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Uranium Distribution in Rocks by Fission-Track Registration in Lexan Plastic

Abstract. *When Lexan plastic is used to register fission tracks from thermal neutron-induced fission of uranium in rocks, a print of the rock texture is formed on the plastic surface after chemical etching. This print allows positive, rapid location of uranium-bearing phases in the rock and accurate determination of uranium abundances.*

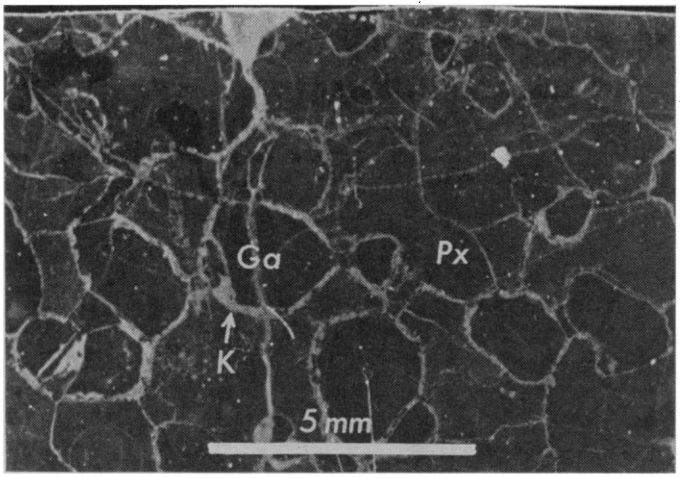
The registration of fission tracks from the thermal neutron-induced fission of U^{235} in uranium-bearing materials (*1*) has been used to determine quantitatively the distribution of uranium in a number of natural materials (*1–4*). Hamilton (*3*) used mica to observe uranium distributions in thin sections of meteorite and rock, while Kleppe and Roger (*4*) used both mica and Mylar for a similar study of a thin section of a granodiorite from the Sierra Nevada batholith. However, both studies were limited by difficulties in comparing the occurrences of fission tracks in the registering material with the source phases in the rock or meteorite section. Fleischer (*5*) partially overcame this difficulty by using a thin skin of plastic which remains tightly bonded to the surface during irradiation, etching, and observation.

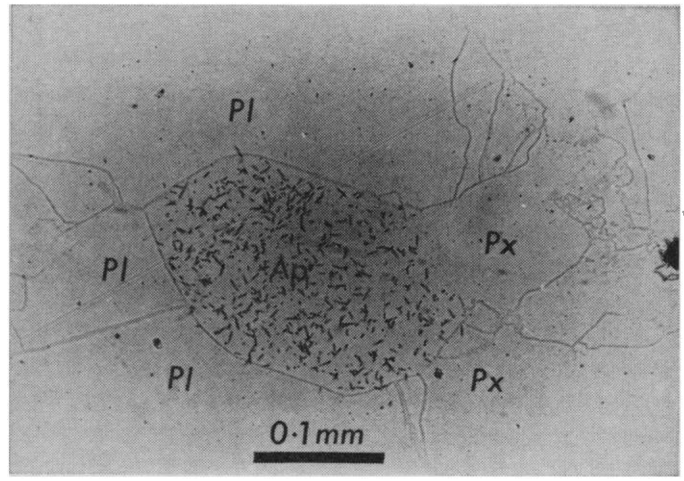
To study uranium distribution in rocks of deep-seated origin by the fission-track method, we prepared polished, thin sections of many of these rocks, placed a sheet of Lexan plastic (*6*) in contact with each sample, and held it there with a clip during irradiation in a predominantly thermal-neutron flux. After irradiation, the plastic was removed and etched in 6*N* NaOH at 70°C for 8 minutes. Location marks had been carefully placed on both rock surface and plastic sheet so that we could refer the occurrence of fission tracks in the plastic to individual phases in the rock section. Despite the use of a rather complicated system of these marks, it would normally be very difficult, if not impossible, to correlate small areas of fission-track aggregations with tiny uranium-bearing phases in the rock section.

However, after the Lexan plastic sheets were etched, the surface which had been in contact with the rock section during irradiation developed a detailed print of the rock surface. Grain boundaries and cracks were shown with remarkable accuracy, and each mineral phase present in the rock could be identified by its shape and characteristic effect on the plastic. The broad features of these Lexan prints are best seen under oblique lighting (Fig. 1), while detailed studies may be made with transmitted light under a microscope (Figs. 2 and 3). Fission tracks in the plastic, arising from uranium-bearing phases in the adjoining rock, are also clearly visible after etching, but the immediate advantage of using Lexan as a track register is that fission-track sources can be seen in accurate and unequivocal relation to the boundaries of the various phases in the rock.

The Lexan print (Fig. 2) of a pyroxene granulite inclusion from the deep-seated basic breccia pipe at Delegate (*7*) shows that the visible fission tracks are randomly distributed within the boundaries of a single mineral grain. Reference to the rock section readily establishes that this mineral is apatite, and the obviously homogeneous uranium content was calculated (*1*) as 2.3 parts per million. A Lexan print of an eclogitic inclusion from the breccia pipe (Fig. 3) shows that the fission tracks are confined within the boundaries of zones of secondary hydrated silicate minerals (kelyphite) which surround the garnets and also form tiny veins through the rock. These secondary phases result from reactions with hydrothermal fluids entering the inclusion from the volatile-rich basic material filling the pipe. We conclude that by far the largest proportion of the total uranium content of this eclogitic inclusion was introduced after the fragment was caught up in the pipe.

The major cause of the contrast between various minerals in the Lexan print is a variation in the density of small, shallow pits present on the plastic surface after etching (Fig. 3). Grain boundaries and cracks in minerals are also visible as the result of an increase in pit densities (Fig. 2). These shallow pits are quite distinct from the long (approximately 10 μ) linear track arising from the passage of massive, charged particles from induced U^{235} fission (Fig. 3). By analogy with the ion explosion spike theory for the origin of fission tracks (*8*), we suggest





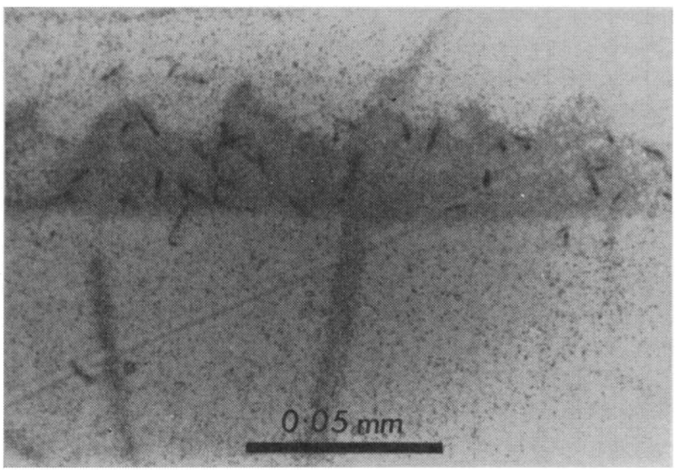


Fig. 1 (top left). Etched Lexan print of a thin section of an eclogite (R117) inclusion from the Delegate pipe, New South Wales, Australia. Oblique lighting with dark background. *Ga*, garnet; *Px*, clinopyroxene; *K*, kelyphite (hydrated silicates from alteration of garnet).

Fig. 2 (top right). Magnified portion (viewed under a microscope with transmitted light) of print of pyroxene granulite (R112) inclusion from the Delegate pipe, showing uniform fission-track distribution in an apatite grain. *Pl*, plagioclase; *Px*, clinopyroxene.

Fig. 3 (lower left). Magnified portion of print shown in Fig. 1, viewed with transmitted light. Fission tracks are confined to kelyphite veins. Variation in density of shallow pits from recoil ions is shown between clinopyroxene areas and kelyphite veins.

that the shallow pits arise from a lower order of damage caused by the passage of less massive, charged particles. A likely source of such particles would be recoil ions ejected from the adjacent mineral surfaces as a result of possible (n,α), (n,d), $(n,2n)$, (n,p), and (n,n) reactions induced by the fast neutron component of the largely thermal neutron flux used in the irradiation. The fast neutron component is about 3×10^9 neutrons per square centimeter in an average irradiation of 3×10^{16} neutrons per square centimeter (*9*). These nuclear reactions can impart sufficient energy to the recoil ions to eject them from the mineral lattice. The number ejected from a given mineral surface will depend on the fast neutron dose, the relative abundance of suitable elements, and their bond strengths within the various mineral lattices.

Other possibilities that we considered were contact thermal effects and α-particle bombardment due to certain reactions with neutrons. We found that the close contact was only necessary for sharp resolution on the plastic, and that temperatures were not expected to rise above 100°C in any case. There are possible (n,α) reactions with thermal neutrons (B,Li) and fast neutrons (O, Al, Si, Cu, S; most at moderate thresholds), and we know that α-particles do form short damage tracks in Lexan (*10*) and other plastics (*11*). However, no unambiguous correlations have been made between mineral composition and pit density to confirm that the pits are the result of α-particle damage.

We observed qualitatively that relatively high pit densities are produced from grain boundaries and cracks, biotite, hydrated silicate (kelyphite) rims around garnets, and aluminum. Medium pit densities are associated with garnets, feldspars, and pyroxenes, and low pit densities are associated with quartz, pyrite, apatite, and ilmenite.

Ions of OH, either present in the lattices and grain boundaries or absorbed onto the surface of the section, are apparently the major contributors of recoil ions. This was verified by irradiating grossular garnet and its OH-bearing counterpart, hydrogrossularite, side by side on the same plastic sheet. After etching of the plastic, hydrogrossularite gave a much greater pit density than grossularite did. The use of Lexan prints has enabled us to carry out detailed and quantitative surveys of the distribution of uranium in rocks of geochemical importance.

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