

Fission track uranium distribution studies on Apollo 11 lunar samples

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Abstract—Lexan plastic print registration of induced U^{235} fission tracks indicates most of the U in the lunar volcanic rocks (Type A, B) is localized in indeterminate interstitial areas of possible glassy material formed during the last stages of crystallization of the rocks. The highest concentrations (some >40 ppm U) seem to be associated with a particular reddish phase within these interstitial areas which may be baddeleyite. Extremely low abundances (≤ 0.005 ppm U) in the major phases (i.e. clinopyroxene, plagioclase and ilmenite) are characteristic of phases crystallizing from melts containing ≤ 1 ppm U.

U levels in the matrices of the breccias are generally 0.3–0.4 ppm U with local concentrations up to >50 ppm U.

The interstitial areas of the Type A and B volcanic rocks have “moderate” Lexan print contrasts characteristic of ~ 1 –5 ppm B or ~ 10 –50 ppm, Li.

INTRODUCTION

A DETAILED knowledge of the uranium distribution between the co-existing phases in the lunar volcanic rocks can place some limitations on the uranium content of the magma with which the phases were in equilibrium (KLEEMAN *et al.*, 1969).

Furthermore recognition of phases showing varying uranium enrichments is an essential first step in a proposed localized study of lead isotopic variations in lunar volcanic rocks using the ion probe with C. A. Andersen and J. R. Hinthorne. High uranium phases suitable for fission track dating studies are also revealed by fission track uranium distribution studies using the Lexan plastic print method of recording uranium distributions (KLEEMAN and LOVERING, 1967a, b).

ANALYTICAL TECHNIQUE

The use of fission track activation methods to determine U abundances in geological materials was first suggested by PRICE and WALKER (1963) and has been subsequently developed by KLEEMAN and LOVERING (1967a, b) who used Lexan plastic rock texture “prints” to study uranium distribution in rocks. Briefly polished thin sections of lunar rocks are prepared and placed in contact with a sheet of Lexan plastic. This couple is then irradiated in a thermal neutron flux along with a standard microscope glass containing a known uranium concentration (e.g. 0.355 ± 0.010 ppm U) determined by neutron activation analysis which acts as a monitor of the flux. After irradiation the plastic in contact with the rock section is removed, etched and induced U^{235} fission tracks recorded in the plastic are observed in relation to the mineral distribution “prints” which also appear on the plastic surface (KLEEMAN and LOVERING, 1969). In this way quantitative measurements of U contents may be made and related exactly with the minerals present in the rock.

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Normally two separate irradiations are made ($\sim 2 \times 10^{16} \text{ n cm}^{-2}$ and $\sim 2 \times 10^{17} \text{ n cm}^{-2}$) so that convenient fission track densities may be obtained from phases with abundances ranging from 43 ppm U to 0.0002 ppm U. However in the present study circumstances out of our control have restricted our work to a single "long term" irradiation which allows us to measure very low U abundances in the major minerals present in the lunar rocks but prevents accurate measurements of abundances in excess of about 5 ppm U. Further studies are being carried out at present with "short term" irradiations.

Track densities are counted at $450\times$ magnification and U abundances are calculated using equations derived by FLEISCHER and PRICE (1964) but modified by KLEEMAN (1969) to take into account the fission fragment stopping power of the various mineral matrices. The results obtained are in good agreement with fission track uranium abundance measurements in lunar materials by CROZAZ *et al.* (1970) and FLEISCHER *et al.* (1970).

DATA AND DISCUSSION

Lunar volcanic rocks

The Type B medium-grained volcanic rock (10047-20) shows U concentrated in highly localized regions (Fig. 1 and Table 1). The highest U concentrations (some

Table 1. Uranium distribution in medium-grained lunar volcanic rock 10047-20

Phase	Uranium (ppm)	Remarks
Site 1 (Fig. 1)	2.8-4.6	Source appears to be interstitial glass with some devitrification
Site 2	7.3-9.1	As for site 1
Site 3	4.0	Three separate areas of U concentration. Source may actually be micron-sized reddish grains (baddeleyite?) scattered in interstitial glass.
	2.9	
	3.8	
Site 4	>30	} Source probably reddish phase (baddeleyite ?)
Site 5	>10	
Site 6	>10	
Site 7	~10-20	
Clinopyroxene	≤ 0.003	—
Plagioclase	≤ 0.002	—
Ilmenite	≤ 0.005	—
Cristobalite	≤ 0.005	—

>40 ppm U) occur in regions (e.g. Sites 4, 5, 6, 7) where the source of the tracks seems to be a reddish phase which may be baddeleyite (ZrO_2) as described by RAMDOHR and EL GORESY (1970) in this particular rock. Other regions (Sites 1, 2, 3) of lower U concentrations ($\sim 1-9$ ppm U) seem to consist of interstitial, partly devitrified glass (determined by petrographic examination) of late-stage formation but even here (e.g. Site 3) the primary source of tracks may be micron-sized grains of the reddish (baddeleyite?) phase. The major phases present (i.e. clinopyroxene, plagioclase, ilmenite, cristobalite) are all relatively depleted in U (Table 1). The clinopyroxene abundance (≤ 0.003 ppm U) is consistent with U partitioning (KLEEMAN, 1969) from a parental magma in which the uranium concentration approximated the values of 0.20-0.78 ppm U observed in the total rocks previously (LSPET, 1969).

Two Type A fine-grained volcanic rocks were also studied (10057-21, 10069-20) and both appear significantly higher in overall U abundance than the Type B rock 10047-20. In 10057-21 most of the U is localized in interstitial areas which, because of the overall fine grained nature of these rocks, is difficult to resolve. However

concentrations in these areas range from <1 to ~ 100 ppm U and the highest abundances appear to be associated with particular phases in the intergrowth (possibly baddeleyite?). The clinopyroxene, plagioclase and ilmenite phases are relatively low in U (≤ 0.1 ppm U) and are probably similar to the depleted abundance levels reported for the Type B rock 10047-20. The second Type A rock examined (10069-20) is even



Fig. 1. Transmitted light photograph (A) and Lexan plastic print (B) of a fragment of Type B medium-grained volcanic rock 10047-20. Selected sites of uranium concentration shown 1-7.

finer grained than 10057-21 but again the highest U levels ($<1\text{--}\sim 60$ ppm U) are associated with irresolvable interstitial regions. The general level in these regions in 10069-20 is 2–8 ppm U and is significantly higher than the 1–5 ppm U normal level in similar regions in 10057-21.

Breccias

Two Type C breccias were studied (10019-12, 10046-20) and U levels in the matrix are typically 0.3–0.4 ppm U. Local concentrations up to >50 ppm U also occur in the matrices so that the overall breccia U abundances would be in the range 0.39–0.60 ppm reported previously (LSPET, 1969). Up to the present it has not been possible to relate the host phases of these local high U concentrations. Where large enough grains were observed, the U abundance in individual clinopyroxene, plagioclase and ilmenite grains is very low (≤ 0.05 ppm U).

Lithium–boron distributions

KLEEMAN and LOVERING (1969) have shown that the Lexan prints result from varying densities of sub-micron etch pits in the plastic arising largely from α -particle damage by Li^6 (n, α) reactions and α -particle and Li^7 recoil damage from B^{10} (n, α) reactions. Rough measurements of these pit densities allow estimates to be made of Li and/or B abundances in the phases responsible for the prints.

In these studies “short term” irradiations ($\sim 2 \times 10^{16}$ n cm^{-2}) give the best pit densities for measurement and such irradiations were carried out on the Type A volcanic rocks 10057-21 and 10069-20 and the breccia 10046-20. The areas of uranium concentration in the Type A volcanic rocks were also areas of “moderate” print contrast which have been previously attributed (KLEEMAN and LOVERING, 1969) to either B abundances of 1–5 ppm or Li abundances of 10–50 ppm. Much of the matrix material of the breccia 10046-20 also showed pit densities similar to those interstitial regions in the Type A volcanic rocks. Further work is in progress to resolve the contributions from B and Li so that abundances of each element may be calculated.

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REFERENCES

- CROZAZ G., HAACK U., HAIR M., HOYT H., KARDOS J., MAURETTE M., MIYAJIMA M., SEITZ M., SUN S., WALKER R., WITTELS M. and WOOLUM D. (1970) Solid state studies of the radiation history of lunar samples. *Science* **167**, 563–566.
- FLEISCHER R. L., HAINES E. L., HANNEMAN R. E., HART H. R., JR., KASPER J. S., LIFSHIN E., WOODS R. T. and PRICE P. B. (1970) Particle-track X-ray, thermal and mass spectrometric studies of lunar material. *Science* **167**, 568–571.
- FLEISCHER R. L. and PRICE P. B. (1964) Glass dating by fission fragment tracks. *J. Geophys. Res.* **69**, 331–339.
- KLEEMAN J. D. (1969) Fission track studies and the geochemistry of uranium in rocks from the crust and upper mantle. Unpublished Ph.D. Thesis, Australian National University.

- KLEEMAN J. D., GREEN D. H. and LOVERING J. F. (1969) Uranium distribution in ultramafic inclusions from Victorian basalts. *Earth Planet. Sci. Lett.* **5**, 449–458.
- KLEEMAN J. D. and LOVERING J. F. (1967a) Uranium distribution in rocks by fission track registration in Lexan plastic. *Science* **156**, 512–513.
- KLEEMAN J. D. and LOVERING J. F. (1967b) Uranium distribution studies by fission track registration in Lexan plastic prints. *Atomic Energy in Australia* **10**, 3–8.
- KLEEMAN J. D. and LOVERING J. F. (1969) Lexan plastic prints: how are they formed? In *Proc. Int. Conf. Nuclear Track Registration in Insulating Solids and Applications*, (editor M. Monnin). Clermont-Ferrand, 6–9 May 1969.
- LSPET (LUNAR SAMPLE PRELIMINARY EXAMINATION TEAM) (1969) Preliminary examination of lunar samples from Apollo 11. *Science* **165**, 1211–1227.
- PRICE P. B. and WALKER R. L. (1963) A simple method of measuring low uranium concentrations in natural minerals. *Appl. Phys. Lett.* **2**, 23–25.
- RAMDOHR P. and EL GORESY A. (1970) The opaque minerals of the lunar rocks and dust from Mare Tranquillitatis. *Science* **167**, 615–618.

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