AN IN-SITU K-AR ISOCHRON DATING SYSTEM FOR A MARS ROVER MISSION.

Y. Cho[1], S. Kameda[1], Y. N. Miura[2], H. Miyamoto[3], and S. Sugita[4], [1]Dept. of Physics, Rikkyo University (3-34-1 Nishi-Ikebukuro, Toshima, Tokyo Japan; cho@rikkyo.ac.jp), [2]Earthquake Research Institute, Univ. Tokyo (1-1-1 Yayoi, Bunkyo, Tokyo, Japan), [3]The University Museum, Univ. Tokyo (7-3-1 Hongo, Bunkyo, Tokyo, Japan), [4]Dept. Complexity Science and Engineering, Univ. Tokyo (5-1-5 Kashiwanoha, Kashiwa, Chiba, Japan).

Introduction: Understanding the evolution of habitable environments on ancient Mars is one of the primary goals of Mars science. We have been developing an in-situ K-Ar isochron dating instrument to measure the age of rocks on Mars. We are investigating the preliminary design of an in-situ dating system for a future Mars rover mission including a Japanese one. Here we outline the scientific objectives, proposed measurement protocols, and the demonstration experiments results using our bread board model.

Science objectives: The scientific goal of our instrument is to understand the nature of the climate change on Mars by determining the absolute age of the Noachian/Hesperian transition. We use the potassium-argon (K-Ar) isochron dating method for measuring the age of rocks on Mars. Such age determination will help improve the accuracy of Martian crater chronology as well.

The K-Ar dating method employs radiometric decay of ^{40}K into ^{40}Ar with half-life of 1.27 Gyr [1]. The K-Ar dating method is easier than other dating methods, such as Ar-Ar, U-Pb, and Sm-Nd dating, because K is relatively abundant in the igneous rocks and Ar can be easily extracted (i.e., simply heat the sample), which leads to a simpler instrumental configuration. Several research groups including ours have developed an isochron-oriented in-situ dating method based on the K-Ar system for future landing planetary missions [2-9].

Recently, Curiosity carried out the first in-situ dating experiment on Martian rock and obtained 4.21±0.35 Ga for a mudstone on the floor of Gale crater [10]. However, the age of the mudstone does not necessarily reflect the age of the geologic unit covering the Gale crater; thus, the absolute age of the Noachian/Hesperian boundary has yet to be determined.

In addition to age data, characterizing the geology of the rocks recording the climate change is important for understanding the environment around the radical climate change. Thus, we propose to conduct geochemical experiments using elemental- and gas-analysis instruments.

Instruments suite: In order to obtain good isochron age measurements, it is very important to find fresh (unaltered) rocks with high enough K concentrations and simple geological context. To find such rocks, we need to measure elemental compositions, minerals, and textures of rock samples. Furthermore, these rocks must represent the geologic unit we desire to date.

The instrument suite consists of three subsystems: LIBS, TOFMS, and sampling devices. The LIBS subsystem includes a laser, a spectrometer and a camera for the context imaging of the LIBS measurements spots. The TOFMS subsystem is composed of a TOFMS, a vacuum chamber, a getter, valves, manifolds, and a turbomolecular pump (Fig. 1). The sampling subsystem is dedicated to selecting and acquiring appropriate rocks for in-situ dating. This subsystem includes a dust removal tool, an imager, a ground penetrating radar (GPR), a coring device, and a sample delivery system (Fig. 2).

Measurement protocols: To achieve the science objectives, we propose to land on a geologic unit recording the transition from clay-rich Noachian to sulfate-rich Hesperian [e.g., 11]. We are currently seeking for such a landing site using remote sensing images and spectral data obtained by OMEGA/Mars Express and CRISM/Mars Reconnaissance Orbiter. After a successful landing, a navigation camera onboard the rover observes the geologic context around the landing site to find rocks suitable for dating. The rover moves around and stops over the rock, taking close-up images of the rock by an imager. The LIBS instrument measures the elemental composition of the rock before the sample acquisition. The ground-penetrating radar (GPR) observes the structure in the ground to a depth of ~10 m to assess whether the rock is a part of bedrock or just a float stone derived from some other places on Mars. If the rock is turned out to be appropriate for K-Ar dating, a rock core sample is acquired and delivered into the sample chamber (Fig. 3). The chamber is locked and evacuated by the pump. The LIBS-MS measurements are then carried out on the cylindrical surface of the rock core. We repeat the LIBS-MS analyses for 5-20 spots for each sample to obtain a K-Ar isochron. In the baseline plan, we are going to measure more than five rocks for dating experiments.

Vacuum sealing is an essential part of gas analyses. In terrestrial laboratories, noble gas analyses are carried out by using metal gaskets. An O-ring seal is easier to use because it requires smaller force than a metal gasket seal does. We have conducted a series of noble gas experiments for evaluating the capability of Orings instead of metal gaskets. Our preliminary results indicate that the degassing from a Viton O-ring is low enough for Ar measurements. We also found that the amount of atmospheric Ar penetrating into the chamber may be negligible under the Martian atmospheric pressure (i.e., ~6 torr).

Isochron measurement demonstration: We measured a couple of gneiss slabs to examine the capability of isochron measurements for natural rocks. A hornblende-biotite-bearing gneiss (485±35 Ma) and a pyroxene-bearing gneiss (1050±10 Ma) were used for the experiment. A more detailed description about the experiment can be found in [5].

When we construct a K-Ar isochron (i.e., $^{40}Ar/^{36}Ar$ vs. $^{40}K/^{36}Ar$), the data points follow a straight line well, strongly suggesting the feasibility of isochron measurements with our LIBS-MS approach. The hornblende-biotite gneiss yielded an isochron age of 640±120 Ma, which is systematically larger than the known value by ~30% but consistent with the reported K-Ar ages within 2-sigma error. This deviation would be attributed to a K calibration curve drift with time [12]. From the intercept of the isochron, we obtained the initial Ar isotopic ratio $^{40}Ar/^{36}Ar$ of 480±130, which is comparable to that of terrestrial atmospheric contamination ($^{40}Ar/^{36}Ar$=296). This also suggests that the isotopic composition of trapped Ar is measurable with this approach. The ability of measuring initial Ar isotopic ratio in magma is important because such measurements would provide insights into the evolution of the parent magma.

Age estimation error and implications for in-situ dating on Mars: The types of rocks and K concentration vary greatly on planetary surfaces depending on geologic units. Thus, we assess the capability of our in-situ K-Ar dating method taking the petrologic properties including K abundance and possible age range of Mars surfaces into account. We calculated the age determination errors as a function of the concentrations of K and radiogenic ^{40}Ar (i.e., age), based on the error propagation of K and Ar measurements. The relatively high (1-3 wt%) K content of rocks found in Gale crater or Gusev crater [13, 14] and the crater model age of the Noachian/Hesperian transition [15] suggest that the K-Ar ages of the rocks recording the Noachian/Hesperian transition would be measurable with 10-15% error.

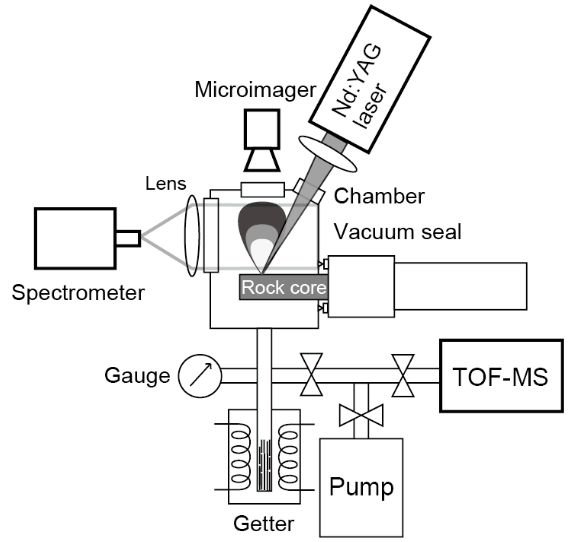

Fig. 1: Schematic diagram of a LIBS-TOFMS measurement. The concentrations of K and Ar are measured with LIBS and TOFMS, respectively.

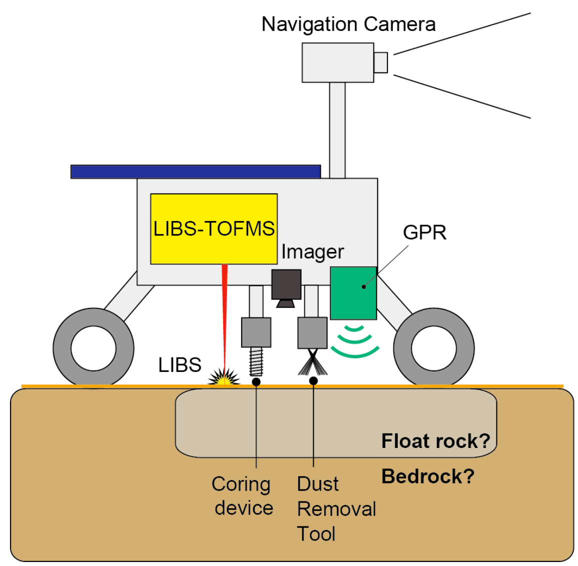

Fig. 2: Conceptual design of a rover equipped with the LIBS-TOFMS instrument, GPR, and the sample acquisition tools. GPR is used to check whether the rock is a part of bedrock or just a float stone.

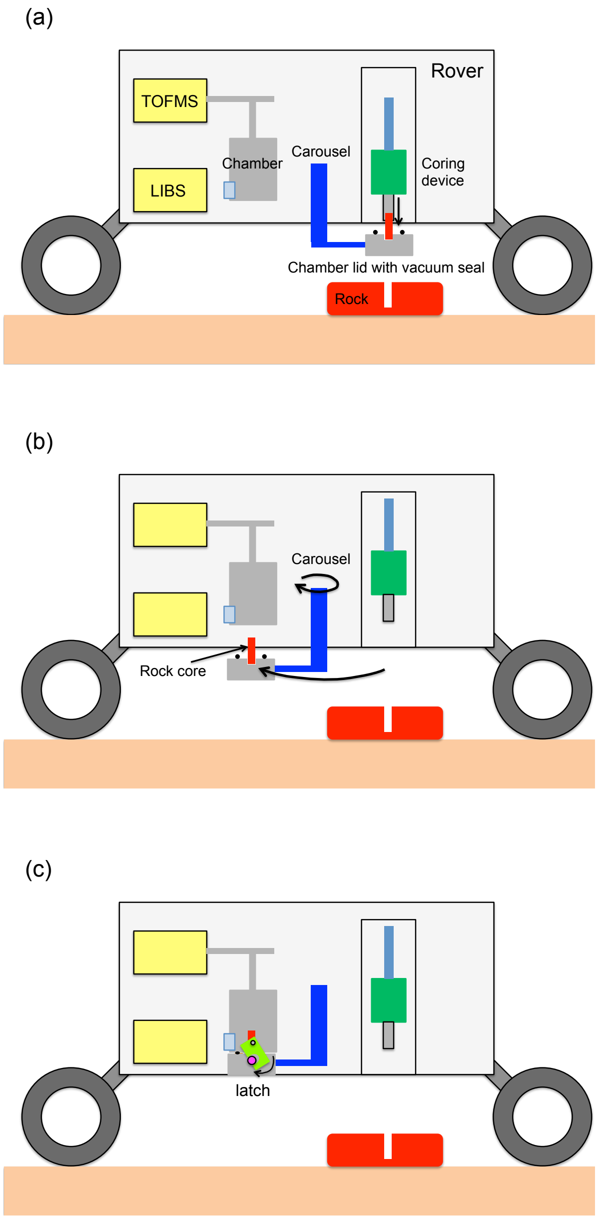

Fig. 3: Schematic diagram showing the sample delivery procedure. (a) A rock sample acquired by a coring device is transferred to a chamber lid. (b) A carousel delivers the rock core toward the position just below the sample chamber. (c) The rock core is inserted into the chamber as the lid elevates. A latch locks the chamber lid, producing a sealing force adequate to maintain vacuum.

References:

[1] Steiger R. H. and Jäger E. (1977) *EPSL, 36,* 359-362. [2] Cho Y. et al. (2011) *PERC Planet. Geo. Field Symp.*, 30. [3] Cho Y. et al. (2012) *IPM-2012*, Abstract #1093[4] Cho Y. et al. (2013) *LPS XLIV*, Abstract #1505. [5] Cho Y. et al. (2014) *LPS XLV*, Abstract #1205. [6] Cohen B. A. (2012) *LPS XLIII*, Abstract #1267. [7] Cohen B. A. et al. (2013) *LPS XLIV*, Abstract #2363. [8] Cohen B. A. et al. (2014) *LPS XLV*, Abstract #1140. [9] Devismes D. et al. (2013) *EPSC VIII*, 71. [10] Farley K. A. et al. (2014) *Science*, 343, 1247166. [11] Bibring J. P. et al. (2006) *Science*, 312, 400. [12] Cho Y. et al. *Spectrochim. Acta B*, in revision [13] Stolper E. M. et al. (2013) *Science*, 341, 1239463. [14] Ming D. W. et al. (2008) *JGR*, 113, E12S39. [15] Deit L. L. et al. (2013) *JGR*, 118, 1-35.