IN SITU ABSOLUTE AGE DATING: SAMPLE RETURN SCIENCE AT A DISCOVERY PRICE. J. B. Plescia[1], [1]The Johns Hopkins University, Applied Physics Laboratory, Laurel, MD (jeffrey.plescia@jhuapl.edu).

Introduction: Understanding the absolute chronology of geologic events on Mars is critical to understanding the geologic, climatologic and possible biologic evolution of the planet. Unlike the Moon, the absolute chronology of Mars is not tied to an analysis of returned samples but rather is based on extrapolations from the lunar data. The result is that significant uncertainties exist in the absolute timing of events. This issue can only be solved by the determination of an absolute age of a sample whose geologic context is well understood. Such analyses have been argued to require the return of a sample to the Earth for an analysis; here I argue that such analyses can be made *in situ* with sufficient precision in a Discovery class mission to achieve the required data. This was the basis for the proposed Mars Scout mission - Urey.

Martian Chronology: The chronology of geologic and climatological events on Mars has been firmly established in a stratigraphic context (i.e., one surface or event is older or younger than another) [1]. However, the absolute timing of events is, in my opinion, weakly constrained as the martian cratering chronology has not been independently determined but estimated only by extrapolation of the lunar chronology [2-7] and that extrapolation carries with it all of the uncertainties of the lunar chronology [8-10] as well as uncertainties that apply only to Mars (e.g., atmospheric pressure variations over time).

In Situ Chronology: A number of instruments concepts for *in situ* dating have been proposed and studied that will provide an absolute age of an igneous rock. Potential techniques include K-Ar, U/Th-He, U/Th and cosmogenic nuclides [11]. The K/Ar, Rb/Sr and cosmogenic nuclide systmes have been studied and significant developments of laboratory and field instrument have been achieved [12-19] making them viable, relatively low risk instruments for flight.

In situ analysis is certainly not as precise as can be achieved in a terrestrial analysis and the number of techniques that can be applied is limited. However, the question is one of low precision vs. no precision. [20-21] have defined some of the requirements and challenges for a viable martian K/Ar system.

Landing Sites: The landing site that is selected for such a mission must consist of igneous rocks forming a surface for which accurate crater counts can be established. That surface should also be as pristine as possible in that it has not been extensively buried, eroded or altered. Regions such as Lunae Planum or the Cerberus Plains represent simple, volcanic surfaces for which an igneous age of the surface volcanics would provide an estimate of the absolute emplacement age of that surface.

In terms of calibrating the cratering chronology, there is a trade-off between determining an absolute age and crater counts. Young surfaces such as Cerberus have volcanics that have the least likelihood of being altered, allowing for a straightforward age determination. However, those surfaces are also lightly cratered with a correspondingly high statistical uncertainty in the crater counts. A range of potential fluxes could be fit through a data point for Cerberus considering both the cratering and analytic uncertainties. Older surfaces such as Lunae Planum have a higher probability of surface alteration which may complicate the analysis. However, these surfaces have much higher crater frequencies and thus a correspondingly smaller statistical uncertainty. Given the older age, a more limited range of potential fluxes would be consistent with the data.

Sample Collection: The techniques that have been studied require only very small samples. However, that sample must be of fresh, pristine rock. Acquisition of fresh rock, under controlled conditions, is mostly easily accomplished by a small robotic drill that acquires cores of a few mm diameter. A small core also allows easy penetration below any altered surface patina. A more significant problem would be surface aeolian cover. Images and thermal data indicate that much of the martian surface is covered with some amount of aeolian material. It could well be that the actual landing occurs on such material preventing direct access form the lander. To avoid this issue a lander-mounted drill could be used to penetrate through the aeolian material into bedrock and acquire a sample. Alternatively, a simple (assuming that word can ever be used for a planetary mission) fetch rover (Pathfinder scale), possibly tethered to the lander, could be used to reach exposed rock and acquire a sample. In order to obtain a statistically significant analysis, multiple samples from the lander-mounted core or from different surface exposures would be analyzed.

Spacecraft: The Urey mission (not to be confused with the Urey organic detection instrument) proposal in 2002 to the Mars Scout Program demonstrated the payload and basic implementation required for such a mission. The mission employed the "spare" 2001 Mars lander and a small Pathfinder-like rover, launched on a Delta II. The instrument suite for such an *in situ* dating mission would include the absolute chronology instrument (ideally two independent isotopic systems) with associated components, a mineralogical analysis system (e.g., XRD), elemental analysis (e.g., XRF, LIBS), and imaging. As noted above, a rover or lander drill as well as a sample transfer and manipulation system would be required.

The total mass of the Urey Mars Scout system was estimated at about 650 kg (wet, including margin), which was well within the capabilities of the Delta launch vehicle. Figure 1 illustrates the system concept from that mission.

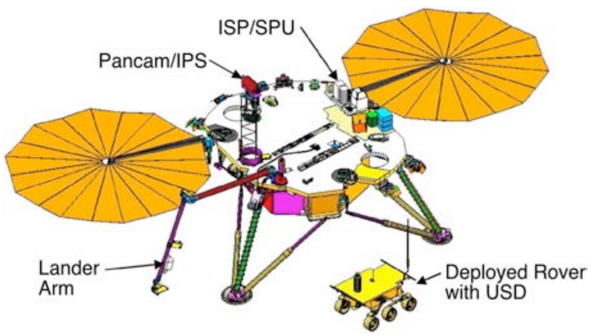

Figure 1. Lander concept with small fetch rover.

Figure 2 illustrates the instrument and system placement on the spacecraft deck.

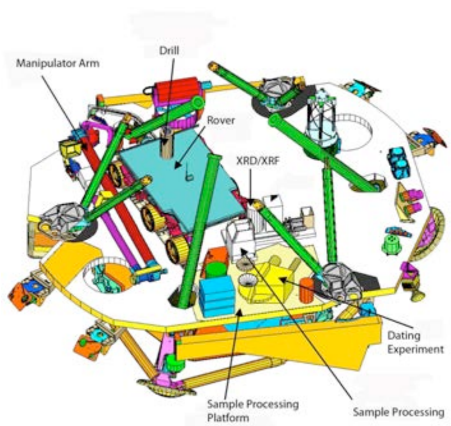

Figure 2. Spacecraft deck layout.

Discussion: The objectives of such an *in situ* age dating mission are to place constraints on the absolute chronology of Mars. Once that is established, the longevity of various geologic and climatologic processes can be verified. In order to accomplish such a goal, age determination precision can be relatively low, 20%. Once a calibration point is established, then the absolute ages of other surfaces would be more accurately established. Most the recent geologic events on the planet have produced surfaces of sedimentary materials which are not easily dated by radiometric techniques, but which have been placed in a stratigraphic context by crater counting.

For example, the question could be posed whether the Cerberus volcanic plains have an age of a few million years, a few hundred million years, or billions of years. The Cerberus plains are the youngest large-scale volcanic surface on the planet. Depending upon the age determined, it would not only provide a calibration point for the absolute chronology for various surfaces but would also provide important constraints on the long-term geologic and thermal history of the planet. The implications of an age of a few million years vs. hundreds of millions is profound in terms of the interior thermal history of the planet.

Summary: A mission of a Discovery-class scale could be used to address fundamental science questions of Mars. The mission would provide an absolute age for an appropriately chosen volcanic surface which in turn would provide an absolute calibration for the martian impact cratering flux. Once the flux can be calibrated, then the absolute age of other surfaces across the planet will known with significantly better accuracy.

References: [1] Tanaka K. L. (1986) *Proc. 17th LPSC, JGR, 91*, Supplement, 139-158. [2] Neukum, G., et al. (2001) Space Sci. Rev., 96, 55-86. [3] Hartmann W. and Neukum, G. (2001) Space. Sci. Rev., 96, 165-194. [4] McEwen, A. and Bierhaus, E. (2006) Annu. Rev. Earth Planet. Sci., 34, 535-567. [5] Ivanov B. (2001) *Space Sci. Rev., 96,* 87-104. [6] Hartmann, W., and Werner, S. (2010), Earth Planet. Sci. Lett., 294, 230-237. [7] Michael, G. and Neukum, G. (2010) Earth Planet. Sci. Lett., 294, 223-229. [8] Neukum, G. (1977) Phil. Trans. Roy. Soc. London, A, 285, 267-272. [9] Hartmann, W., et al. (2000) in Origin of hte Earth and Moon, U. Ariz. Press, 493-512. [10] Stöffler D. and Ryder G. (2001) *Space Science Rev., 96*, 9-54. [11] Doran, P. et al. (2004) Earth Sci. Rev., 67, 313-337. [12] Swindle T., et al., (2003) 34th Lunar Planet. Sci. Conf., Abstract 1488. [13] Swindle, T. (2001) 11th Goldschmidt Conf., Abstract 3718. [14] Swindle, T. (2001) 32nd Lunar Planet. Sci. Conf.., Abstrac 1492. [15] Plescia, J. and Swindle, T. (2007) 7th Int. Conf. Mars, Abstract 3278. [16] Anderson, F., et al. (2007) 38th Lunar Planet. Sci. Conf., Abstract 2153. [17] Anderson, F., et al. (2012) 43rd Lunar Planet. Sci. Conf., Abstract 2844. [18] Anderson F. and Nowicki, K. (2011) 42nd Lunar Planet. Sci. Conf., Abstract 2067. [19] Anderson, F., and Nowicki, K. (2009) 40th Lunar Planet. Sci. Conf., Abstract 2290. [20] Bogard, D., 2009, Met. Planet. Sci., 44, 3-14. [21] Park, J., et al. (2009) AAS, DPS, Abstract 68.21.