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PROGRESS REPORT FOR AINGRA07089P

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|---------------------------|---|---|
| PROJECT TITLE | Atomic Force Microscopy nanoscale study of implanted heavy ions as a proxy for spontaneous ^{238}U fission fragments | |
| INVESTIGATOR(S) | Institution and Department | |
| Chief Investigator | A/Prof. Barry Kohn | Earth Sciences, The University of Melbourne |
| Other Investigators | Prof. A.J.W. Gleadow | |
| Students | F. Kohlmann | |
| ANSTO Investigators | Rainer Siegele | |
| Specialist Committee | A | |

SCIENTIFIC OBJECTIVES

Atomic Force Microscopy provides unique insights to the nanoscale surfaces of rock forming minerals such as apatite and muscovite. The Atomic Force Microscope (AFM) is capable of acquiring an image of a latent fission track opening, caused by the spontaneous fission fragments released by the spontaneous fission of ^{238}U . The heavy ions implanted, will simulate these fission fragments and their energies. To obtain an improved understanding of fission track development in muscovite and especially apatite, heavy ion impact sites on the mineral surface will be imaged by the AFM.

PROGRESS REPORT and RESEARCH OUTCOMES

In this experiment the response of muscovite, zircon and apatite to implantation of swift heavy ions is being investigated. To achieve this we made use of the 10MV Tandem Accelerator at ANSTO, which provided us with iodine ion beams with energies up to 101 MeV.

Forty two samples were prepared for irradiation - these comprised 30 muscovite, 6 apatite and 6 zircon mounts. On each apatite and zircon mount, two crystal sections of a single crystal were made, one parallel and one perpendicular to the *c*-axis. These were mounted close to each other over an area of 1 cm² and polished to an optical finish using fine diamond paste.

For the series of experiments which were carried out in July, we applied different energies to the polished crystals and these covered the range of energies over much of the spectrum of spontaneous fission fragments. The energies were 11.5 MeV, 18 MeV, 25.9 MeV, 35.2 MeV, 45.9 MeV, 58 MeV, 70.5 MeV, 86.5 MeV and 101 MeV. Iodine ions were chosen due to their common occurrence as fission fragments during the spontaneous fission of ^{238}U .

Following the irradiation experiments all samples are now awaiting the next stage of the project which will use Atomic Force Microscopy. The size of the measured area to be scanned on the mineral surface is 250 nm by 250 nm. To obtain a sufficient density of fission tracks for imaging with an Atomic Force Microscope it is necessary to have at least a density of 1×10^{11} fission tracks per square centimetre. The AFM to be used is housed in the Microanalytical Research Centre (MARC), School of Physics at the University of Melbourne and will provide a Nano-3D-topographic image of the unetched track openings. Early experiments evaluating the suitability of this approach have shown that AFM is an appropriate tool to image the nanoscale surface of muscovite [Kohlmann, F., Gleadow, A.J.W., Kohn, B.P., Pakes, C.I. and Alves, A. 2006. Atomic force microscopy of fission tracks in

fluorapatite and mica: a tool for nanoscale investigations. (Abstract) 16th V.M. Goldschmidt Conference, Melbourne, August 2006].

Preliminary data in muscovite suggests that unetched fission track openings form crater-like structures on the mineral surface with diameters between 16-28 nm. In that study the surface topography of the irradiated muscovite was analysed in air by AFM, under operating conditions in the non-contact mode using Pt-coated Si cantilevers with a 10° opening and 10 nm tip.

Due to some recent problems with the configuration and set up of the AFM no further measurements have been carried out so far. All samples are ready for imaging at the nanoscale and will be processed as soon as the AFM will again achieve a stable configuration. This is scheduled to take place during November-December this year.

DATA

The tables below show the irradiated samples, the irradiation time, the iodine ion flux and the fission track density in the sample surface, which will be analysed with AFM.

11.5 MeV:

| Sample No. | Irradiation time [sec] | Iodine ion flux [atoms per cm ²] | Fission track density [atoms/cm ² /sec] |
|------------|---------------------------|---|---|
| M13 | 15 s | 3.0 x 10 ¹¹ at/cm ² | 2.0 x 10 ¹⁰ at/cm ² /sec |
| M14 | 50 s | 1.0 x 10 ¹² at/cm ² | 2.0 x 10 ¹⁰ at/cm ² /sec |
| M15 | 15 s | 3.0 x 10 ¹¹ at/cm ² | 2.0 x 10 ¹⁰ at/cm ² /sec |
| AP 4 | 15 s | 3.0 x 10 ¹¹ at/cm ² | 2.0 x 10 ¹⁰ at/cm ² /sec |
| M10 | 17 s | 3.0 x 10 ¹¹ at/cm ² | 1.9 x 10 ¹⁰ at/cm ² /sec |
| M11 | 57 s | 1.0 x 10 ¹² at/cm ² | 1.9 x 10 ¹⁰ at/cm ² /sec |
| M12 | 17 s | 3.0 x 10 ¹¹ at/cm ² | 1.9 x 10 ¹⁰ at/cm ² /sec |
| ZR 6 | 17 s | 3.0 x 10 ¹¹ at/cm ² | 1.9 x 10 ¹⁰ at/cm ² /sec |

18 MeV:

| Sample No. | Irradiation time [sec] | Iodine ion flux [atoms per cm ²] | Fission track density [atoms/cm ² /sec] |
|------------|---------------------------|---|---|
| M16 | 22 s | 3.0 x 10 ¹¹ at/cm ² | 1.38 x 10 ¹⁰ at/cm ² /sec |
| M17 | 73 s | 1.0 x 10 ¹² at/cm ² | 1.38 x 10 ¹⁰ at/cm ² /sec |
| M18 | 22 s | 3.0 x 10 ¹¹ at/cm ² | 1.38 x 10 ¹⁰ at/cm ² /sec |
| AP 1 | 22 s | 3.0 x 10 ¹¹ at/cm ² | 1.38 x 10 ¹⁰ at/cm ² /sec |
| ZR 2 | 22 s | 3.0 x 10 ¹¹ at/cm ² | 1.38 x 10 ¹⁰ at/cm ² /sec |

25.9 MeV:

| Sample No. | Irradiation time [sec] | Iodine ion flux [atoms per cm ²] | Fission track density [atoms/cm ² /sec] |
|------------|---------------------------|---|---|
| M5 | 50 s | 1.0×10^{12} at/cm ² | 2.06×10^{10} at/cm ² /sec |
| M6 | 15 s | 3.0×10^{11} at/cm ² | 2.06×10^{10} at/cm ² /sec |

35.2 MeV:

| Sample No. | Irradiation time [sec] | Iodine ion flux [atoms per cm ²] | Fission track density [atoms/cm ² /sec] |
|------------|---------------------------|---|---|
| M19 | 34 s | 3.0×10^{11} at/cm ² | 8.8×10^9 at/cm ² /sec |
| M20 | 114 s | 1.0×10^{12} at/cm ² | 8.8×10^9 at/cm ² /sec |
| M21 | 34 s | 3.0×10^{11} at/cm ² | 8.8×10^9 at/cm ² /sec |
| AP 2 | 34 s | 3.0×10^{11} at/cm ² | 8.8×10^9 at/cm ² /sec |
| ZR 4 | 34 s | 3.0×10^{11} at/cm ² | 8.8×10^9 at/cm ² /sec |

45.9 MeV:

| Sample No. | Irradiation time [sec] | Iodine ion flux [atoms per cm ²] | Fission track density [atoms/cm ² /sec] |
|------------|---------------------------|---|---|
| M28 | 12 s | 3.0×10^{11} at/cm ² | 2.56×10^{10} at/cm ² /sec |
| M4 | 40 s | 1.0×10^{12} at/cm ² | 2.56×10^{10} at/cm ² /sec |

58 MeV:

| Sample No. | Irradiation time [sec] | Iodine ion flux [atoms per cm ²] | Fission track density [atoms/cm ² /sec] |
|------------|---------------------------|---|---|
| M29 | 50 s | 1.0×10^{12} at/cm ² | 1.9×10^{10} at/cm ² /sec |
| M30 | 16 s | 3.0×10^{11} at/cm ² | 1.9×10^{10} at/cm ² /sec |

71.5 MeV:

| Sample No. | Irradiation time [sec] | Iodine ion flux [atoms per cm ²] | Fission track density [atoms/cm ² /sec] |
|------------|---------------------------|---|---|
| M22 | 15 s | 3.0×10^{11} at/cm ² | 1.99×10^{10} at/cm ² /sec |
| M23 | 50 s | 1.0×10^{12} at/cm ² | 1.99×10^{10} at/cm ² /sec |
| M24 | 15 s | 3.0×10^{11} at/cm ² | 1.99×10^{10} at/cm ² /sec |
| AP 5 | 15 s | 3.0×10^{11} at/cm ² | 1.99×10^{10} at/cm ² /sec |
| ZR 3 | 15 s | 3.0×10^{11} at/cm ² | 1.99×10^{10} at/cm ² /sec |

86.5 MeV:

| Sample No. | Irradiation time [sec] | Iodine ion flux [atoms per cm ²] | Fission track density [atoms/cm ² /sec] |
|------------|---------------------------|---|---|
| M25 | 22 s | 3.0×10^{11} at/cm ² | 1.38×10^{10} at/cm ² /sec |
| M26 | 75 s | 1.03×10^{12} at/cm ² | 1.38×10^{10} at/cm ² /sec |
| M27 | 22 s | 3.0×10^{11} at/cm ² | 1.38×10^{10} at/cm ² /sec |
| ZR 5 | 22 s | 3.0×10^{11} at/cm ² | 1.38×10^{10} at/cm ² /sec |
| M1 | 25 s | 3.0×10^{11} at/cm ² | 1.26×10^{10} at/cm ² /sec |
| M2 | 83 s | 1.0×10^{12} at/cm ² | 1.26×10^{10} at/cm ² /sec |
| M3 | 25 s | 3.0×10^{11} at/cm ² | 1.26×10^{10} at/cm ² /sec |
| AP 3 | 25 s | 3.0×10^{11} at/cm ² | 1.26×10^{10} at/cm ² /sec |

101 MeV

| Sample No. | Irradiation time [sec] | Iodine ion flux [atoms per cm ²] | Fission track density [atoms/cm ² /sec] |
|------------|---------------------------|---|---|
| M7 | 53 s | 3.0×10^{11} at/cm ² | 5.72×10^{10} at/cm ² /sec |
| M8 | 180 s | 1.0×10^{12} at/cm ² | 5.72×10^{10} at/cm ² /sec |
| M9 | 53 s | 3.0×10^{11} at/cm ² | 5.72×10^{10} at/cm ² /sec |
| AP 6 | 53 s | 3.0×10^{11} at/cm ² | 5.72×10^{10} at/cm ² /sec |
| ZR 1 | 61 s | 3.0×10^{11} at/cm ² | 5.72×10^{10} at/cm ² /sec |

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| Signature of Investigator preparing the report for After signing this report please fax this page with your signature for our files | Proj: AINGRA07089P Date: 10 September, 2007 |
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PUBLICATIONS / REPORTS arising as a result of your work.

PhD STUDENTS

Fabian Kohlmann (anticipated submission in late 2008). Low-temperature thermochronology of the northern Canadian shield and new studies of fission track behaviour in solids.