

ULTRAHEAVY COSMIC RAY TRACKS IN METEORITES:
A REAPPRAISAL, BASED ON CALIBRATIONS WITH RELATIVISTIC IONS

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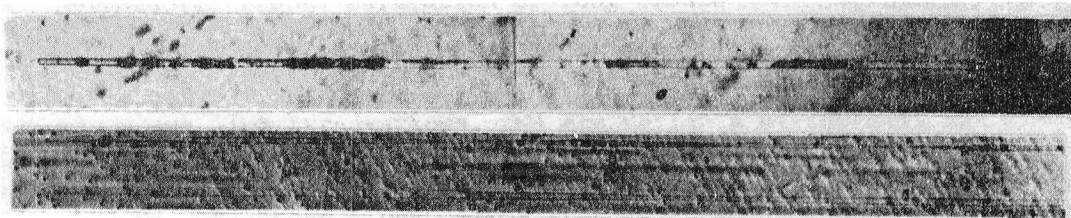
Experiments have been carried out on tracks of high energy U ions in olivine, a common meteoritic mineral. The results offer an explanation for the lack of success of previous attempts to derive the Ultraheavy Cosmic Ray composition from the study of tracks in meteorites. They also suggest how such experiments should be performed. The methods we are testing are described and illustrated.

1. Introduction

Prompted by the observation that the Cosmic Ray actinide abundance is extremely low (1,2), and difficult to measure with a satellite born experiment, a study of heavy ion tracks in a meteoritic mineral (olivine), has been started in our laboratory (3), to reevaluate the feasibility of a measurement of this abundance by means of tracks in meteorites. To this end, experiments have been carried out, which made use of high energy U ions, first to try to better understand the processes involved in very heavy ion track registration and etching in a mineral, then possibly, to achieve a real calibration of the meteoritic detectors.

The last results obtained allow us to fully confirm our statement (3) that the main difficulties of an Ultraheavy Cosmic Ray abundance measurement by means of tracks in meteorites would lie in the etching process itself. They demonstrate that, with classical techniques, and for very heavy ions, one should not expect any relationship between ion atomic number Z and etched track length. However, techniques can be devised to restore this relationship. Here we summarize what we have learnt about heavy ion tracks, without going into technical detail, before briefly describing the methods we are presently testing and the first results obtained with them, which make us reasonably optimistic about the chance of succeeding.

Fig. 1. see caption on last page of paper.



2. Heavy ion tracks: results and implications

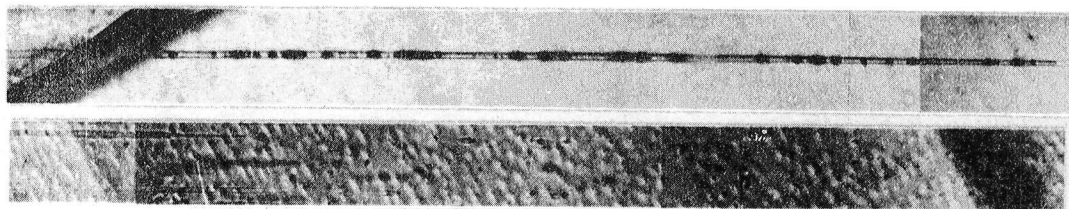
Most important is the observation that the track etch rate in olivine (and probably in other mineral track detectors as well) is not only governed by the radiation damage intensity, but also by the etching chemistry (4). The etch rate may be limited, by the etching process, to a much lower value than would be allowed by the radiation damage intensity alone. In addition, the etch rate allowed by the etching process decreases as etching proceeds (i.e. as the etched track length gets longer). For relatively short tracks (i.e. "light" ions) this is generally not of much importance. But for very long tracks, it turns out that after some time, the etch rate becomes so low, that etching finally stops, although the remaining part of the latent track is still potentially etchable (5). Thus, with the usual techniques, in which a track is revealed from one point, generally by means of a crystal fracture - natural or artificial - which intersects it, and through which the etchant can penetrate, the long tracks can only be partially revealed. Since the length of the etched portions are only determined by the etching chemistry, they do not reflect the atomic numbers of the ions which induced the tracks. This may explain the lack of success of previous experiments.

In order to maintain the relationship between track length and Z, one has to reveal the whole etchable track length. For that, a method must be used, which allows the etchant to reach every track at many points along the ion path, so that the revelation of a long track comes to that of many short portions of it.

3. Methods for proper revelation of long tracks

We are presently testing 2 closely related methods allowing the complete revelation of any track. Both make use of medium energy (10-20 MeV/u) heavy ion irradiations, and are variants of the TINT and TINCLE techniques (6). In the first one, olivine crystals are bombarded by a low intensity heavy ion beam (about 10^6 ions per cm^2). Upon etching, the tracks of these ions allow the etchant to penetrate inside the crystals, and reveal the long tracks which they happen to intersect. Each long track intersects many of these "feeding" tracks. In the second one, the crystals are bombarded by a much higher flux ($\sim 10^9$ cm^{-2}), through a mask, sufficiently thick to stop the ions, leaving them pass only through regularly spaced, narrow, parallel slits. Upon etching, the tracks of these ions in turn make sort of parallel grooves in the olivine, through which the long tracks, which cut many of them, can be entirely revealed. These techniques have been applied to the revelation of tracks of 190 MeV/u U ions from the Bevalac, and gave

Fig. 1. cont'd.



satisfactory results.

As an illustration, a photomicrograph of a U ion track in olivine, revealed by the TINT technique, is shown in Fig.1 (top), which has been cut into 4 parts, one on each page of the paper. The path of the 190 MeV/u U ion is parallel to the plane of the figure. The ion entered the crystal on the right hand side (this page) and came to rest on the left hand side (first page). The crystal has also been irradiated by 14 MeV/u Pb ions from the GSI accelerator (Darmstadt, FRG), perpendicularly to the plane of the figure. The tracks of these ions (seen as black dots on the photo) allowed the revelation of the track of the high energy U ion. It is seen that this track is etchable over the whole ion range (~ 2.8 mm) contrary to what we announced earlier (3), misled by an etch induction time effect (4,5). With usual techniques, less than one half of this length can be revealed (5). The high energy part of the track appears discontinuous. This is because the radiation damage intensity, linked to dE/dx , is getting lower in this region, so that in turn the etch rate is very low, and the different portions of the track have not been etched enough to meet.

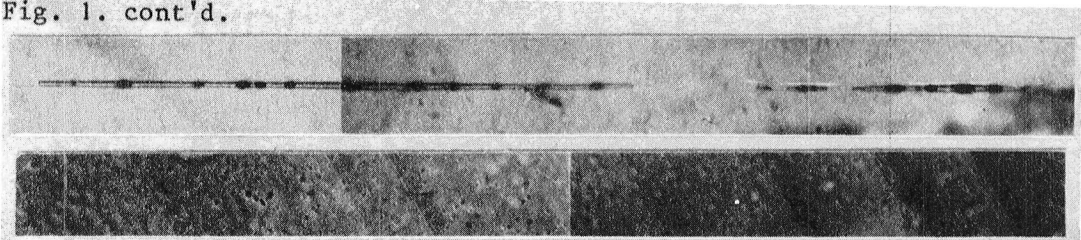
This part is also the most thermally fragile, and may be responsible for a large broadening of the track length distribution corresponding to a given Z, for Cosmic Ray tracks in meteorites, because of differential annealing in space. The solution to maintain the charge resolution, may be to make length measurements after a stronger annealing in the laboratory (3,7). In Fig.1 (bottom) two 190 MeV/u U ion tracks can be seen (with some difficulty) after partial annealing by heating at 425°C during 5 hours. The length of the tracks have been reduced to 1.1 mm (so that they are seen only on the first 2 parts of the figure). After such a thermal treatment, the tracks of Kr and lighter ions are completely erased, and those of Xe ions reduced to 80 μm . The best conditions for an ion identification experiment in the U region are still to be determined. This will be done by comparing the results obtained for high energy U ion tracks with those for Au ions of a similar energy, which we should get at the Bevalac in the near future.

4. Conclusion

We feel that the results we have obtained, thanks to modern heavy ion accelerators, are extremely encouraging, and suggest that tracks in minerals might serve for ion identification purposes. Of course, tracks are tricky, and success is far from being certain. However, we may soon switch over, with some confidence, to real Cosmic Ray tracks.

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Fig. 1. cont'd.



(Berkeley) and to R. Spohr (Darmstadt) for assistance with the heavy ion irradiations.

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Fig.1. Top: photomicrograph of the track in olivine of a 190 MeV/u U ion from the Bevalac, revealed by the TINT technique. The photo has been cut into 4 parts. The ion entered the crystal on the right hand side (this page) and came to rest on the left hand side (first page of the paper). The feeding tracks (14 MeV/u Pb ions) perpendicular to the plane of the figure, are seen as black dots. For the discontinuous appearance of the U ion track at the high energy end, see text. Bottom: same as top, but here, the tracks have been partially annealed (5 h at 425 ° C). Their etchable length has thus been reduced, and they are seen only on the first two pages of the paper.

100 μm

