvio-lacustrine environment at Gale Crater



Organics in the near sub-surface

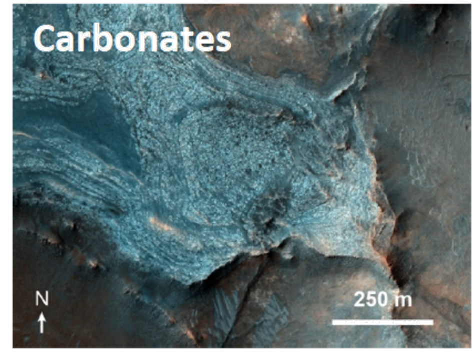
Hydrothermal systems & silica deposits



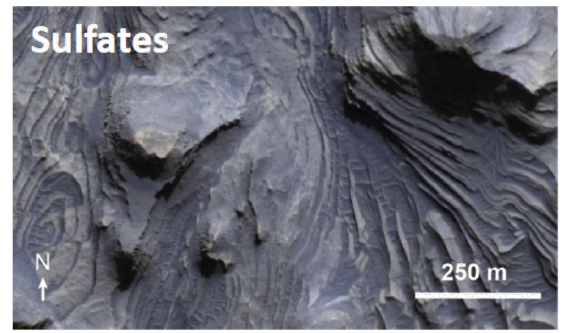
Mission Results – Minerals Detected

	Class	Group/mineral/phase	Formula
Primary	Framework silicates	Olivines	$(Mg, Fe)_2SiO_4$
		Orthopyroxenes	$((Mg, Fe)_{0.95+x}, Ca_{0.05-x})Si_2O_6$
		Clinopyroxenes	$(Ca, Mg, Fe)Si_2O_6$
		Plagioclase feldspars	$(Ca, Na)(Al, Si)AlSi_2O_8$
		Alkali feldspars	$(K, Na)AlSi_3O_8$
	Sulfides	Pyrrhotite[b]	$Fe_{1-x}S$
		Pyrite/marcasite[c]	FeS_2
	Oxides	Magnetite[d]	$Fe_{3-x}Ti_xO_4$
		Ilmenite[d]	$FeTiO_3$
Secondary	Oxides	Hematite	Fe_2O_3
		Goethite[d]	$FeO(OH)$
		Akaganeite[b]	$Fe(O, OH, Cl)$
	Phyllosilicates (clay minerals)	Fe/Mg smectites (e.g., nontronite, saponite)	$(Ca, Na)_{0.3-0.5}(Fe, Mg, Al)_{2-3}(Al, Si)_4O_{10}(OH)_2 \cdot nH_2O$
		Al smectites (e.g., montmorillonite, beidellite)	$(Na, Ca)_{0.3-0.5}(Al, Mg)_2(Al, Si)_4O_{10}(OH)_2 \cdot nH_2O$
		Kaolin group minerals (e.g., kaolinite, halloysite)	$Al_2Si_2O_5(OH)_4$
		Chlorite	$(Mg, Fe^{2+})_5Al(Si_3Al)O_{10}(OH)_8$
		Serpentine[e]	$(Mg, Fe)_3Si_2O_5(OH)_4$
		High-charge Al/K phyllosilicates (e.g., muscovite, illite)	$(K, H_3O)(Al, Mg, Fe)_2Al_xSi_{4-x}O_{10}(OH)_2$
	Other hydrated silicates	Prehnite	$Ca_2Al(AlSi_3O_{10})(OH)_2$
		Analcime	$NaAlSi_2O_6 \cdot H_2O$
		Opaline silica ($n > 0$), quartz ($n = 0$)	$SiO_2 \cdot nH_2O$
	Carbonates	Mg/Ca/Fe carbonates	$(Mg, Fe, Ca)CO_3$
	Sulfates	Kieserite ($MgSO_4 \cdot H_2O$); szomolnokite ($FeSO_4 \cdot H_2O$); Fe(II)-, Fe(III)-, and Mg-polyhydrated sulfates	$(Fe, Mg)SO_4 \cdot nH_2O$
		Gypsum ($n = 2$), bassanite ($n = 0.5$), anhydrite[b] ($n = 0$)	$CaSO_4 \cdot nH_2O$
		Alunite	$KAl_3(SO_4)_2(OH)_6$
		Jarosite	$KFe_3(OH)_6(SO_4)_2$
		Not a named mineral	$Fe^{3+}SO_4(OH)$
	Chlorides	Chlorides	e.g., $NaCl$, $MgCl_2$
	Perchlorates	Perchlorates[f]	e.g., $(Mg, Ca)(ClO_4)_2$

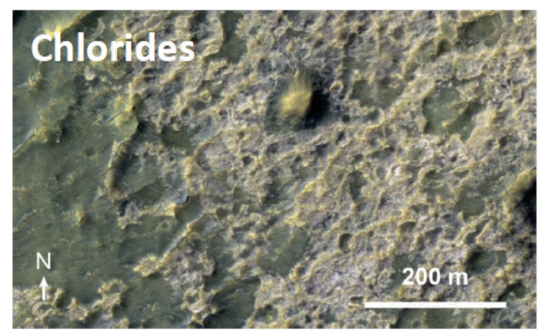
[Ehlmann et al., Annu. Rev. earth Planet. Sci. 2014]



MRO/HiRISE



MRO/HiRISE

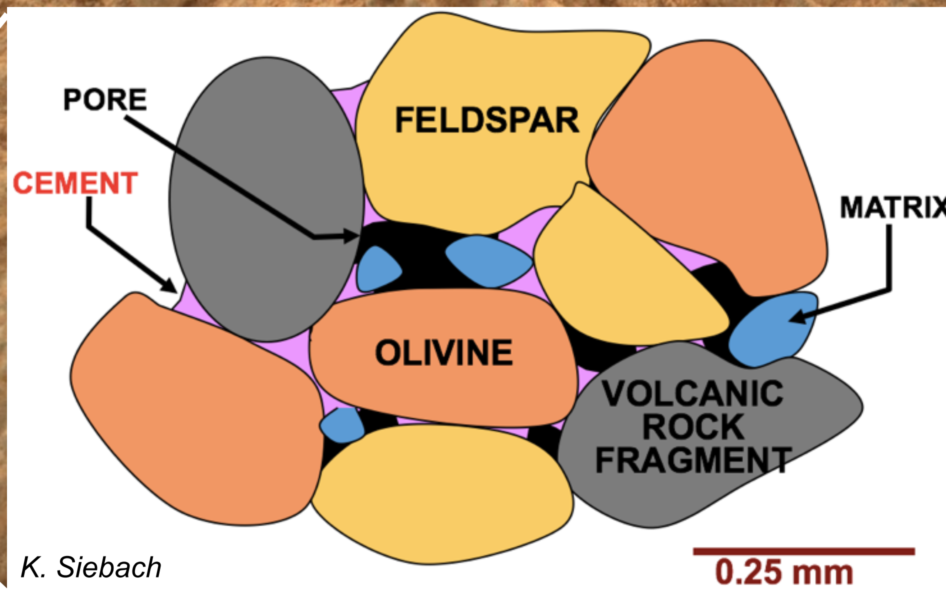


MRO/HiRISE

How do the minerals relate to each other?

We need to reduce our spatial focus

Modern "grain-by-grain" sediment analysis



Volcanic Frags (Provenance)
- source lithologies
- nature / history of mantle sources
- source ages

Feldspar (Provenance)
- source lithologies
- age / age history of source

Olivine/Pyrox. (Provenance)
- source lithologies
- T/P history of sources

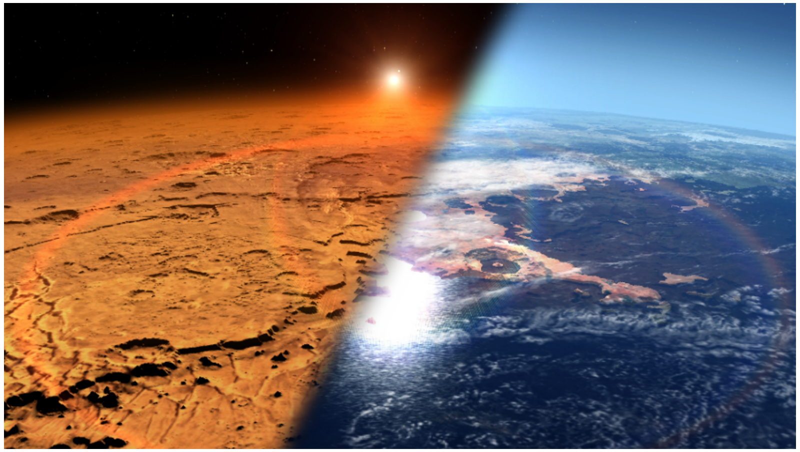
Matrix (Provenance & Diagenesis)
- source lithologies
- fluid chemistry / fluid interactions
- clay mineral origins and diagenesis

Cements (Diagenesis)
- cement "stratigraphy"
- fluid chemistry (e.g., pH, Eh)
- fluid sources / fluid histories

From McLennan et al. (2018)

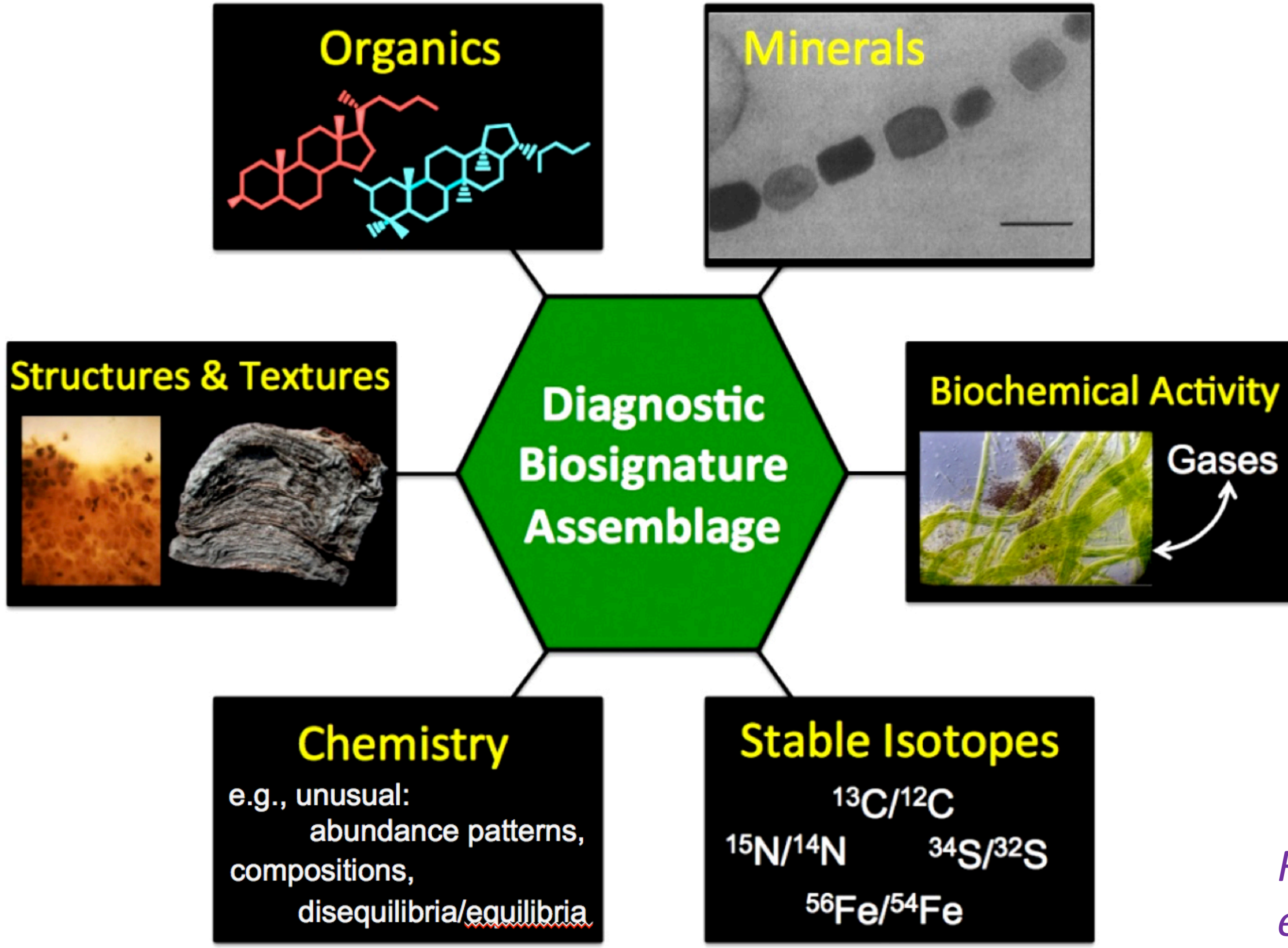
3. Astrobiology

- Although the **search for extra-terrestrial life** has long been the key driver of Mars exploration, we now have a much better understanding of the **potential for preservation** in the geologic record, the **evolution of Mars as a habitable planet**, and (by means of the study of **biochemistry on Earth**) the details of biological processes.



Samples allow for far more effective search strategies.

Biosignature Categories



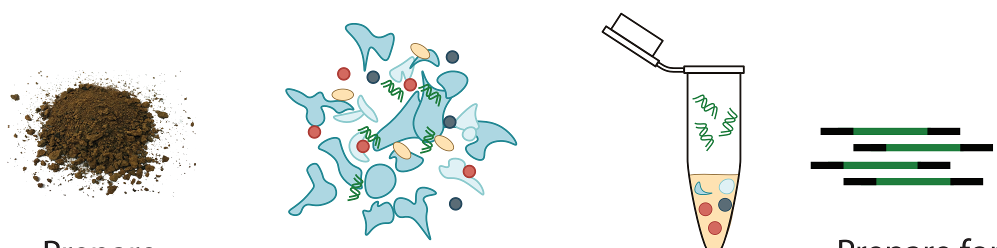
From Des Marais et al. (2018)

Coordinated analyses of several categories of potential biosignatures can greatly strengthen our interpretations of their origins and significance

Why RSS is Important to Astrobiology

Samples require special handling

- Soil and mineral samples are difficult, requiring optimization
- Processing is a multi-step process requiring human attention
- Low biomass samples require extra precision



Example: DNA extraction and sequencing

Investigation pathway is discovery-dependent

We don’t know:

- What form life might take
- Whether it would be alive upon return to Earth
- Its ability to grow and metabolize on Earth
- Whether it is related to life on Earth

The answers to these questions would dictate downstream experiments

From Mackelprang et al. (2018)

4. Human Exploration

We have a greatly improved understanding of the ways in which the **risks**, **performance** and **cost** of putting humans on Mars can be improved by acquiring advance information—especially sample-related information.

Dust on Mars


20-km high dust devil, viewed from orbit (MRO)

Photo Credit: NASA/JPL

From Harrington et al. (2018)

Biological Hazards – Crew and PP

- Apollo demonstrated pervasiveness of surface dust
  - Longer duration martian missions will exacerbate
- What is the threat that a martian organism (or community of organisms) poses to mission (e.g. pathogenicity to the crew, ability to compete for or spoil critical resources, AND threat of degrading hardware/systems performance)?
- **Evaluate martian biohazards related to the Planetary Protection of Earth**

HUMAN RESEARCH PROGRAM

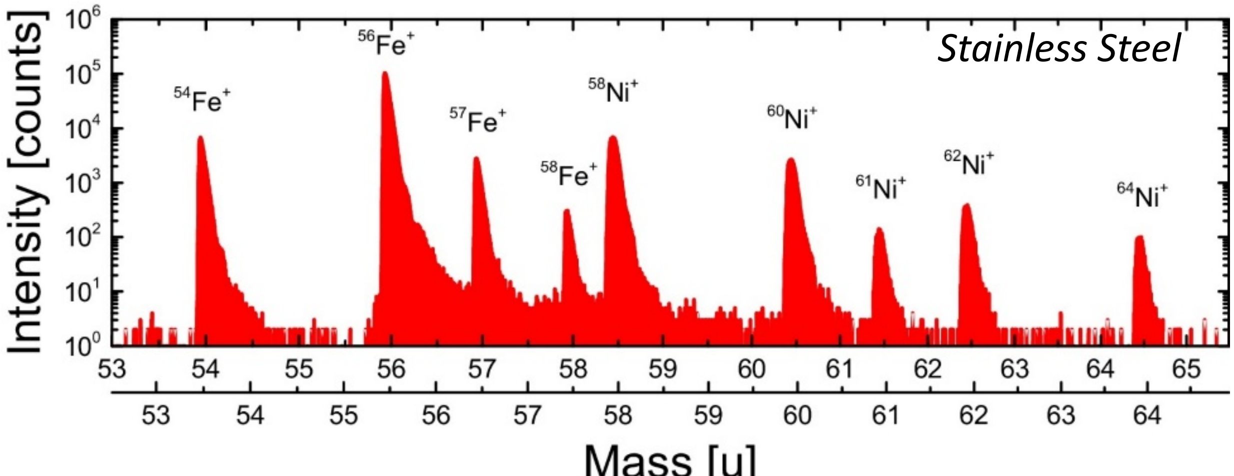
From Harrington et al. (2018)

5. Instruments/Sample Prep

- We are seeing unprecedented improvements in our ability to prepare and analyze very small samples. Highly visible recent examples are the work on Hayabusa asteroid samples (JAXA) and the Stardust comet samples (NASA).

EXAMPLE

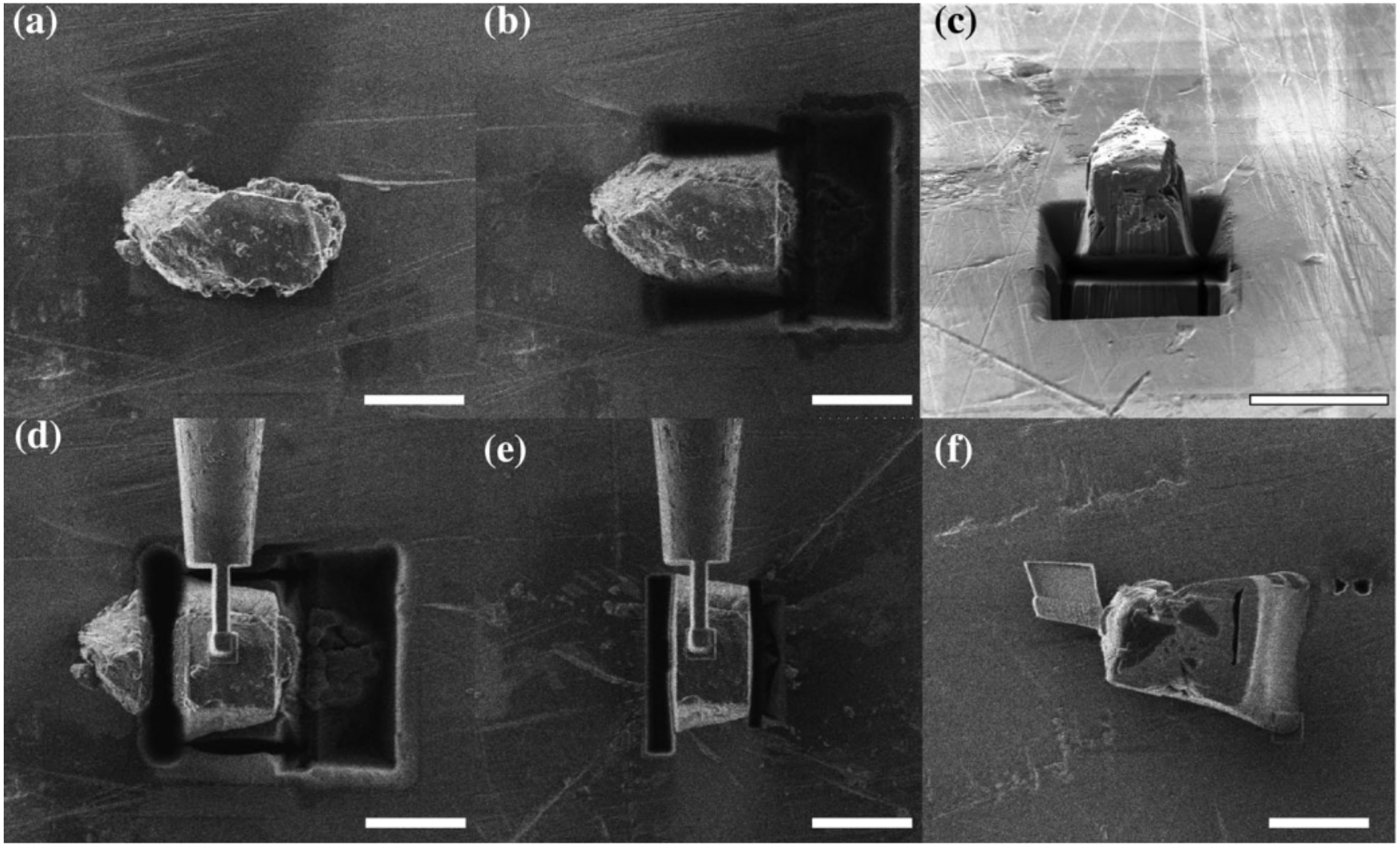
CHILI, the Chicago Instrument for Laser Ionization, a new resonance ionization mass spectrometer developed for isotopic analysis at **high spatial resolution** and **high sensitivity** of **small samples**



From Stephan et al. (2016) Int. Jour. Mass Spec., v.407, p.1-15.

5. Instruments/Sample Prep

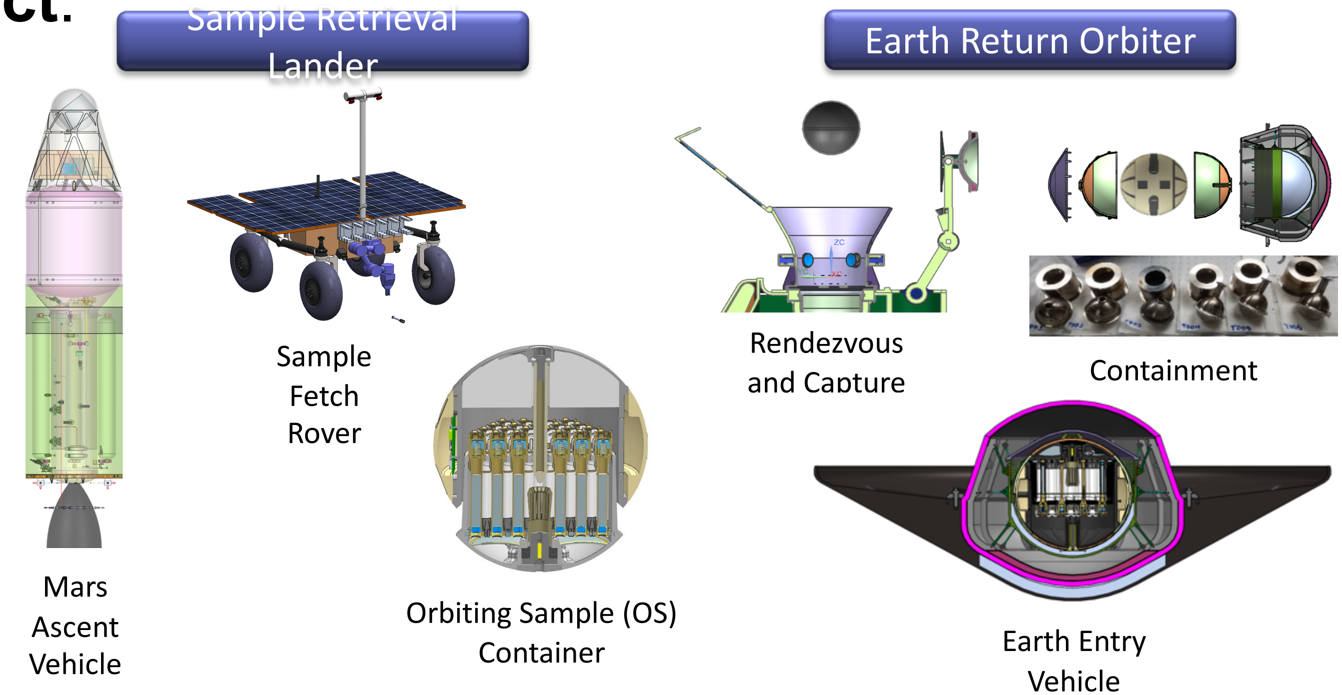
Investigation of cutting methods for small samples of Hayabusa and future sample return missions. Hayabusa grain RA-QD02-0265. All scale bars are 10 microns.



From Uesugi et al. (2014) MAPS 49, p. 1186-1201

6. Engineering

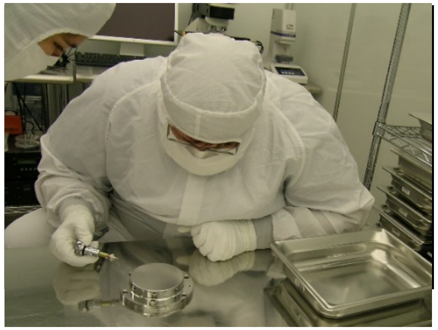
Over the past decade there have been substantial **improvements in the capability** of the world's space agencies to acquire and preserve samples (most notably, the M-2020 sampling system), the development of the **Mars Ascent Vehicle**, and critical progress in **breaking the chain of contact**.



Future mission concepts-From Edwards et al. (2018)

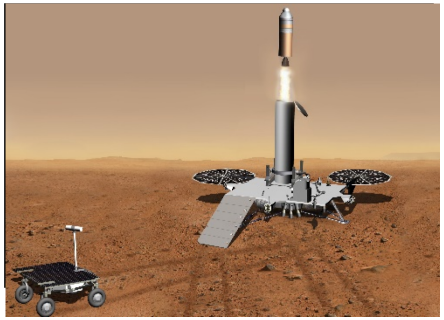
Mars Sample Return

SCIENCE



- *Civilization-scale science*
- *Samples: the gift that keeps on giving*
- *Definitive scientific results*
- *Only way to advance critical sectors of planetary science & astrobiology*

ENGINEERING



- *Unique technical challenges drive unprecedented innovation*
- *Advances will benefit future robotic and human missions.*
- *Crucible for engineering as a discipline.*

PREPARATION

- *Prepare for humans to Mars*
- *Inform planetary protection policy evolution to enable future missions*

INSPIRATION

- *Inspire and train the next generation*
- *Magnet for international cooperation*

We have the opportunity and motivation to carry out MSR on an international basis

Back-Ups