Analogues for planetary missions: the engineer point of view

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Analogue?

For me, an analogue is something terrestrial presenting characteristics more or less representative of something extra-terrestrial.

Analogues can be used to:

- Test and calibrate instrumentation

- Help *in situ* interpretation

- Make science

Two main categories

Analogue sites

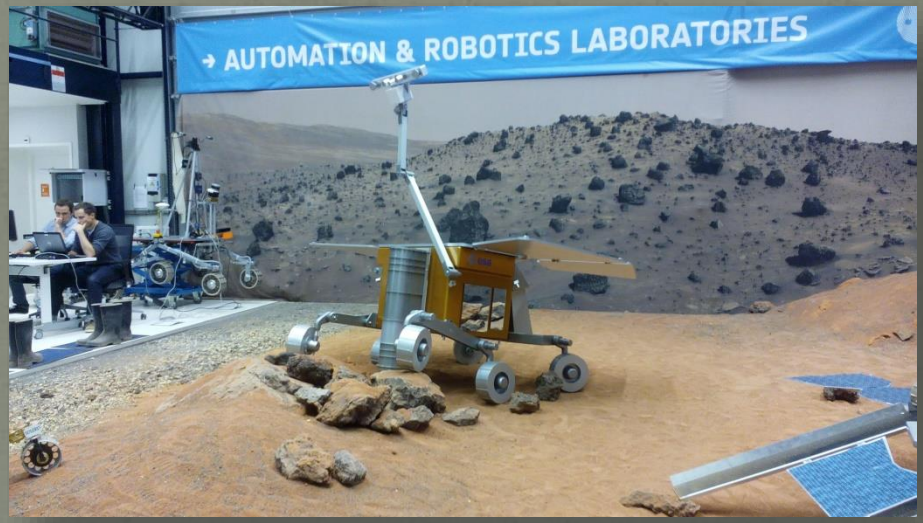
Analogue samples

Analogue sites

From mobility testing to fundamental science

Artificial analogue areas

Rover mobility testing



Mobility testing area at ESA ESTEC

Human space flight

Mars 500 facility at IBMP near Moscow

Natural analogue areas

In situ instrument testing

Rover testing during the Arctic Mars Analog Svalbard Expedition (AMASE) 2009

Human exploration

Mars Desert Research Station, Utah (Foing et al. 2011)

HI-SEAS (Hawaii Space Exploration Analog and Simulation), since August 28th 2015

Natural analogue areas

Planetology

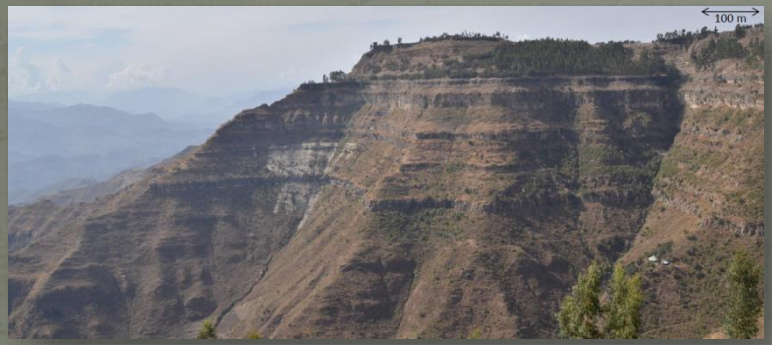
Meteor Crater, Arizona, USA

Processes

Mars analogue for the mechanical and chemical alteration of volcanic Martian rocks in Iceland (Mangold et al., 2011)

Natural analogue areas

Mineralogy

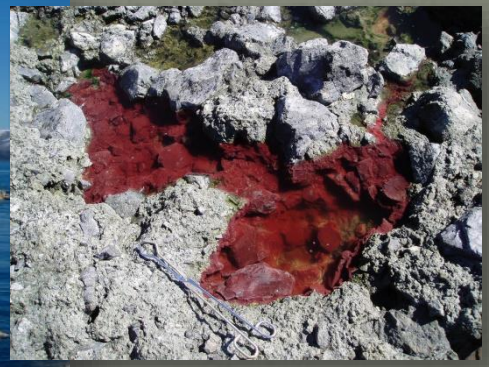


Opal deposit, Ethiopia (credit B. Chauviré)

Mineral deposit in Rio Tinto, Spain

Biology

Early Mars analogue of hypersaline environment at Mono Lake, California, USA



Kulp 2014

Analogue sites

Type	Relevance	Example	A few references
Artificial	Rover mobility	- ESA ESTEC - JPL	
	Human exploration	- Mars 500 experiment at IBMP	
Natural	*In situ* missions testing	- Svalbard, AMASE	Steele, 2007 Amundsen et al., 2010
	Human exploration	- Utah desert - Hawaii - Atacama desert	Ehrenfreund et al., 2011 Foing et al., 2011
	Planetology	- Impact craters (Meteor crater, Rochechouart, Lonar crater…) - Hotspot volcanoes (Hawaii, La Réunion, …)	
	Processes	- Iceland - Cyprus	Mangold et al., 2011 Bost et al., 2013
	Mineralogy	- Rio Tinto, Spain	Edwards et al., 2007
	Biology	- Mono Lake, USA - Yellowstone, USA - Patagonia	Wolfe-Simon et al., 2010 Campbell et al., 2015

General reports:

- Foing, Stoker & Ehrenfreund, (2011) Astrobiology field research in Moon/Mars analogue environments, *Special Issue of International Journal of Astrobiology*, 10:3, 137-305.
- Preston, Grady & Barber, (2012) CAFE, Concepts for Activities in the Field for Exploration, TN2: The Catalogue of Planetary Analogues, written by The Planetary and Space Sciences Research Institute, The Open University, UK

Analogue samples

From sample handling to fundamental science

Calibration vs testing

Calibration

→ Dedicated standards

ColorChecker

Testing

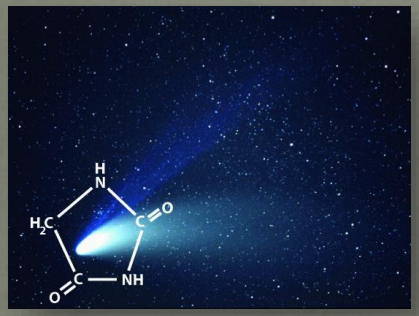
→ Analogue samples

CLUPI image (ExoMars) of a chert from Kitty's Gap, South Africa, 3.5Ga.

Different types of analogue samples

For instrument testing: samples of particular mechanical, physical or chemical properties.

For geology: rocks and minerals.



For chemistry: molecules and reactions.

For biology: life in analogue sites and fossils.

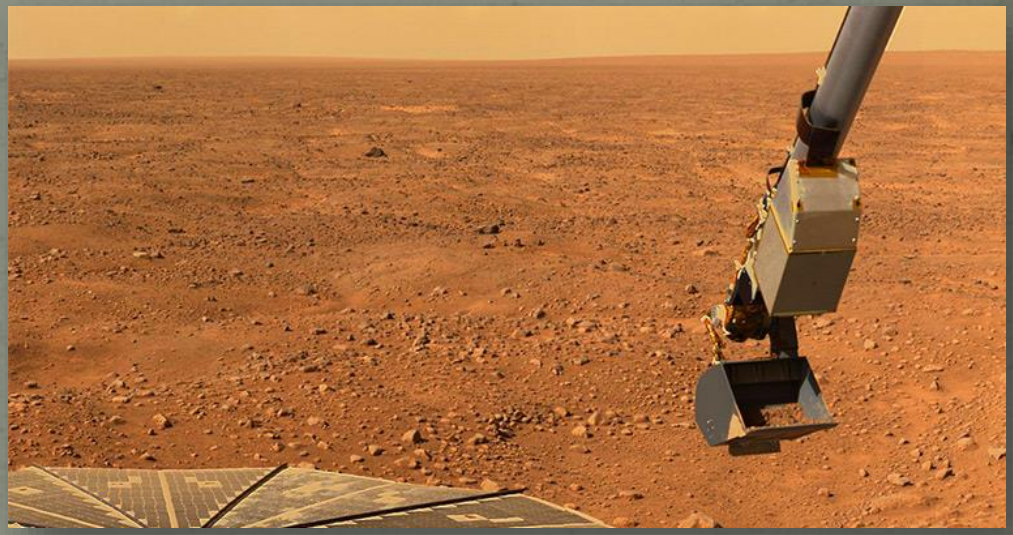
Material samples

Handling and preparation

Material samples

Samples with analogue properties:

- Size (drill core)
- Porosity (pumice)
- Density (hematite, d~5)
- Roughness (polished quartz)
- Consistency (sand)
- Physical properties (ice)



Samples particularly pertinent for testing sample handling and preparation (*in situ* missions and sample return missions).

Geological samples

Most obvious analogues

Variety of samples

Volcanic rocks

Slag 09IT01

Komatiite 10ZA09

Komatiite 11CA02

Sedimentary rocks

Chert 00AU04

Chert 00AU05

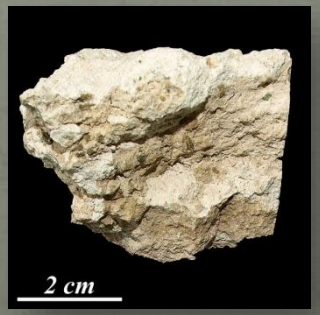
Minerals

Aragonite 12FR02

Apatite 12UN05

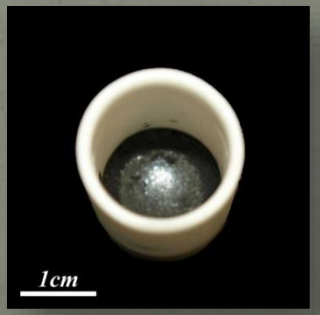
Epidote 12PK01

Products of altered rocks



Carbonate 11CY04

Artificial samples



Basalt 11AR02

ISAR
International Space Analogue Rockstore

Chemical samples

Compounds and reactions

Space chemistry

2 types of molecules:

"Known" molecules:
- Molecules detected in the interstellar medium
- Molecules found in meteorites (e.g. amino acids)

→ Just buy them ! *(except IOM)*

"Unknown" molecules:
- Molecules formed in comets and icy particles
- Molecules formed in extra-terrestrial atmospheres (tholins)

→ Simulate the conditions of synthesis

Simulation chambers

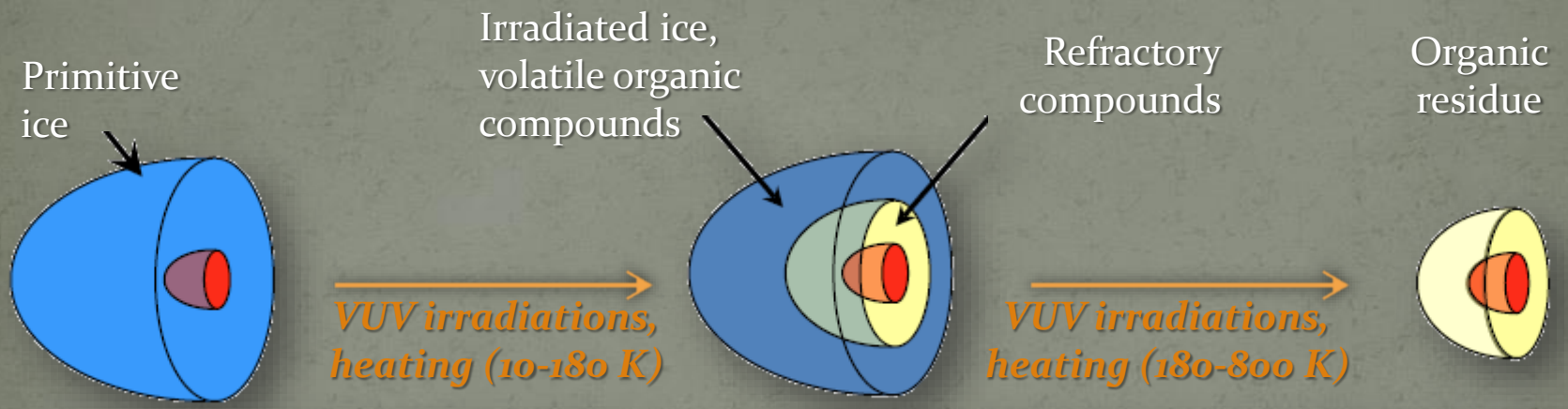
Analogue environments allowing us to synthesize analogue molecules still detected in space or not.

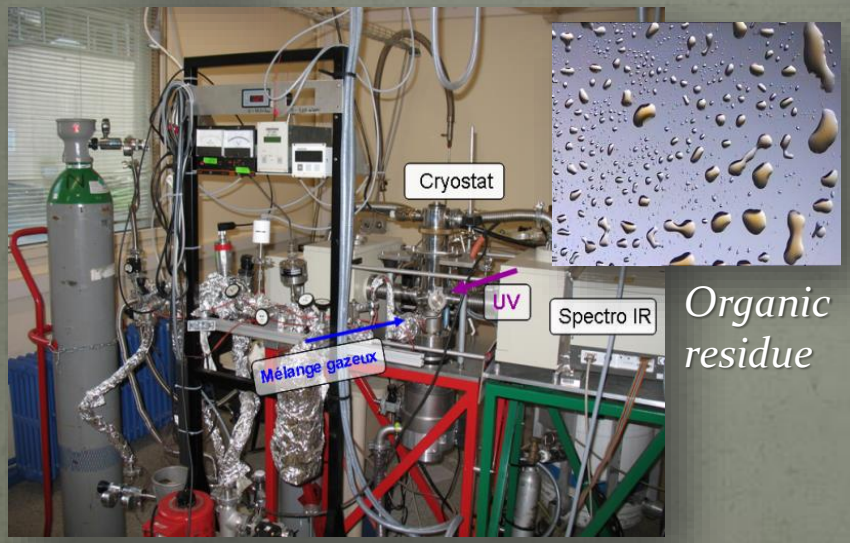
- **Understand the extra-terrestrial chemical reactions forming detected molecules.**

- **Synthetize analogue molecules.**

- **Discover the formation of molecules not yet detected in space and thus orientate the future instrumentation.**

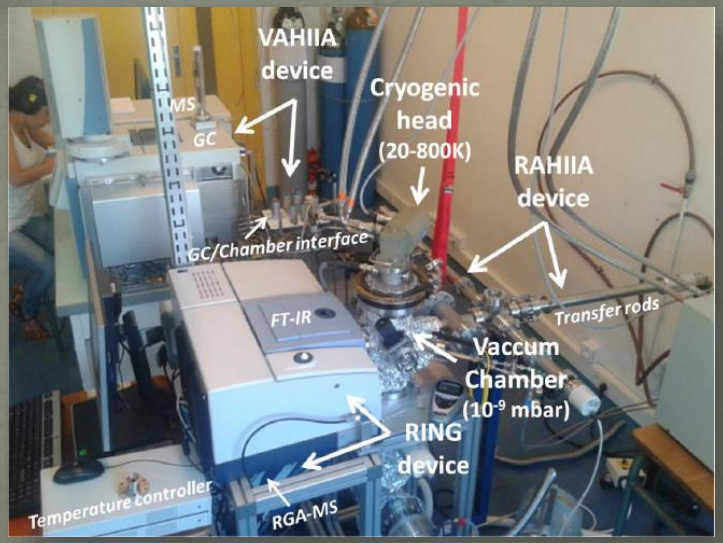
Comets and interstellar ices





Organic residue

L. Le Sergeant d'Hendecourt, IAS, CNRS-University of Paris Sud, Orsay



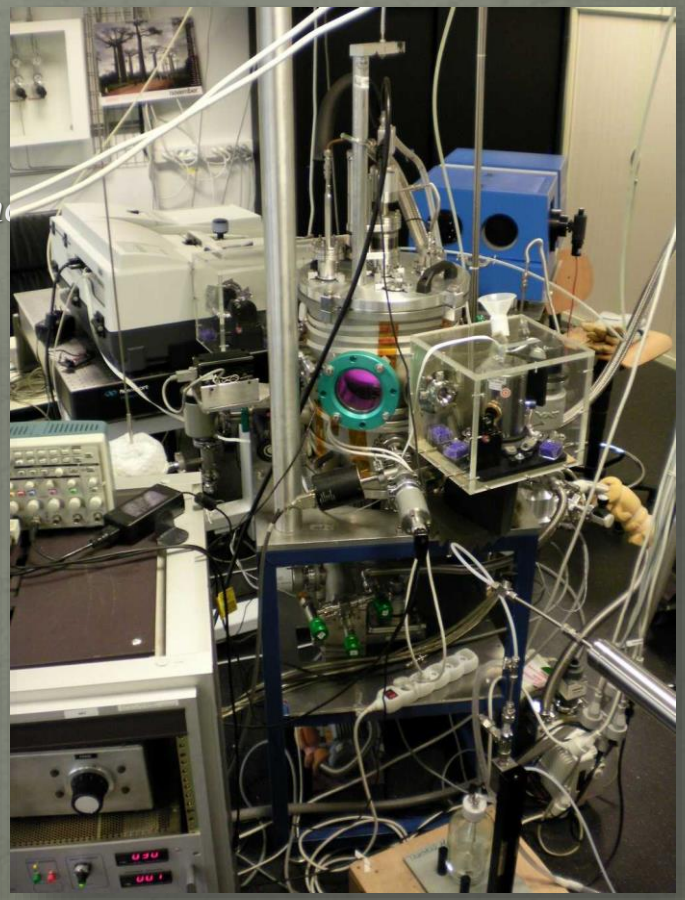
G. Danger, PIIM, CNRS-University of Marseille

Tholins

Titan's atmospheric aerosol analogue

Synthesis of tholins and analysis by IR, ellipsometry and HRMS by N. Carrasco, at LATMOS, UPMC, Paris.

Deposit of the produced solid particles

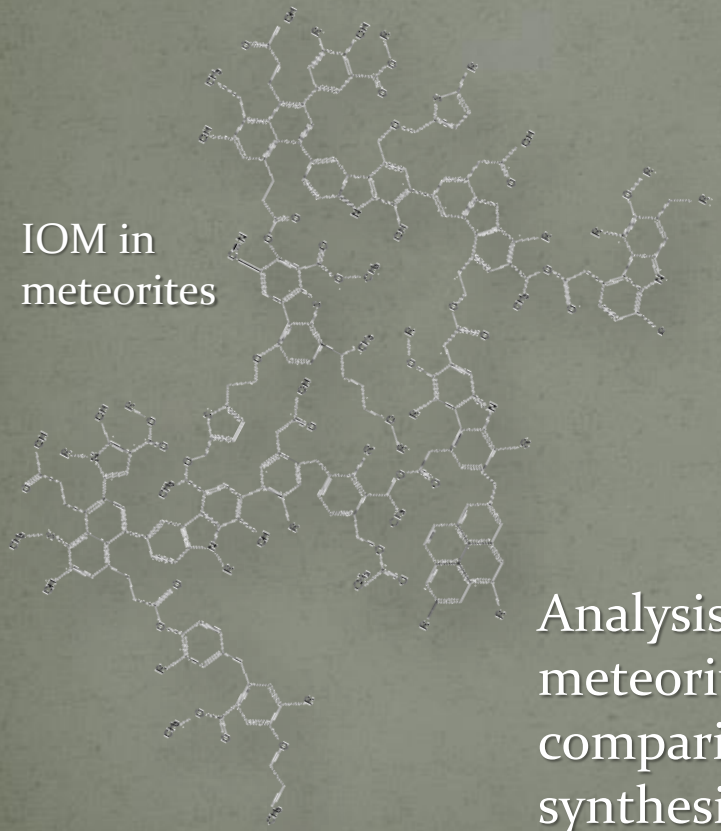


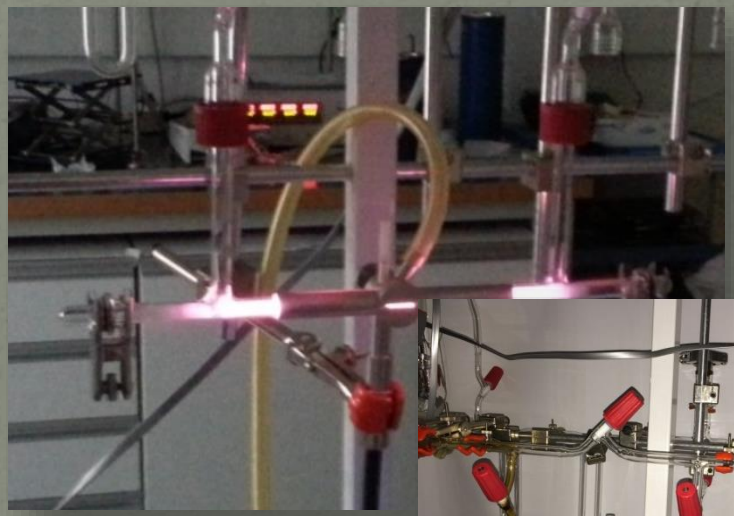
The PAMPRE device.

Insoluble Organic Matter

IOM found in meteorites is very complex and must be synthesized.

IOM in meteorites





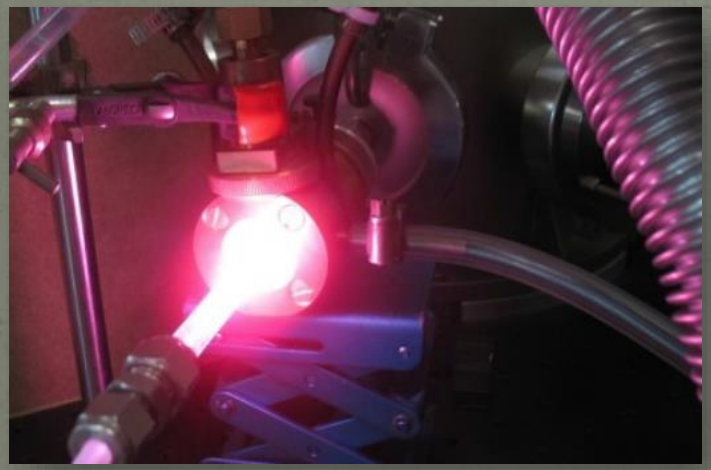
Analysis of IOM in meteorites and comparison with IOM synthesized in laboratory.

S. Derenne, BIOEMCO, UPMC, Paris

Problem of analogue molecules = low quantities

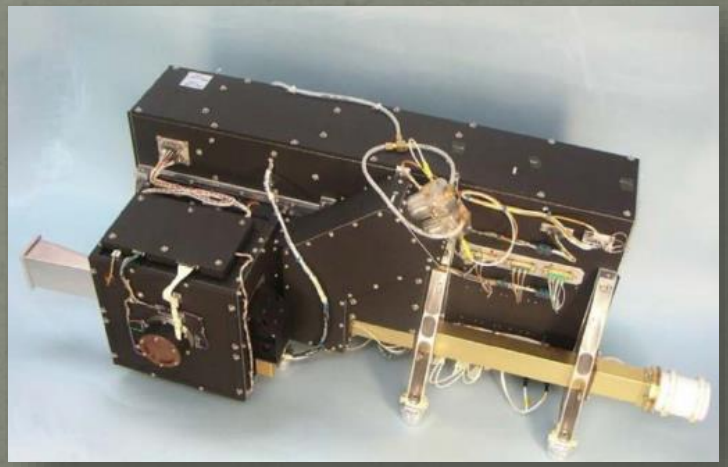
Only a very small amount of material is produced by these simulation chambers, generally not enough for instrument testing.

Synthesis of cometary analogues to test the COSIMA instrument on board ROSSETTA.



Experiment OREGOC

N. Fray, LISA, UPEC, Paris



Observation COSIMA

Biological samples

Speculative analogues

Analogue?

For me, an analogue is something terrestrial presenting characteristics more or less representative of something extra-terrestrial.

Example:

We have found basalts on Mars.

→ Thus, terrestrial basalts can be considered as analogues of Martian rocks.

Problem here:

We have never found any traces of extra-terrestrial life!

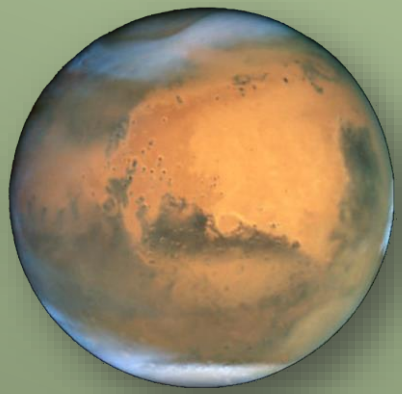
→ The analogy between terrestrial life and extra-terrestrial life is purely speculative.

What to search for?

In general we search for self-replicating systems made with organic molecules in contact with liquid water and the remains of these systems.

On Mars:

- Mars was habitable during the Noachian (~3.8 Ga ago).



→ Life may have appeared at this time and disappeared since.

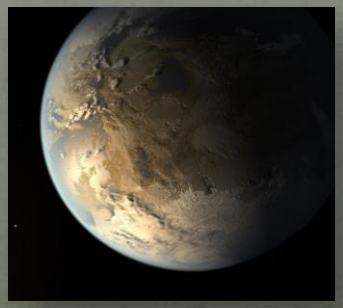
↳ Search for past traces of microbial life.

→ Life may have appeared at this time and still survives today in ecological niches.

↳ Search also for present microbial life.

On icy satellites:

- Microbial life may be present below the icy crust.



On exoplanets:

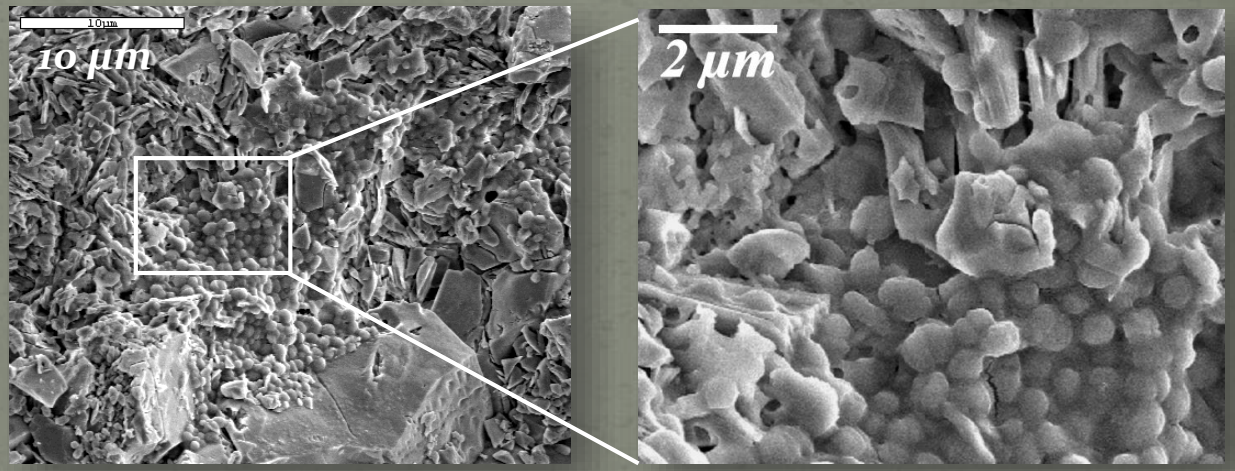
- Complex life is possible.

Analogues of past traces of life on Mars

Search for microfossils more or less similar to the oldest traces of primitive life on Earth.

Silicified microfossils from the Kitty's Gap Chert, Pilbara, Australia, -3.446 Ga

Westall et al., 2011



We can expect to find carbonaceous structures more or less similar in size and shape than those found in ancient silicified sediments.

Westall et al., 2015, Astrobiology.

Analogues of present life

Life appeared more than 4 Ga ago on Earth and evolved, adapting to various environments.

It is very unlikely that life based on DNA appeared on another body and evolved in exactly the same way as on Earth.

Study the metabolisms of organisms living in analogue environments to search for the fundamental requirements necessary to live in these particular environments, *i.e.* study convergent evolution to find convergent biosignatures (C. Flores Martinez, 2015).

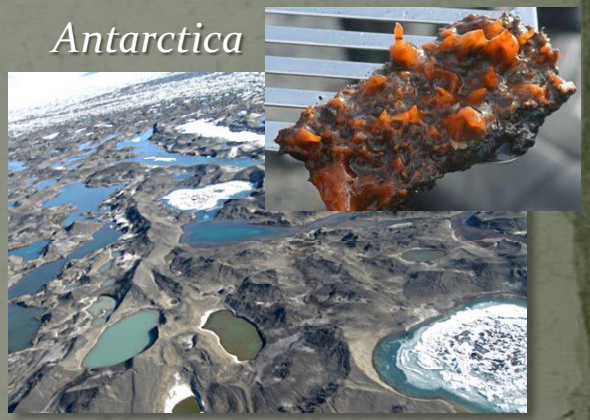
Life in analogue environments = extremophiles

Extremophiles from extremely hot, cold, acidic, alkaline, saline environments…

Yellowstone

Credits: Fouke lab.

Antarctica

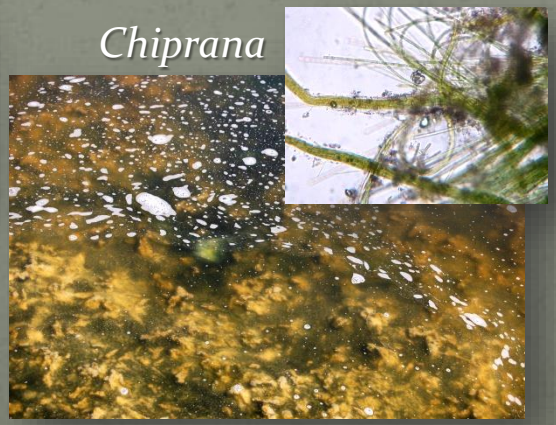


Credits: Ian Hawes.

Yellowstone

Credits: Ken Stedman.

Chiprana



Credits: Pascale Gautret.

Mono Lake

Credits: Kulp et al.,

Planetary protection and Panspermia

Panspermia, 2014, by Colonel82, Digital Art / Mixed Media / Sci-Fi©2013-2015

Analogues for Euro-Cares

A slightly different point of view

Euro-Cares

The aim of the Euro-Cares project is to develop a roadmap for a European Sample Curation Facility, designed to curate precious samples returned from Solar System exploration missions to asteroids, Mars, the Moon and comets.

www.euro-cares.eu

The samples brought back to the Earth will be very precious. Thus, it will be crucial to optimize the sample preparation protocols, to minimize the loss of matter, and to avoid any contamination.

The Working Package WP5 is dedicated to analogue samples that can be used to test the curation conditions and to establish sample preparation protocols.

What analogues samples are required?

Selection of analogue samples

What do I need to know to test the curation conditions and to define protocols?

- May samples contain active life or past traces of life?
- What type of samples: solid, gas or liquid?
- What consistency if solid? Dust, sand, grains, hand sample?
- What quantity?
- What sort of study will be carried out: mineralogy/petrography or chemistry?
- If mineralogy/petrography, what sorts of rocks and minerals are expected?

Answers to these questions permit us to define the curation conditions, to select the instruments that will be used both inside and outside of the curation facility, and to propose sample preparation protocols.

Then, it is possible to select terrestrial samples that can be used to test the curation conditions (preservation of the samples, prevention of any contamination) and to anticipate the future analyses.

Selection of analogue samples

What do I need to know to test the curation conditions and to define protocols?

- May samples contain active life or past traces of life?
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Potential traces of life

If the sample may contain traces of life, the first objective will be to search for them and there will be important planetary protection restrictions to consider.

Which analogues for what purpose?

- Test the potential contamination.
- Establish and elaborate protocols.

Examples of pertinent samples:

- Analogue samples with microorganisms to test and validate the planetary protection procedures and the sterilization protocols
- Martian regolith simulant + chemicals and/or microorganisms to improve the protocols for astrobiology
- Samples from the Earth landing site (potential contaminants)
- Analogue samples with fossilized microorganisms to optimize sample preparation protocols

Selection of analogue samples

What does I need to know to test the curation conditions and to define protocols?

- May samples contain active life or past traces of life?
- What type of samples: solid, gas or liquid?
- What consistency if solid samples: dust, sand, grains, hand sample?
- Which quantity?
- What sort of study will be carried out: mineralogy/petrography or chemistry?
- If mineralogy/petrography, what sorts of rocks and minerals are expected?

Type of sample

Gas or liquid:

Can be atmospheric gas or solid/liquid that turn into gas (or liquid) at storage condition.

Which analogue for what purpose?

- Test the potential contamination coming from the storage box materials.
- Test the permeability of the storage box.

Examples of pertinent samples:

- Hydrogen (very volatile, easy to detect and not dangerous)
- Relevant gases (analogues) to optimize the protocols of analyses
- Potential contaminants

Solid:

Most expected samples to be brought back to Earth.

Selection of analogue samples

What does I need to know to test the curation conditions and to define protocols?

- May samples contain active life or past traces of life?
- What type of samples: solid, gas or liquid?
- What consistency if solid samples: dust, sand, grains, hand sample?
- Which quantity?
- What sort of study will be carried out: mineralogy/petrography or chemistry?
- If mineralogy/petrography, what sorts of rocks and minerals are expected?

Solid?

Between dust, sand, gravel, hand sample, crushed sample and drill core, protocols will differ.

Which analogue for what purpose?

- Test the potential contamination.
- Establish and elaborate sample preparation protocols.

Examples of pertinent samples:

- Martian regolith simulant to test contamination
- Martian regolith simulant + chemicals to test the limit of detection and to improve the analysis protocols
- Clays, sands and crushed rocks to optimize and organize the analyses in order to carry them out using the smallest amount of sample
- Samples from the Earth landing site (potential contaminants)
- Structural and morphological analogues to optimize sample preparation (e.g. numerical models and samples obtained by 3D printing)
- Standards for the different instruments

Selection of analogue samples

What does I need to know to test the curation conditions and to define protocols?

- May samples contain active life or past traces of life?
- What type of samples: solid, gas or liquid?
- What consistency if solid samples: dust, sand, grains, hand sample?
- Which quantity?
- What sort of study will be carried out: mineralogy/petrography or chemistry?
- If mineralogy/petrography, what sorts of rocks and minerals are expected?

The amount of sample available will be important for curation conditions, for sample preparation and for analysis protocol establishment.

Selection of analogue samples

What does I need to know to test the curation conditions and to define protocols?

- May samples contain active life or past traces of life?
- What type of samples: solid, gas or liquid?
- What consistency if solid samples: dust, sand, grains, hand sample?
- Which quantity?
- What sort of study will be carried out: mineralogy/petrography or chemistry?
- If mineralogy/petrography, what sorts of rocks and minerals are expected?

Objectives

Depending on the main objective(s) of the mission, protocols may be different due to destructive analyses.

Which analogue for what purpose?

- Elaborate protocols.

Examples of pertinent samples:

- Analogue samples to organize the analyses.

Selection of analogue samples

What does I need to know to test the curation conditions and to define protocols?

- May samples contain active life or past traces of life?
- What type of samples: solid, gas or liquid?
- What consistency if solid samples: dust, sand, grains, hand sample?
- Which quantity?
- What sort of study will be carried out: mineralogy/petrography or chemistry?
- If mineralogy/petrography, what sorts of rocks and minerals are expected?

Geological analogue samples

Depending on the type of rocks, sample preparation is different.

Which analogue for what purpose?
- Improve sample preparation.
- Optimize protocols.

Examples of pertinent samples:
- Analogue rock samples

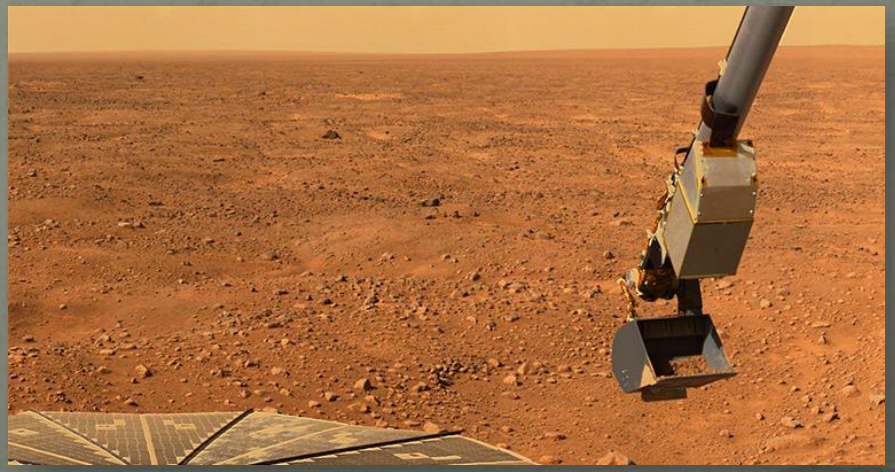
Examples of analogues

Mars Sample Return and Lunar Sample Return

Mars Sample Return

What do I need to know to test the curation conditions and to define protocols?

- May they contain active life or past traces of life? **YES**
- What type of sample: solid, gas or liquid? **SOLID**
- What consistency if solid samples: dust, sand, grains, hand sample? **CLAYS and DRILL CORES**
- Which quantity? **10 g OF CLAYS, CYLINDERS 3 CM LONG, 1 CM WIDE**
- What sort of study will be carried out: mineralogy/petrography or chemistry? **BOTH**
- If mineralogy/petrography, what sorts of rocks and minerals are expected? **PHYLLOSILICATES, BASALTS**



Analogue selection for MSR

Samples may contain active life

⇒ First objective: search for potential microorganisms (optical and SEM observations, cell culture…)

⇒ Protect the Earth and the samples from potential contamination

Most important samples required to prepare the mission would be biological and chemical (potential "analogues", potential contaminants from the lab, potential contaminants from the Earth landing site)

Samples may contain ancient traces of life

⇒ First objective: search for potential microfossils (optical and SEM observations, Raman analysis…)

Most important samples required to prepare for the mission would be samples containing fossilized microorganisms (potential analogues)

Analogue selection for MSR

Some samples consist of 10 g of clays, mostly composed of phyllosilicates

Secondarily important samples required to prepare for the mission would be Martian Regolith Simulant, various phyllosilicates (e.g. montmorillonite, kaolinite, serpentinite…), finely crushed analogue rocks + soil samples from the Earth landing site.

Some samples consist of basalt drill cores

Secondarily important samples required to prepare the mission would be cylinders of analogue rocks.

Lunar Sample Return

What do I need to know to test the curation conditions and to define protocols?

- May they contain active life or past traces of life? **NO**
- What type of samples: solid, gas or liquid? **SOLID**
- Which quantity? **10 g**
- What consistency if solid samples: dust, sand, grains, hand sample? **DUST**
- What sort of study will be carried out: mineralogy/petrography or chemistry? **MINERALOGY**
- If mineralogy/petrography, what sorts of rocks and minerals are expected? **ANORTHOSITE**

Analogue selection for LSR

The sample consists of 10 g of dust mostly composed of anorthosite

Most important samples required to prepare the mission would be finely crushed anorthosite + soil samples from the Earth landing site.

Comments

- Elaboration and optimization of the protocols could be done without any planetary protection consideration. They can be done somewhere other than in the future curation facility using a large variety of analogue samples.

- Validation and testing of the storage conditions and protocols, and determination of the potential contaminants must be done in the curation facility, even if they can be defined somewhere else previously.

- Calibration samples for the instruments available in the curation facility must be stored in sterile conditions.

Conclusion

- The samples required to prepare a return mission are dependent on the mission.

- They can be calibration samples, contaminant samples, or analogue samples.

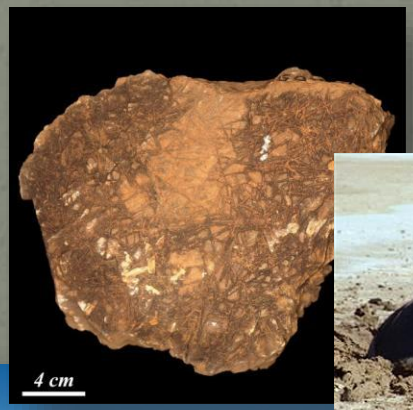
- Contaminant samples can be:
  - Materials used for the storage box
  - Contaminants from the lab (material, chemical, or biological)
  - Contaminants from the landing site (chemical, mineralogical, or biological)

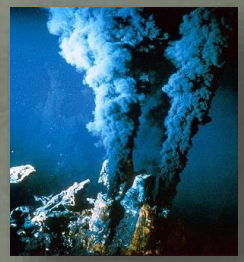
- Analogue samples can be:
  - Microorganisms considered as potential analogues (*i.e.* organisms living in analogue sites)
  - Samples containing past traces of life considered as potential analogues
  - Geologically relevant samples coming from analogue sites
  - Samples relevant for their size, shape, consistency… They can be natural analogues or not, depending on their use.

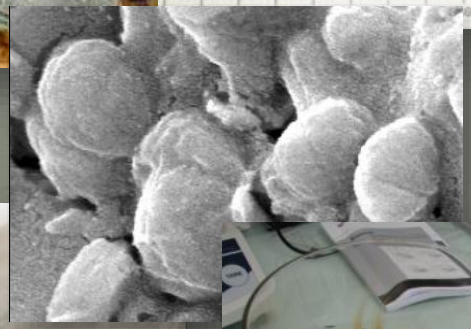
Summary

There is a huge variety of analogues which could be useful : materials, rocks, molecules, fossils, environments…











Thank you!