A NEW METHOD – POTENTIALLY SUITABLE FOR SPACECRAFT INSTRUMENTATION – FOR DATING RECENT VOLCANISM ON PLANETARY SURFACES.

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Introduction: Craters of the Moon National Monument and Preserve in Idaho (COTM) is a site of plains volcanism which has often been considered a planetary analog [1-3]. It is one of the study areas for the SSERVI team named FINESSE (Field Investigations to Enable Solar System Science and Exploration; J. L. Heldmann, PI [4]). While investigating volcanism at COTM and surroundings we have been exploring a method of dating the volcanism using the thermoluminescence properties of the lavas.

Thermoluminescence-based instruments have been proposed for robotic spaceflight application as a means of obtaining dates for recent fluvial and aolean processes [5,6]. The technique is relatively simple and the instrument has low weight, low power, and low data rate transmission needs. Previous groups are proposing to use the technique in the way it is used for Quaternary dating on Earth. That is, they use the natural TL signal to measure the radiation dose absorbed, determine the radiation dose for the environment, and divide the first quantity by the second to determine the time interval since the start of the build-up of the signal [7]. This would typically be the time since emplacement of the sample in the present location. Ages of up to 10^5 years are measureable above which the TL signal saturates and no longer changes with time. The technique is in widespread use terrestrially using optical stimulation, rather than heat, to release the signal.

While the apparatus is the same, we are proposing an entirely different approach based not on the accumulated natural TL signal, but the level of TL that can be induced in a sample by a standard radiation dose. We will call this “induced TL dating”. The approach derives from several decades of meteorite studies, both chondrites [8] and basaltic meteorites [9] where changes in induced TL are used to monitor time-dependent changes caused by metamorphism. The idea was briefly described in ref. [10]

There is some precedence for the approach explored here. In the late nineteen-seventies Rod May [11,12] showed that the induced TL of Hawaiian basalts increased with age. We decided to perform similar measurements to those of May as part of our studies at COTM [13]. With help from members of the FINESSE team, we collected basalt samples from 23 volcanoes of known age (Table 1) and measured their induced TL. We report the initial results here.

Table 1. COTM basalt samples, ages, and induced TL

Location	Age (ka)	Ind TL
Antelope Butte	470±25	626±127
Basalt of Portneuf Valley	430±70	4520±302
Big Cinder Butte NW	6.02±0.16	140±36
Blue Dragon flow	2.076±0.045	90±17
Carey Flow	12.01±0.15	116±57
Carey Kipuka flow	6.6±0.06	177±56
Cedar Butte	400±19	1620±35
Grassy	7.36±0.06	140±52
Grassy flow	7.36±0.06	375±206
Hell's Half Acre	5.2±0.15	31±7
Little Park flow	6.5±0.06	250±50
Mosby Butte	265±30	286±105
North Robbers	11.6±0.3	132±11
Packsaddle Butte	340±15	573±101
Pratt Butte	263±20	346±50
Quaking Aspen Butte	64±20	87±12
Serviceberry Butte	120±12	350±43
Split Top Butte	113±10	1106±61
Spud Butte	57±30	306±106
Sunset	12.01±0.15	245±64
The Blow Out	116±15	1233±321
Wagon Butte	120±25	1066±153

Methods: The basalt samples and their ages from the literature (radiocarbon and K-Ar methods) are listed in Table 1. The basalt samples were crushed and sieved and 4 mg aliquots placed in copper pans in a modified Daybreak Nuclear and Medical Co. TL rig. Crushing was gentle and performed in red light to avoid spurious effects. After draining the naturally present TL by a brief heating to ~500°C, samples were placed in a ^{90}Sr beta source and irradiated for 3 minutes. This gave an absorbed dose of 12.7 krad. Their induced TL was then measured. This was repeated three times to determine precision.

Results: The “glow curves” obtained (plots of TL against heating temperature) for the COTM basalts were very similar to the curves May obtained for his Hawaii samples. The induced TL values obtained range over a factor of 100, as indicated in Table 1 in counts per second. One sigma uncertainties in the TL data are about 20% compared with about 10% for the ages, but there is considerable variation on this and uncertainties are smaller for larger TL values.

Discussion: The similarity of the glow curves for basalts from Idaho and Hawaii suggests that similar mineralogy and processes operate at both sites. This is reassuring and suggests that the technique, if successful, can be applied to any volcanic site.

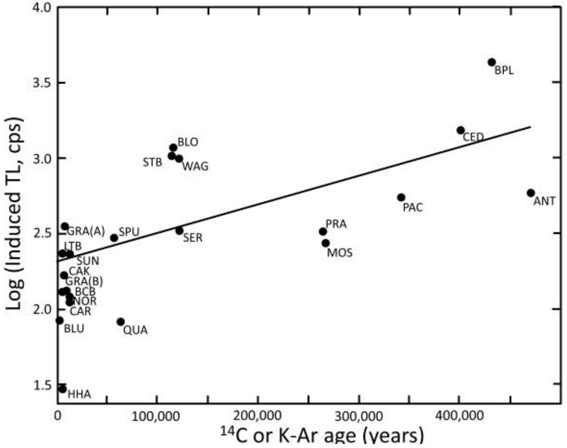

Figure 1. A plot of the log of the induced TL against the radiocarbon or K-Ar age for basalts from 23 volcanoes in the COTM region. The correlation has an R^2 value of 0.5, n = 23.

The induced TL values are compared with the radiocarbon and K-Ar dates in Fig. 1. A correlation is observed, similar to the correlation May reported for Hawaiian volcanics. While there is much to be resolved, such as the cause of the scatter in Fig. 1 and the large uncertainties on the TL data, there is the promise of a new, non-isotopic dating method being available for dating volcanic activity. Since there is no indication that the build-up in induced TL is saturating, and that pure feldspars have induced TL values 10^4-10^5 times higher that those of the present basalts, the technique could have a range of 10s or 100s of millions of years.

The main weakness of the radiocarbon method is that burned wood needs to be available for the flow being dated while the main weakness of the K-Ar method is the long half-life of ^{40}Ar and loss of Ar, although this is mitigated somewhat by the ^{40}Ar-^{39}Ar version of K-Ar dating. The main weakness of the TL method, while still in its early days, is that the mechanism needs to be identified and quantified so that the method can be put on an absolute basis and its applicability to various locations addressed. This is aside from needing to reduce the scatter and experimental uncertainty.

May suggested that the cause of the correlation between induced TL and age was that TL traps (electron storage locations) were being created by radiation damage. This was an idea he adopted from meteorite literature of the time. However, this mechanism has been disproved, at least for meteorites [14]. Instead, work with chondrite meteorites and basaltic meteorites indicates that induced TL levels are governed by mineralogical and phase changes in the mineral producing the signal, namely feldspar.

In the case of chondrites, the induced TL increases in strength by a factor of 10^5 in ordinary chondrites with increasing metamorphism experienced by the meteorite. The mechanism seems clear. The mineral responsible for the TL signal in ordinary chondrites is feldspar. Primary unmetamorphosed ordinary chondrites do not contain crystalline feldspar but instead the feldspathic elements are in glass. With metamorphism, the glass crystallizes and the TL signal increases. Thus induced TL is acutely sensitive to metamorphism, e.g., devitrification.

Induced TL also increases with metamorphism in eucrites (basaltic meteorites), by about a factor of 100, but the mechanism is quite different. In this case, it is the diffusion of Fe out of the feldspar during metamorphism that causes the increased TL signal.

Either or both these mechanisms could be operative in the basalts which are rapidly formed nonequilibrium assemblages that will tend towards equilibrium with time.

Conclusions: While much work remains to be done induced TL measurement has the potential to be a new and very different means of dating volcanic rocks. Furthermore, it is a technique that should be readily adaptable for use on robotic spacecraft that land and can provide samples to the instrument.

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References: [1] Greeley *et al.* 1977. In "Volcanism of the Eastern River Plain, Idaho", 171. [2] Kuntz *et al.* 1982. in "Cenozoic Geology of Idaho", 423. [3] Hughes *et al.* 1999. In "Guidebook to the Geology of Eastern Idaho", 143. [4] Heldmann *et al.* 2013. AGU Fall Mtg, abs #P54B-01. [5] McKeever *et al.* 2003. *Radiat. Meas.* 37, 527-534. [6] Jain *et al.* 2006. *Radiat. Meas.* Vol. 41, 755–761. [7] Bailiff et al. 2009. Proc. 12th Inter. Conf. Luminescence and Electron Spin Resonance Dating. [8] Sears et al. 1980. Nature, 287: 791-795. [9] Batchelor and Sears 1991. Geochim. Cosmochim. Acta 55, 3831-3844. [10] Sears 2015. Ancient TL 33, 15-19. [11] May 1977. J. Geophys. Res. 82: 3023-3029. [12] May 1979. Geol. Surv. Prof. Paper 1093. [13] Sears and Hughes 2015. AGU fall mtg. [14] Sears 1980. Icarus 44, 190-206.