EVIDENCE FOR ANCIENT LIFE IN MARS METEORITES: LESSONS LEARNED. D. S. McKay, Mail Code SN, NASA Johnson Space Center, Houston TX 77058, USA (david.mckay@ jsc.nasa.gov).

The lines of evidence that we first proposed [1] might support a hypothesis of early life on Mars are discussed by Treiman [2] who presents pros and cons of our hypothesis in the light of subsequent research by many groups. Our assessment of the current status of the many controversies over our hypothesis is given in Gibson et al. [3]. Rather that repeat or elaborate on that information, I prefer to take an overview and present what I think are some of the "lessons learned" by our team in particular, and by the science community in general as a result of the martian meteorite studies:

1. Mars meteorites are more complicated than we thought. Returned Mars samples are likely to be more complicated than we can imagine.

First, we have learned that ALH 84001 is an exceeding complex rock which has had multiple shock and heating events (Treiman—meteoritics). It is an igneous rock with an overprint of impact features and secondary alteration some of which is high temperature and some of which is low temperature (Gooding, Wentworth). The time and place of the low temperature alterations are not well understood. Some may have occurred on Mars and some may have occurred in Antarctica. One of the first lessons is that, at least for Antarctic meteorites is that it is very difficult (but not impossible) to separate indigenous features from features acquired in Antarctica or the laboratory. However, it adds enormously to the task of reconstructing the histories of these meteorites. For returned Mars rocks, we will be dealing with samples from a planet whose geologic history is only poorly understood, whose impact, volcanic, sedimentary, metamorphic, and weathering processes are each major mysteries. The returned samples are likely to show effects of any of these processes and may show effects of all of them. And that's before we consider the possible effects of living systems. Unless we are extremely careful, we may also have alteration and contamination acquired during sampling, return, unloading, and initial processing. Then we are faced with a situation analogous to the Antarctic contamination problem.

2. We need better and more reliable biomarkers.

The problem with ALH 84001 is not the lack of potential biomarkers. It clearly has *potential* biomarkers including organic compounds (PAHs, amino acids, and kerogen-like forms), carbonates, magnetites, sulfides, and fossil-like forms. The problem is that we do not understand any of these biomarkers well enough to be confident that the properties of these features in ALH 84001 truly indicate life-related processes as opposed to strictly non-biologic processes. Are the minerals precipitated by strictly inorganic chemistry, or with the aid of living organisms or with the aid of organic compounds derived from living organisms? Are the PAHs and amino acids all derived from living systems or were they generated by inorganic processes? (This is a separate question from possible Antarctic contamination). Are the fossil-like morphologies truly formed from microbes and their products or are they formed by non biologic precipitation? Is the extreme carbon isotope fractionation a result of biologic processing? All of these features are present in ALH 84001. But do we understand their properties and occurrences well enough to be confident which are true biomarkers and which are impostors? I think the answer is no. Before we bring samples back from Mars we must have in a data base, a set of tested, reliable, and certified biomarkers with well-documented distinguishing properties so that we can search for and describe these biomarkers in the returned samples and use them to unequivocally answer the question of whether or not there is evidence for life in these Mars samples. We need to be confident that the biomarkers we use cannot be formed by any conceivable non biologic process. We also need to decide whether a single biomarker is sufficient or whether we need several. Conversely, we need to decide whether the absence of known biomarkers is sufficient to eliminate the possibility of Mars life.

3. We need ways to date secondary processes.

It has been extraordinarily difficult to date the age of the carbonate pancakes in ALH 84001. No one has attempted to date the multiple shock and heating events recorded in this sample. The formation age of the magnetites, iron sulfides, gypsum, and other secondary minerals is simply not known. If we could date their formation ages, we would have a better understanding of the rock history, the possibility that some are biomarkers, and even where they were formed. Returned Mars rocks (as well as samples from Europa, Titan, Io, etc.) are likely to also have both primary features and secondary features, and telling them apart and determining their formation and alteration timetables becomes very important to understanding their history. Primary crystallization age dating, while important, is not the only game in town.

4. A robotic mission analyzing ALH 84001 would have totally missed the data, the hypothesis, and the whole controversy.

If we had sent a mission to Mars and that mission encountered ALH 84001 on the surface and analyzed with the Pathfinder/Sojourner instruments or the instruments proposed for subsequent lander missions, it is likely that the data and observations would not have included any of the major lines of evidence we and others have described in this rock: PAHs and their location and profile, submicrometer minerals of several types, carbonate pancakes of widely ranging mineral, elemental, and isotopic compositions, and small microfossil-like features. Furthermore, without the

ALH 84001 experience, it is unlikely that a rock with a basaltic composition and obvious igneous texture, would even be considered as a possible site for microbial life forms. None of the data which has caused the controversy about ALH 84001 comes from the bulk major element composition or the major mineralogy. If we only had that data, however accurate, we would likely have missed what we consider to be the most interesting features of this rock.

This is not to criticize the flight instrument packages, but to point out how subtle and small the features are, how important their spatial locations are within the rock, and how difficult it is to analyze for them. Clearly, the entire ALH 84001 controversy could only come from analysis of returned rocks analyses with complex state-of-the-art laboratory equipment.

5. It is sometimes difficult to either prove or disprove a hypothesis.

Our original hypothesis was that several observed features in ALH 84001 could all be reasonably explained by the presence of early life on Mars. This was a hypothesis and the original paper was filled with qualifiers. The hypothesis was based on circumstantial evidence or scientific observations of several different types, and the hypothesis seemed to explain all of the evidence with a single kind of event, namely the presence in the rock of microbial activity. Many other investigators have been able to reproduce our original data, although a number of new kinds of data have been added by others to our original observations. Only in one or two cases have completely contradictory data been reported.

Refuting one line of circumstantial evidence supporting a hypothesis (by either showing that the data were wrong or that the proposed explanation can be replaced by a clearly better one) does not mean that the hypothesis is wrong, it simply means that that line of circumstantial evidence is incorrect. While it may weaken the case for the hypothesis, it does not invalidate the hypothesis. Only when all proposed lines of evidence supporting a hypothesis are refuted can that hypotheses be considered to be wrong (and wrong hypotheses may benefit scientific progress as much as right ones). A hypothesis can be also be considered wrong if none if its predictions are correct.

Conversely, the hypothesis can only be proven to be correct when either multiple kinds of circumstantial evidence become overwhelming, or a single line of evidence is so strong that it cannot be explained by any alternate hypothesis — in other words, a smoking gun. A hypothesis can be greatly strengthened if its predictions are subsequently shown to be true. In our view, the ALH 84001 hypothesis of early life on Mars is still valid and has neither been adequately refuted nor adequately proven. The people who propose a hypothesis are not necessarily responsible for proving it because they may not have the correct tools, technical specialties, or samples, although they may have a moral obligation to either try to prove it or to refute it themselves. For ALH 84001 and the other Mars meteorites, the question is still open, and may not be answered until martian samples are returned by a space mission.

When we do get samples back, we should expect that a number of different hypotheses will be advanced by various investigators, because as discussed above, the rocks (and soils) may be very complex and may record many overlapping processes. The hypotheses advanced to explain their features may even be mutually exclusive and contradictory. But we should concentrate on the data, give all the hypotheses a fair hearing, and attack the problems, not the people.

References: [1] McKay et al. (1996) *Science, 273*, 924. [2] Treiman, this volume. [3] Gibson et al., this volume.