FINDINGS

OF THE

ASTROBIOLOGY FIELD LAB SCIENCE STEERING GROUP (AFLSSG)

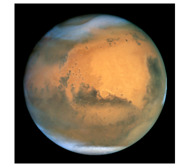
Andrew Steele and David Beaty (co-chairs), on behalf of the AFL SSG

April 22, 2004

Notes:

- *This is the presentation version of the white paper "Astrobiology Field Lab Science Steering Group Final Report". If there are any discrepancies between the two documents, the white paper should be judged to be superior.*
- *This document has been approved by JPL Document Review for public release (Ref. # CL-03-3456).*

AFL SSG Membership



Science Members	
Andrew Steele	Carnegie Institute of Washington
Bob Anderson	University of Colorado
David Blake	Ames Research Center
Hunter Waite	University of Michigan
Jack Mustard	Brown University
Jan Amend	Washington University
Jan Toporski	Carnegie Institute of Washington
Janok Bhattacharya	Univ. of Texas, Dallas
Jennifer Biddle	Penn State
John Lindsay	JSC/LPI
Liane Benning	Leeds University
Luther Beegle	JPL
Pan Conrad	JPL
Rocco Mancinelli	SETI/ARC
Sherry Cady	Portland State

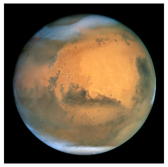
Engineering Members	
Greg Mungas	JPL
Knut Oxnevad	JPL
Roger Diehl	JPL

Program	
David Beaty	Program Office--JPL
Marguerite Syvertson	Program Office--JPL
Jim Garvin	Program Office--HQ

AFL subcommittees

- **Sedimentary sub-team**. Pan Conrad, leader.
- **Hydrothermal sub-team**. David Blake, leader
- **Ice sub-team**. Luther Beegle, leader
- **Sample prep sub-team**. Jan Toporski, leader
- **Definitions sub-team**. Pan Conrad, leader
- **Water sub-team**. Jan Amend, leader

Key Definitions



Habitability

- **A general term referring to the potential of an environment (past or present) to support life of any kind.** In the context of planetary exploration, two further concepts are important: Indigenous habitability is the potential of a planetary environment to support life that originated on that planet, and exogenous habitability is the potential of a planetary environment to support life that originated on another planet.

Habitat

- An environment (defined in time and space) that is or was occupied by life.

Biosignature

- **Any phenomenon produced by life (either modern or ancient).** Two sub-definitions: Definitive Biosignature: A phenomenon produced exclusively by life. Due to its unique biogenic characteristics, a definitive biosignature can be interpreted without question as having been produced by life. Potential Biosignature: A phenomenon that may have been produced by life, but for which alternate abiotic origins may also be possible.

Life detection

- The process of investigating the presence of biosignatures (including potential biosignatures). Life detection can apply to either past or present life.

Assumptions for this Study

1. Assume AFL will need to be ready to launch as early as the 2013 opportunity
2. Assume all missions scheduled before 2013 are successful.
   - The MSL entry-descent-landing (EDL) system has successfully been demonstrated, and the engineering heritage can be used on AFL.
3. Assume the primary goal of AFL is to make a major advance in astrobiology.
4. Assume a cost cap no more than that of GB-MSR.

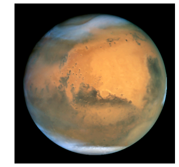
AFL History

The Astrobiology Field Lab was created as a concept by the Mars Science Program Synthesis Group (MSPSG) during their Pathways planning discussions in 2002-03.

From MSPSG (2003)

Astrobiology Field Laboratory. "This mission would land on and explore a site thought to be a habitat. Examples of such sites are an active or extinct hydrothermal deposit or a site confirmed by MSL to be of high astrobiological interest, such as a lake or marine deposits or a specific polar site. The investigations would be designed to explore the site and to search for evidence of past or present life. The mission will require a rover with "go to" capability to gather "fresh" samples for a variety of detailed *in situ* analyses appropriate to the site. *In situ* life detection would be required in many cases." (emphasis added)

However, MSPSG deferred to a successor team the definition of AFL's specific scientific and engineering constraints, possibilities, and priorities.



Assertion

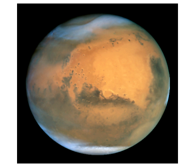
1. Predicted future state. By 2013 the habitability of Mars, organized by environment, and applicable to both the present and the geologic past, will be partially understood. The Mars Program will have to choose:
   - Select one environment with high habitability potential, and test for habitation.
   - Continue to refine the habitability models to allow better targeting of a subsequent habitation mission.

STATE OF FUTURE KNOWLEDGE	Ancient Life	Modern Life
Models of habitability require further definition or confirmation before a test for habitation should be attempted	***LESS LIKELY***	***MORE LIKELY***
At least one environment with high habitability and preservation potential has been identified, and a habitation test could be justified.	***MORE LIKELY?***	***LESS LIKELY***

***QUESTION**: Will AFL be effective in all of these scenarios?*

Possible Relationship of AFL to Long-Range A/B Strategy

Habitability vs. Habitation



- Two primary scientific objectives of the Mars Exploration Program include (MEPAG, 2004):
  - Determine indigenous habitability (past and/or present).
  - As appropriate, assess indigenous habitation.

FINDING: Organisms and their environment together constitute a system, and each produces an effect on the other. Some kinds of investigations of this system can simultaneously provide information about both.

Find an environment (past or present) for which data show habitability potential → ?

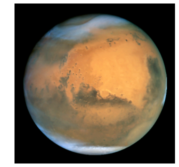
MGS ODY MEX MER PHX ExoMars MSL

Investigate whether the habitable environment (past or present) is or was inhabited.

AFL?

← *It is possible to configure missions that do both*

MEPAG (2004), Scientific Goals, Objectives, Investigations, and Priorities: 2003. Unpublished document, http://mepag.jpl.nasa.gov/reports/index.html.



Extant vs. Extinct Life

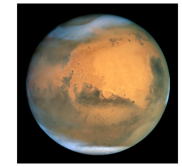
- Traditional Mars mission planning has involved choosing scientific objectives and investigations for EITHER extinct OR extant life. (PP policy is structured the same way.)
- However, some kinds of scientific investigations will respond to both without providing information as to whether the life form is extant or extinct.

FINDING: It is both possible and reasonable to do life detection first, then distinguish whether it is extinct or extant later.

***EXAMPLE:* C isotope ratios, which can be a sign of either extinct or extant life.**

Possible Relationship of AFL to Long-Range A/B Strategy

Life Detection Process



The process of life detection on Mars involves two sequential steps:

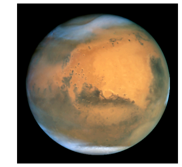
- Proposing that a set of phenomenon are, or could be, biosignatures. This will constitute a working hypothesis that life is or was present. Such hypotheses can be made relatively easily.
- Establishing that a definitive biosignature is present requires extensive effort and careful planning (c.f. Allan Hills experience).

LIFE DETECTION INVESTIGATIONS

	Investigation of potential biosignatures	→	Confirmation that a definitive biosignature is present
INFERENCE:	***Life may exist***		***Life does exist***

FINDING: AFL can reasonably begin the process of life detection by characterizing potential biosignatures.

AFL Scientific Objectives



FINDING: The following overall scientific objective is both achievable by AFL, and is a significant extension of currently planned missions:

For at least one martian environment of high habitability potential, quantitatively investigate the geological and geochemical context, the presence of the chemical precursors of life, and the preservation potential for biosignatures, and begin the process of life detection.

Start life detection through measurement of potential biosignatures

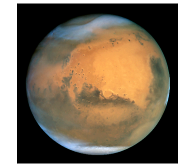
Our knowledge of habitability will not be complete by 2013—plan for more work.

Will allow planetary scale life-related predictions.

Implies a response to prior discoveries

Understanding preservation is key to life detection—also critical feedforward.

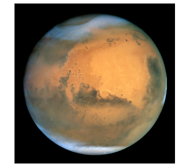
AFL Scientific Objectives



Further Amplification of Objectives

1. Within the region of martian surface operations, identify and classify martian environments (past or present) with different habitability potential, and characterize their geologic context. Quantitatively assess habitability potential by
   - Measuring isotopic, chemical, mineralogical, and structural characteristics of samples, including the distribution and structure of C compounds.
   - Assessing biologically available sources of energy, including chemical and thermal equilibria/disequilibria.
   - Determine the role of water (past or present) in the geological processes at the landing site
2. Investigate the factors that have affected the preservation of potential biosignatures (past or present) on Mars
3. Investigate the possibility of prebiotic chemistry on Mars (including non-carbon chemistry)
4. Document any anomalous features that can be hypothesized as possible biosignatures
   - This will constitute a set of working hypotheses, which will need refinement (perhaps by experimentation and by observing Earth systems) and further testing on Mars.

Preservation Potential



FINDING: An understanding of biosignature preservation, guided by data from AFL, will be critical to long-term martian life detection strategy.

Long-range A/B exploration of Mars will require an understanding of the preservation potential of biosignatures. This is an important part of the scientific logic of going from possible biosignature to confirmed biosignature.

Lessons from Earth

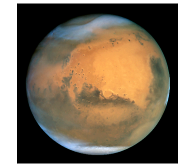
- Life processes produce a range of biosignatures, and geological processes progressively destroy them.
- Understanding the potential for preservation is a key component of biosignature detection and interpretation.

Application to Mars

- We don't know the biosignatures of martian life forms (if they exist).
- However, with appropriate data, it should be possible to postulate a preservation model relating biosignatures as we understand them on Earth to various martian geologic environments. This model will likely have important predictive value in guiding future search strategy.

AFL Science Objectives

Prebiotic Chemistry



Investigating early planetary surface chemical processes on Mars is important to understanding two possible program-level exploration outcomes:

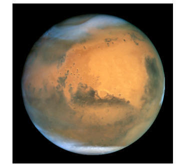
- If life is not present at a specific test site, can we predict that it might exist elsewhere?
- If life never formed on Mars, WHY?

Specific goals, issues

- – Understand planetary evolution through elucidating organic chemical input i.e. meteoritic versus abiogenic synthesis reactions.
- – Mars may give clues to the prebiotic evolution of the Earth. On Earth an unaltered geologic record of early planetary evolution (4.5-3.5 Ga) does not exist.
- – Allow conjecture as to why life did not start on Mars (should that be the outcome). Were the chemical processes and building blocks present there as on Earth?

FINDING: This science objective has high program value.

AFL Mission Concepts



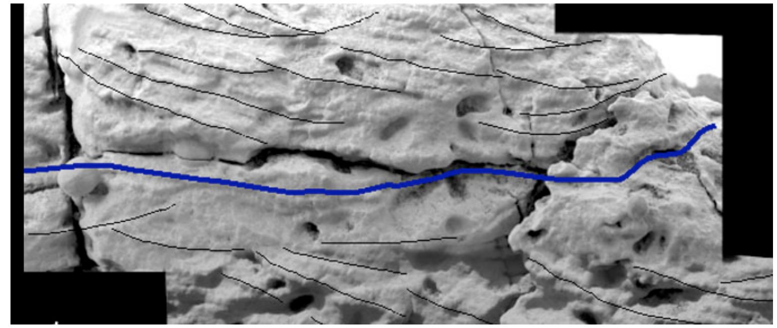
FINDING: There are four obvious general types of site in which the overall scientific goal of AFL (major advance in A/B) can be pursued:

- The (aqueous) sedimentary record.
- Fossil (inactive) hydrothermal systems
- Sites with ice
- Sites where it may be possible to sample liquid water

We do not have enough information as of this writing to know how these four options would be prioritized by a future SDT. Future discoveries could have a major effect on planning.

AFL Mission Concepts

Sedimentary AFL

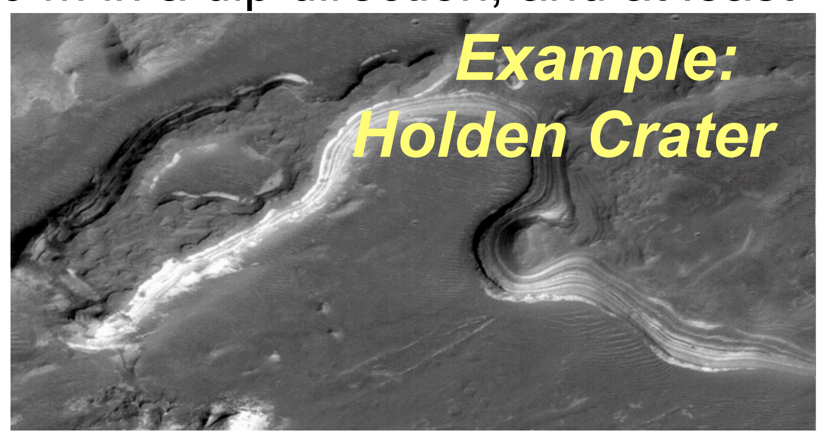


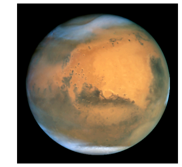
Science Theme

Assess past martian astrobiology by studying the stratigraphic record

Proposed science strategies

- Land in a region with multiple outcrops of layered sedimentary rocks. Through remote sensing means (at several spatial scales), acquire information about several outcrops, at scales sufficient to resolve individual layers.
- Then visit at least one 3-D outcrop of layered sedimentary rocks.
- Measure the variation in chemistry and mineralogy of the strata in the outcrop over a distance of at least 10 m in a dip direction, and at least 100 m in a strike direction. This will require subsurface penetration.
- Acquire subsurface samples from a depth at least great enough to get below the level of oxidation. In horizontal areas this may mean 1m.

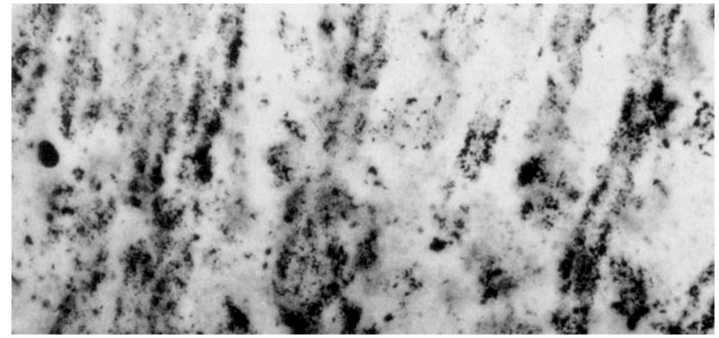




Hydrothermal AFL

Science Theme

Assess past martian astrobiology in an inactive hydrothermal system



microbes preserved in a terrestrial hot spring deposit (Paleozoic, Australia)

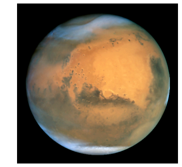
Possible Landing Site Geologic Setting

- Igneous-driven convection systems.
- Impact-generated h-t zones
- “Serpentinizing terranes”—regional chemical reactions
- Regional areas Meridiani w. potential h-t minerals
- Sub-ice volcanism type areas.

Proposed science strategies

- Through studies of geologic samples (mineralogy, texture, geochemistry), document the activity of volatiles (esp. water), identify organic compounds, and characterize a suite of potential biosignatures that include redox couples and geochemical equilibria, (bio)minerals, morphological fossil-like objects and layered deposits, and the isotopes of elements utilized by life.

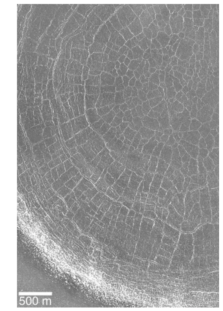
NOTE: Exploration of an active h-t vent would be covered under our Liquid Water AFL scenario.



Subsurface Ice AFL

Science Theme

Determine the potential for extant life at a site where H_2O is present.



Northern Plains (70°N)

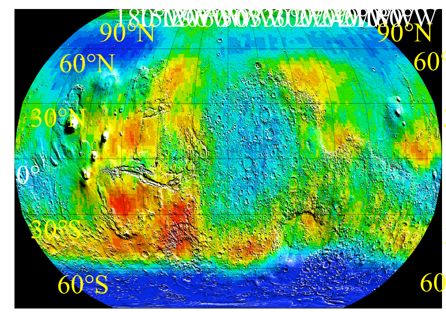
Possible Landing Sites and Mobility Requirements

Sites where “go-to” mobility is necessary include:

- Northern Polar Layered Deposits
- Site of recent liquid water (i.e. sub-ice volcanism)

Sites where “go-to” mobility and a trade between horizontal access to more vertical access would be desirable.

- Permafrost region in response to Phoenix discovery

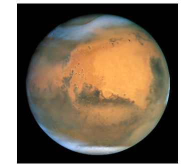


Proposed science strategies

- Determine if liquid water exists in a sample to determine if extant life could be present.
- Acquire and analyze ice-bearing core to identify volatiles and highly complex organic compounds (amino acids, lipids, proteins etc.).
- Characterize physical parameters such as Redox potential, pH, etc. and determine potential chemical disequilibria.
- For the northern polar layered deposits, examine the strata of layered terrain to determine chemistry and mineralogy in differing layers.

AFL Mission Concepts

Polar Icecap AFL

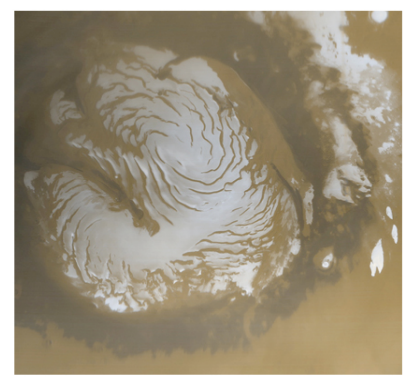


Science Theme

Asses past (and possibly present) Martian astrobiology by studying the northern polar cap.

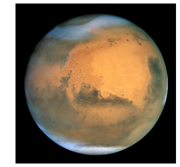
Proposed science strategies and Mission requirements

- Northern polar cap requires little (~1 km) or no horizontal mobility, but potentially large vertical mobility. By accessing vertical profiles a determination of the history of the Martian polar caps and atmosphere can be determined.
- Determine the concentration of organic compounds including amino acids, carboxylic acids, sugars, and PAHs. Sample processing requires separating ice from interesting constituents (Aeolian deposited dust and molecules, meteoritic in fall, etc.) as well as potentially concentrating those components.
- Determine the other chemical properties of the polar ice by measuring concentrations of major ions and redox sensitive aqueous compounds including O_2, Fe_2^+, HCO_3^-, NO_3^-, H_2S, NH_4^+etc.
- Determine CO_2 and H_2O cycles both daily and over a Martian year to better understand the nature of the polar caps as well as Martian atmospheric dynamics. This can potentially determine if a biosphere is in direct contact with the Martian surface.



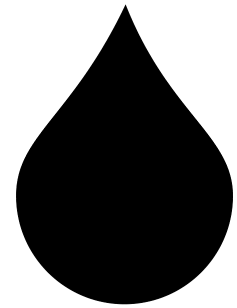
AFL Mission Concepts

Liquid Water AFL



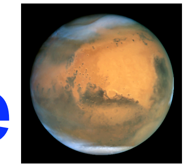
<u>*Science Theme*</u>

Assess Martian astrobiology by studying liquid water in the shallow subsurface.



<u>*Proposed science strategies*</u>

- Drill, core, or otherwise obtain liquid water sample.
- Measure pH, temperature, conductivity, and concentrations of major ions and redox sensitive aqueous compounds, including O_2, H_2, HCO_3^-, NO_3^-, Fe^{2+}, SO_4^{2-}, H_2S, NH_4^+ *(e.g., microelectrodes, micromanipulators).*
- Determine presence (if possible, concentrations) of DOC and aqueous organic monomers, including carboxylic acids, amino acids, sugars, hydrocarbons and/or corresponding functional groups *(e.g., liquid and gas chromatography, IR).*
- Determine presence (if possible, sequence or composition) of aqueous and particulate organic polymers, including proteins, lipids, nucleic acids, saccharides.
- Attempt to visualize and enumerate variably stained microbial cells in suspension or on particulate matter *(e.g., light or scanning electron microscopy, microspectroscopy, fluorescent nanoparticulate tagging)*.
- Consider culturing on 1-3 samples using ~10-100 pre-designed growth media at several different temperatures *(microfluidics, microculturing, "lab-on-a-chip")*.

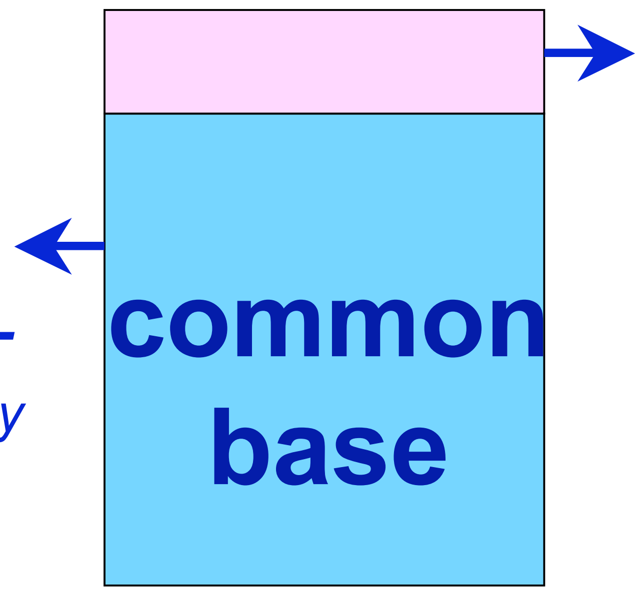


Concept of AFL Common Base

FINDING: As shown on the previous slides, there are multiple possible variations on the AFL theme. Different scientists see these variations in different context, and with different systems of priority. However, it is possible to define an invariant base which is common to most versions, along with a discovery-responsive and competition-responsive cap.

Basic system required for all versions of AFL

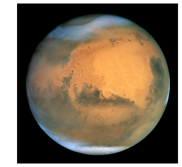
- *Required technology must be supported for the long haul.*



Theme-specific instruments and/or engineering

- *Multiple alternative technologies must be supported up to pre-defined decision points.*

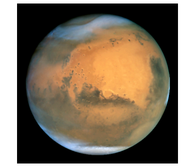
Payload Strategy



The payload of AFL should accomplish four basic functions:

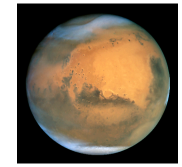
Acquire the right samples	• *Location with high general habitability potential* • *Use understanding of preservation potential.* • *High ability for scientific sample selection* • *Capable sample acquisition system*
Know the context	• *Setting, mineralogy, chemistry, relationships*
ID best place on the sample	• *Mid-scale observations.* • *Precision sub-sampling (down to mm scale) for investigation by analytical suite*
At least 3 mutually confirming A/B measurements	• *Suites of observations by different means of the same or related phenomena will be necessary to reach definitive conclusions.*

AFL Baseline Measurements



Requirement	Baseline Measurements	Poss. Location
Acquire the right samples	• Color stereo imaging, telescopic capability	mast
	• Reconnaissance-scale mineralogy and/or composition	Mast/arm
	• Experiment related to redox potential	Lab/arm
	• Meso-micro scale color imaging	arm
Context	In addition to the above,	
	• Definitive mineralogy	lab
	• Elemental geochemistry / carbon chemistry	arm
ID best place on the sample	• Meso-scale optical microspectroscopy/ imaging for the presence of redox couples and/or carbon phases and macrostructures	lab
3+ mutually confirming A/B measurements	<u>Examples</u>	
	• stable isotopes	lab
	• Abundance, molecular structure and isomeric distribution, of carbon	Lab/arm
	• Specific tests indicative of biochemical activity (past or present)	lab

Sample Acquisition Strategy



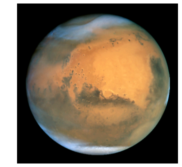
SSG CONSENSUS: Required Sample Acquisition systems:

- Corer: On the end of the arm, a device that can obtain a core to a depth of at least 20-30 cm, and with a core diameter of ~ 1 cm. Must be able to obtain 100 samples.
- RAT: A device on the end of an arm to remove the outer cm of weathered material and dust. Without this, all of the rocks on a dust-covered planet may look the same.
- Scoop: A device on the end of an arm, which can collect either fragments from a RAT, unconsolidated relogith or permafrost material from the surface, or small loose rocks.

No SSG CONSENSUS:

- Drill: A system which can obtain a sample from a distance underneath regolith (1-3 m). There are strong feelings both ways. This issue is deferred to a subsequent team to debate in more detail.

Sample Preparation



The following kinds of sample preparation are needed:

SAMPLE TYPE	***PREPARATION***
Drill core, surface rocks, regolith	• Precision sub-sampling (size, positional accuracy, and form to be specified). • Extraction (either by heat or by solvents, or both). • Comminution
Drill cuttings	• none
Ice	• No melting of sample above ambient melting temperature (or –20C?). • Minimal contact with daylight to avoid sublimation or volatilization of constituent molecules.
Liquid Water	• TBD

Precision Subsampling

FINDING: Analyses of habitability, chemical precursors, & biosignatures are strongly enhanced by the ability to perform measurements on scientifically selected sub-fractions of heterogeneous solid samples.

Measurements confined to subsamples from an identified context can both amplify and clarify chemical, mineralogical, isotopic, organic, and other signatures of high interest.

Proposed Design Requirements

Assume that a means of holding the sample and presenting the specified spot to the subsampling device is present.

- Scale of sub-sampling: **Approximately 4-5 mm**
- Mass of sample to be acquired/delivered: **100 mg**.
- Condition of sample to be delivered: **Homogenized**.
- Positional accuracy: **within 2 mm of a specified point**.
- Lifetime requirement: **At least 50 samples**.

Proposed Operational Requirements

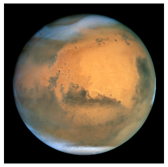
- T: for ice: **no heating of sample above -20C**.
- Time: **TBD**.

Size (mm)	Mass (mg)
2	20
3	68
4	160
5	313
6	540

Assumes ρ = 2.5

AFL Payload Analysis

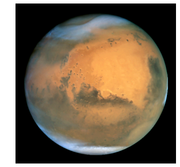
Infrastructure Strategy



Required elements

Acquire the right samples	• Mini-corer (10-30 cm?) • Mobility
context	• RAT
ID best place on sample	• Precision sub-sampling at mm scale
3+ mutually confirming A/B meas.	• Secondary sample preparation should be left to instrument designers (I.e. sieving, wet chemical extraction)

Environment –specific Δ



FINDING: The following incremental changes would need to be made to the AFL Baseline Measurements (Slide #22) to carry out the various theme missions.

Hydrothermal AFL

- NO CHANGE—AFL CORE IS SUFFICIENT

Sedimentary AFL

- NO CHANGE—AFL CORE IS SUFFICIENT

Ice AFL

- REQUIRED: Instrument to detect liquid H_2O (inclusions, thin films) in collected samples
- OPTIONAL: Subsurface ice- and water-detecting geophysics
- May require 2-3 m drill

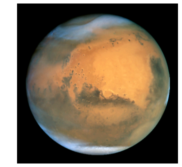
Liquid Water AFL

- Different collection and sample handling.
- Instrument to detect liquid H_2O in collected samples
- Compound-specific analytical suite.
- Various tests for viable life.
- Recon-scale min. and comp. OR Definitive Mineralogy
- Mid-scale imaging

Polar Icecap AFL

- Different sampling/prep system as for ice AFL
- Drop target acquisition instruments
- Possibly drop mobility
- Add drill or cryobot

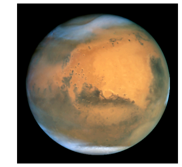
Primary Science Trades



1. The science team has developed the following priorities:

	SCIENCE PRIORITY		
	HIGH	**ESSENTIAL**	**MEDIUM**
	AFL Core	**FLOOR**	**AUGMENT**
Science System			
Precision Subsampling	YES	YES	YES
# of Instruments	10	8	11
# of drill cores	>30	20	>50
# of analyses not limited by consumables	>100	100	300
# of consumable-limited analyses	25	10	>25
Overall Surface System functionality			
Mobility	5 km	3 km	>10 km
Subsurface depth	30 cm	20 cm	50 cm
Mission lifetime	>6 mo	6 mo	>1 yr
Ability to Access more difficult terrain			
Pinpoint landing	<2.5 km	<5 km	<1 km
Hazard tolerance/avoidance	TBD	TBD	TBD

Planetary Protection



The different variants of AFL may end up in any of three Planetary Protection classifications.

- Category IVb is applied to missions that investigate extant martian life forms. This may include AFL-Liquid Water and AFL-Ice (depending on the instruments).
- Category IVc is applied to missions that access Mars "special regions". This would include AFL-Liquid Water, AFL-Ice, and perhaps other AFL versions, depending on landing site.
- Category IVa is applied to landed missions other than the above. This could apply to AFL-Sedimentary and AFL-Hydrothermal (depending on landing site).

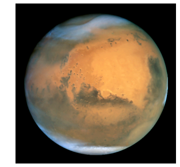
FINDING: To achieve maximum flexibility, mission engineering should be planned assuming IVb, and de-scoping, if appropriate, can take place from there.

Engineering Analysis - Core

Engineering Assumptions (Level 1 Requirements)

- Launch: Not earlier than 2013 (ref MEP roadmap)
- Launch vehicle: Atlas V or Delta IV series
- All instrument and subsystem technologies: All current technologies either being developed, or are to be developed under existing technology road maps. Technology Readiness Level of 6 for entire system will be 2009
- Desired latitude ranges: Sedimentary/hydrothermal: +60 to –60 and ice: +45 to +85.
- Landing altitude: 2.5 km or less relative to the MOLA geoid.
- Precision landing: 10x10 km (3-sigma) landing dispersion ellipse
- “Go-to” mobility: 10-15 km (linear traverse) with autonomous hazard avoidance and continual drive
- Sample and sample acquisition: Core acquisition (10 cm in length and 1 cm in diameter) with precession sub sampling with analytical analysis system
- Number of physical samples for detailed pyrolysis and wet chemistry analyses: 25-75
- Handling, processing, and analysis capabilities: rock, regolith, ice and water
- Expected terrain features: 10% rock abundance, and slopes up to 30%
- Telecom: Mars Telecom Orbiter, second generation available for increased data transmission
- Power source: Radioisotopic Thermal Generator (RTG)
- Redundancy: Functional on subsystems, science payload not included

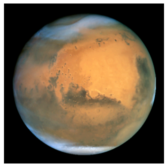
Engineering Analysis - Core



AFL 2013 Baseline mission: AFL SSG Core

- Cost (RY$B, 30% reserves): Mission - 1.55, Rover - 0.5, Science payload - 0.2
- Mass (30% reserves): Launched - 2456 kg, Rover - 548 kg, Science payload - 114 kg
- Launch: November, 2013 to January, 2014; Arrival: August - September, 2014 (Depending on S or N preference); Launcher: Atlas V521 or similar Delta IV
- Payload infrastructure: Core and detailed sample handling system, ability to extract subsamples >4 mm from acquired core/sample
- Selected 10 instruments: 2 remote sensing -, 2 contact -, and 6 analytical laboratory instruments. All the contact and remote sensing instruments are able to analyze the obtained core.
- Telecom: X-Band, Rover to MTO (10 bps – 1024 kbps, 0.3 m HGA); UHF-Band, MTO to rover (1 kbps - 8 kbps, Monopole); X-band DTE only as Back-Up
- Avionics: X2000 - cPCI-based avionics, RAD750, 16 Gbits memory
- Data volume per sol: 1-3 Gbits
- Power: 4 Brick Small RPS system (50 We/1200WeHRS); 2 x 8 Ahr-Li-Ion Batteries
- Drive train: Brushless Wheel Actuators (16-25 W per wheel:100-150W for all wheels)
- Thermal: Passive system/thermal switches: Dissipate RPS energy (1000Wt) and keeps WEB at stable temperature

MSL-AFL Evolution



MSL	AFL: Δ to MSL
Overall science objective • Quantitatively investigate habitability	• pre-biotic chemistry + initial life detection + preservation
Ability to access high-priority terrain • Landing accuracy 5 km • Hazard tolerance/ avoidance capability not determined • go-to mobility not required	• Poss. Improvement to 1-2 km • hazard tolerance/avoidance • go-to mobility
Sample preparation, analytic instruments • Bulk sample crushing • Some A/B instruments • Simple extractions	• Precision sub-sampling • More, better A/B instruments • Complex extractions (pyrolysis and probably also liquid)

AFL Technology Development

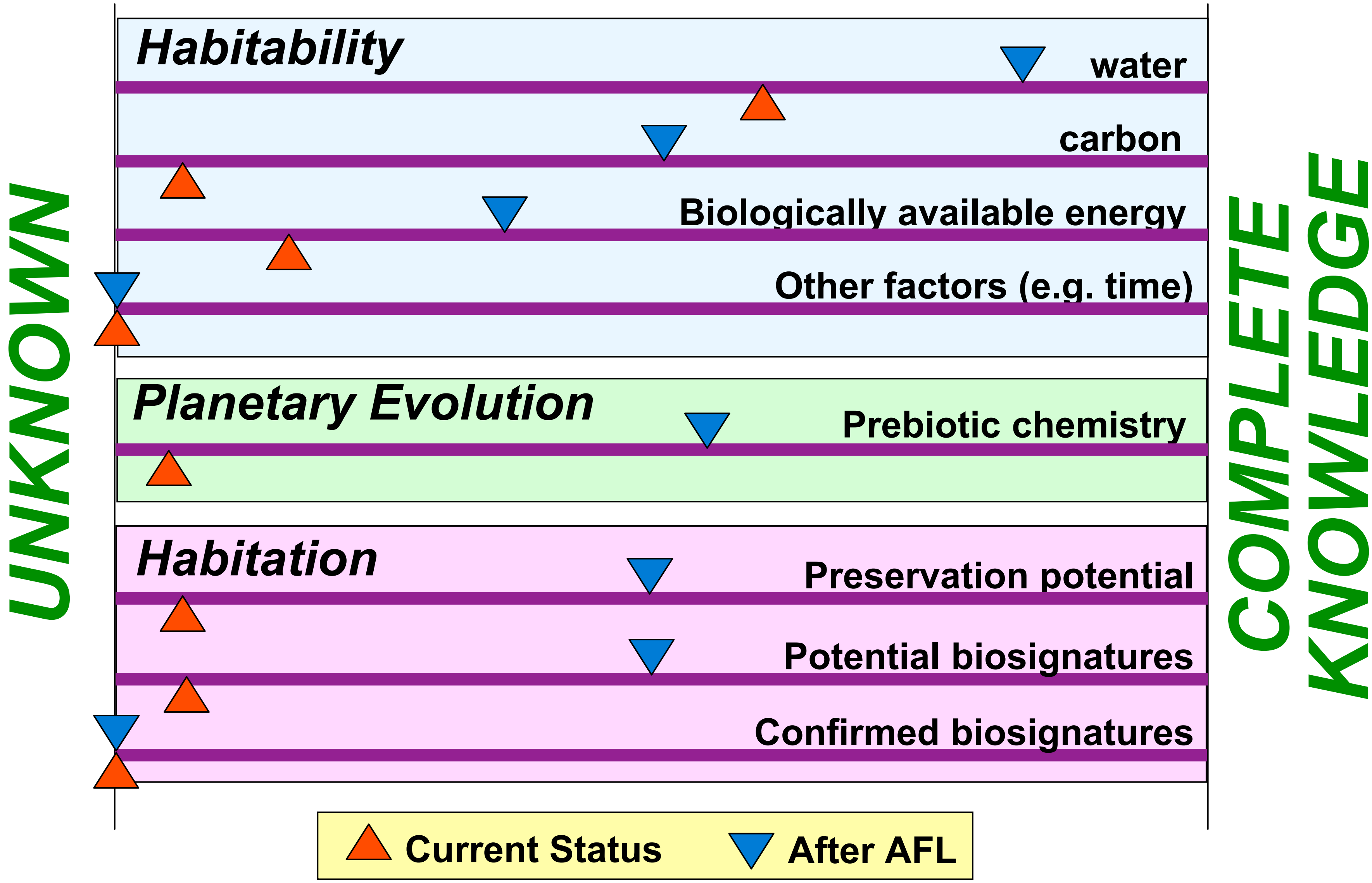
Technology Need	Priority	TRL	Cost
Precision landing	TBD	TBD	TBD
Hazard tolerance/avoidance	TBD	TBD	TBD
Instrument development			
Micro Total Analytical Systems	High	TRL 2 -4	TBD
High resolution High Atomic mass Mass Spectrometry	High	TRL 2 -5	TBD
Microscale spectroscopy and Imaging	High	TRL 2 -5	TBD
Indicators of biochemical activity (growth, DNA, ATP etc)	High	TRL 2 - 5	TBD
Advanced sample preparation system development			
Precision sub-sampling	High	TRL-2	TBD
Rock crushing system	Low	TRL-5/6	TBD
Ice-related sample handling	Medium	TBD	TBD
Drilling 2-3 metres	TBD	TBD	TBD

AFL and Pathways

The following mission sequences were proposed by MSPSG (2003), as part of the Pathways planning process.

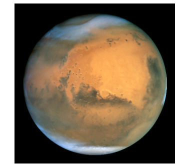
Pathway	2009	2011	2013	2016	2018	2020	NOTES
Search for Evidence of Past Life	MSL to Low Lat.	Scout	Ground Breaking MSR	Scout	Astrobio. Field Lab or Deep Drill	Scout	All core missions to mid-latitudes. Mission in '18 driven by MSL results and budget.
Explore Hydrothermal Habitats	MSL to Hydrothermal Deposit	Scout	Astrobiology Field Laboratory	Scout	Deep Drill	Scout	All core missions sent to active or extinct hydrothermal deposits.
Search for Present Life	MSL to N. Pole or Active Vent	Scout	Scout	MSR with Rover	Scout	Deep Drill	Missions to modern habitat. Path has highest risk.
Explore Evolution of Mars	MSL To Low Lat. (Netlanders)	Scout	Ground Breaking MSR	Aero-nomy	Network	Scout	Path rests on proof that Mars was never wet.

Mars A/B Scorecard



Backup Slides, Appendices

Appendix I. Definition of terms



In addition to the definitions on Slide #3:

Extant life

- General reference to living or recently dead organisms which may also possess a fossil record.

Extinct life

- General reference to past life (and no longer present on the planet). If evidence remains, it is ONLY fossil.

Present life investigation

- One that specifically targets living or recently dead organisms. Time resolved studies on seasonal and daily (with perhaps higher frequency) time scales may be required to *confirm* observations that a biosignature of present life has been detected.

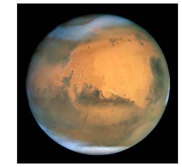
Primary Sample

- Geological material (e.g. rock, regolith, dust, atmosphere, ice) acquired from its natural setting on Mars. Note: specific locations where data are collected by contact instruments are referred to as "targets", not samples.

Secondary Sample

- Any sample derived from the primary, including splits, extracts, sub-samples, etc.

Appendix I. Definition of terms



Prebiotic Chemistry

- Mainly carbon based chemistry the speciation and composition of which has a complexity and has produced a number of polymeric systems that could be used for structural, metabolic processes and information storage and retrieval.

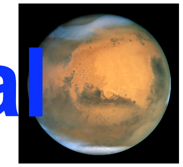
Abiotic Chemistry

- Mainly carbon based chemistry the speciation and composition of which has remained simple with the production of all different isomeric possibilities and show no chiral or species preferences. In this scenario complex molecules may only be kerrogenous in nature (type iv) and similar to that found in meteorites.

Micro BioSensors (not to exclude organic chemical detection)

Miniaturized instruments or instrument suites that are developed from technology such as Micro Electronic Machine Systems (MEMS), Micro electronic optic systems (MEOS), Microfluidics, Micro Total Analytical Systems (uTAS) or Lab-on-a-Chip (LOC).

Appendix II. Habitability Potential



The potential habitability of an environment is related to the probability that ALL of the factors required by life are ore were simultaneously present. Since this involves joint probability, we can quantify habitability in the following way:

$$\text{Habitability} = P_1 * P_2 * P_3 * P_4 \ldots\ldots * P_n$$

Until we discover martian life and measure its life processes, it is not possible to know all of the terms. A current model (to be revised by future research) is that three factors dominate:

- liquid water.
- A biologically available energy source.
- The availability of the chemical building blocks of life

<u>*Proposed Definition*</u>

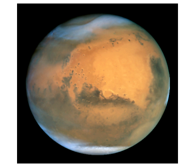
The HABITABILITY INDEX is defined as follows:

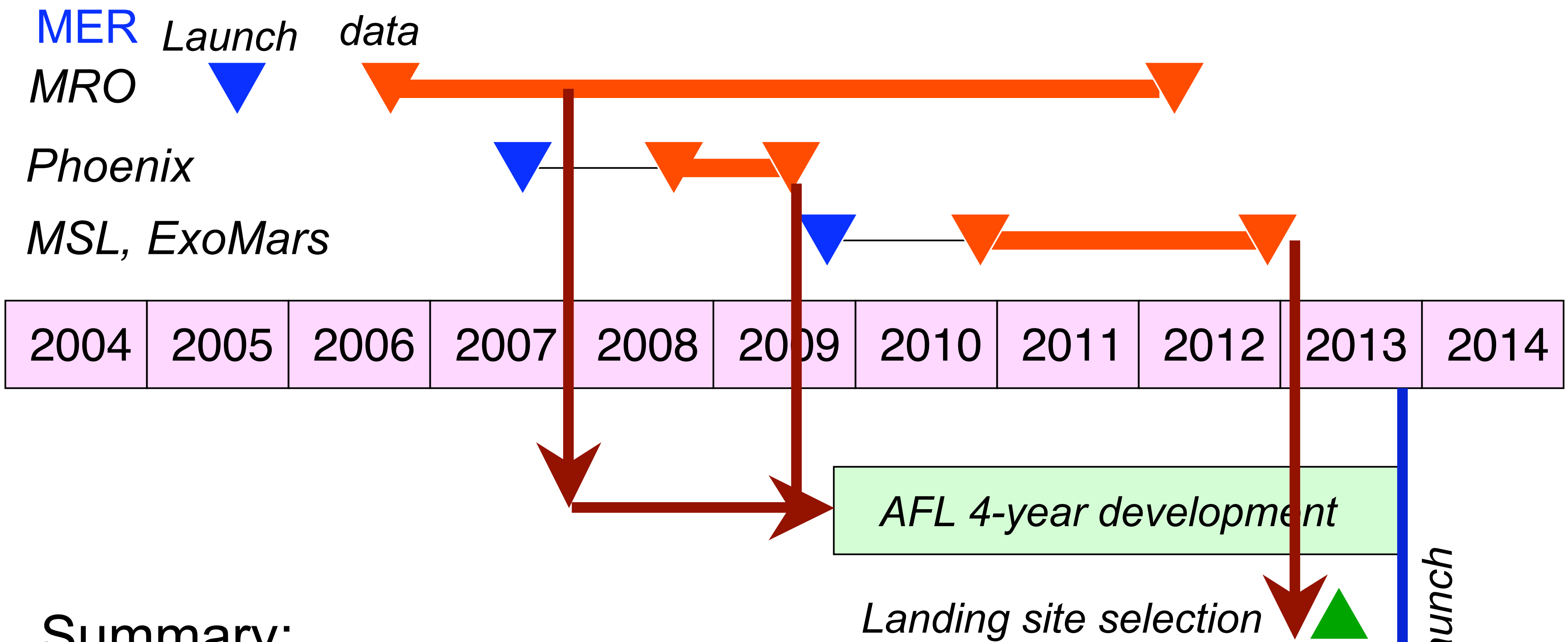
$$HI = P_{lw} * P_e * P_c * 100$$

Appendix III.

Antecedent Discoveries of Primary Relevance to AFL

Antecedent Discoveries

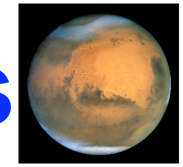




<u>Summary</u>:

- We must plan to incorporate results from MRO and Phoenix into mission design.
- Results from MSL (and/or ExoMars) can influence landing site selection, but not basic engineering.

Most Relevant Discoveries



FINDING: Relevant data may already be available but two major classes of discovery would be of **essential** relevance to AFL mission planning:

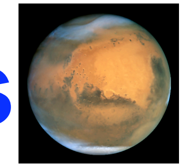
MRO

- Sending AFL to a hydrothermal site is impossible with present knowledge, because none are known. However, the CRISM spectrometer on MRO is very powerful, and it has potential to discover the mineralogic expression of hydrothermal zones.

Phoenix

- Phoenix will be the first lander designed to acquire and analyze ice-bearing samples.
- It will collect data of relevance to each of the three primary components of habitability (water, carbon, energy), and thus is capable of returning a result which significantly improves or reduces our interest in sending AFL to an ice-related site.

Most Relevant Discoveries



MER

- Discovery of water-lain sediments by the Opportunity rover may significantly increase the priority of the sedimentary version of AFL. This is a discovery that MUST be followed up!!

MEX

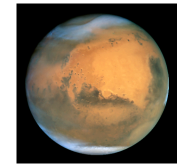
- Sedimentary outcrops from MEX and would increase number of possible sites of interest

Several other possible discoveries (by MER, MEX, MRO, PHX) would be of interest, but would not have a major effect on AFL design.

Appendix IV.

Current technology in Life Detection.

A/B Measurement Strategy



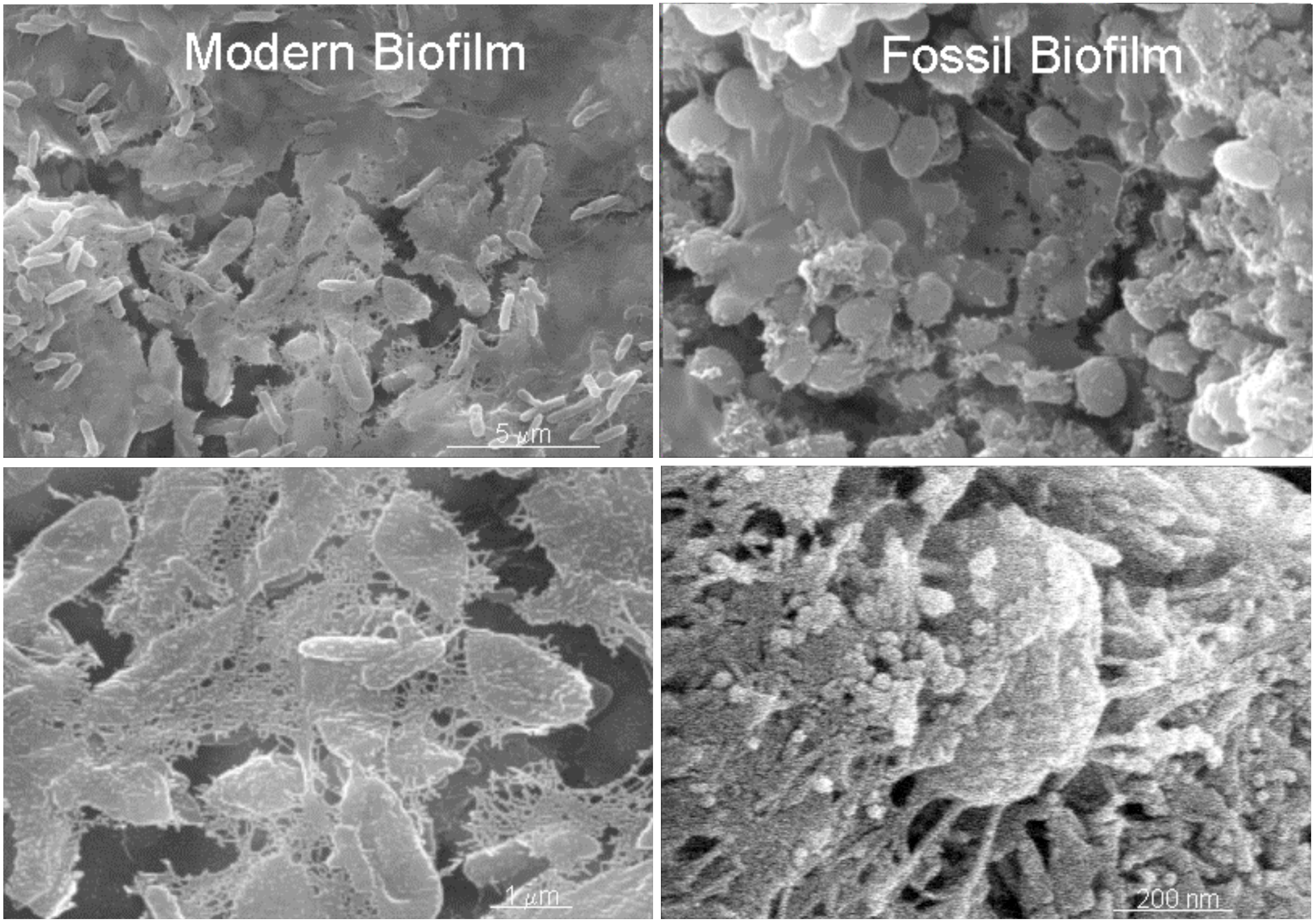
	Habitability	Extant	Fossil
Morphology (Imaging at several scales)	✓	✓	✓
Mineralogical compositions / isotopes etc (i.e. context, redox couples)	✓	✓	✓
Organic chemical inventory, molecular complexity (presence of biopolymers) and isotope measurements.	✓	✓	✓
Measurements for metabolic processes – and trace gases	✓	✓	X*

<u>FINDING</u>: Many experiments can be applied to all objectives

Note - Each of the individual measurements are by themselves insufficient to detect habitability, extant or extinct life and a variety of measurements must be made to corroborate a single positive from any technique. For example morphology information without corroborating chemical information is ambiguous so preferentially both measurements must be made.

** - Measurements of metabolism may be important for planetary protection and contamination monitoring experiments*

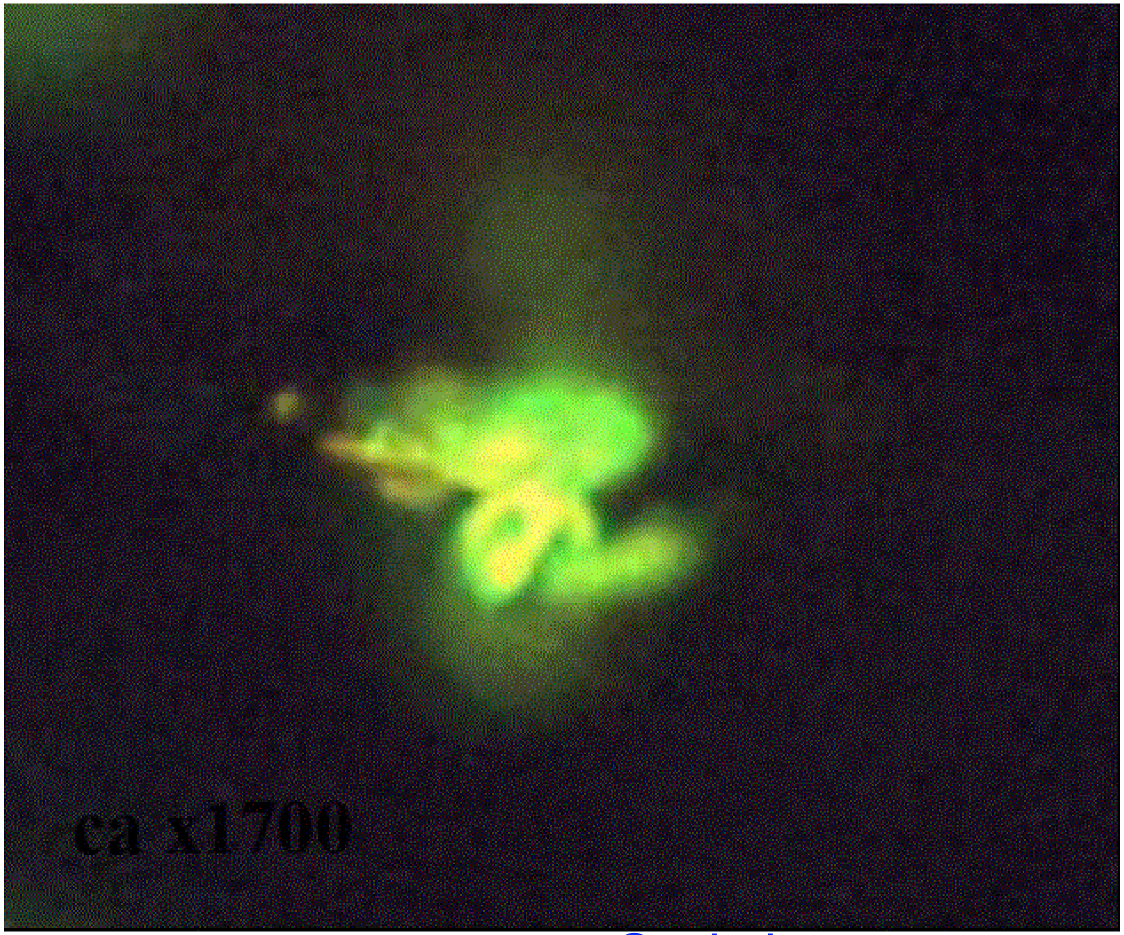
Life Detection Methodology
Imaging



Oligocene (ca. 25 ma) Enspel formation, Germany

Spectroscopy

i.e. Fluorescence imaging of stained cells on Nakhla

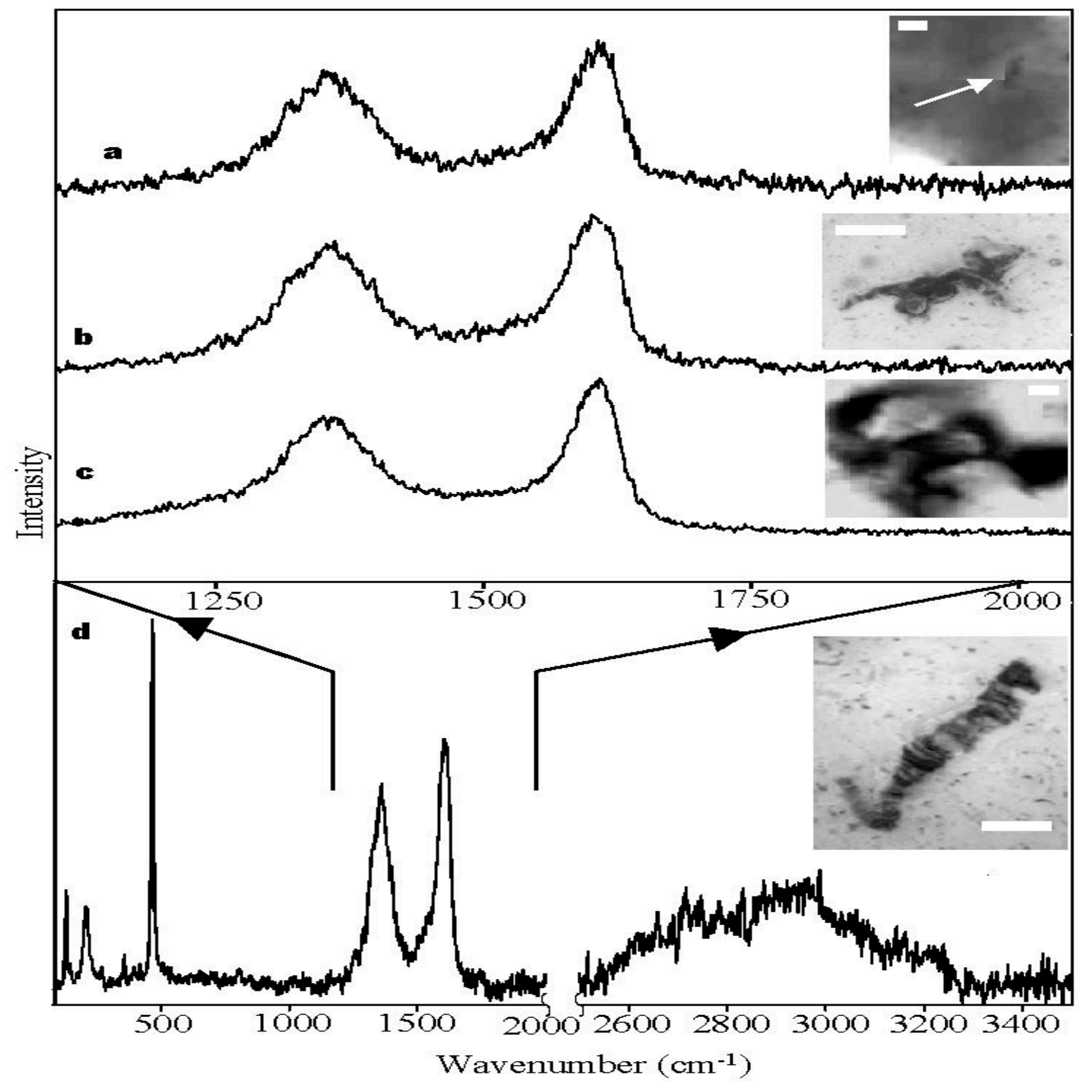


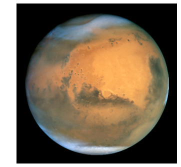
Scale bar

Spectroscopy

Pan – images from raman and deep UV fluorescence of cryptoendoliths

Figure 5. Brasier et al.



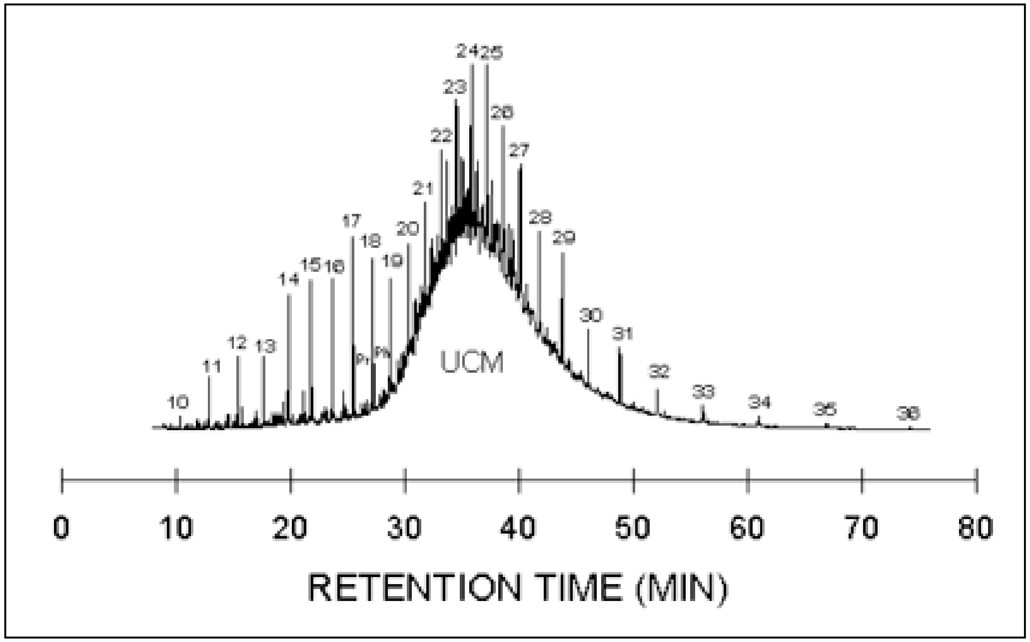


Life Detection Methodology

Organic Inventory

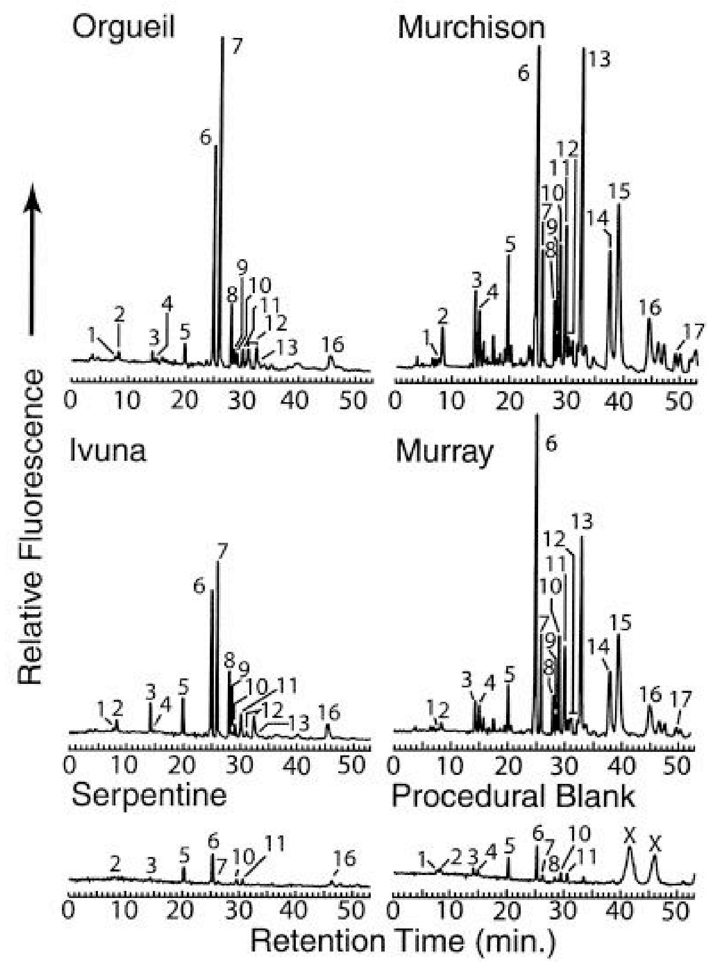
Example investigations

Biotic N-Alkane distribution

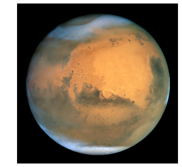


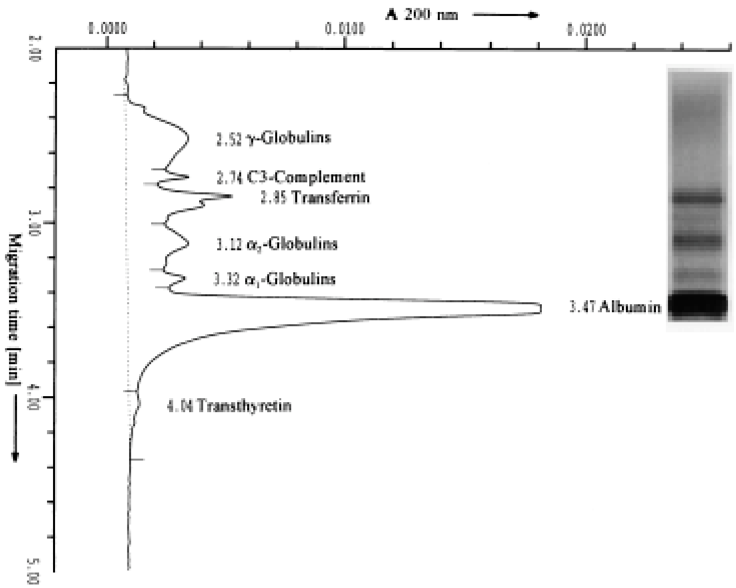
In the case of alkanes, the above distribution is a biogenic signature. A distribution showing a decrease in concentration with increasing carbon number would indicate abiotic processes. Similarly a predominance of biogenic amino acids with an excess of the L isomer would indicate extant or recently extinct life. A suite of racemized biogenic amino acids may indicate fossil life

Abiotic amino acid distributions



Life Detection Methodology
Biopolymers





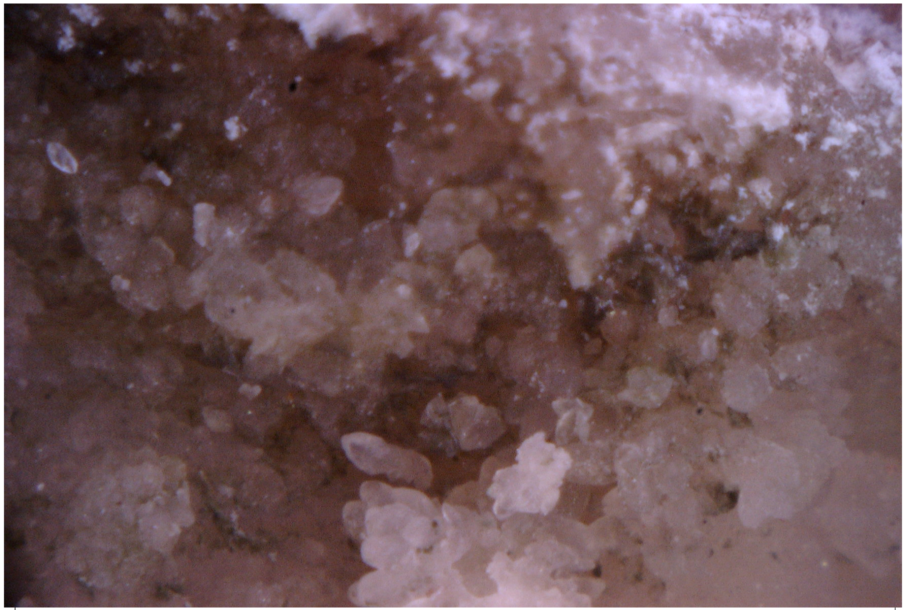
Detection of large proteins by Capillary electrophoresis

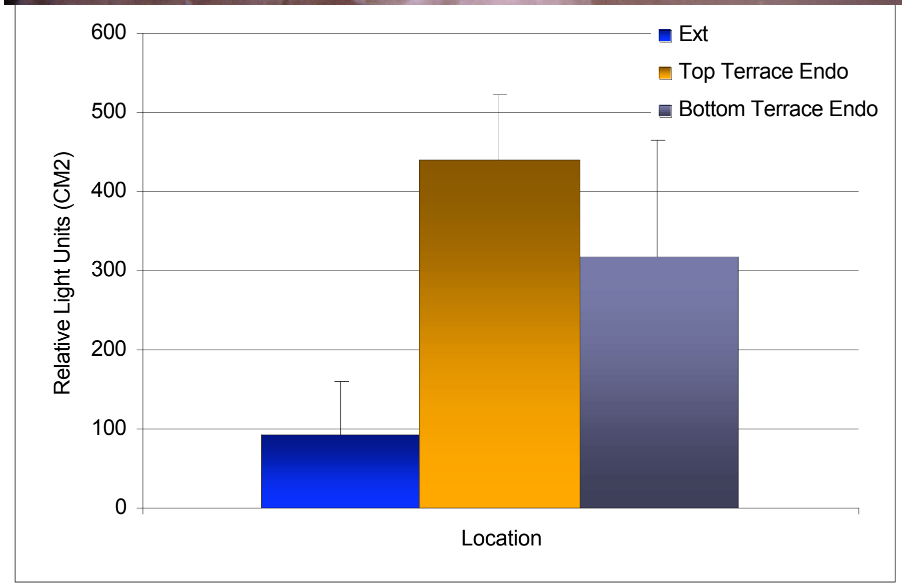
Detection of hopanes by Time of Flight Mass Spectrometry

Must include diagnostic peak

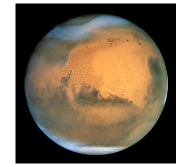
Metabolism

In Field ATP luminometry measurements of the cryptoendolithic communities pictured. Provides a rapid method of detecting relative amounts of metabolic turnover in these communities





Appendix V. Time-separated repeat measurements



- For some versions of AFL, time-separated repeat measurements (to observe changes) will be valuable, and these were strongly advocated by some members of the SSG.
- Given current understanding of Mars, we do not know enough to design the time gap that would be needed in such an experiment (minutes?, hours?, days?, months?), or the fidelity to which the subsequent experiment(s) needs to duplicate the conditions of the first in order to provide a meaningful hypothesis test.
- The AFL SSG takes the position that time-separated repeat measurements are not essential to all versions of AFL. Thus, this should not be a part of the common overall mission scientific objectives.
- The AFL SSG recommends that the capability to do at least some time-separated repeat measurements be a general functionality of the surface science system, and that the decision on how and when to use it be deferred to the competitive process.

AFL Payload Analysis

De-scope Plan, Science Floor

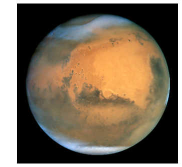
	AFL CORE	AFL CORE -1	AFL CORE -2
Number of samples:	**25-75**	**25-75**	**25-75**
Instruments			
Remote			
Color stereo imaging	Yes	Yes	Yes
Reconnaissance scale mineralogy	Yes	Yes	Yes
Contact			
Mid-scale imaging/spectroscopy	Yes	Yes	Yes
geochemistry/mineralogy	Yes	Yes	Yes
Analytical Lab			
Redox Potential	Yes	No	No
Definitive mineralogy	Yes	Yes	Yes
Meso-scale microspectroscopy/ imaging, incl. UV source	Yes	Yes	Yes
A/B instruments (choose 3)			
Abundance, molecular structure of carbon	Yes	Yes	Yes
Isotopic composition of carbon	Yes	Yes	No
Micro Biosensors	Yes	Yes	Yes
TOTAL # OF INSTRUMENTS	**10**	**9**	**8**

Recommended Baseline

Decreasing return

Science Floor

AFL SSG Charter



The AFL Science Steering Group was chartered on behalf of MEPAG to complete the following:

1. Develop a single mission concept for AFL which is judged to have the highest science value from the point of view of the SSG, consistent with realistic resource constraints.
2. This mission concept should include (but perhaps not be limited to) the following kinds of details:
   - high-level science objectives, and a science floor.
   - Identify and evaluate the primary science trades
   - Define which measurement sets must be achieved to meet the science objectives
   - Define the specific types of locations that would be targeted
   - sample acquisition and sample preparation required to achieve the desired scientific measurements.