Lecture 1.03: Fundamentals of the Practice of Science

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BIO 181, General Biology for Majors

Outline

1. Lowell's search for life on Mars
2. Scientific Process
   - Hypothesis
   - Theory
3. Viking's search for life on Mars
   - Mission background
   - LR methods
   - LR results

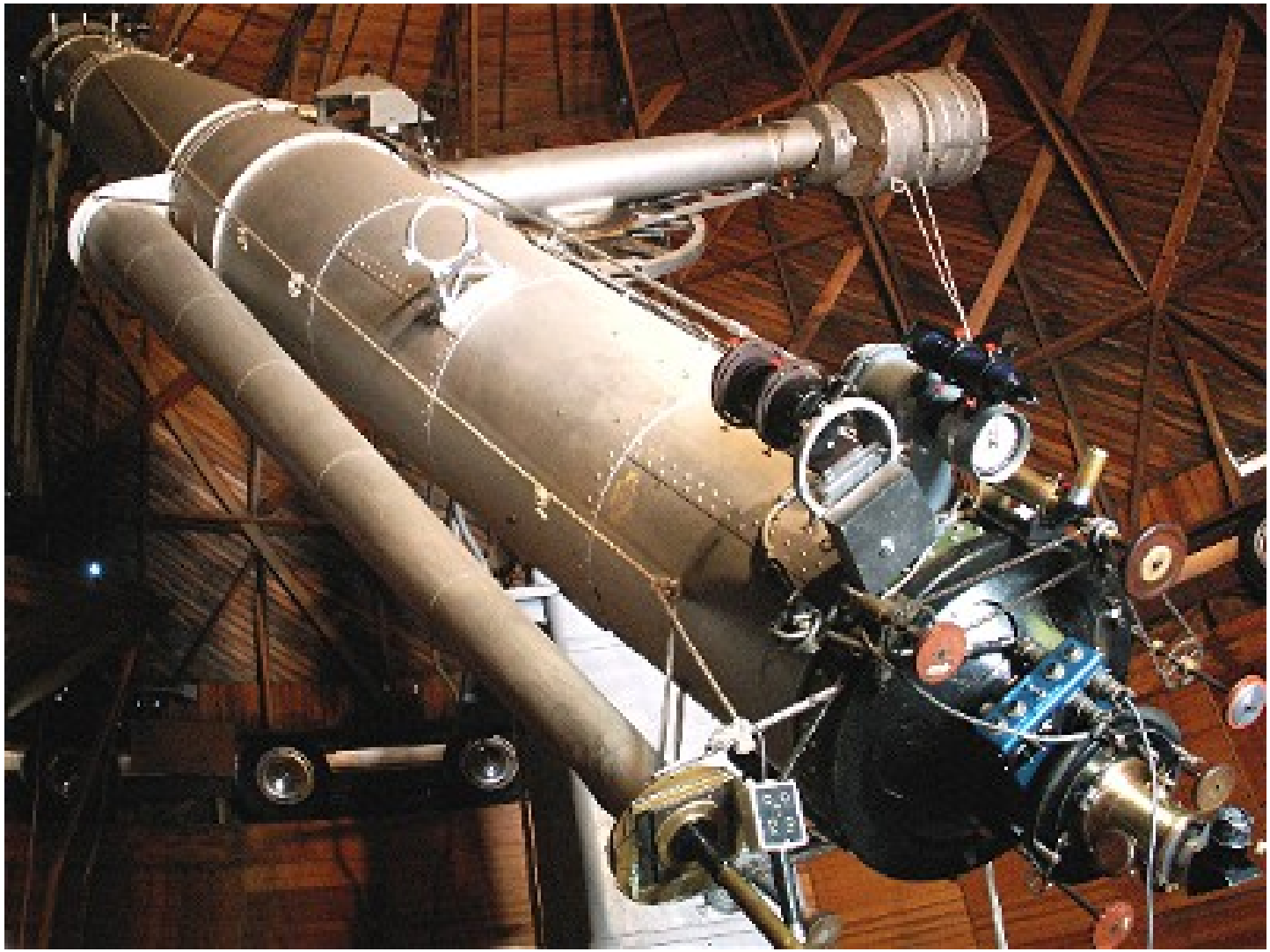
The search starts on Mars Hill in Flagstaff

Established by Percival Lowell in 1894.

The search starts on Mars Hill in Flagstaff

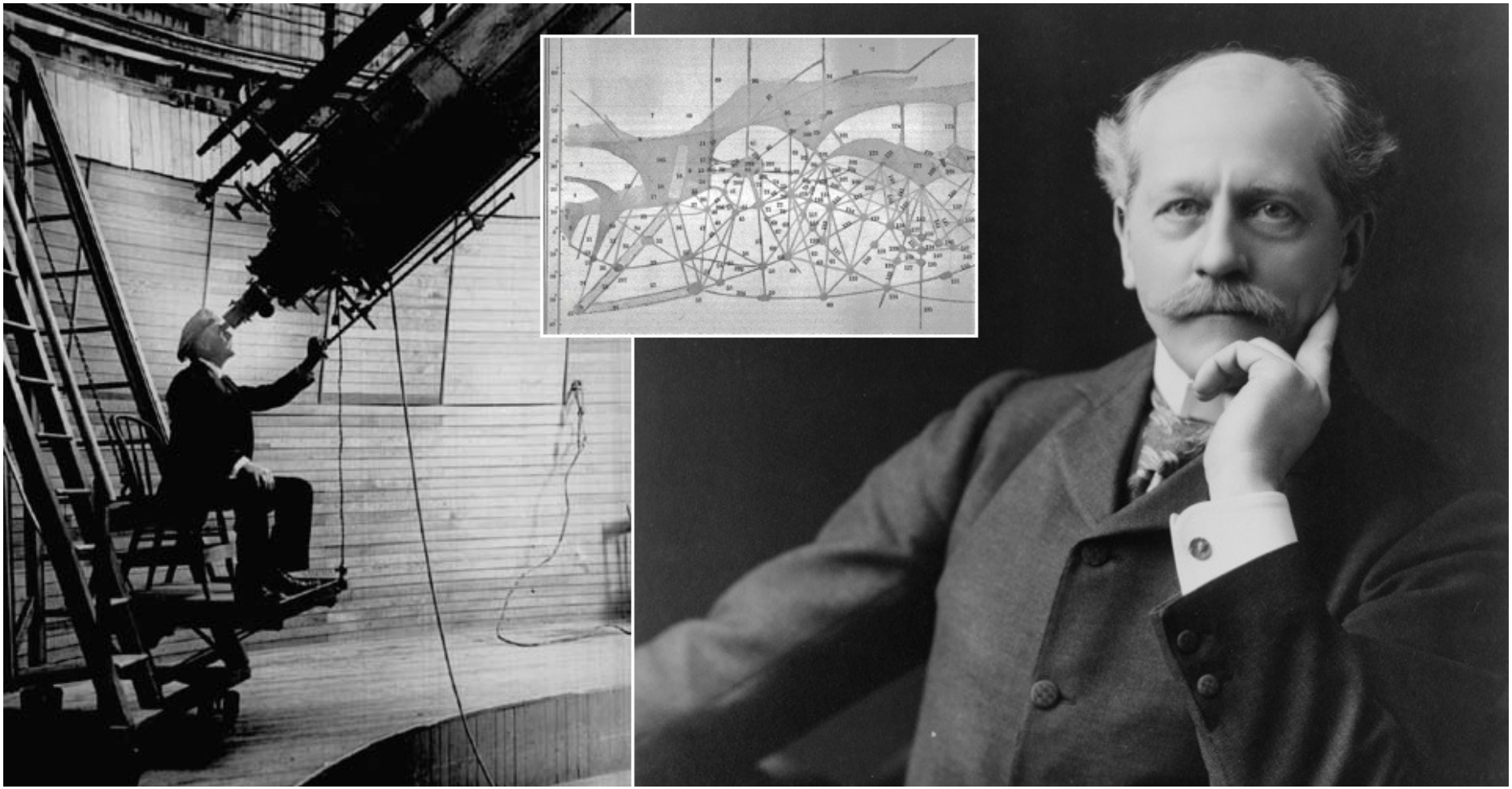
The telescope dome built by Lowell.

The search starts on Mars Hill in Flagstaff

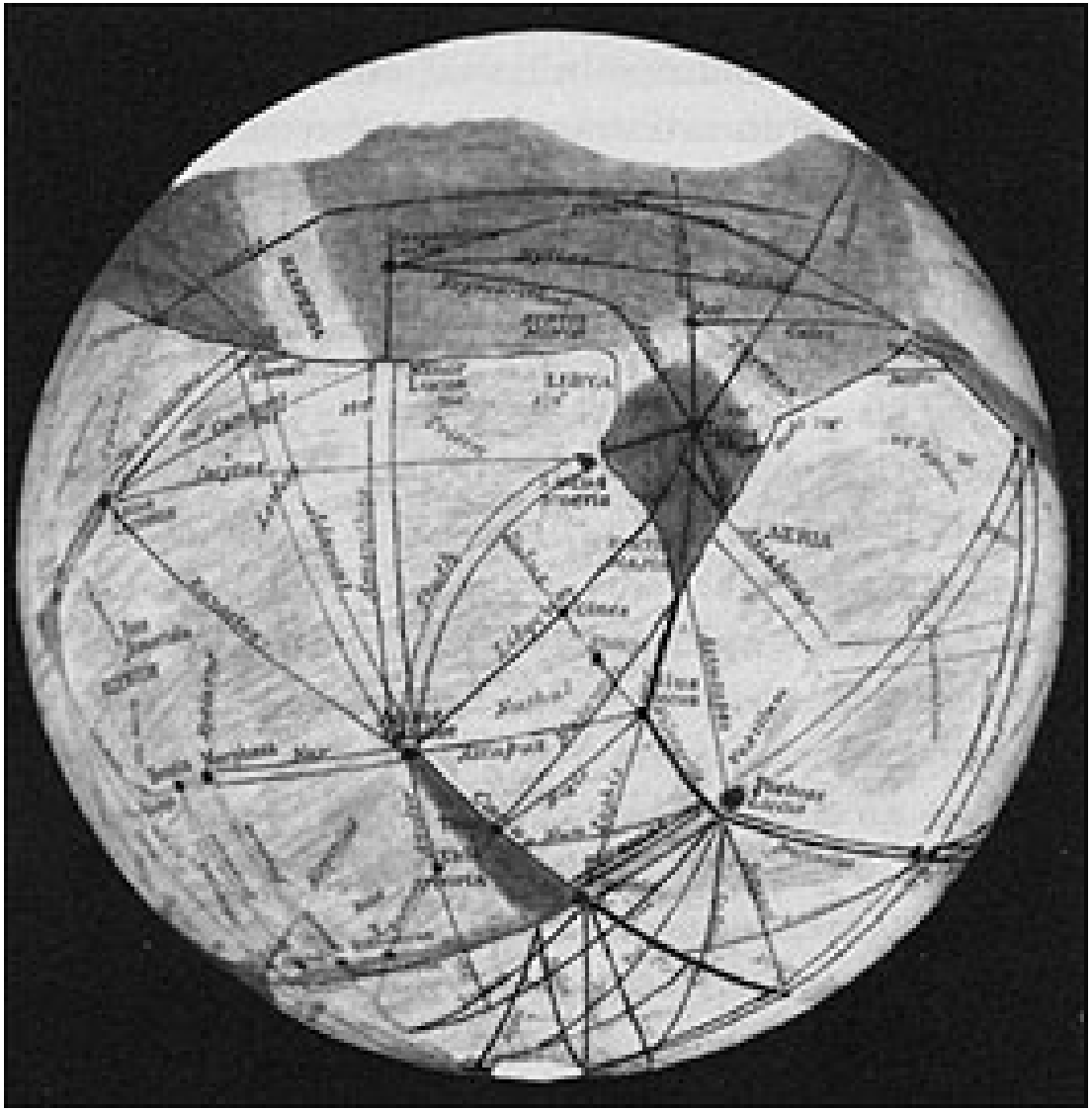


The Clark telescope commissioned by Lowell.

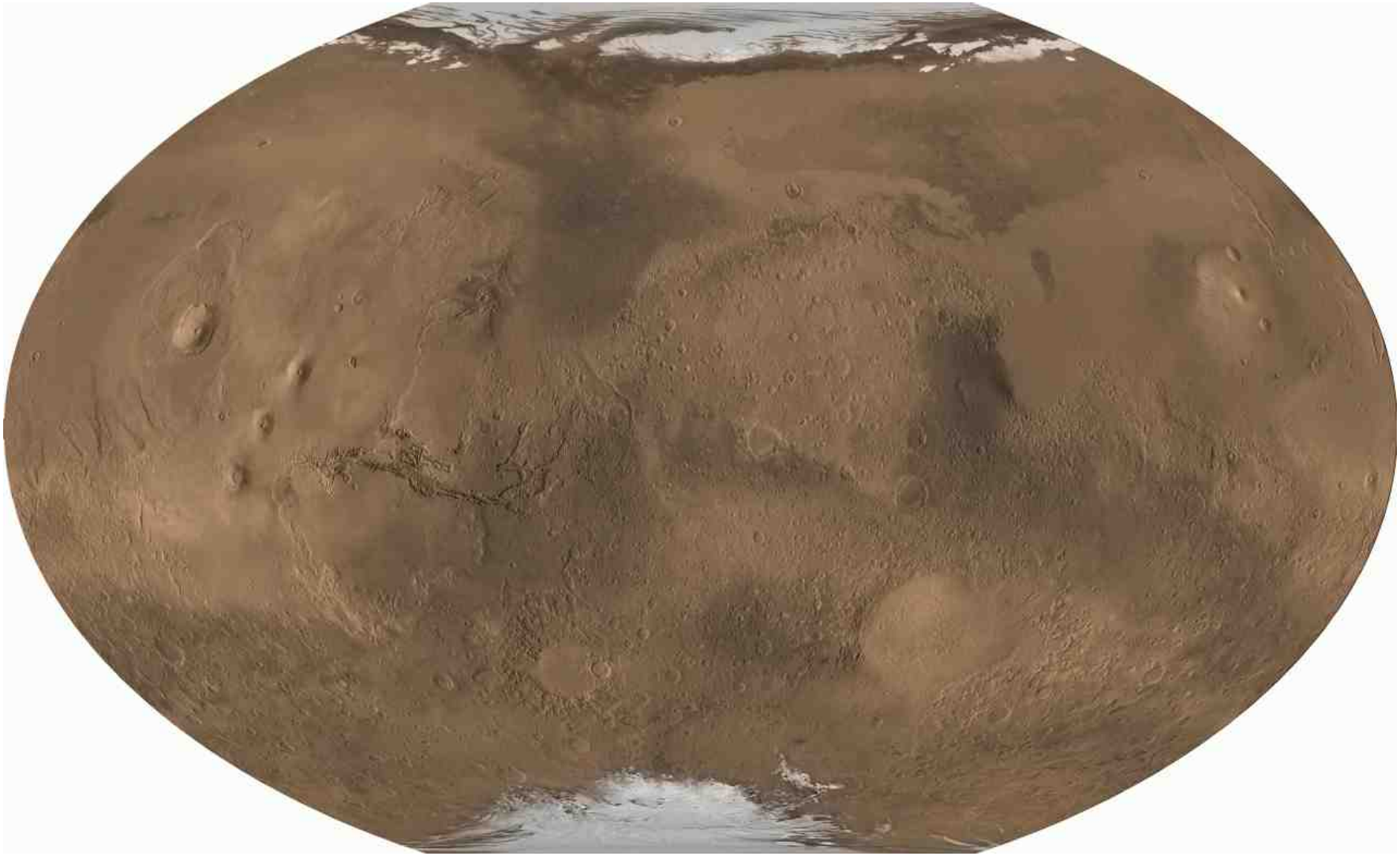
Lowell was obsessed with Mars



Lowell's Martian "canals"



Mars' true appearance (Mars Global Surveyor)



Lowell's scientific process

Lowell's thinking illustrates some key elements of scientific practice:

- Careful observation of the natural world is the beginning of knowledge.
- Observation inevitably leads to questions.
  What was Lowell's question?
- Scientists propose tentative answers to the questions.
  What are these tentative answers called?

The concept of hypothesis

Definition: hypothesis

A scientific **hypothesis** is an explanation of a natural phenomenon or a set of observations of the real world. They are often thought of as tentative, but they need not be; if they pass many tests then we say the hypothesis is confirmed, *but it remains a hypothesis.*

What was Lowell's hypothesis?

First principle of scientific thought

All hypotheses must be tested and discarded if they either

- are shown to be logically inconsistent; or
- fail to fit evidence from the real world.

What was the test of Lowell's hypothesis?

Why is this not Lowell's *theory*?

True or false:

- Theory and hypothesis mean the same thing.
- Theories are highly speculative.
- If a hypothesis is tested and passes the test, it becomes a theory.
- If it passes further tests, it becomes a natural law.
- The goal of science is to produce theory.

The answers based on *scientists'* definitions

True or false:

- Theory and hypothesis mean the same thing. False
- Theories are highly speculative. False
- If a hypothesis is tested and passes the test, it becomes a theory. False
- If it passes further tests, it becomes a natural law. False
- The goal of science is to produce theory. True

What is a theory?

Definition: Theory (Gerald Holton and Stephen Brush*)

"...a conceptual scheme ...[that explains] to ourselves, and to others, observed phenomena and the relationships among them, thereby bringing together into one structure the concepts, laws, principles, hypothesis and observations from often very widely different fields. ...On a simple level, a theory helps us to interpret the unknown in terms of the known."

Definition: Theory (National Academy of Sciences)

"A well-substantiated explanation of some aspect of the natural world that can incorporate facts, [natural] laws, inferences and tested hypotheses.

*Harvard professors, both physicists and historians of science.

The important concept of theory

The second principle of scientific thought

Theory is the main product of science. The goal of science is to produce correct, consistent theories that explain natural phenomena in the most general and elegant way. A perfect theory would be a simple statement (probably mathematical) that explains all of Nature.

This statement confuses the general public because they consistently conflate the concepts of "theory" and "hypothesis."

A short list of successful scientific theories:

- Theory of universal gravitation.
- Theory of plate tectonics.
- Theory of natural selection.
- Theories of relativity.
- Quantum theories.

Percy Williams Bridgeman* on "the scientific method"

"The scientific method, as far as it is a method, is nothing more than doing one's damnedest with one's mind, no holds barred. . . . This means in particular that no special privileges are accorded to authority or to tradition, that personal prejudices and predilections are carefully guarded against, that one makes continued checks to assure oneself that one is not making mistakes, and that any line of inquiry will be followed that appears at all promising. All of these rules are applicable to any situation in which one has to obtain the right answer, and all of them are only manifestations of intelligence."

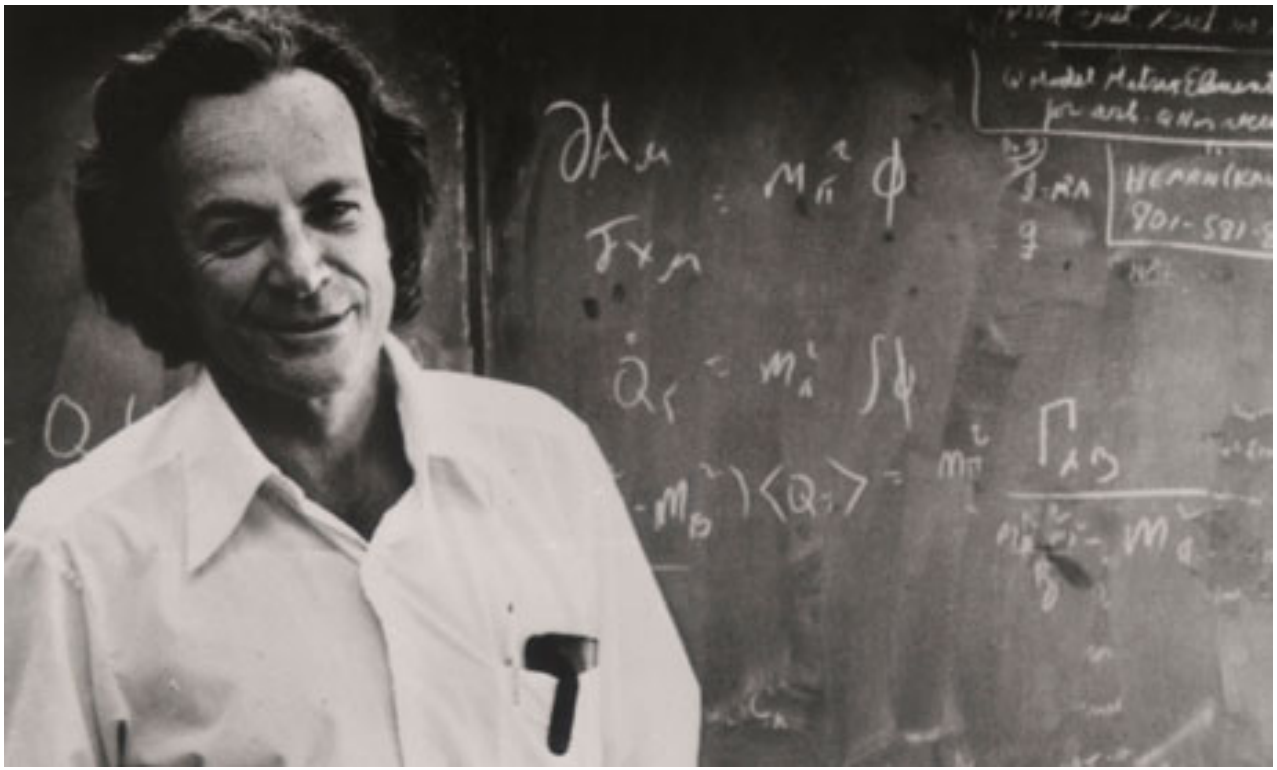
*Physics Nobel laureate (1946)

Holton and Brush on the same topic

"If by scientific method we mean the sequence and rule by which scientists now do and in the past actually have done their work, then two truths soon become obvious. First, as for every task, there are not one but many methods and uncountable variants and, second, even those different methods are for the most part read into the story after it has been completed, and so exist only in a rather artificial and debatable way."

"...we may perhaps agree ...that the main business of science is to trace in the chaos and flux of phenomena a consistent structure with order and meaning, and in this way to interpret and to transcend direct experience."

Richard Feynman's* restatement of the first principle



"It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong."

*Physics Nobel laureate (1965)

Viking missions to Mars

Carl Sagan and a mockup of the Viking Lander.

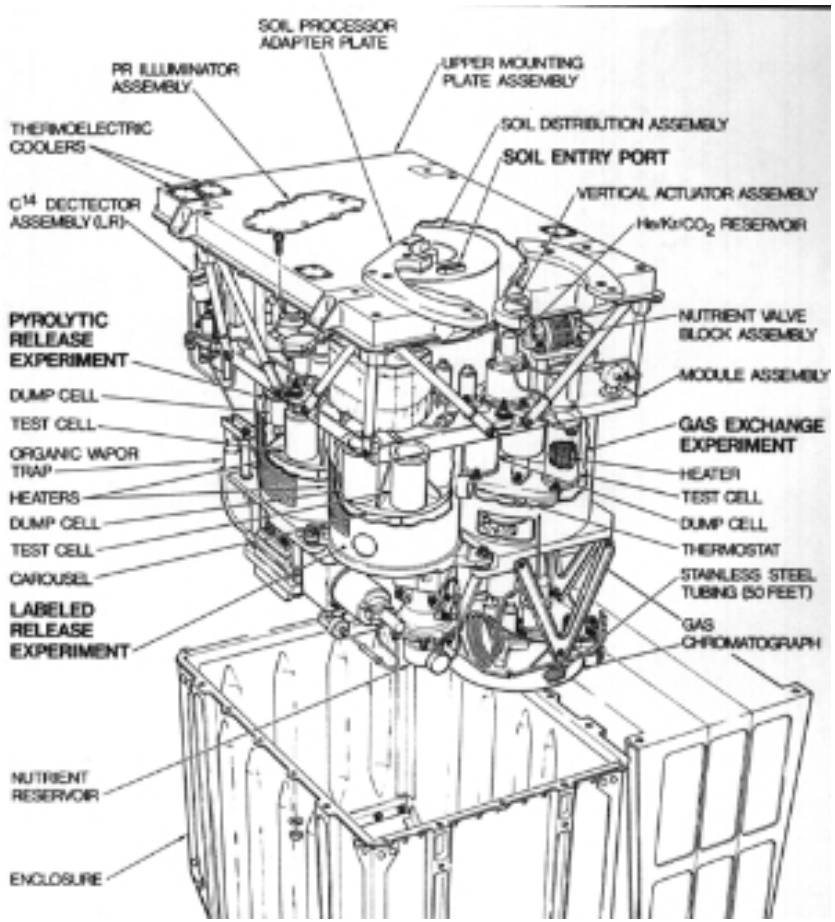
Viking missions to Mars

- Two misstions, Viking I and Viking II.
- Viking I launched Aug 20, 1975; landed on Mars July 20, 1976 in Chryse Planitia.
- Viking II launched Sept 9, 1975; landed on Mars Sept. 3, 1976 in Utopia Planitia.

First color image from VL1

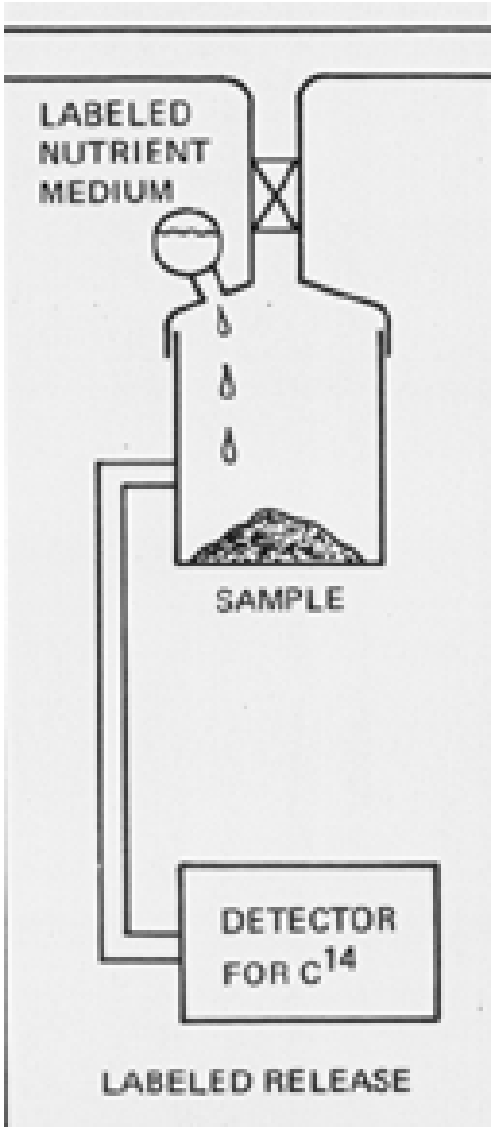
Is there life in the soil?

Schematic of the Viking biology package



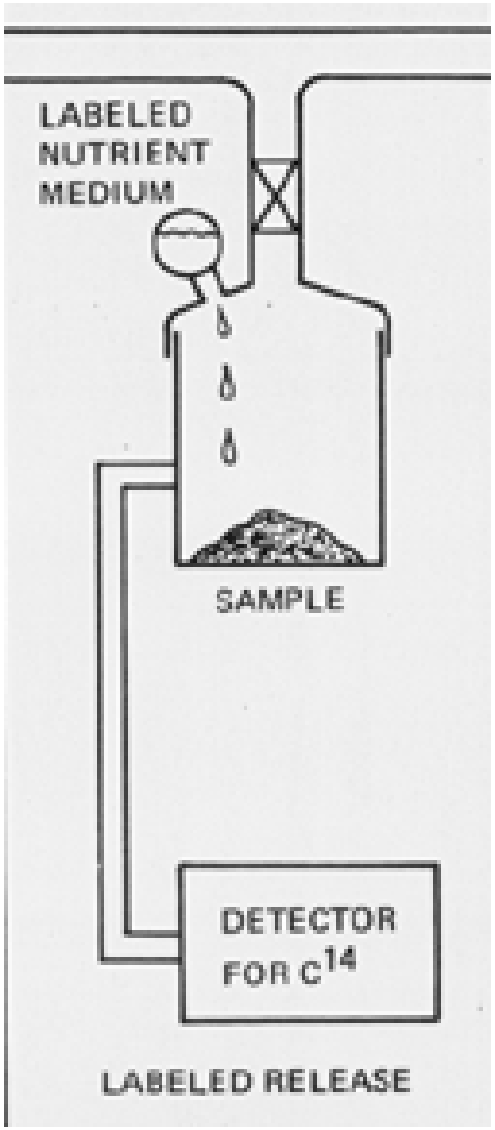
Contains 3 experiments: Labeled Release (LR), Pyrolytic Release (PR), and Gas Exchange Experiment (GEX)

Details of the LR experiment



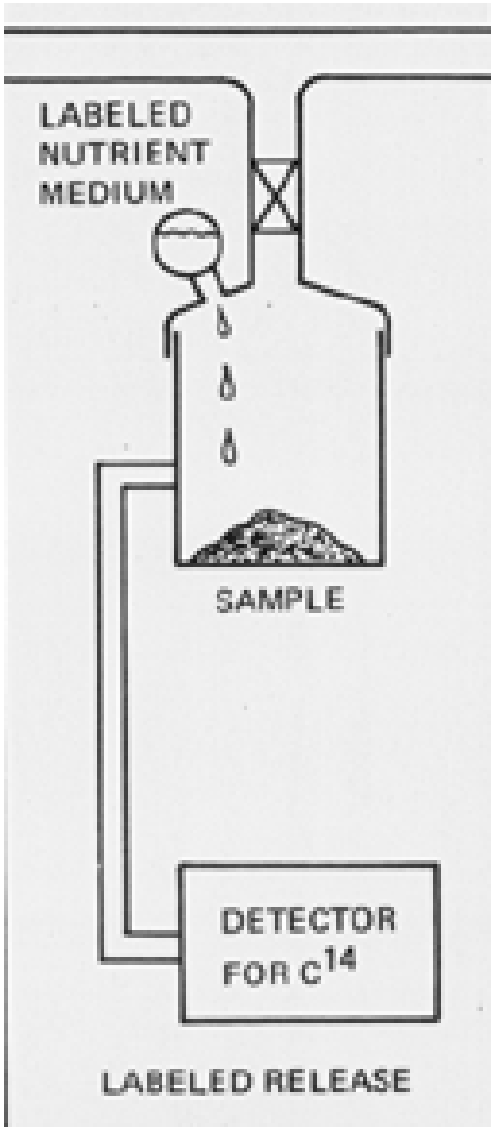
- Chamber is opened; scoop of Martial soil is deposited at the bottom.
- Vessel sealed; headspace cleared with He.
- Radiolabeled (with ^{14}C) nutrient broth added to the soil sample.
- Dependent variable (measured): amount of radioactivity (from ^{14}C) in the headspace.
- If microbes in the soil metabolize organic compounds in the nutrient broth, they are expected to release radioactive CO_2 gas (hence, "Labeled Release").

How do we interpret the LR experiment?



- What would be a **positive result** in this experiment?
- What would be a **negative result** in this experiment?

How do we interpret the LR experiment?



- What would be a **positive result** in this experiment?

  Radioactivity (^{14}C) in the headspace $\Rightarrow$ microbes in the soil.

- What would be a **negative result** in this experiment?

  No radioactivity (^{14}C) in the headspace $\Rightarrow$ no microbes in the soil.

Controls

Before we fly this experiment to Mars, we have to test it to make sure it works.

The third principle of scientific thought

Experiments must always be thoroughly tested to make sure they are working properly.

Definition: Experimental control

An **experimental control** is a test of the validity of an experiment. One performs the experiment under controlled conditions to force the experiment to give an expected result. If the experiment fails to produce the expected result, it fails the control and the experiment is deemed invalid.

How will we test this experiment using experimental controls?

Positive and negative controls

Definition: Positive control

A **positive control** in an experiment run under controlled conditions to force a positive result. If the positive control fails to give a positive result, the experiment is invalid.

Definition: Negative control

A **negative control** is an experiment run under controlled conditions to force a negative result. If the negative control fails to give a negative result, the experiment is invalid.

Example: When we test a patient for HIV disease, we also always run the test on their blood alongside tests of blood from known HIV positive and negative individuals, which are the positive and negative controls, respectively.

LR positive and negative controls on Earth

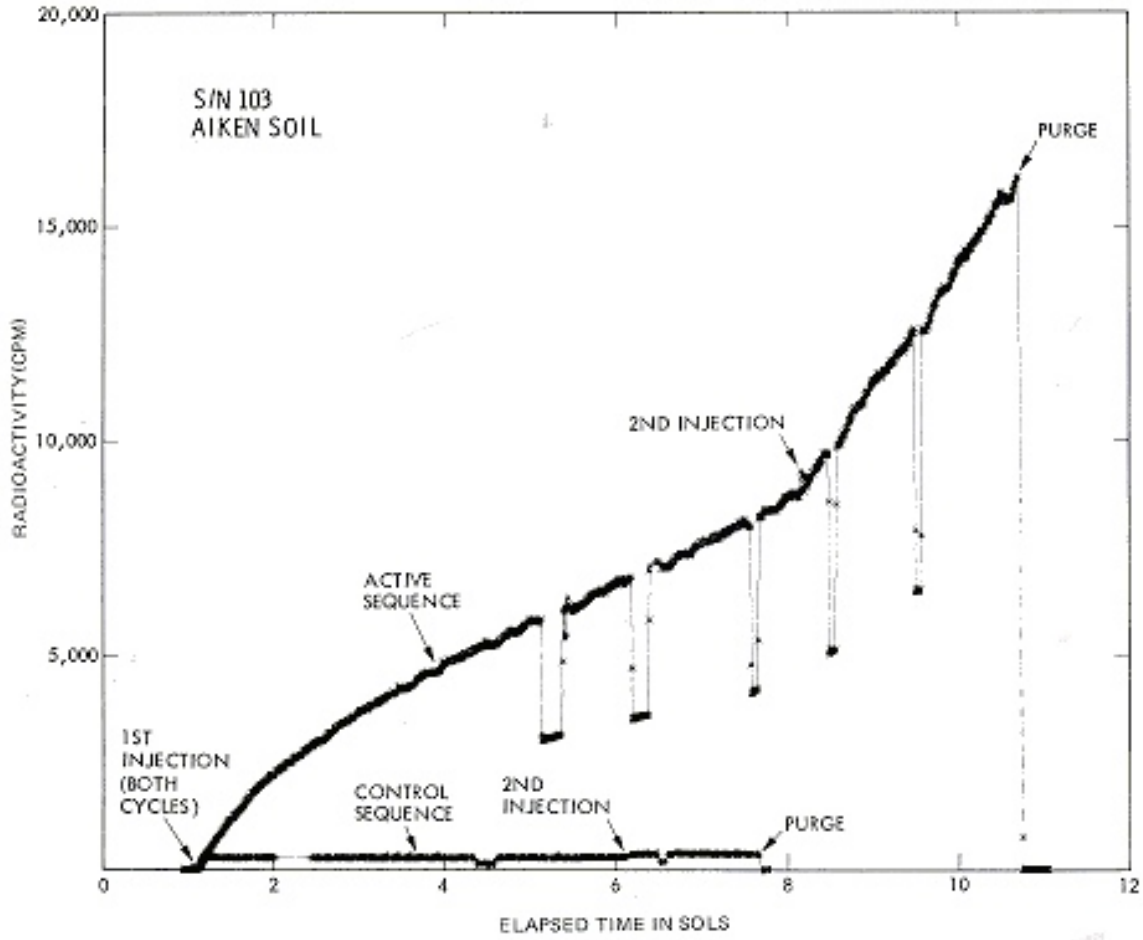


Fig. 1. Test of viable terrestrial soil in LR flight-type instrument under simulated Mars conditions.

Should we risk flying this experiment to Mars based on these data?

Actual data from LR experiment on Viking 1

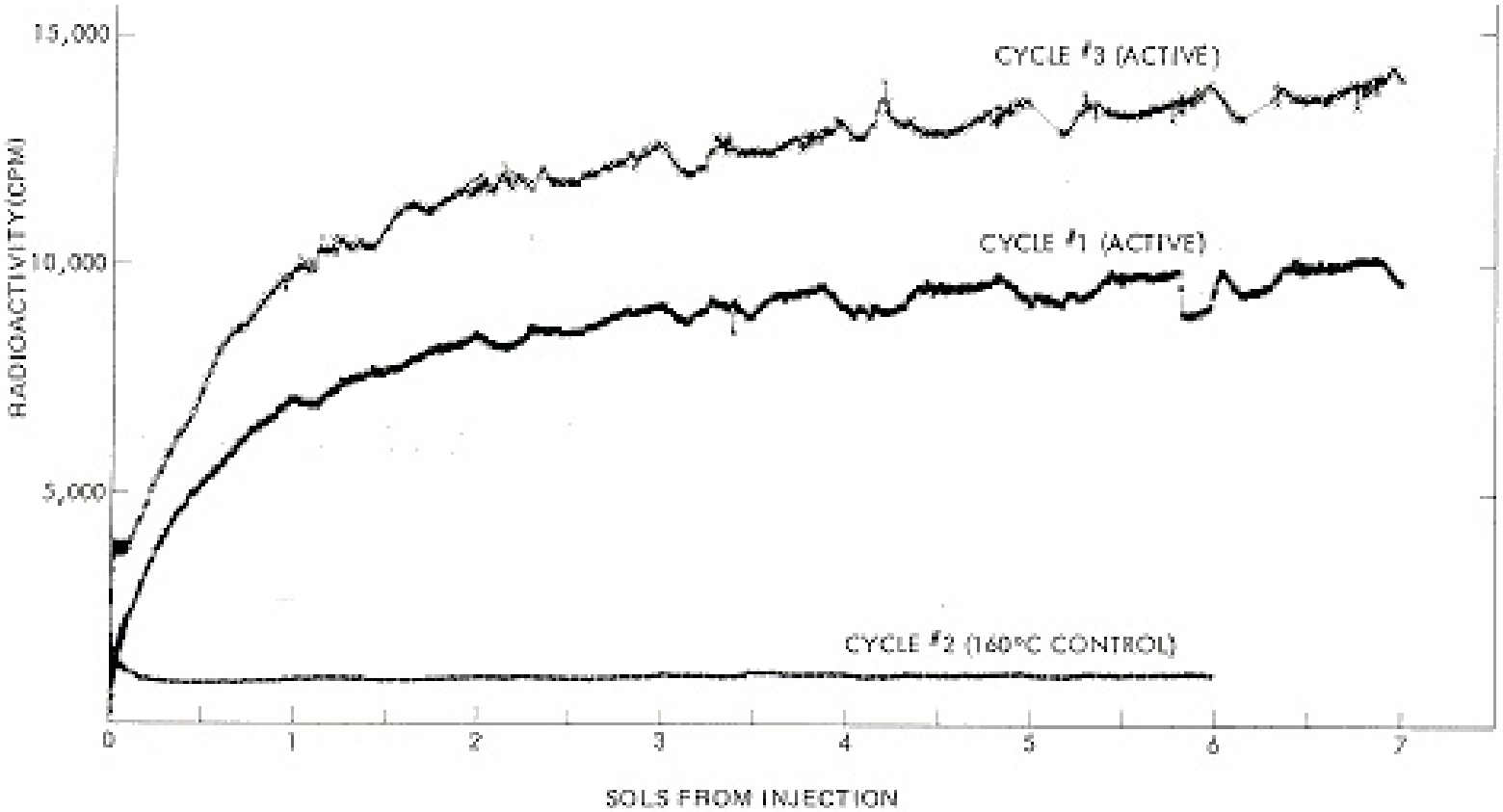


Fig. 3. Viking 1 LR data.

Are these results consistent or inconsistent with the hypothesis of organic life on Mars?

Actual data from LR experiment on Viking 2

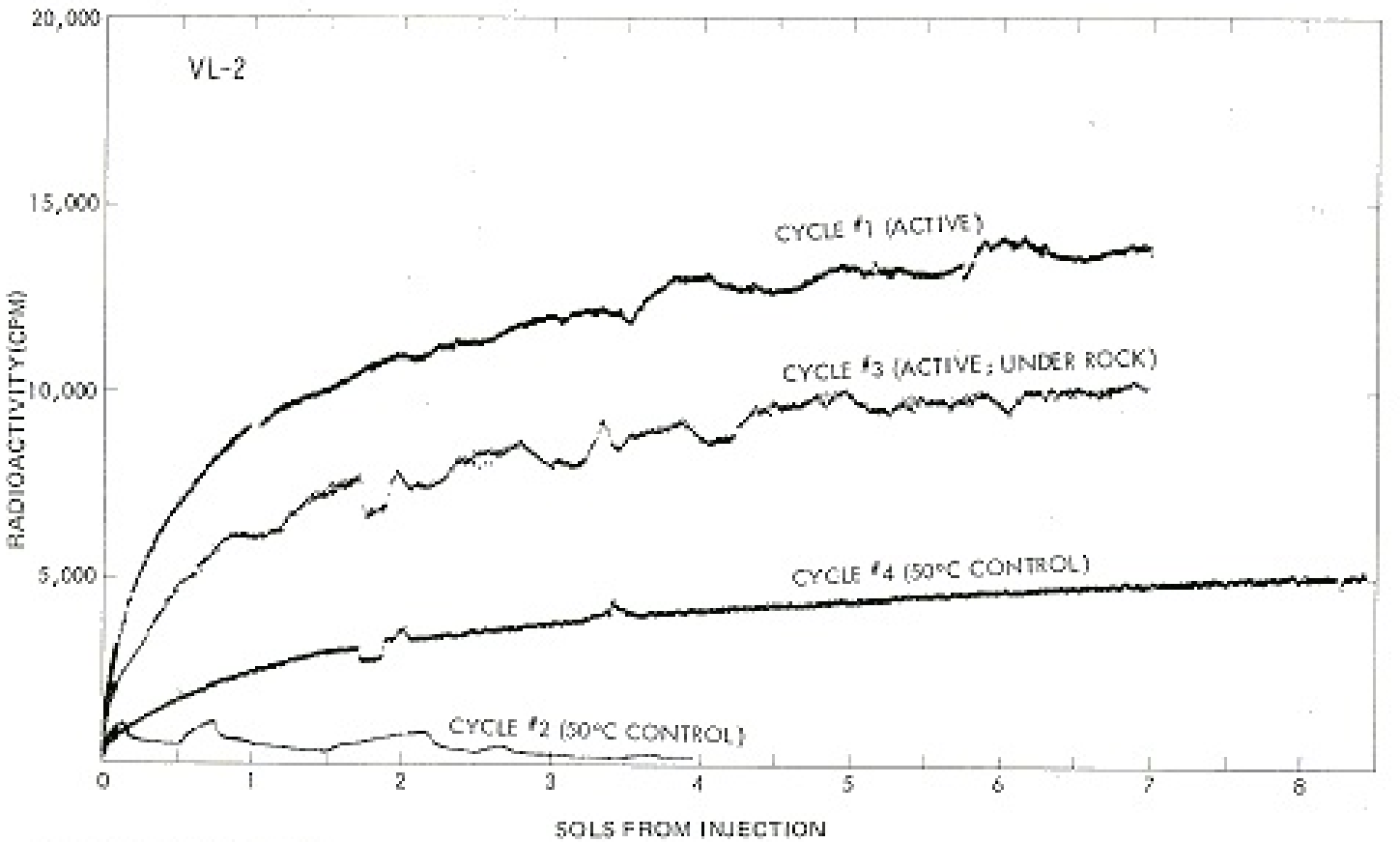


Fig. 4. Viking 2 LR data.

Are these results consistent or inconsistent with the hypothesis of organic life on Mars?