

The logo for Imperial College London, featuring the text "Imperial College London" in white on a dark blue background with a bokeh effect of light blue circles.

Imperial College
London

Geochemistry, Meteorites & Missions

Professor Mark A. Sephton, Earth Science & Engineering

Presentation Outline

The Planetary Geologist

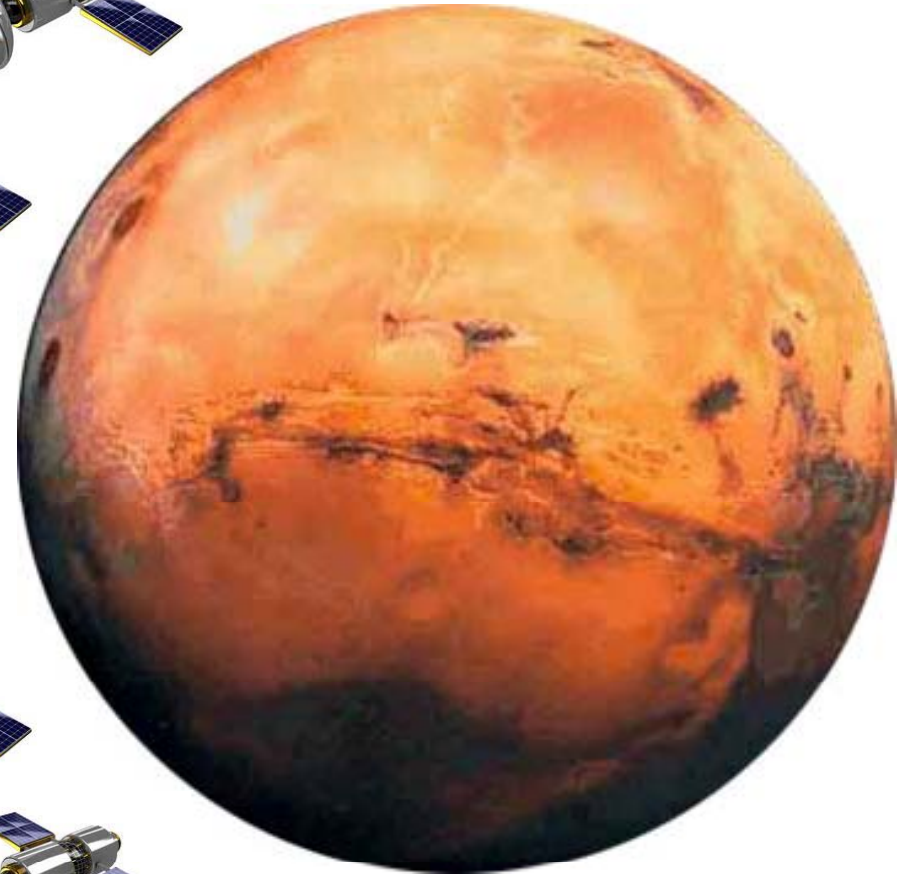
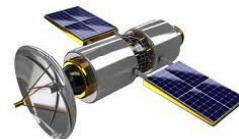
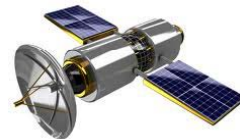
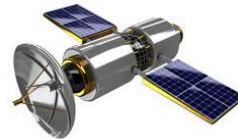
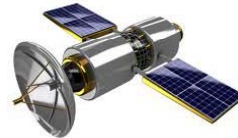
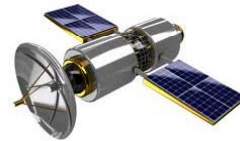
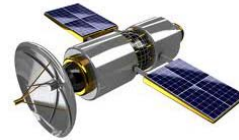
E.g. - The Life Marker Chip

Knowledge Transfer

Use of Analogues

Organic Matter

Minerals



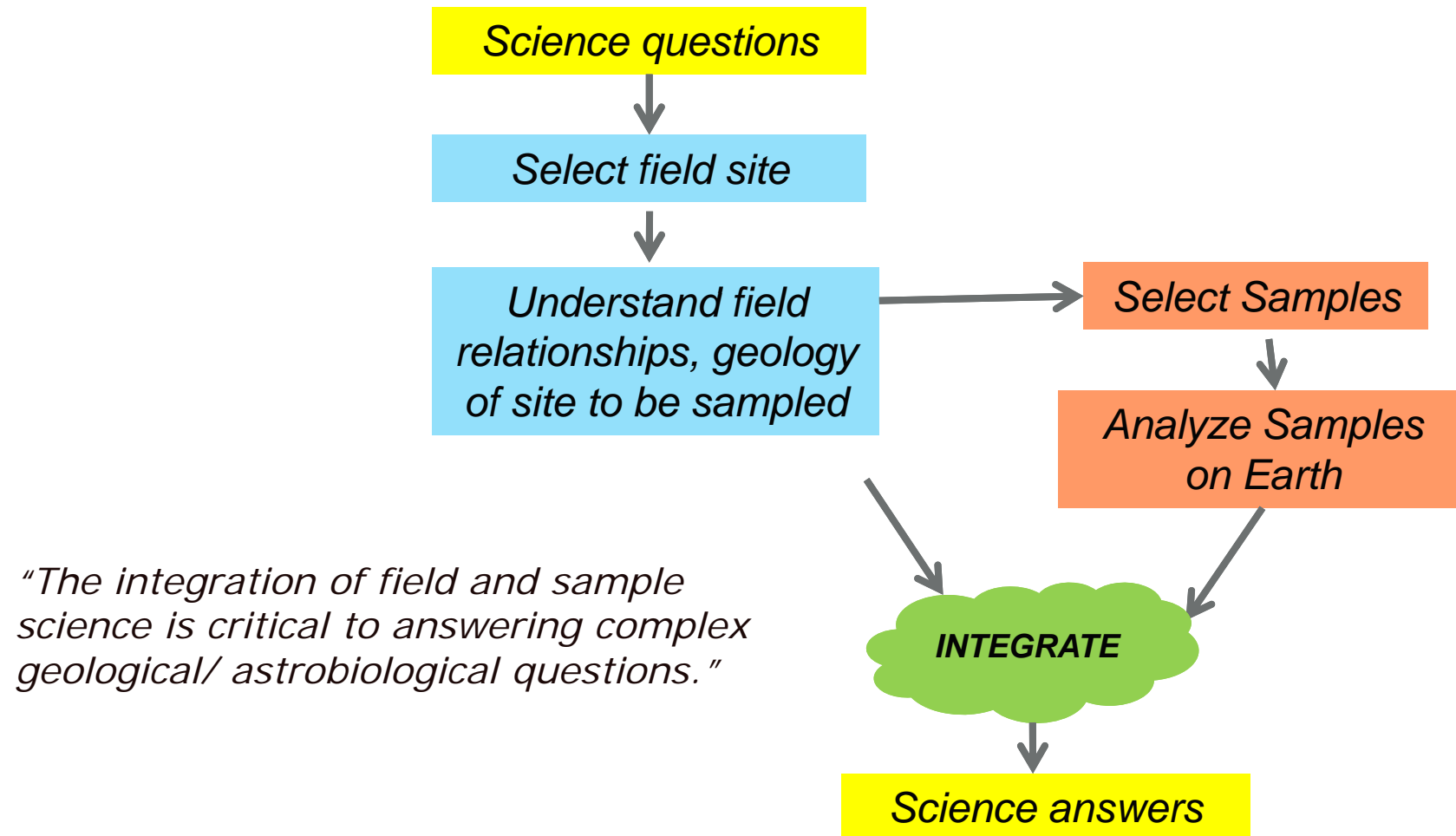
Rise of the Planetary Geologist

Mariner 9 was an Orbiter that reached Mars in 1971, becoming the first spacecraft to orbit another planet



“Mariner 9 cameras took thousands of pictures. A whole new world was taking shape. NASA called in a new type of scientist – Planetary Geologists .”

Integrating field and sample science

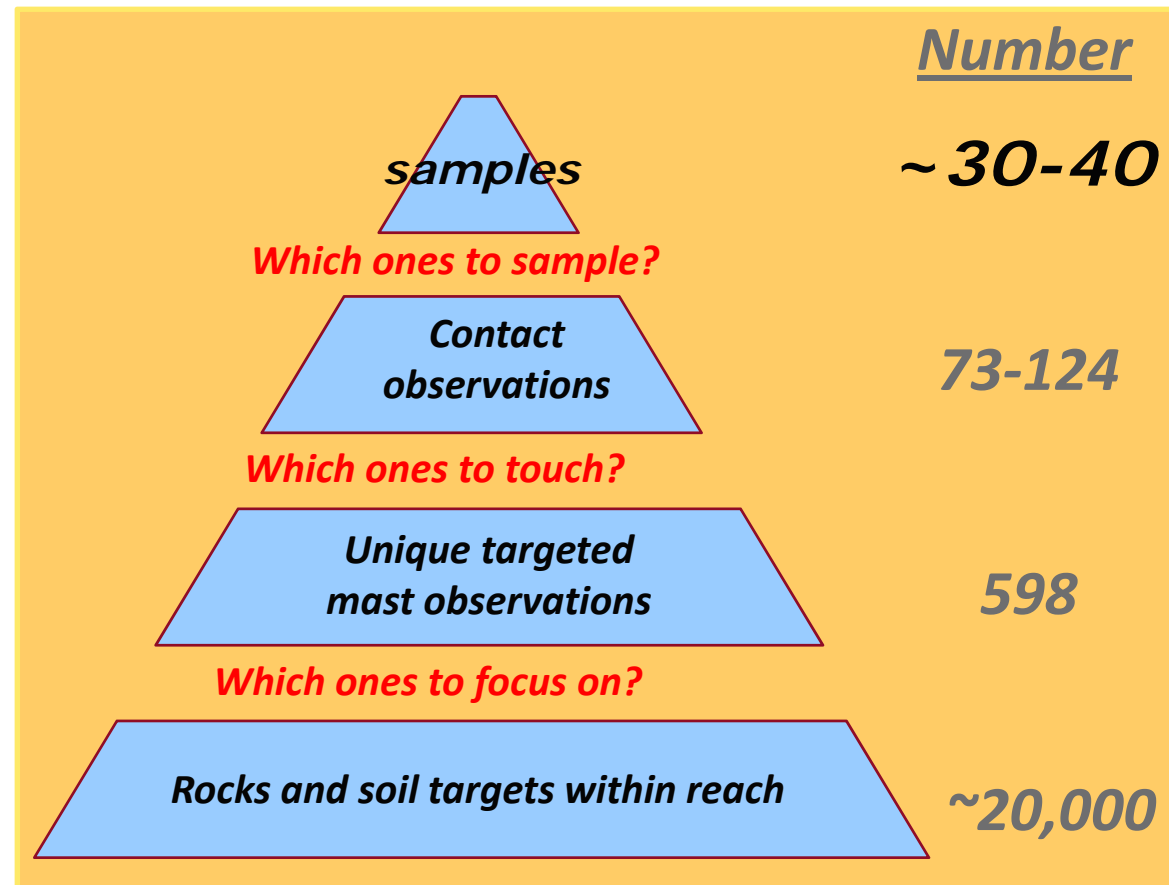


Hierarchical need for information

Putting together effective sample suites requires collecting information in the field on many more rock and soil candidates than the number eventually collected.

Example:

Counts from first Mars year of Spirit's exploration of Gusev Crater, 2004-2006.



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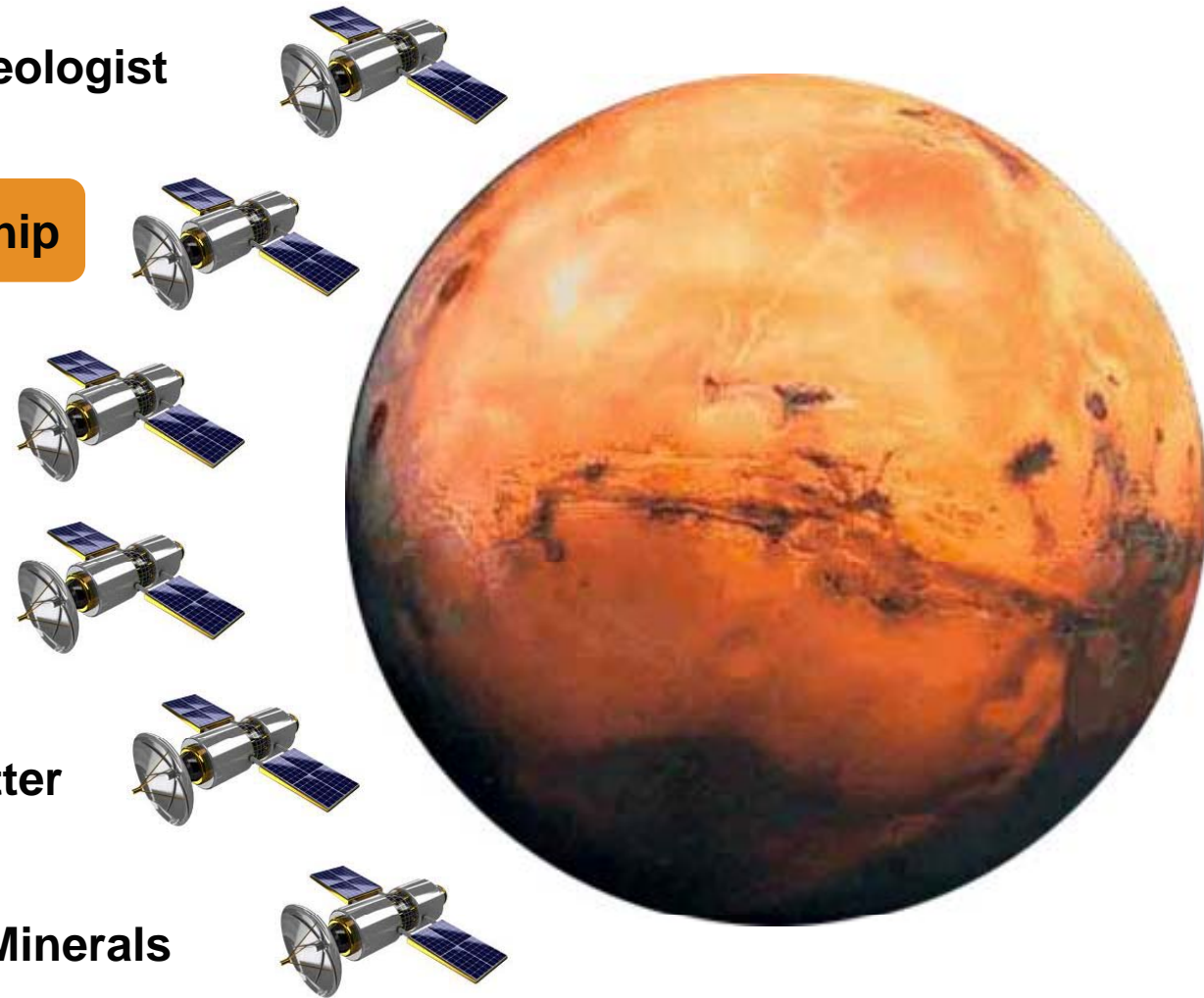
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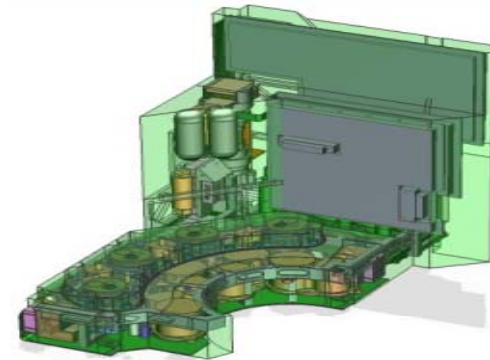


The Life Marker Chip

Thanks to Mark Sims, Dave Cullen, Richard Court

Life Marker Chip

- Detects organic compounds
- Uses an antibody array
- Specific and sensitive

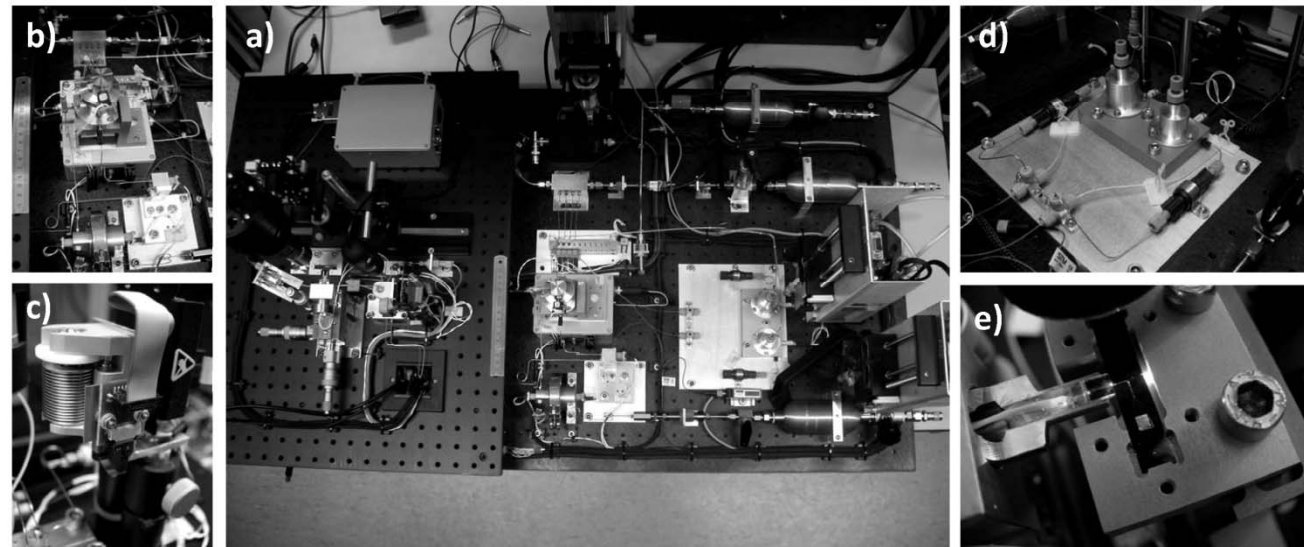


(a) End to End demonstrator
at Uni. Leicester

(b) SPS system, flight-like
inlet volume (top), waste
chamber (bottom),

(c) flight-like bellows pump
from AS,

(d) flight-like fluid cartridges,
(e) proof of concept silicon
nitride waveguide.



Conventional geochemistry

Conventional organic
geochemistry extraction

- Eglinton 1969

Remove surface

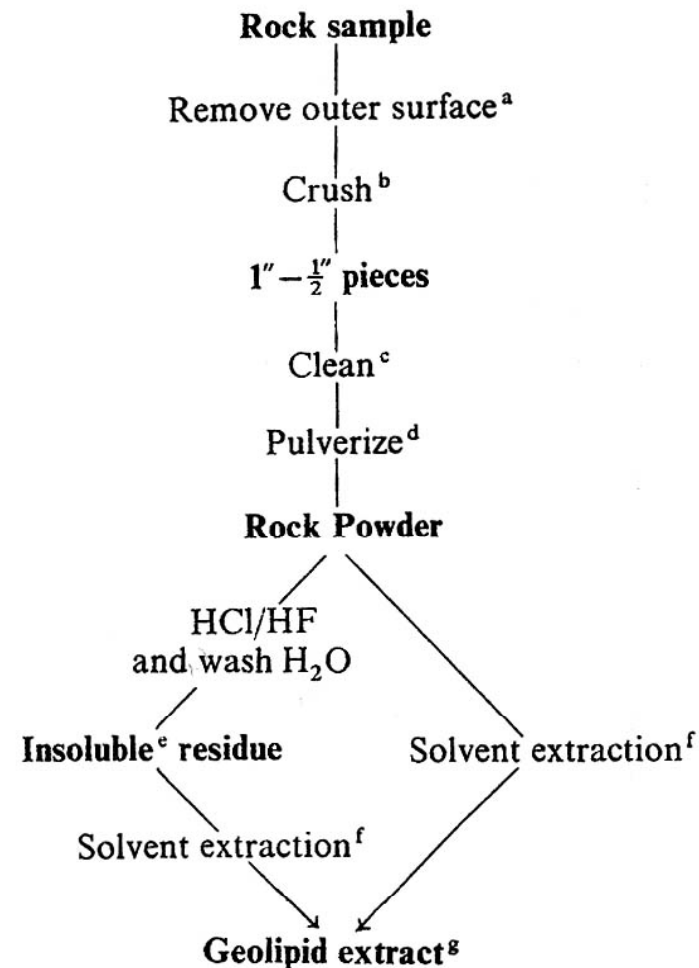
Powder

Organic solvent

- Free compounds
- “Like dissolves like”

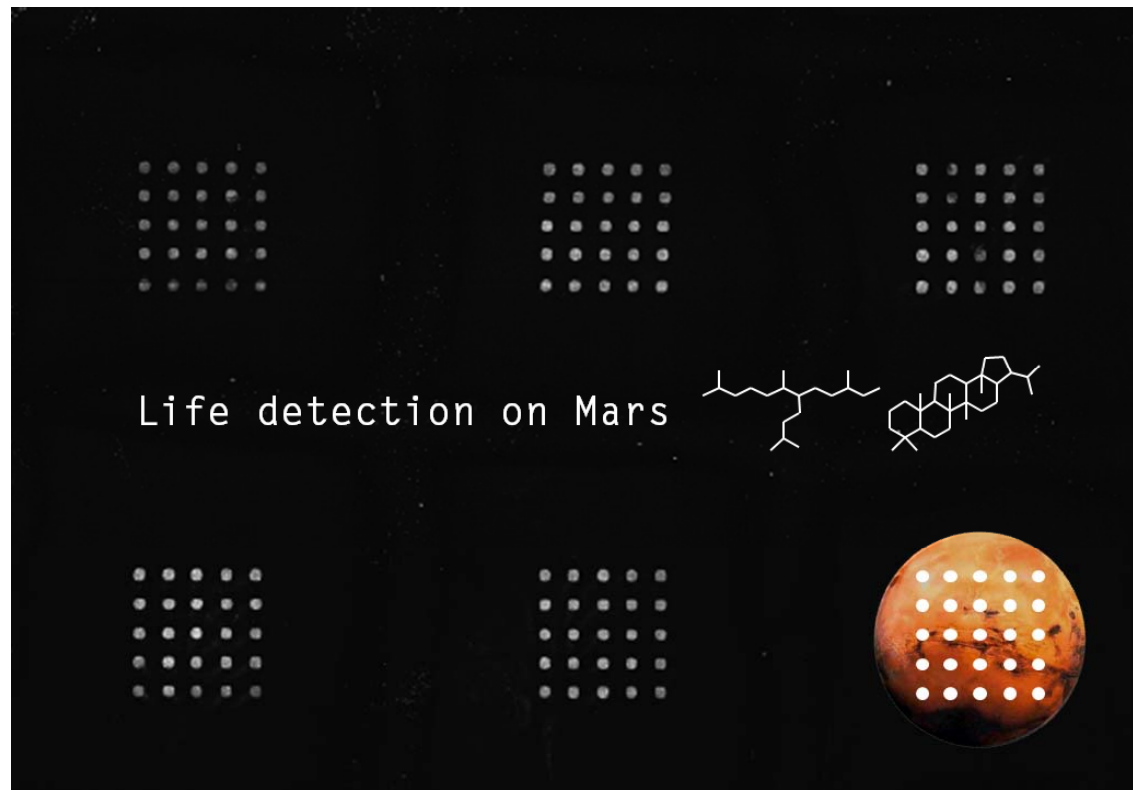
Demineralizing acids

- Kerogen



Unconventional geochemistry

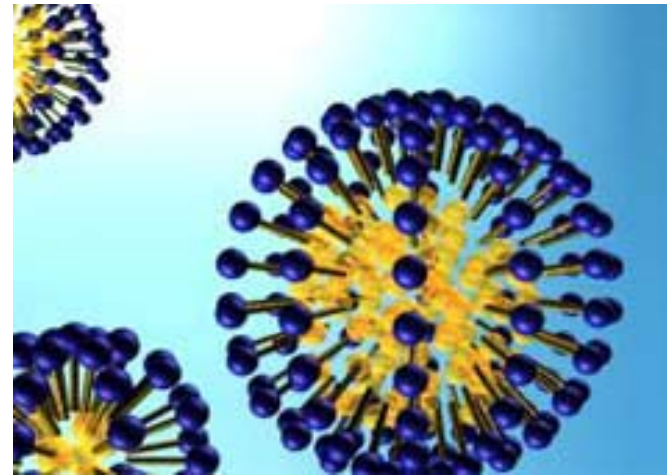
Life Marker Chip Detector relies on **antibodies** which are proteins so new water-based solvents are needed



New solvents

Surfactant solutions

- Organic additives with water loving and water hating parts
- Spontaneously form spheres with analyte inside
- Polysorbate 80 for Mars - Court et al. 2010



Subcritical Water

- Polarity changes with temperature and pressure
- Polar compounds at low temperatures
- Hydrocarbons at high temperatures
- Tuneable for selective extraction



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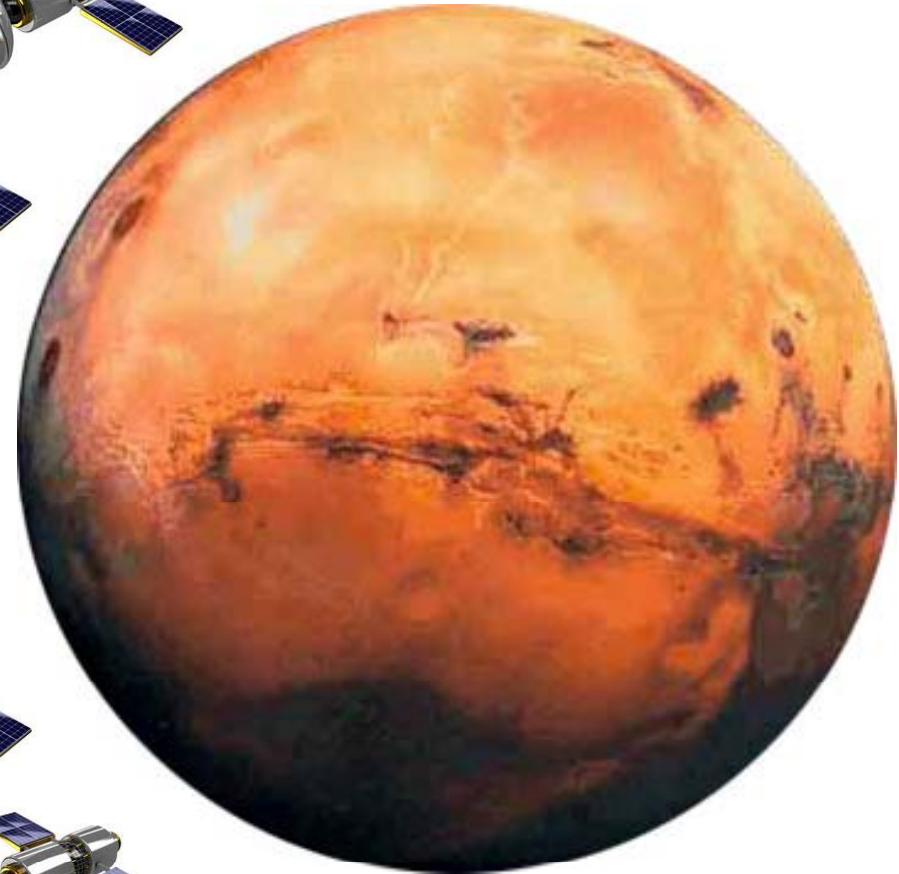
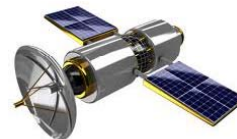
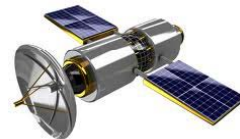
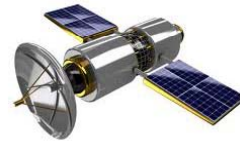
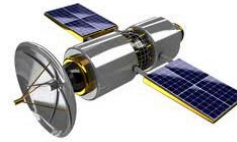
E.g. - The Life Marker Chip

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Minerals

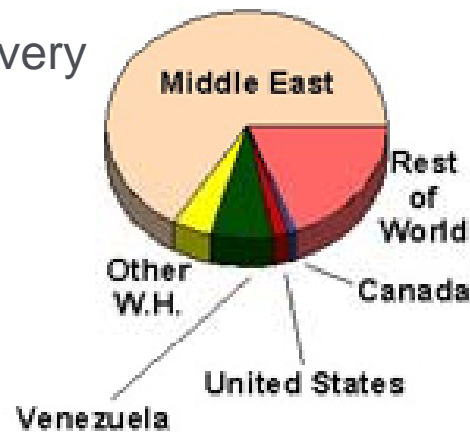


Unconventional solutions to unconventional oil

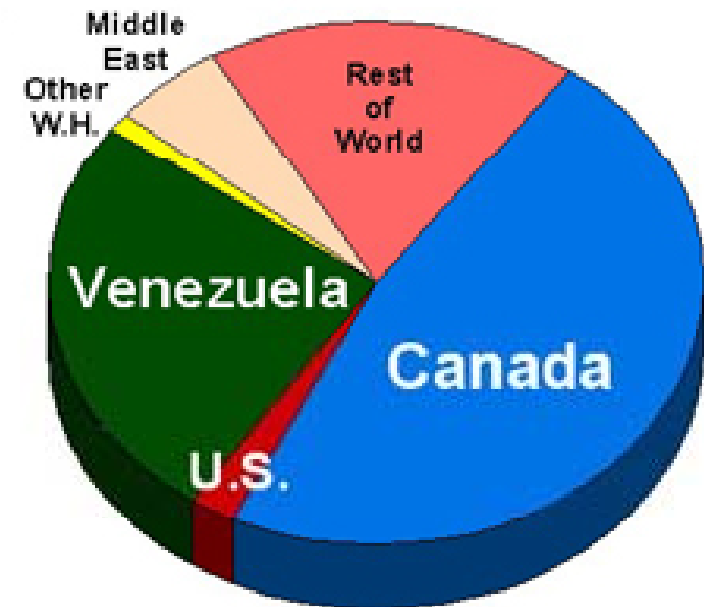
- Global resources.
- Dominated by heavy oil.
- Politically stable.
- Difficult to extract.
- Water use
- Steam assisted recovery



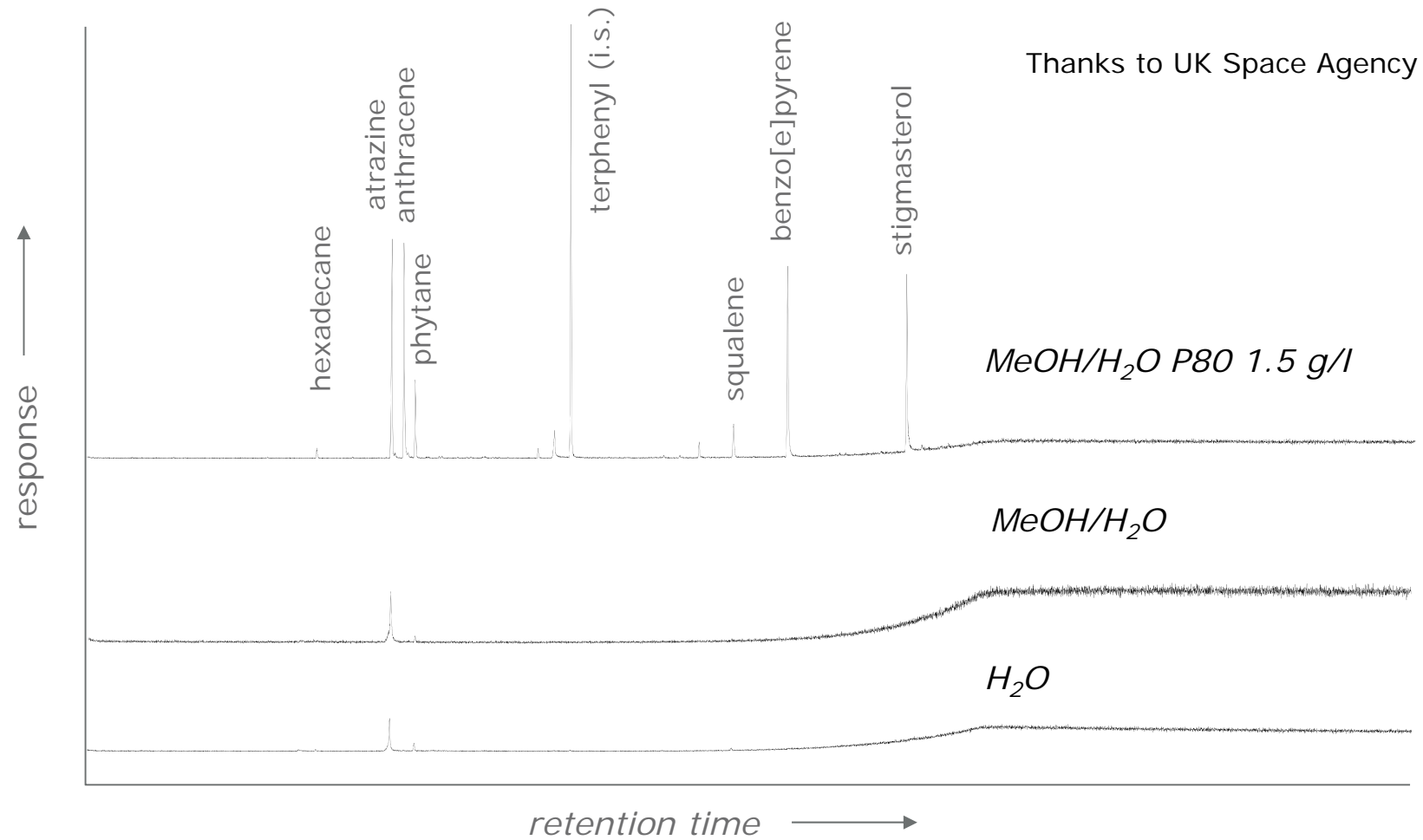
Conventional Crude Oil
1.02 trillion barrels



Heavy Oil and Bitumen
5.6 trillion barrels

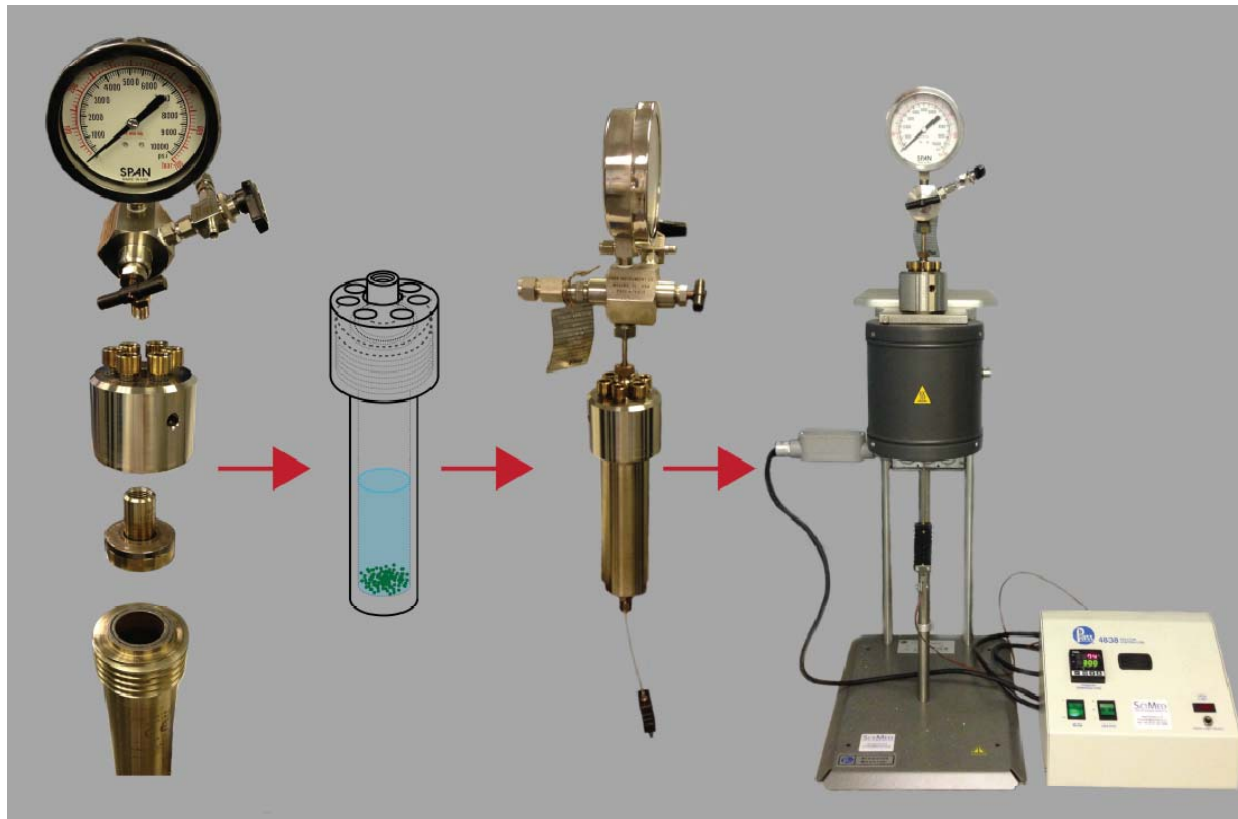


Aqueous vs surfactant solvents



Subcritical Water

Thanks to UK Space Agency



Montgomery et al. 2013, Fuel 113, 426-434

(James Lewis – Figure)

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The Planetary Geologist

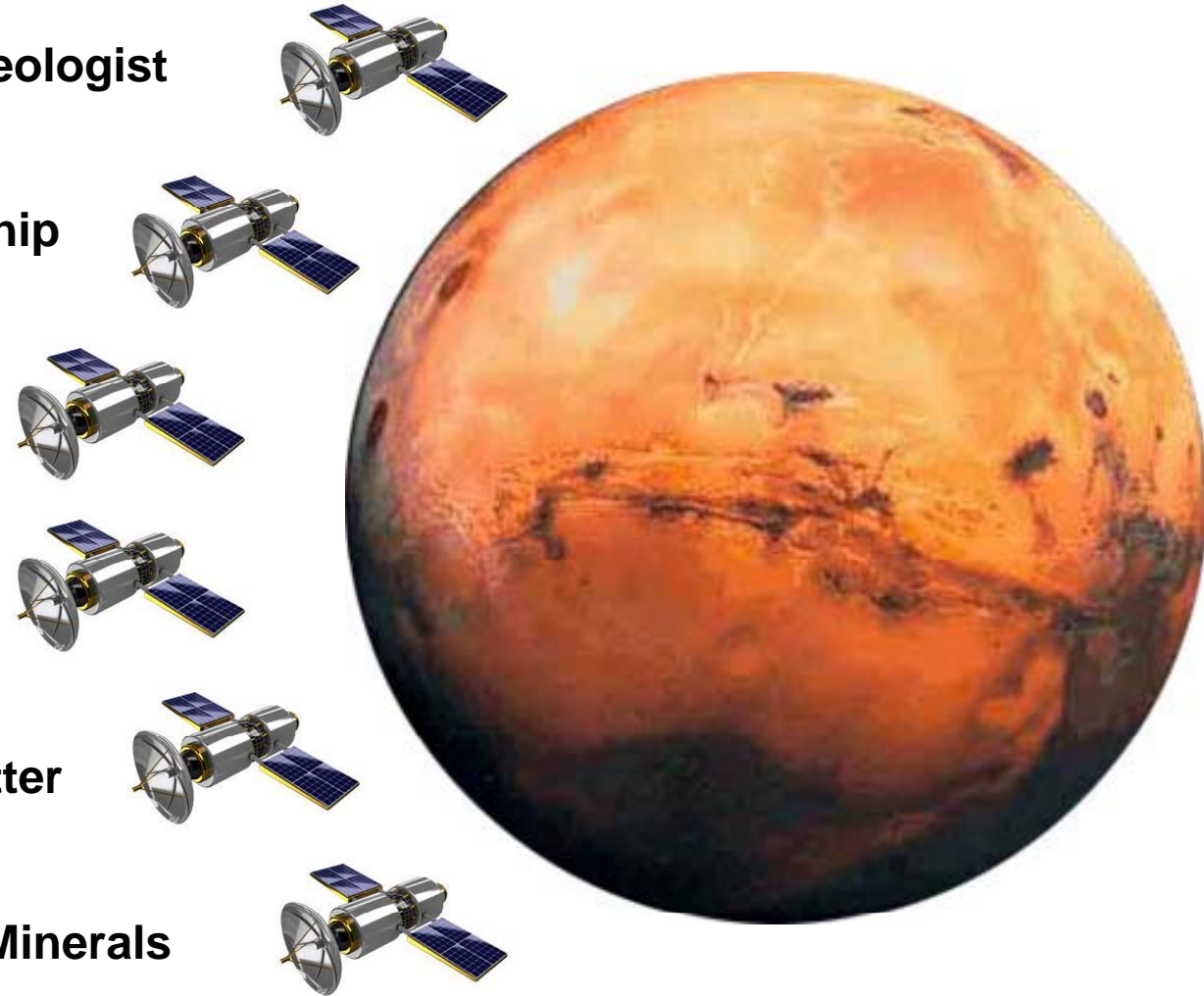
E.g. - The Life Marker Chip

Knowledge Transfer

Use of Analogues

Organic Matter

Minerals



The use of analogues

EMBARGOED

Presentation Outline

The Planetary Geologist

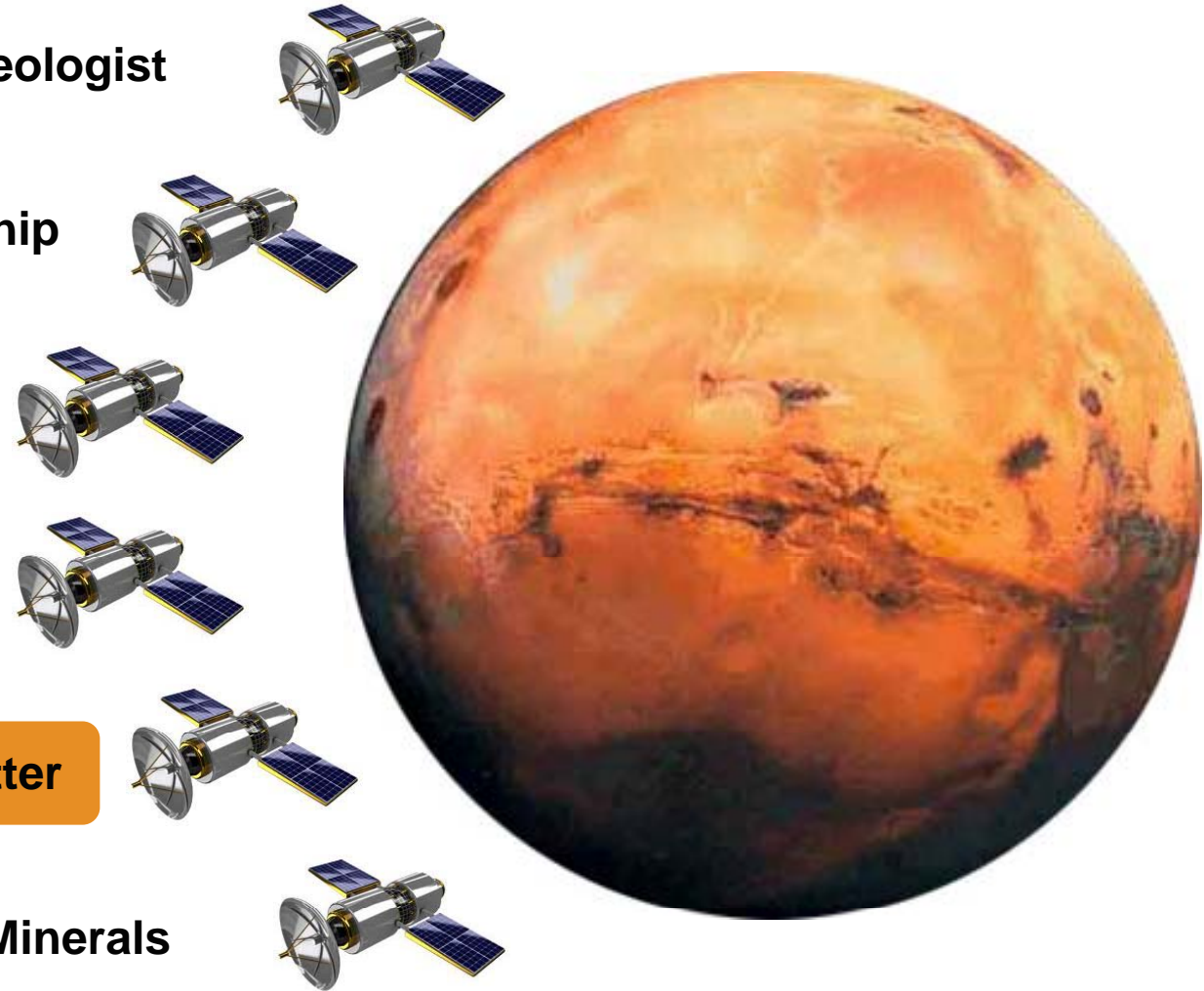
E.g. - The Life Marker Chip

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Organic Matter on Mars

Non-biological

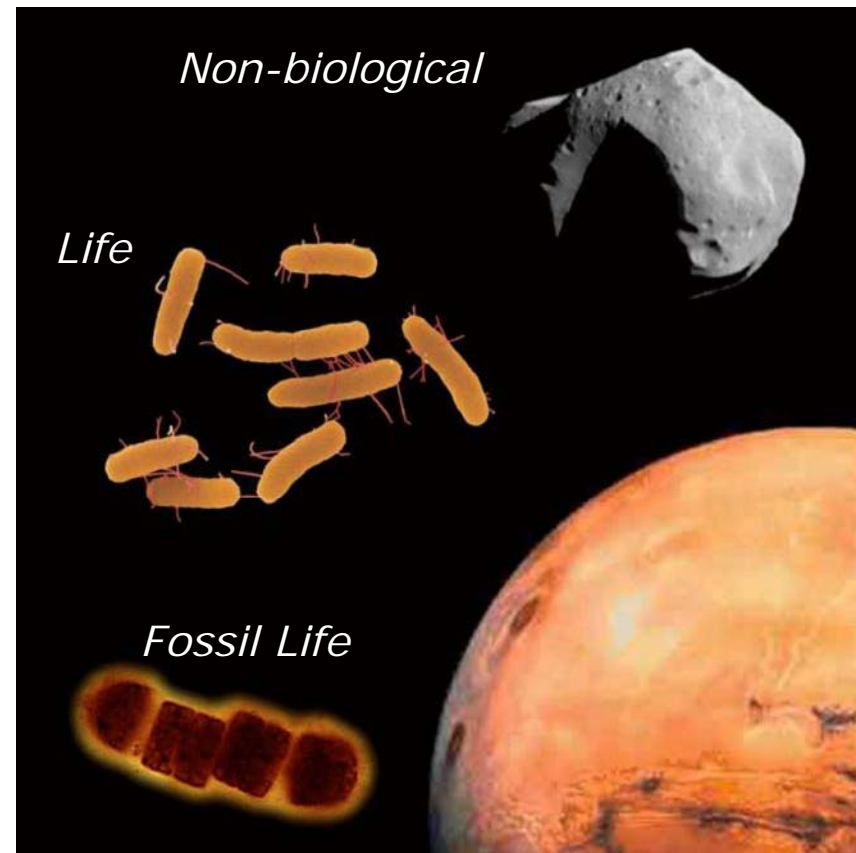
- Life's precursors
- Diverse structures

Life

- Biological
- Delicate
- Specific structures

Fossil life

- Robust remnants
- Degraded and metamorphosed
- Stable structures



Life constitution

Bacterium	% wt	No types of each molecule
Water	70	1
Inorganic ions	1	20
Small organic molecules	6	750
Very large organic molecules	22	5 000

Most of the molecules in a living system

- Very large organic molecules
- Macromolecules

Macromolecules can be subdivided into four different types:

- Lipids
- Carbohydrates
- Proteins
- Nucleic acids

Macromolecules are products of combining many individual organic units

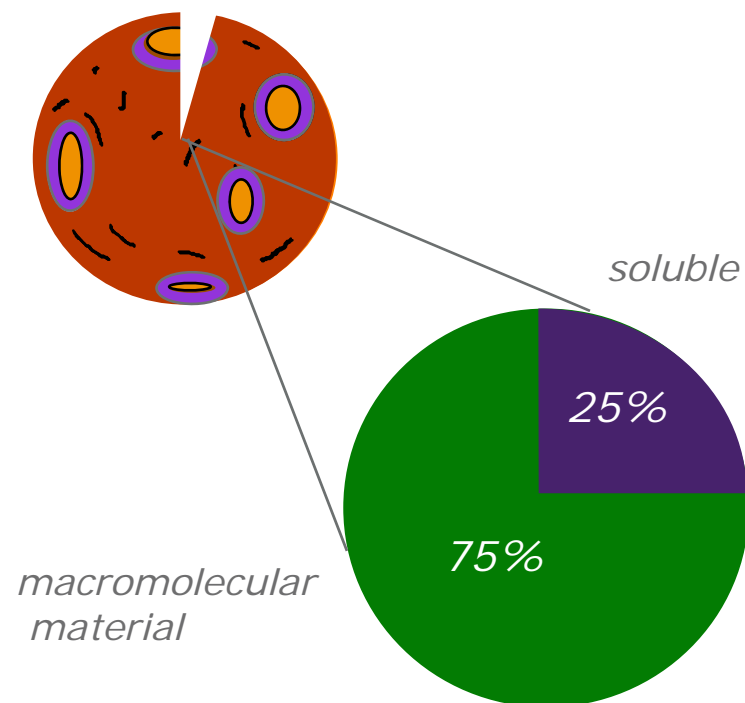
- Hydrocarbon-dominated units
- Sugars or polyols
- Amino acids
- Nucleobases, etc.



Meteorite constitution

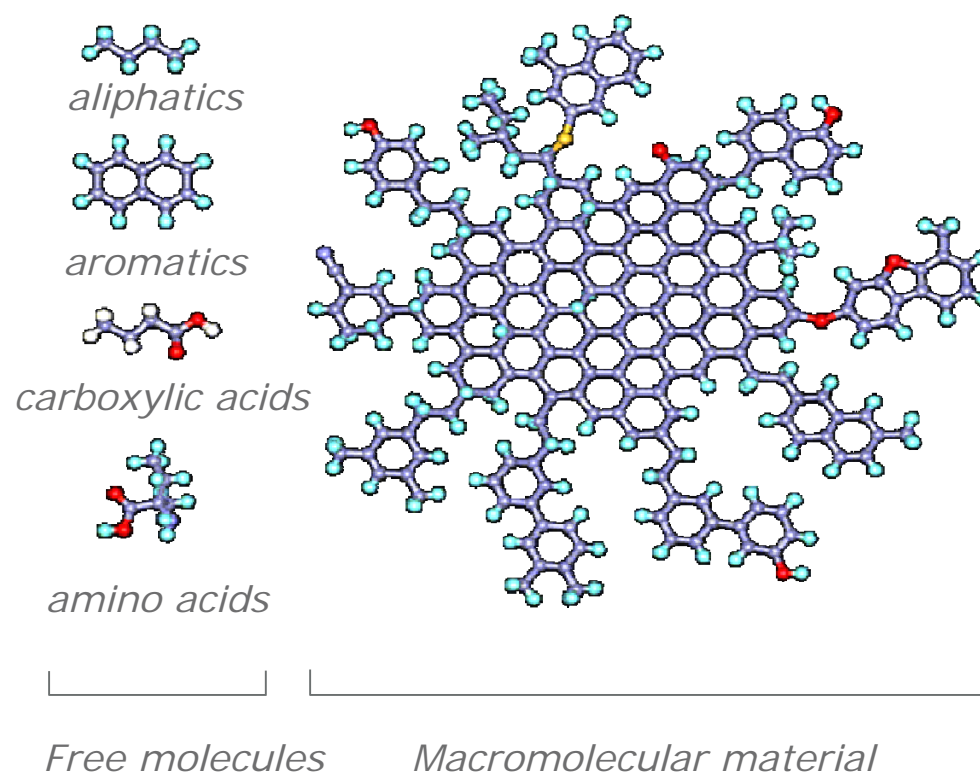
Carbonaceous chondrites

- Up to 5% organic matter

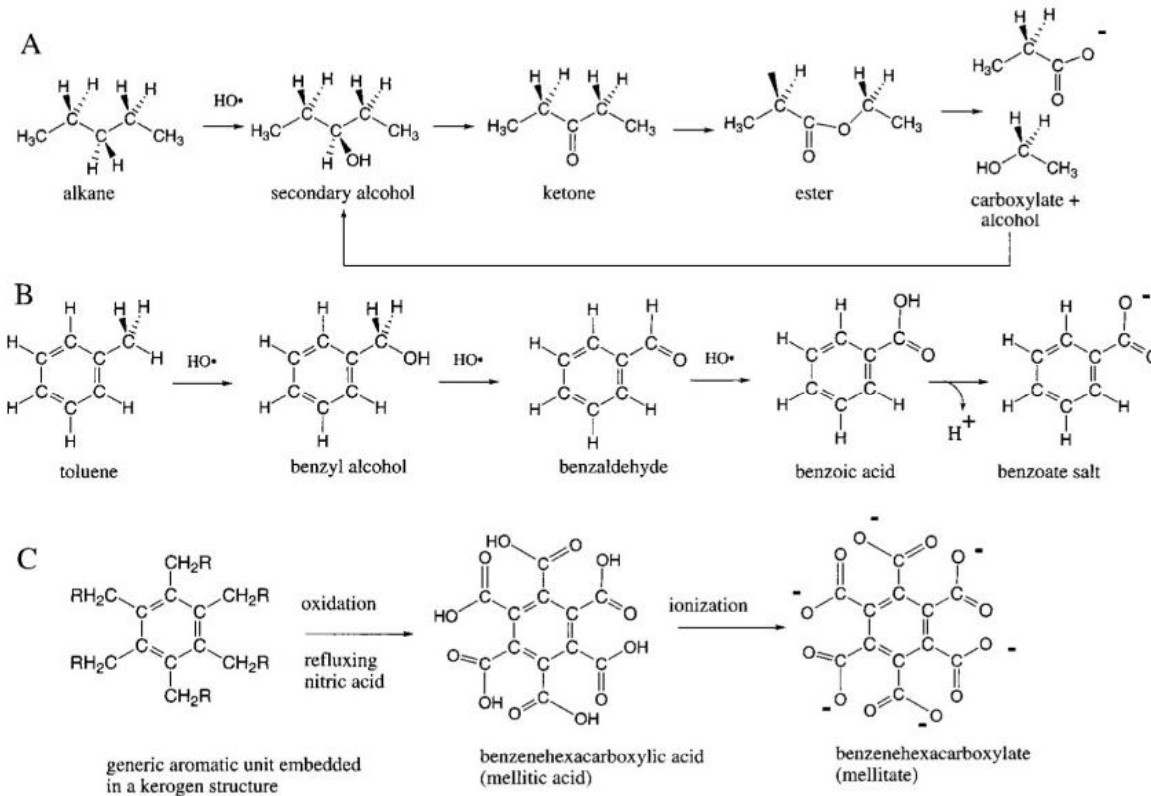


Meteoritic organic matter

- 25% solvent soluble or "free"
- 75% insoluble, macromolecular
- $C_{100}H_{71}O_{12}N_3S_2$ (Hayatsu et al. 1977)



Mars & degradation



No organic molecules detected by
Viking GC-MS

2.4×10^8 g carbon comes to Mars each
year via meteorites

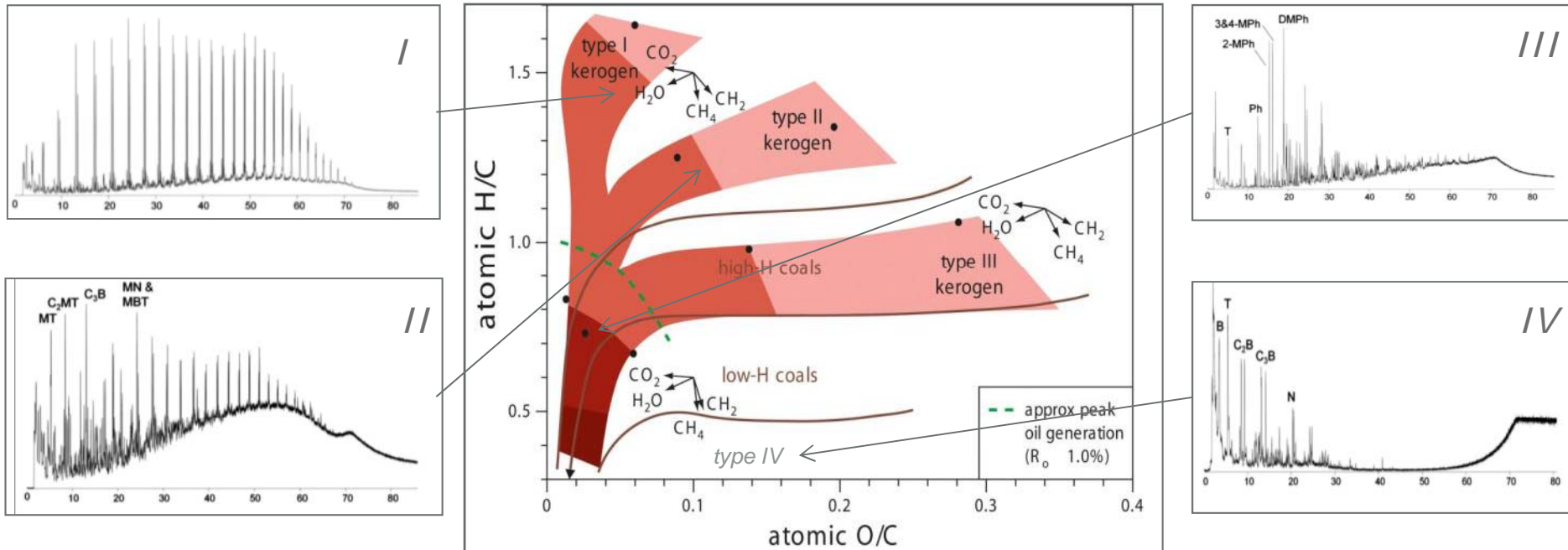
Oxidative degradation

- Units lost, residues produced

Benner et al. 2000 PNAS 97, 2425–2430

- A) pentane, B) toluene, C) kerogen

Kerogen Evolution

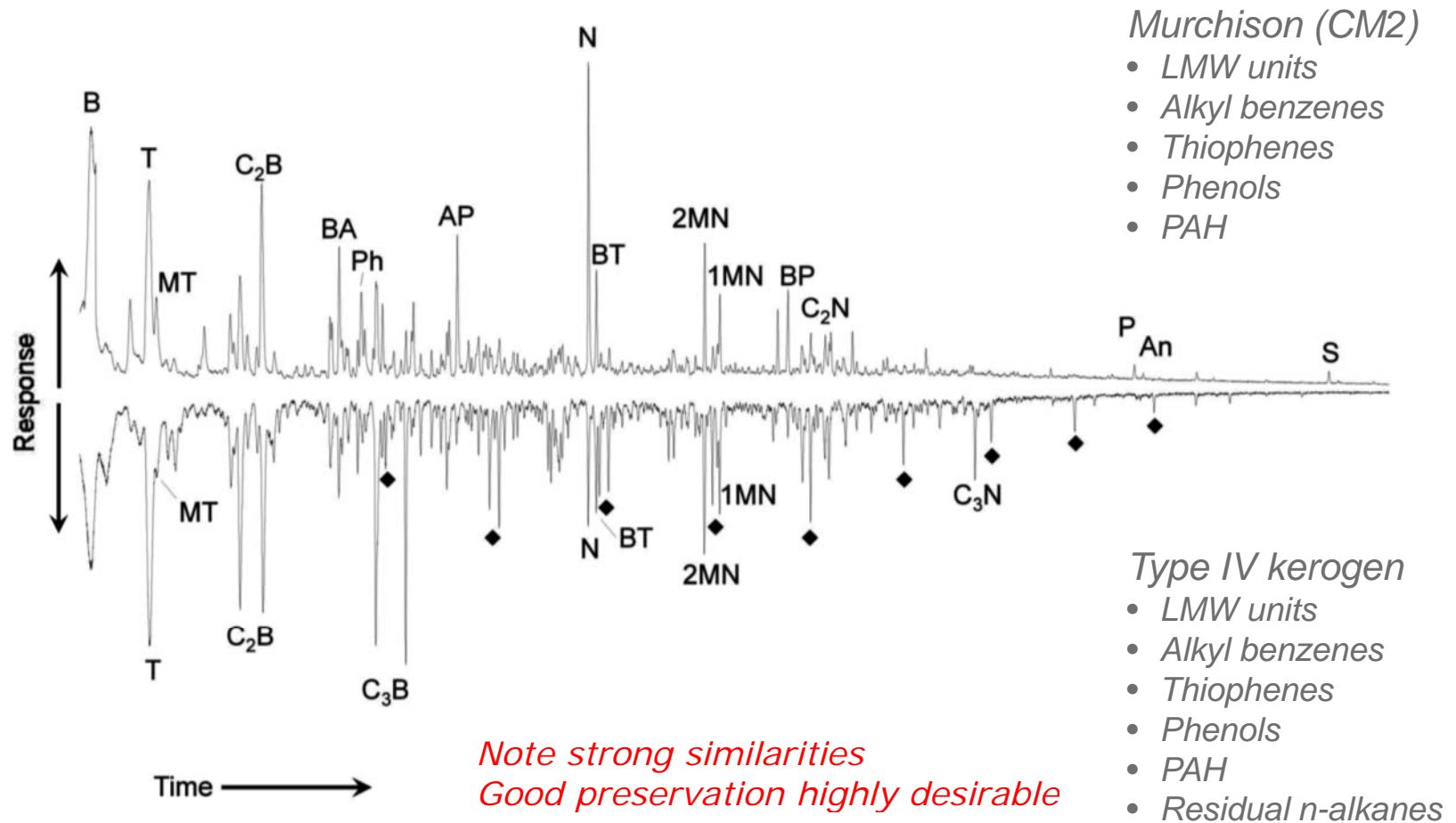


- *Types I to III appear biological*
- *All kerogen types approach origin*
- *Mature and degraded kerogens less faithful*

stage	zone	main fluids evolved	approx vitrinite reflectance (R_o)
diagenesis	immature	carbon dioxide & water	0.5-0.6%
catagenesis	oil	liquid hydrocarbons	1.3%
	wet gas	gaseous hydrocarbons	2.0%
metagenesis	dry gas	methane	

- *Type IV kerogens are highly degraded*

Meteorite & type IV organic matter



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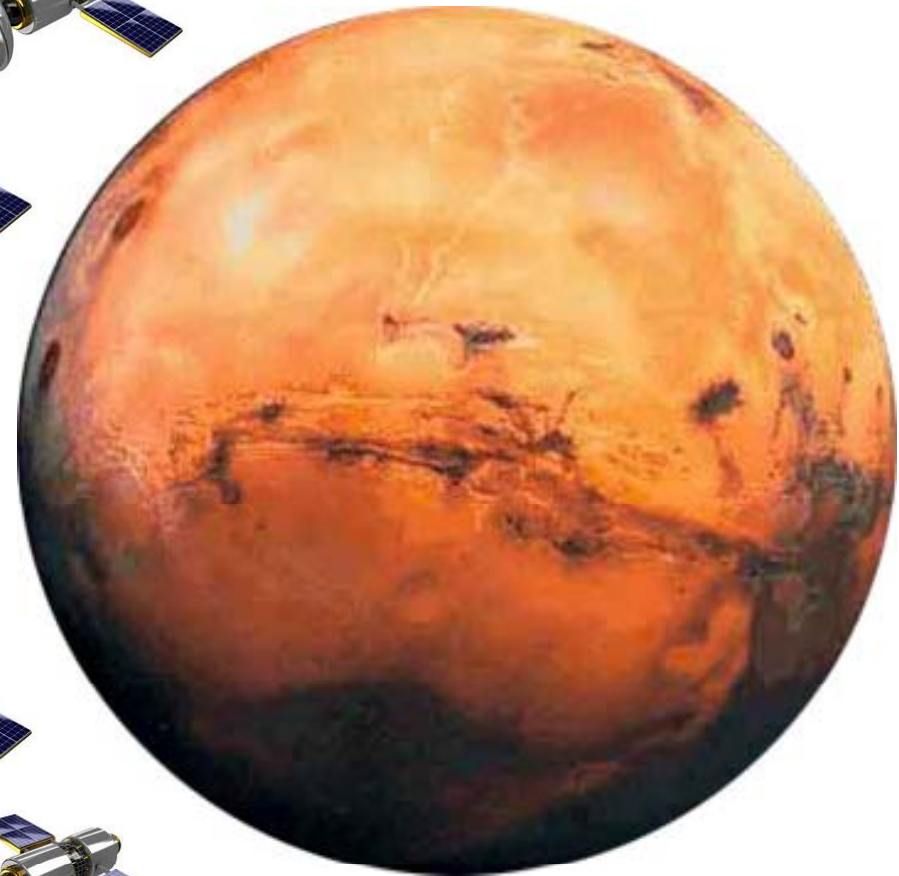
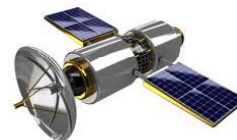
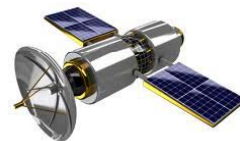
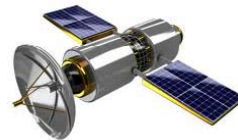
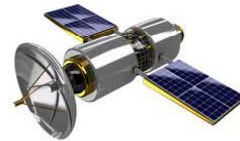
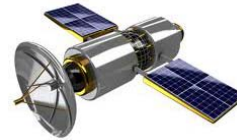
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Knowledge Transfer

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Minerals



Earth's organic matter and minerals

Earth's organic matter

- 90% of that accumulating is in coastal margins
- Intimately associated with mineral surfaces

Mineral hosted organics

- 83% organic matter on minerals is irreversibly adsorbed
 - » Hedges & Keil 1995
- Organic content directly related to minerals surface area
- Equivalent to a monolayer coating ($0.86 \text{ mgC}_{\text{org}} \text{ m}^{-2}$)
 - » Meyer 1984



Minerals

Mineral	Surface area m ² /g	Organic coating mg/g	Irreversible mg/g
Ferrihydrite	134	120.6	76.3
JSC Mars-1	106	95.4	96.5
Smectite	52.7	47.4	37.9
Dunite	2.8	2.6	2.0
Volcanic tuff	13.7	12.3	9.9
Volcanic tuff & Mg sulfate (1:3)	11.3	10.2	8.1

- Surface areas of Martian mineral analogues calculated by Pommerol et al. (2009).
- Data can be used to predict monolayer organic contents.
- Phyllosilicates are particularly important minerals for the entombment and preservation of organic matter. Phyllosilicate formation requires water and therefore conditions that are conducive to life.
- Such deposits are important targets for life search missions.

Mars minerals in time

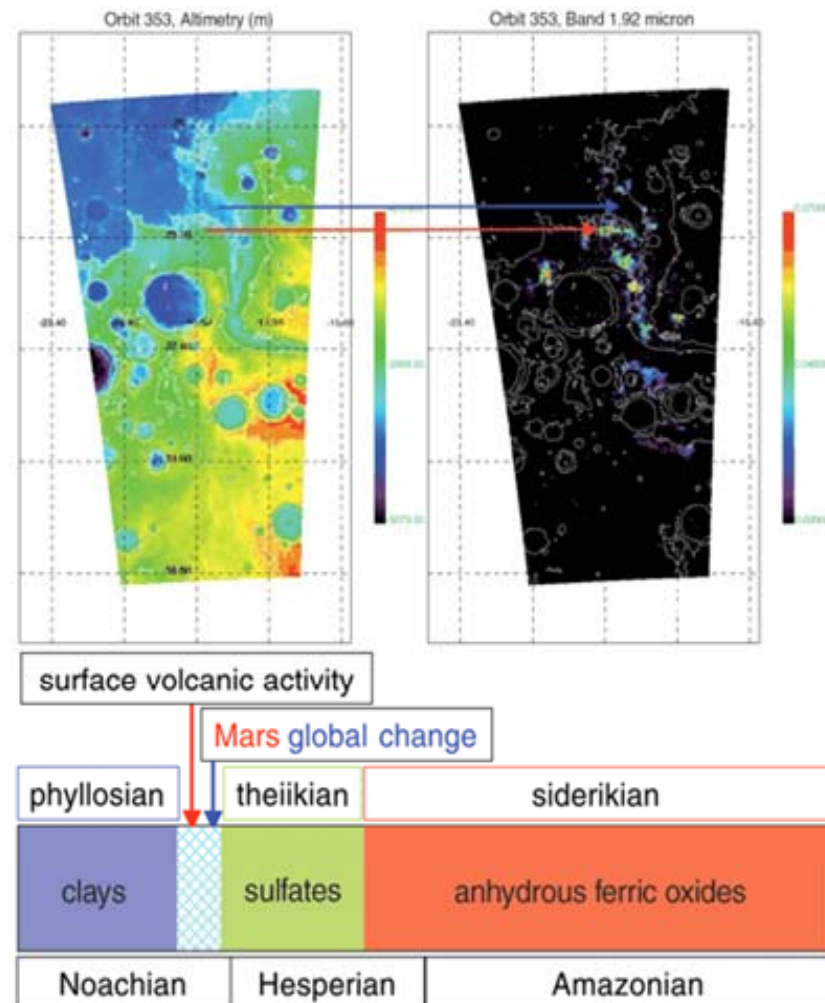
The OMEGA/Mars Express
imaging spectrometer

- Bibring et al. 2006, Science
312, 400 - 404

Recognized mineralogically and
temporally-distinct areas on
Mars

- Phyllosilicates
- Sulfates
- Ferric oxides

Will organic contents be directly
related to mineral surface as on
Earth?



Earth Science & Engineering

Name	Area
Dr Gareth Collins	Impact Cratering
Dr Richard Court	Astrobiology
Dr Matthew Genge	Meteoritics
Prof Sanjeev Gupta	Surface processes
Prof Joanna Morgan	Geophysics
Dr Adrian Muxworthy	Magnetics
Dr Zita Martins	Astrobiology
Prof Mark Rehkamper	Geochemistry
Prof Mark Sephton	Organic Geochemistry



Mars Extracts



Thank you ...