

DEVELOPING OSL GEOLOGICAL DATING TECHNIQUES FOR USE ON FUTURE MISSIONS TO MARS. M. W. Blair^{1,2}, R. Kalchgruber¹, S. Deo¹ and S. W. S. McKeever¹, ¹Oklahoma State University, Department of Physics, 145 PS II, Stillwater, OK 74078, ²email: michael.blair@okstate.edu.

Introduction: The surface of Mars has been subject to aeolian, fluvial, and periglacial activity in the (relatively) recent past [1-4]. Unfortunately, chronological dating of recent events on Mars is difficult as the errors associated with crater counting are comparable to younger ages (~ 1 Ma). Consequently, techniques to quantify the ages of geological processes on Mars have become an important area of research [5,6].

Optically stimulated luminescence (OSL) dating is one candidate technique for *in-situ* dating of the deposition of Martian surface sediments [7]. This method can aid in developing a geological and climatic history of the last million years on Mars.

The current paper addresses some of the challenges and progress associated with developing OSL as a viable *in-situ* dating technique for Mars. Some of the challenges include the mineral composition, the effectiveness of solar resetting under Martian conditions, the temperature regime, and determining the natural dose rate on Mars. All of these topics are currently under investigation, and some preliminary results are presented.

OSL Dating Principles: Luminescence dating is based on solid-state properties of mineral grains that allow them to record their exposure to radiation. The recorded radiation exposure can be measured by stimulating the sample with light of one wavelength and monitoring the emitted luminescence at another wavelength (optically stimulated luminescence, OSL). The intensity of luminescence is a function of the absorbed natural radiation dose. If the *rate* of natural irradiation of the grains is constant and can be determined, then dividing absorbed dose by dose rate gives a radiation exposure age, according to:

$$\text{Age, } T \text{ (a)} = \frac{\text{Equivalent natural dose, } D_e \text{ (Gy)}}{\text{Annual dose rate, } R \text{ (Gy/a)}}$$

where the SI unit for dose is the Gy (Gray, 1 J/kg).

The equivalent natural dose (D_e) absorbed during burial may be determined from the response of the OSL signal to radiation. Most often the so-called single-aliquot regenerative-dose (SAR) procedure [9] (Table 1) is used to determine the D_e .

The technique of luminescence dating is well established for age-dating sediments on Earth. There is an abundance of published examples throughout the terrestrial geologic literature describing successful applications of the technique. Recent examples can be found in the proceedings of the Luminescence and

Electron Spin Resonance Dating conferences: *Quaternary Geochronology* V.13 no.5-7, V.16 no.3-5, V20 no.5-9.

Challenges on Mars:

Mineral composition. Much research has focused on identifying the minerals present in the Martian soil. Intermediate to calcic feldspars (Andesine, Labradorite, Bytownite), high-Ca pyroxenes (Augite, Diopside), volcanic glass, and hematite have so far been identified in the Martian crust, with small or no abundance of K- or Na- feldspars, olivine, sulfates, and quartz [10,11]. In principle most (if not all) of these minerals can be used with OSL dating procedures, but terrestrial dating techniques have only been developed using either quartz or K- or Na- feldspars. As a result, in order to develop relevant dating techniques for Mars there is a necessity to examine the OSL properties of many of the above materials.

Solar resetting. The entire premise of OSL dating is that the sediments to be dated were exposed to sufficient amounts of light at the time of deposition to erase any previously accumulated signal. In terrestrial applications, this “zeroing” of the signal is accomplished within a few minutes of exposure to sunlight [12], but the solar spectrum on Mars is different from that on Earth and may lead to different bleaching efficiencies.

Modeling of the Martian solar spectrum indicates that the visible part of the spectrum is less intense than that on Earth, but the UV portion of the spectrum (~200-300 nm) is more intense. As these differences in the solar spectrum may have profound consequences for OSL dating, we have simulated the Martian spectrum with a solar simulator and tested the bleaching characteristics of various feldspars. After bleaching irradiated samples for a few hours, a 10 % residual signal was still present in the samples. Initially bleached samples showed a small signal after the simulated sunlight exposure as well. However, the results are preliminary and the full implication of these experiments is not yet apparent.

Temperature regime. The OSL process is dependent upon temperature in several different ways. First, the ambient temperature of the sediments dictates which traps are thermally stable and contribute to the natural OSL signal. This subsequently impacts what thermal pretreatments are necessary within the SAR procedure to isolate geologically stable signals. Also, the intensity of the OSL signal is dependent upon the measurement temperature.

As the average ambient temperature on Mars is considerably lower than on Earth, research is being conducted to determine OSL characteristics at low temperatures. Initial research indicates that relevant minerals do have optically active traps at temperatures below (terrestrial) room temperature, and these traps may be important for OSL dating on Mars.

OSL procedures. The previously mentioned SAR procedure [19] has been effectively used for quartz and a slightly modified version has been shown to be effective for polymineral fine-grain materials [13]. The procedure uses the OSL signal from a test dose to monitor, and thereby correct for, any sensitivity changes that the sample experiences during the measurement process. For polymineralic grains a particular sequence of heating/annealing coupled with calibration irradiations (steps #2, 5 in Table 1) was found to be optimal for dating mixtures of quartz and feldspar grains. By using a range of regeneration doses, a calibration curve can be obtained and the natural dose can be determined through interpolation. In particular, our experiments show that the SAR procedure can be used for feldspars, but the two heating steps in the procedure should be identical in both temperature and duration [14]. Using this slight modification of the SAR procedure, we have been able to recover known laboratory doses from coarse-grain feldspar, quartz, quartz/feldspar mixtures, and other minerals. For example, measurements with labradorite and diopside indicate the potential to recover doses as high as 400 Gy, with an 8% deviation of the measured dose from the administered dose.

OSL dating procedures developed for use on Mars need to be focused on coarse-grain, polymineralic samples since a procedure for chemical mineral separation will likely not be possible on an *in-situ* instrument.

Dose rate calculations. The annual dose rate comes from a mix of galactic cosmic rays (GCR), solar particle events (SPE), and radioisotopes (U, Th, K) in the soil. For Mars, the contribution from radioisotopes expected to be considerably lower than on Earth (of the order of 0.4 mGy/yr [15]). Using particle transport calculations with the HZETRN code [16], the GCR and SPE contribution can be expected to be 53.7 mGy/yr at the surface of Mars [9]. Thus, down to a depth of ~2 m, the dose rate is expected to be dominated by GCR and SPE and a reasonable estimate of the dose rate can be calculated as a function of depth.

Summary: Developing OSL dating for use on the surface of Mars involves many scientific challenges that are currently being addressed as part of a PDIP project. OSL properties of minerals found on Mars, solar resetting under Martian conditions, the effects of

ambient temperature, development of a polymineralic procedure, and dose rate calculations are some of the topics being considered in current research. Overcoming these challenges may ultimately lead to a technique that can elucidate a wealth of knowledge about the recent geological and climatic activity on the Martian surface.

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| <ol style="list-style-type: none"> 1. Regeneration radiation dose (D_i) 2. Preheat at $T_x^{\circ}\text{C}$ for 10 s 3. Measure OSL at 125°C (R_i) 4. Fixed test radiation dose (TD_i) 5. Cutheat to $T_y^{\circ}\text{C}$ 6. Measure OSL at 125°C (T_i) 7. Repeat steps 1-6 for a range of regeneration doses 8. Find sensitivity-corrected OSL ($L_i=R_i/T_i$) |
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Table 1: Steps in the SAR procedure. T_x and T_y determined from experiment.