END-TO-END VALIDATION OF AN IN-SITU K−AR ISOCHRON DATING METHOD FOR PLANETARY LANDERS: ISOCHRON ANALYSIS OF NATURAL ROCKS.

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Introduction: The absolute age of a rock is an important observable for interpreting the geologic record of planetary surfaces. In the Curiosity mission, Farley et al. [1] performed a milestone in situ geochronology experiment on Mars, demonstrating the feasibility of K−Ar dating on another planet. While the interpretation of the obtained age (4.21 ± 0.35 Ga) is still difficult due to the complexity of the nature of the measured mudstone, this measurement underscored the value of geochronology during rover explorations.

Several groups or researchers including ours have been developing an isochron-based in situ K−Ar dating method [2−14] to improve the capability of K−Ar dating on Mars and to solve problems concerning whole-rock analyses, including excess ^{40}Ar and insufficient Ar degassing with an onboard furnace [15]. This approach uses the combination of flight-proven techniques: laser-induced breakdown spectroscopy (LIBS) [16] and a quadrupole mass spectrometer (QMS) [17] for K and Ar measurement, respectively. For example, Cohen et al. [10] developed a K−Ar dating method called KArLE (K−Ar Laser Experiment) and reported isochron ages for a 28 Ma tuff and a 1714 Ma granite using their breadboard instrument. Devismes et al. [13] reported the measurement of a 160 Ma basalt using a UV laser. Our group has developed a possible design of the actual geochronology instrument suite for a rover [4, 7]. We also conducted end-to-end experiments using our breadboard instrument to examine the performance of the K−Ar isochron method. In this abstract, we summarize the results obtained in our recent paper where we measured two gneiss slabs to validate the isochron analysis [6].

K−Ar dating experiment: We placed two gneiss samples in a vacuum chamber. The different portions of the samples, preferably various minerals containing different K concentrations, were measured by laser pulses. The laser spot was approximately 500 μm in diameter. A series of laser pulses excavate the samples and liberate K and Ar simultaneously. The emission line of K at 769 nm was measured to obtain the concentration of K in each ablation pit [5]. The QMS measured the abundance and the isotopic composition of Ar after the purification by a getter. Here, the mass of the sample needs be determined to relate the concentration of K (wt%) with the absolute amount of Ar (cm^3 STP, or mol). We estimate the ablated volume and multiply it by the density of the sample to estimate the sample mass that released K and Ar. In this study, however, we used an external microscope to measure the volume of the pits. In actual missions, the pit volume would be measured either with an imager [18] or with the feature of LIBS spectra [12]. We also used the bulk density of the rock slabs here for age calculations. The elemental and mineral compositions obtained by LIBS may be used for the density estimation in a flight instrument [10].

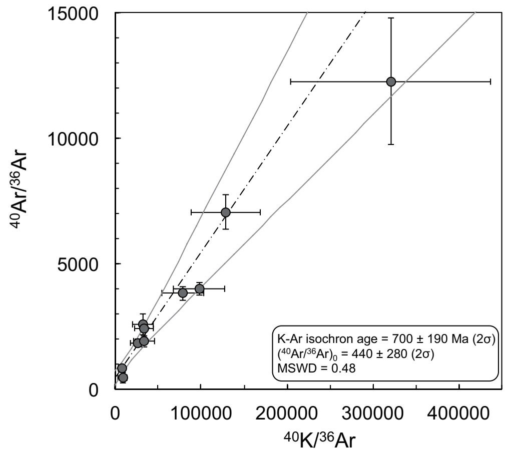

Fig. 1 K−Ar isochron for the hornblende-biotite bearing gneiss [6].

Isochron results and discussion: We obtained a K−Ar isochron (^{40}Ar/^{36}Ar vs. ^{40}K/^{36}Ar) for a gneiss containing hornblende and biotite phenocrysts. The data points distribute along a straight line, strongly suggesting the feasibility of isochron measurements with our LIBS−MS approach (Fig. 1). The isochron slope yielded the age of 700 ± 190 Ma (2σ), which is consistent with the K−Ar age obtained with conventional method with biotites. The isochron intercept exhibited a trapped Ar isotopic ratio of ^{40}Ar/^{36}Ar = 440 ± 280, which is consistent with that of atmospheric contamination (^{40}Ar/^{36}Ar = 296). This non-zero intercept suggests that the isotopic composition of trapped Ar is measurable with our approach. Such a measurement is useful for understanding the evolution of parent magmas or planetary atmosphere trapped as the magma solidified.

In contrast, we could not derive the K−Ar isochron for the other sample (a gneiss containing pyroxene crystals) because it had very low ^{36}Ar contents from the terrestrial atmosphere. Thus, we also constructed ^{40}Ar−K plots based on the concentrations of K and ^{40}Ar. The "isochron" slopes yielded 420 ± 210 Ma of age for the 492 ± 30 Ma hornblende-biotite gneiss and 1050 ± 190 Ma for the 1052 ± 58 Ma pyroxene gneiss, demonstrating the validity of this approach. The intercept of the ^{40}Ar−K plot of the pyroxene gneiss yielded a best-fit trapped ^{40}Ar concentration on the order of 10^{-6} cm^3 STP/g, comparable with the amount of excess ^{40}Ar contained in the shergottites [15]. These results strongly suggest that the LIBS−MS method is capable of deriving both isochron age and the contribution of initially trapped ^{40}Ar with local analyses of different minerals in a single rock.

The spot-by-spot analysis has several advantages over whole-rock analysis techniques proposed in previous studies. For example, a wide range (e.g., a factor of ~50 in this study) of K contents obtained from different minerals in a single rock is favorable for obtaining accurate isochron. In addition, the degree of the departure of data points from a single straight line would enable us to assess whether or not the sample consists of minerals of different origins. Furthermore, if minerals with different closure temperatures coexist in a rock, these spots will follow different isochrons and thus we cannot obtain a single age. Nevertheless, such a result could provide information on the cooling rate of the parent magma.

Error assessment indicates that the in situ K−Ar dating with our LIBS−MS approach would determine the absolute ages of a variety of key geologic events for Mars evolution, such as Noachian/Hesperian and Hesperian/Amazonian transitions with 10−15% and 10−20% errors, respectively. Because no radiometric age data have been directly linked to a geologic unit on Mars yet, such a measurement will greatly improve our understanding of Martian history. Since the LIBS−MS system used in this study can be constructed with flight-equivalent components, landing geochronology using our method could be achieved with existing technologies.

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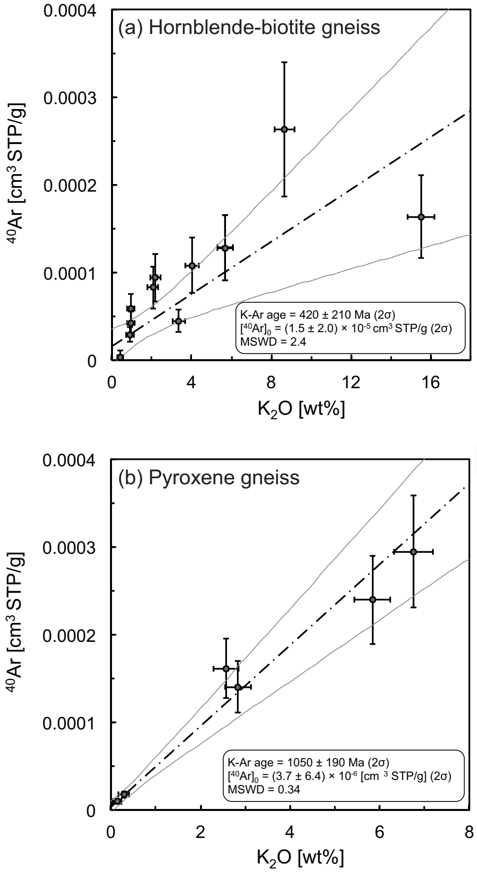

Fig. 2: ^{40}Ar−K plots for two gneiss samples [6].

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