Modern habitability and the possibility of extant life on Mars

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Origin of Life

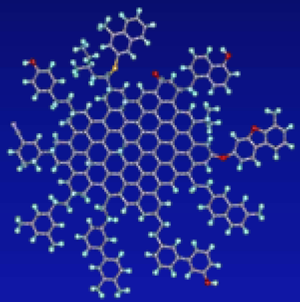
Abiotic synthetic reactions on the early Earth

Organics from space

Prebiotic soup

↓

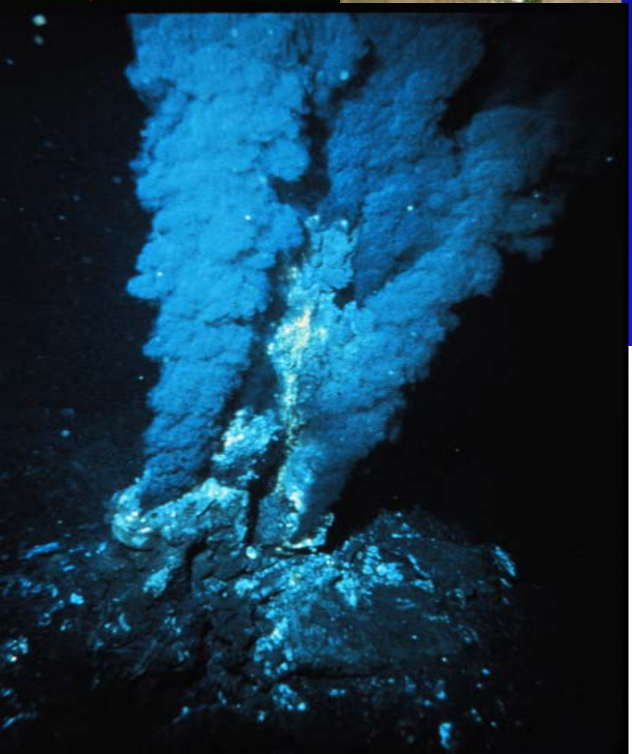
The origin of life



Origin of Life on Earth …..

First evidence for life ~ 3.5 billion years ago;

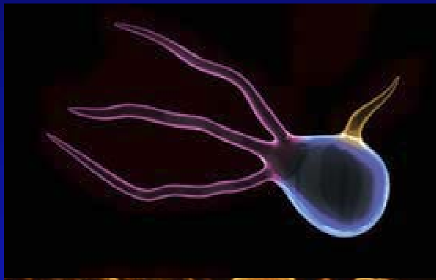
prokaryotic, anaerobic, heterotrophic ?

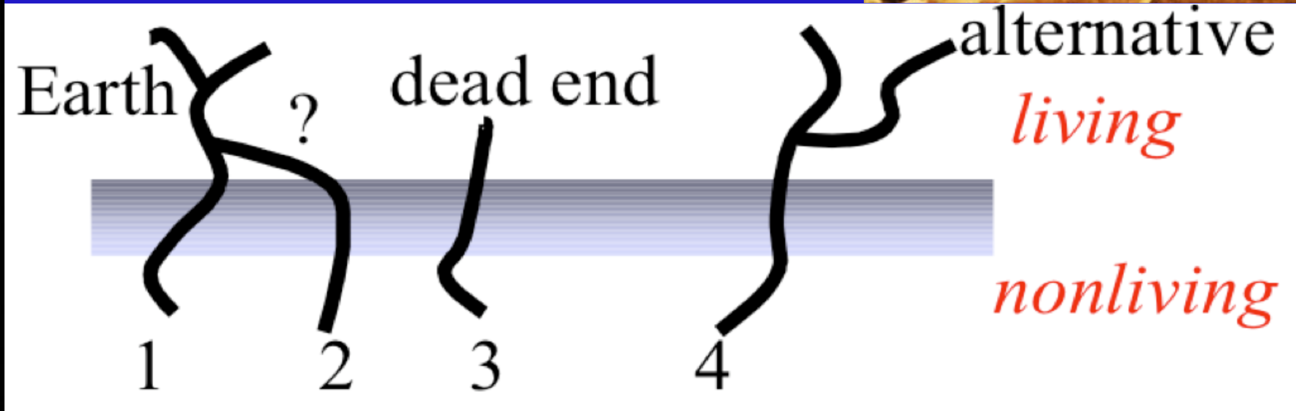


Life needs ….

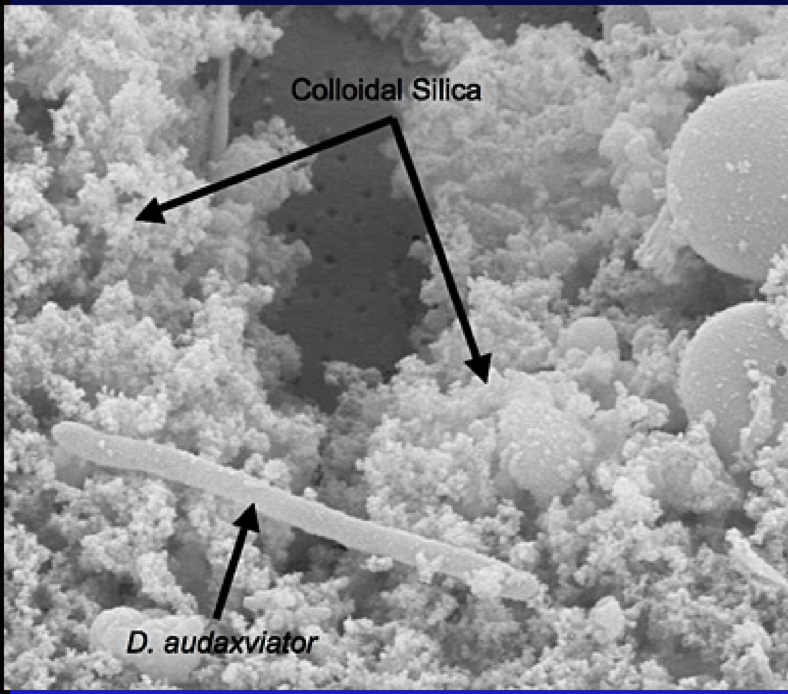
- Water
- Energy
- Organic molecules

→ Information mechanism





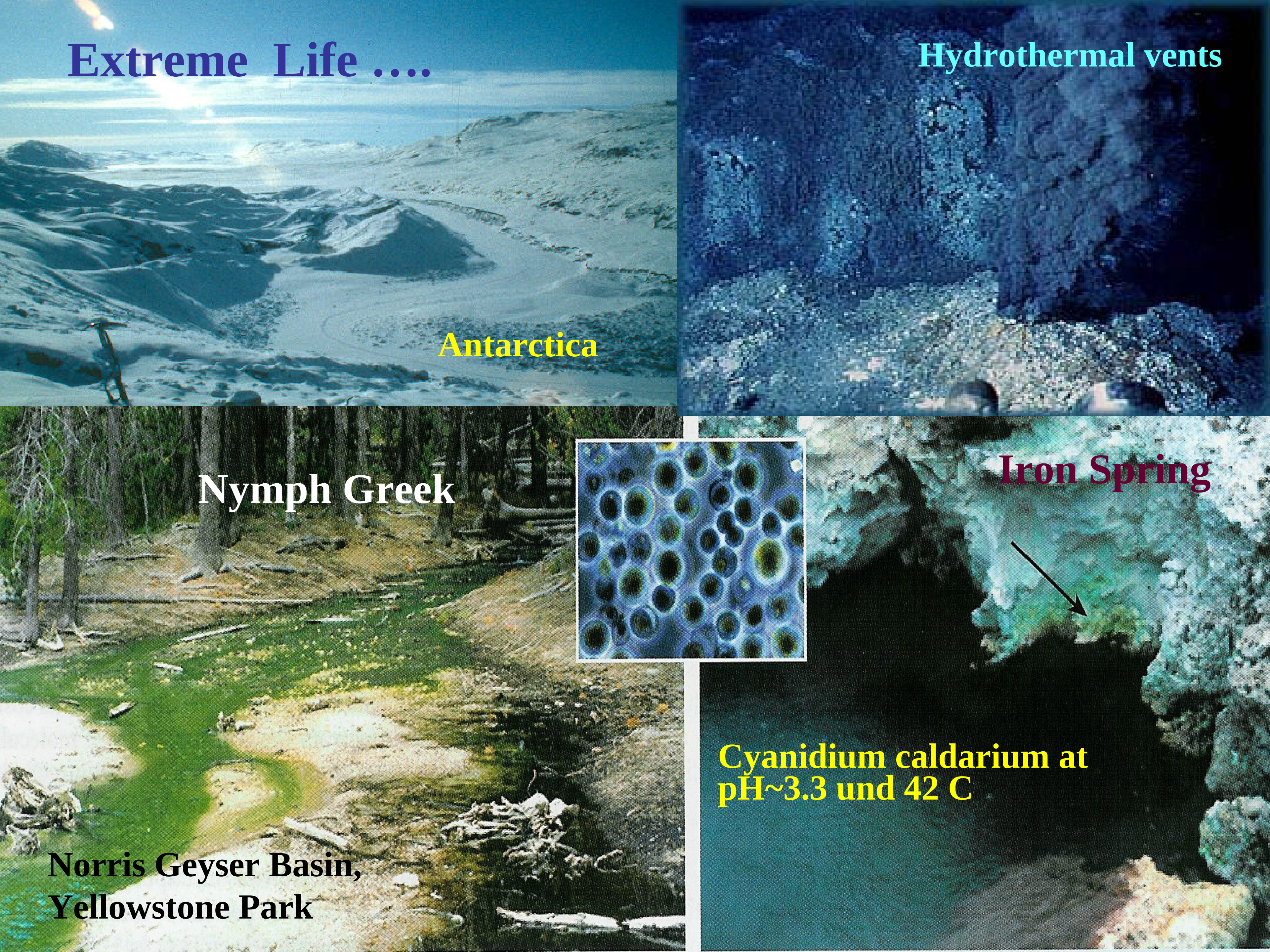
Bacteria rule the Earth



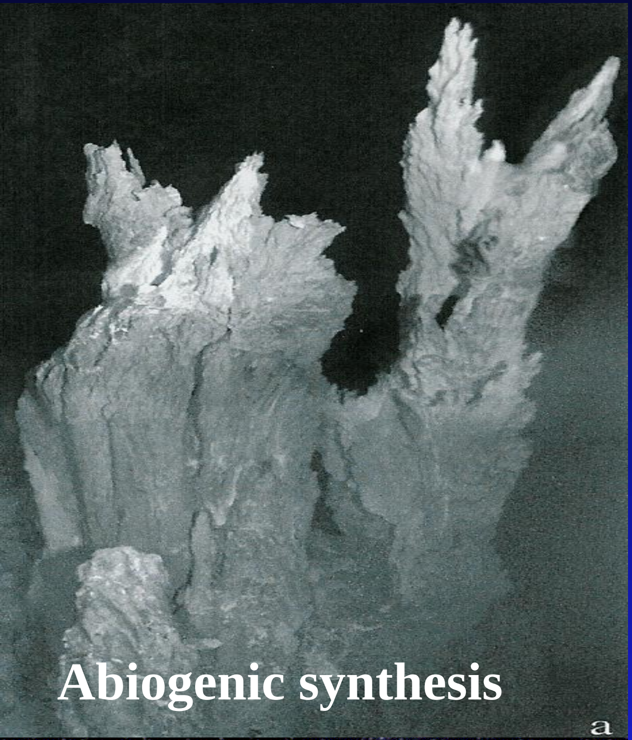
Credit: Tullis Onstott

- **5×10^{30} ?**
- ***92 % of bacteria live underground***
- **Bacteria produce oxygen, fix nitrogen, they decay as pollutants and dissolve rocks**

…. 4000 species in a gram of soil


Extreme Life ….
Hydrothermal vents
Antarctica
Nymph Greek
Iron Spring
Cyanidium caldarium at
pH~3.3 und 42 C
Norris Geyser Basin,
Yellowstone Park

Potential sources of organics on Mars



The direct synthesis of organic compounds and/or the development of life may have taken place on Mars early in its history …

Meteoritic infall should have delivered organic compounds to Mars at a rate of

2.4×10^6 kg yr^{-1} or ~ 0.1 nm

coverage per year (Zent 1994, Flynn 1996)

$CO_2/H_2O/C_xH_y$ + energy → organics

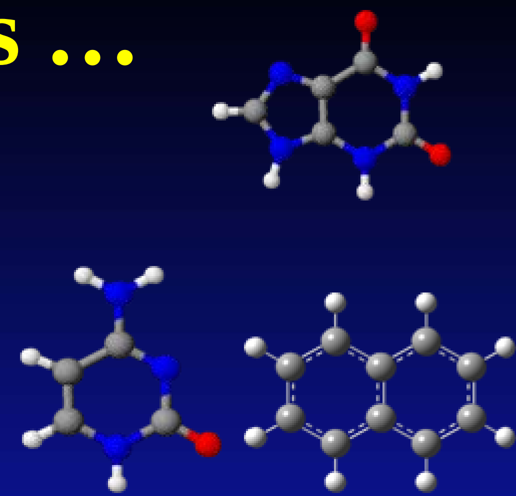
LOCALIZED AND LOW BIOMASS

Martian conditions

UV flux (190-325 nm)	***Flux:*** **~1.4 × 10^{15} photons s^{-1} cm^{-2}** ***Intensity:*** **~37 W m^{-2}**
Ionizing radiation	***Dose:*** **~ 0.2 Gy/year**
Atmospheric composition	**95.3% CO_2; 2.7% N_2;** **1.6% Ar; 0.13% O_2; 0.03% H_2O, CH_4?** **photochemically produced transient species**
Surface temperature	**140 to 300 K; *average*: 210 K**
Oxidants	**H_2O_2 ; γ-Fe_2O_3 ; dry acids from SO_3 ;** **perchlorates ; O_3, O_2, O …**
Dust/atmospheric pressure	**Plasma exposure, winds; 7mbar**

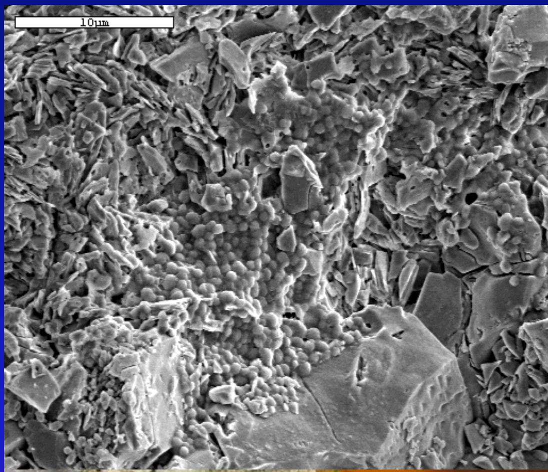
Extant life may be present in ecological niches and in the subsurface

Searching for extant life on Mars …



- ➢ **Growing life**
- ➢ **Dormant life**
- ➢ **Geochemical tracers**

MEPAG Goal 1: Objective B (2010)



- ✓ **Evidence of ongoing metabolism/chemical gradients**
- ✓ **Characterize organic chemistry and bioessential elements**
- ✓ **Seek evidence of organic and mineral structure that may be associated with life**

Martian habitats

Caves: Pit craters in Tharsis region may host cave entrances (Cushing 2011); access to minerals, gases, ices, and any subterranean life: ACCESS Mars (ISU 2009)

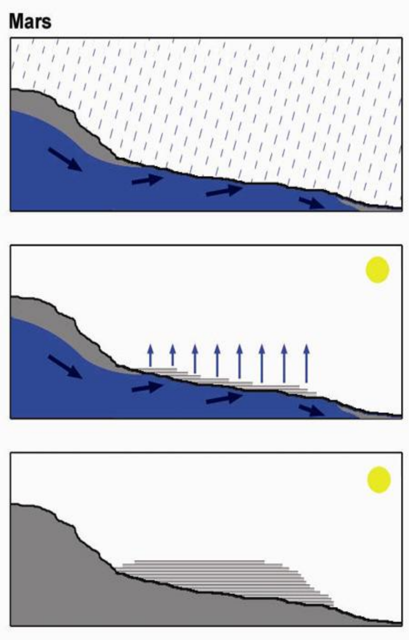
Hydrothermal vents: Deposits of pure silica identified; (geologic activity and water/ice); on Earth hydrothermal deposits team with life

Subsurface: Life has been detected a few km below Earth's surface; bacteria, recently nematodes in 1.3 km depth (Halicephalobus mephisto)

Gaetan Borgonie

Subsurface ice: Polar regions, northern plains, impact basins and rims etc.; microbes may be preserved

Martian habitats

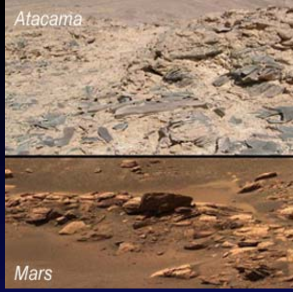


Evaporite deposits: Upwelling groundwater is responsible for the abundant evaporite deposits; Terra Sirenum chloride salt deposits similar to Atacama Desert salt deposits

Antarctic-like paleosols: Microbial life in paleosols with minor amounts of Fe available, argues for potential of microbial life

Surface rocks: Clay-carbonate rocks identified (CRISM/HiRISE) that date back to the Noachian period – conditions in the region could have been suitable for life (analog to Pilbara, Australia)

Defining extant life environments on Mars



- Imaging of Mars habitable regions
- Earth analogue field research in extreme environments
- Laboratory simulations of biota and biomarkers under Mars condition: radiation, temperature, oxidation, racemization…
- Experiments in Low Earth Orbit (ISS and small platforms)
- Supporting surface chemistry and theoretical modelling

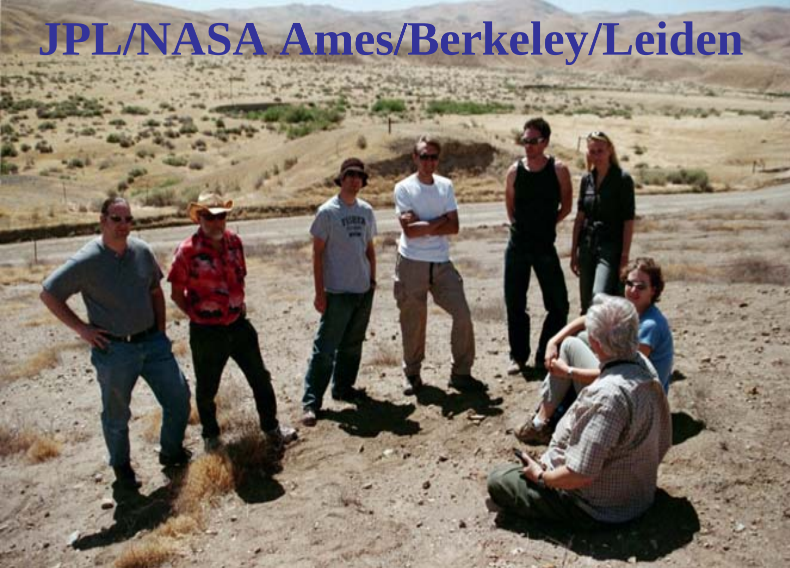
- Optimize payload performance for missions in development
- Optimize extraction procedures, sample handling, sample processing and planetary protection
- Optimize geo-context for biomarker measurements, concerning deposition history, diagenesis and instrument performance
- Adapt extant life search strategies to landing site constraints

JPL/Ames/Leiden crew in the Atacama Desert - Peru 2005

Na^+	163
NO_3^-	64
pH	4
AA	1000 ppb

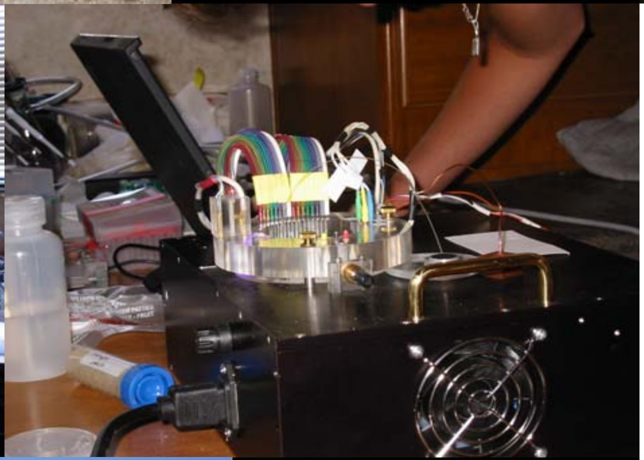
Na^+	6780
NO_3^-	5270
pH	7
AA	50 ppb

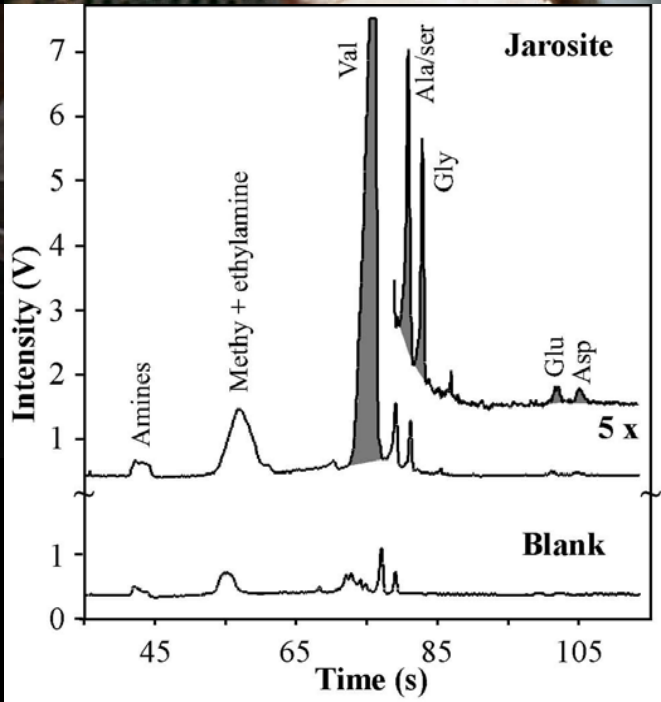
Low abundance of organic material - strong diversity in composition within areas of several m



UREY Field test Panoche Valley May 2004

Skelley et al. 2005





Amino acids in jarosite

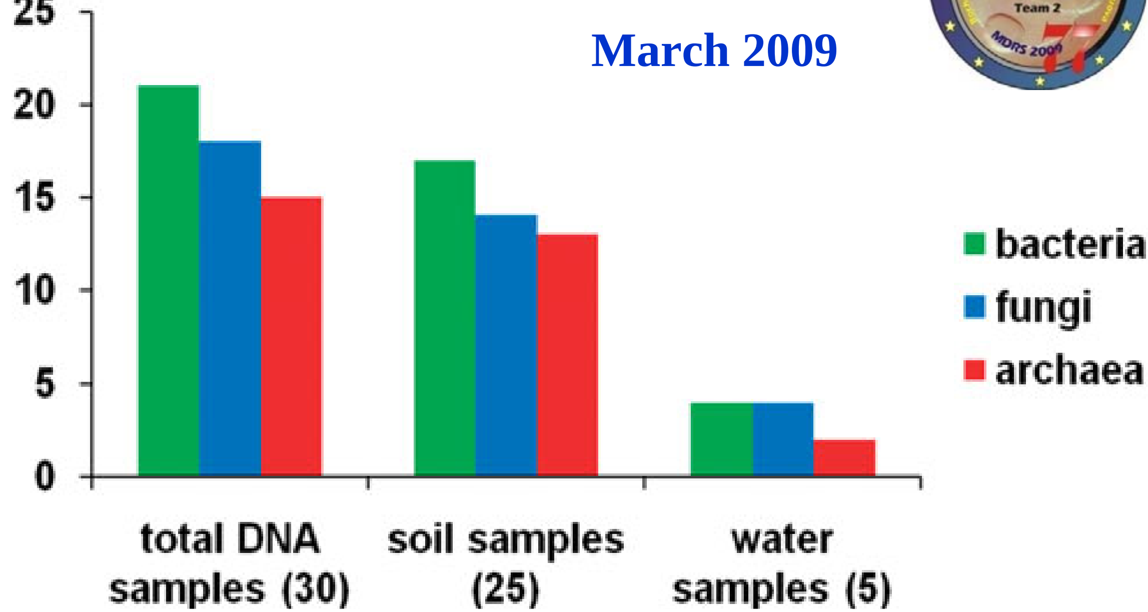
Detection
50 pptr to 100ppb level

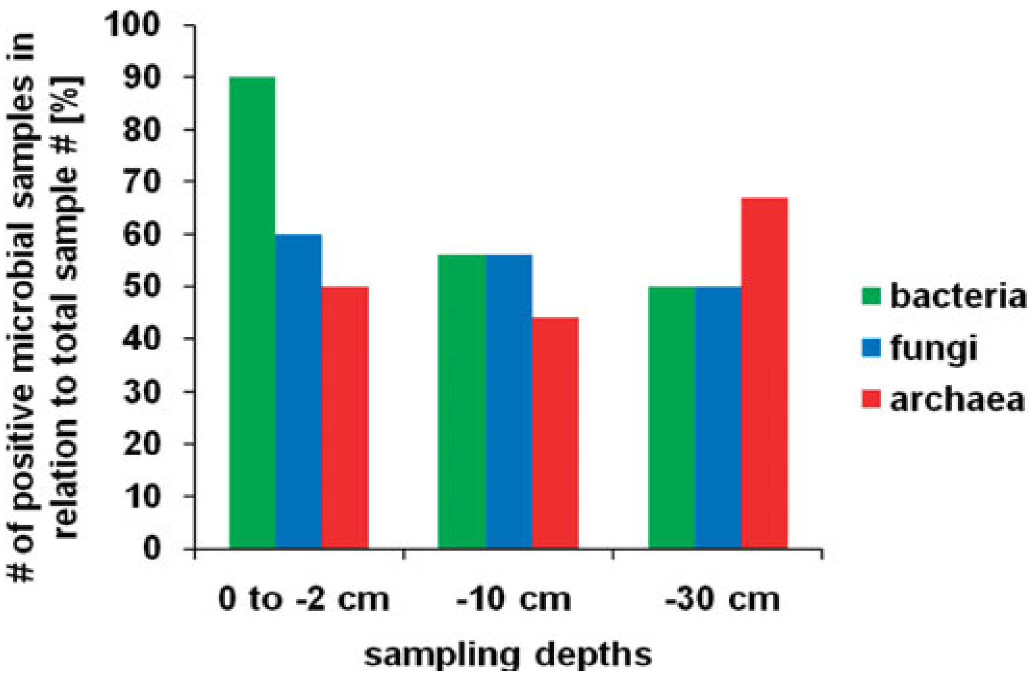
First time on-site DNA analysis by PCR at MDRS

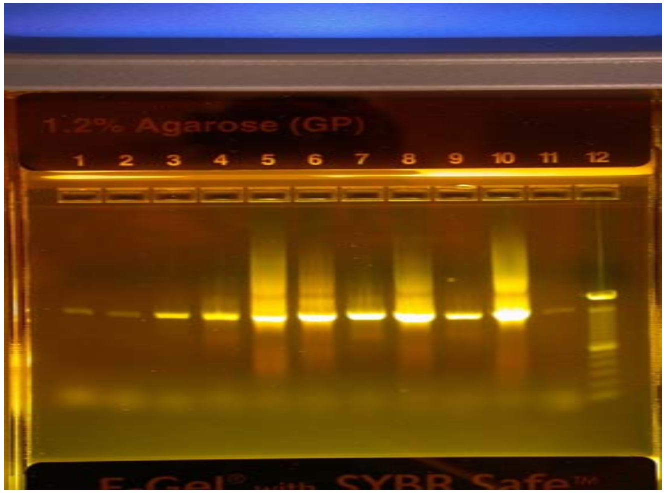
March 2009

Total number of samples positive for bacterial, fungal and/or archaeal DNA

Thiel et al. 2011

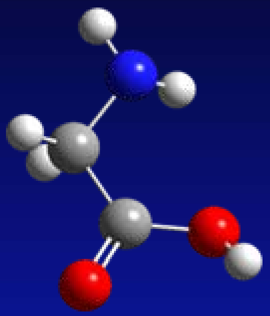






Life and Amino Acids in dry deserts….

Atacama: Biomass 8.5x10^6 – 6x10^7 cells/g (PLFA)
6.3x10^2-5.2x10^3 CFU/g
600 ppm TOC (Lester et al. 2007)



Amino Acid (ppb)	Atacama Peru	Atacama Yungai	Utah Morrison	Utah Mancos	Utah Dakota
Glycine	91	102	92	1324	17390
L-Alanine	283	92	76	1114	32934
L-Glutamic Acid	62	116	194	600	10892
L-Aspartic Acid	35	57	102	220	7775

Peeters et al. 2009, Martins et al. 2011

Mars simulations

How do microbes thrive in a desiccated, cold, salty, hypobaric martian environment and how do they cope with soil oxidation and ionizing radiation ?

Worldwide activities: many species have been tested to survive one or several environmental conditions such as desiccation and UV radiation, low temperature etc. ⟶ There are no simulations that are able to test for all parameters simultaneously !

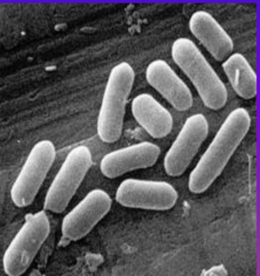
Examples: ***Halobacterium salinarum NRC-1, Halorubrum chaoviator, Chroococcidiopsis sp. 029, Bacillus pumilus, Psychrobacter Cryohalolentis, homogenized bacterial permafrost community, E.coli …..***
(Mancinelli et al. 2004, Cockell et al. 2005, Schuerger et al. 2006, Beaty et al. (2006), Osman et al. 2007, Peeters et al. 2009, Smith et al. 2009, Hansen et al. 2009, Berry et al. 2010)……

Low pressure growth limit

Growth of *Bacillus subtilis* cells was progressively inhibited by lowering of pressure and ceased at 2.5 kPa (Nicholson et al. 2010)

Hypobaria likely species specific; no bacteria has shown replication below 25 mbar, most resistant is *Serratia liquefaciens* (Schuerger et al. 2011)

Active metabolism (methanogenesis) at 400 and 50 mbar of *Methanothermobacter wolfeii, Methanosarcina barkeri and Methanobacterium formicicum* on JSC-1 analog (Kral et al. 2011)



Strong link to Planetary Protection

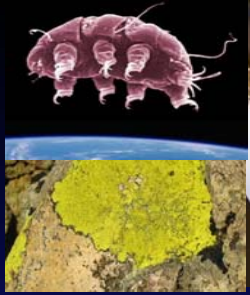
Adaptation for enhanced growth at low pressures possible… ? Punctuated equilibrium ? (Gould 2007)

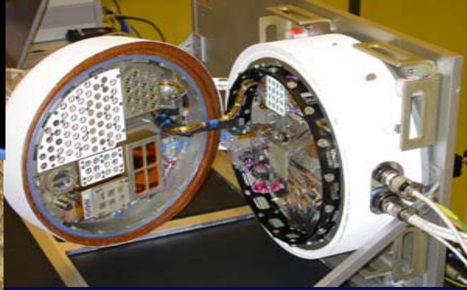
Space Exposure Facilities

Long Duration Exposure Facility (LDEF), ERA/EURECA, BIOPAN/FOTON, EXPOSE-E and EXPOSE-R

Extended space exposure allows us to collect data on multiple samples

Recent Biopan Results





BIOPAN 5/6:

ORGANICS: Investigations of large organic molecules, such as polycyclic aromatic hydrocarbons (PAHs): Minimal destruction (Ehrenfreund et al. 2007)

UVOLUTION: Investigation of half-lives of several amino acids, urea and HCN polymers and the stability of carboxylic acids and carbonates on simulated martian surface: Results differed from ground truth (Guan et al. 2010, Stalport et al. 2010a,b)

MARSTOX: Investigation of protective and/or toxic effects of Mars regolith simulant on bacterial spores in outer space or simulated Mars environment: High lethality of solar extraterrestrial UV radiation (Rettberg et al. 2004)

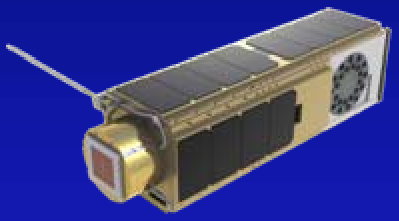
LICHENS: Experimental test of Lithopanspermia hypothesis with lichens on natural rock habitat: High survival (Sancho et al. 2007, De la Torre et al. 2010)

TARDIS: Tardigrades survive exposure to space in LEO (Jönsson et al. 2008)

O/OREOS
(Organism/Organics Exposure to Orbital Stresses)

Dual payload:

Monitor how exposure to space radiation and weightlessness changes biology and organic molecules

Goal 1: Measure the survival, growth and metabolism of two different microorganisms using in-situ colorimetry

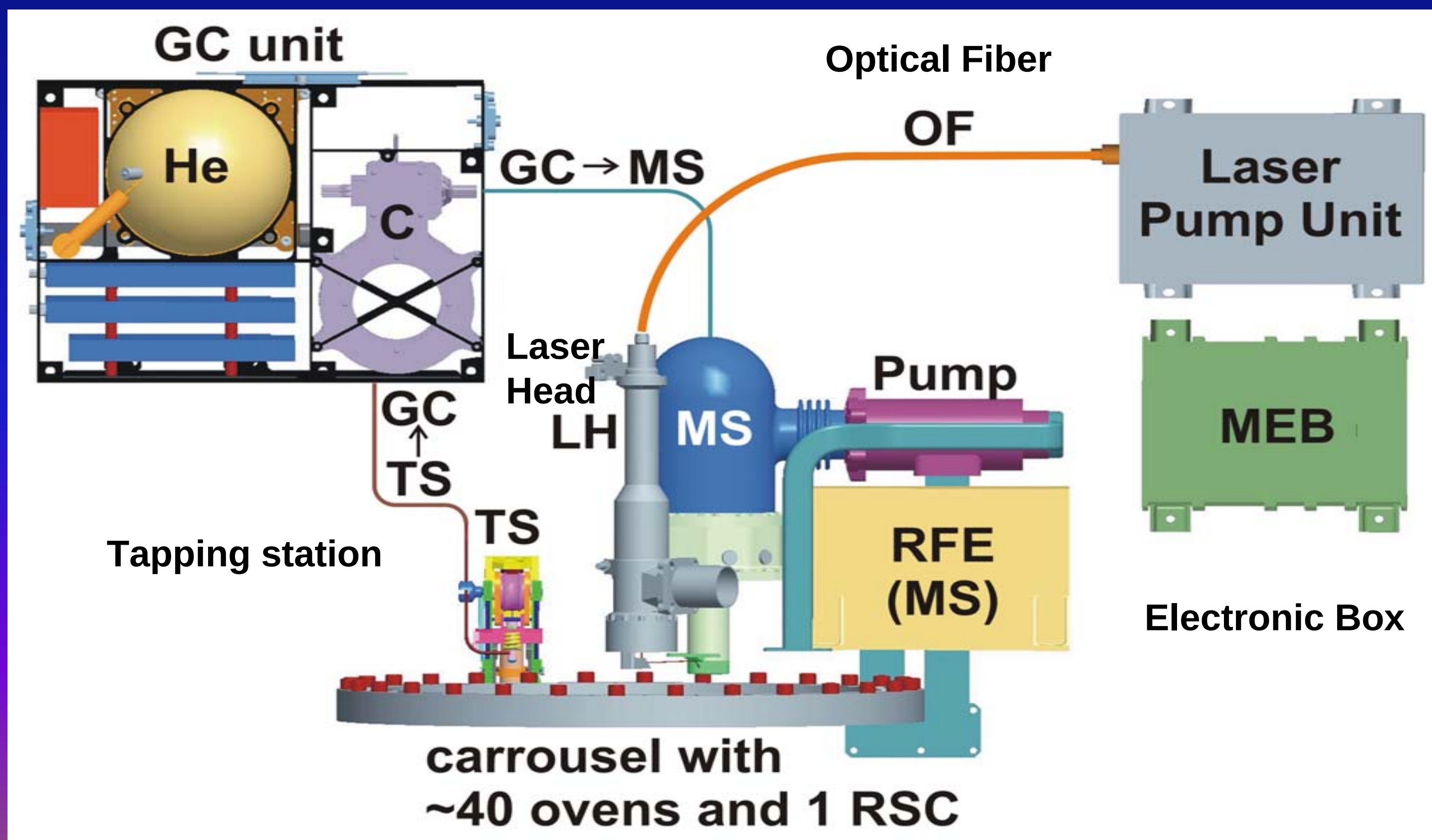
Goal 2: Measure the changes induced in organic molecules and biomarkers using ultraviolet and visible spectroscopy

MOMA: Mars Organic Molecule Analyzer

MOMA is a joint European and US instrument that combines gas chromatography and laser desorption to an ion trap mass spectrometer.

GC-MS: detection of volatile molecules (atmosphere/sediments)
LDMS: detection of less volatile molecules

Exomars 2018



Life Marker Chip

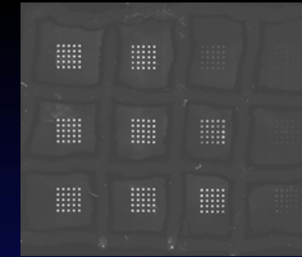


Fig 5b. Example fluorescent LMC microarray assay for benzo[a]pyrene (B[a]P); 1.6 x 1.6 mm^2, 25 spot homogeneous arrays – used in development – varying intensity between arrays due to detection of different concentration of B[a]P

Antibody micro-array technology

Antibodies immobilized to a surface act as receptors to capture specific organics

- ✓ Extinct Life – preservation / diagenetic products of ancient life (geo-molecules)
- ✓ Extant Life – short lived products of present life (bio-molecules)
- ✓ Abiotic organics – examples of meteoritic in-fall, preservation / diagenetic product of early Mars organics inventory

Exomars 2018

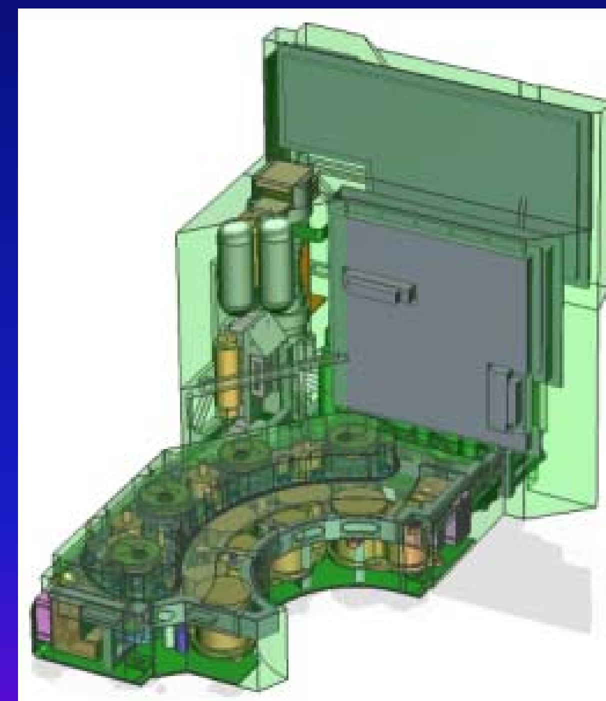


Fig 4b. Design early June 2011

Life Marker Chip Flight Model design (June 2011)

List of possible LMC targets

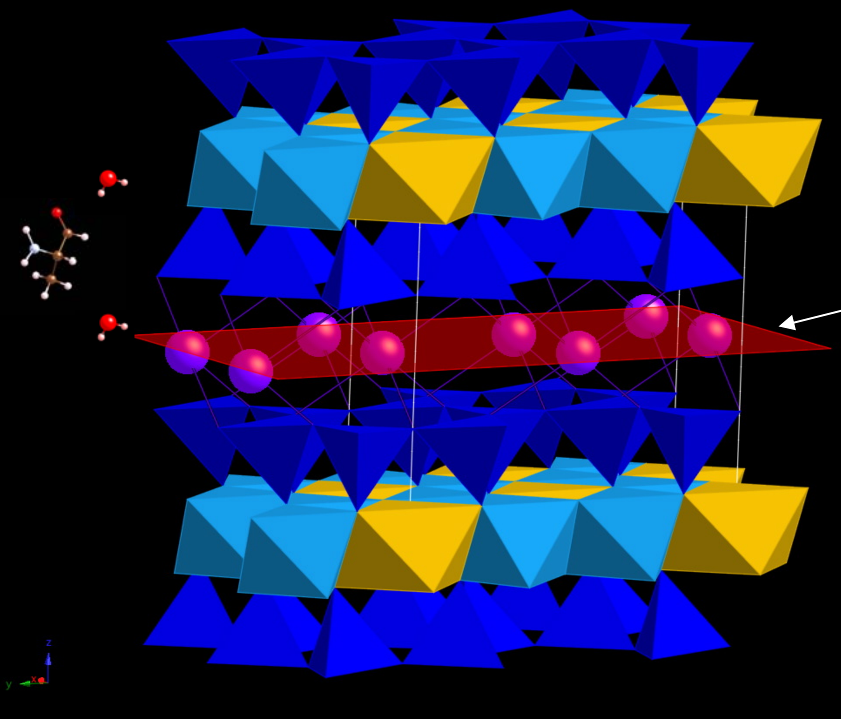
Extant		Extant		Meteoritic	
1	ATP	26	Melanoidins	47	Napthalene
2	Phosphoenolpyruvate	27	Sediment/cell extracts: 1. Acid mine drainage	48	Coronene
3	Acetyl phosphate	28	Sediment/cell extracts: 2. Methanogens	49	Pyrene
4	cyclic AMP	29	Sediment/cell extracts: 3. Cyanobacteria	50	1,3 Dimethylbenzene
5	Generic pyrimidine base	30	Sediment/cell extracts: 4. Mars Energy Users	51	1,4 Dimethylbenzene
6	Generic purine base	31	Sediment/cell extracts: 5. Extract/abiotic mix	45	Generic amino acid
7	DNA			52	isovaline
8	Nicotinamide (generic NAD, NADP)	Extinct		53	a-aminoisobutyric acid
9	Flavin (isoalloxazine ring)	32	Generic isoprenoid	54	Generic aromatic carboxylic acid
10	Fe-S centres	33	Pristane	55	Experimental abiotic
11	Quinones	18	Phytane		
12	Generic carotenoid	34	B-carotane	Contaminants	
13	Phycocyanin	35	Tetramethyl benzenes	56	Generic fungal
14	Thiol Esters	36	Tetramethyl cyclohexanes	20	Teichoic Acid
15	Generic porphyrin	37	Squalane	21	LPS
16	Chaperons	38	Generic ABC terpane	57	Staphylococcus
17	ATP Synthase	39	Generic hopane	58	Streptococcus
18	Phytane	40	Gammacerane	59	Bacillus
19	Fatty acids (1 or 2)	41	Generic diasterane	60	Micrococcus
20	Teichoic Acid	42	Generic sterane	61	Pseudomonas
21	LPS	43	Generic porphyrin (ancient)	62	Dipicolinic acid
22	Ectoine	44	Generic Straight-chain	63	Hydrazine (or equivalent fuel marker)
23	Trehalose	19a,b	2 individual Fatty Acids		
24	Squalene	45	Generic amino acid		
25	Diploptene	46	Quaternary carbon alkane		

Parnell et al. 2007

Expandable smectite minerals

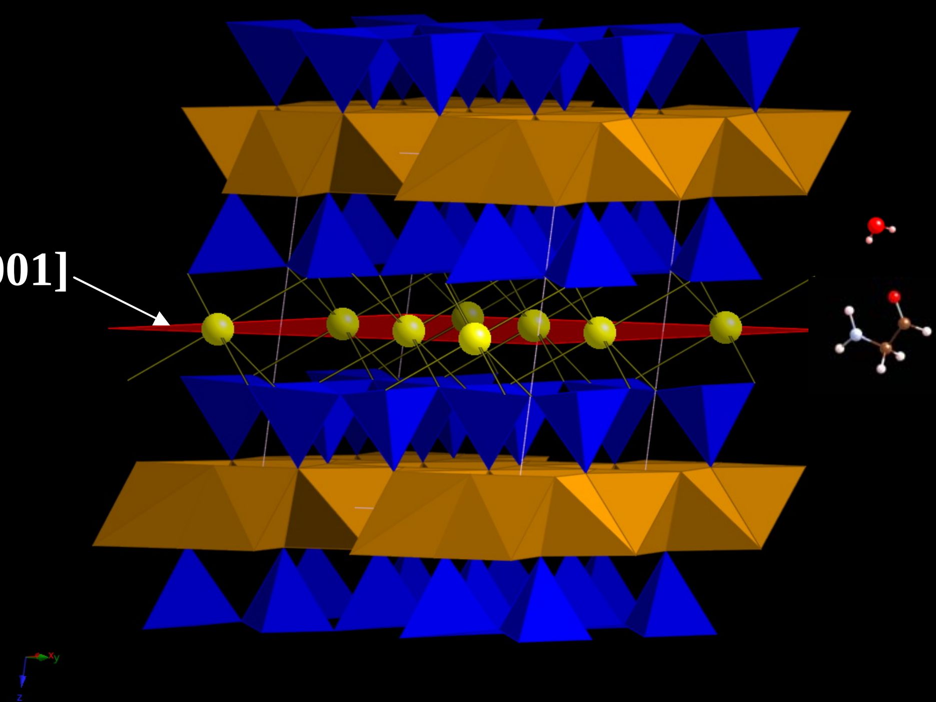
Clay mineral group- interlayer spacing (001) expands with the absorption of water or organic molecules between the 001 layers

Montmorillonite



[001]

Nontronite

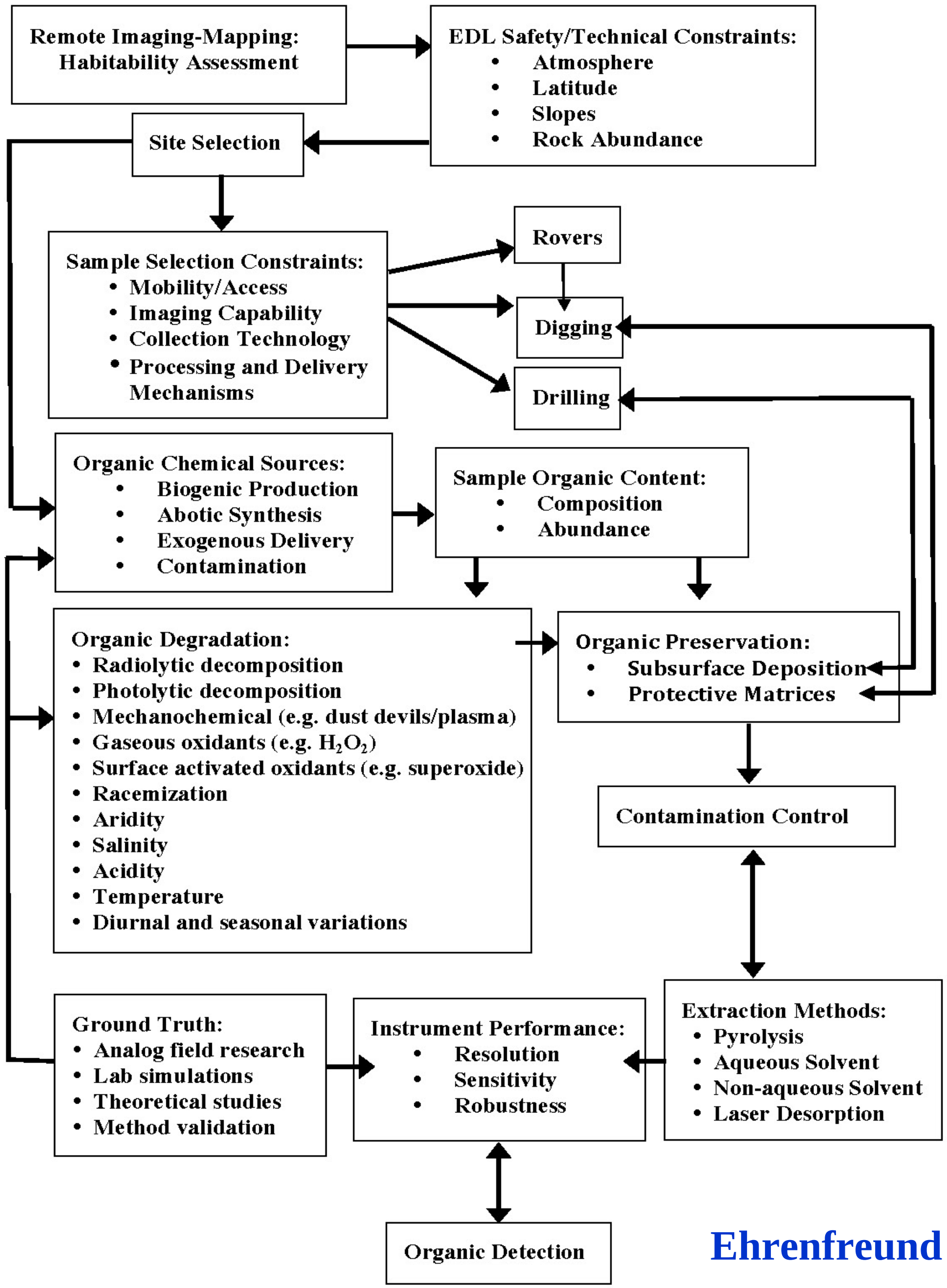


$(K,Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 * nH_2O$

$Na_{0.3}Fe_2(Si,Al)_4O_{10}(OH)_2 * nH_2O$

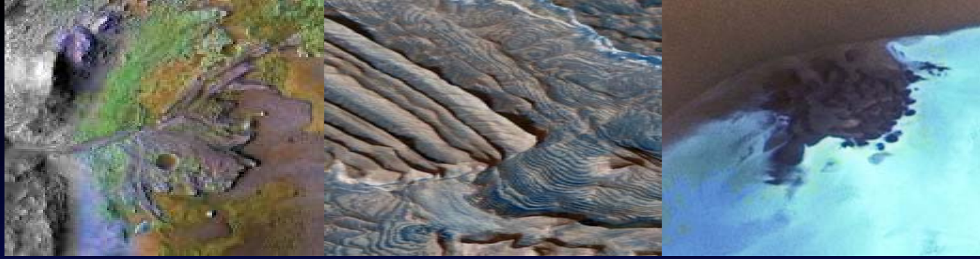
Monoclinic C 2/m

Critical aspects and constraints for organic and life detection on Mars



Ehrenfreund et al. 2011

Recommendations



- **Search for extant life should be a targeted international effort**
- **Optimize existing mission payloads for extant life search**
- **Develop new mission concepts and instrument technology**
- **Discovery-type missions, dedicated, focused, with specific instrumenation to identify extant life (Davila et al. 2010)**
- **Create long-term program in synergy with Earth Science to exploit analogue sites in preparation for MSR**