On Track

The Newsletter of the International Fission-Track Community

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Contents

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Editor's Notes

On track has enjoyed mixed fortunes since the last issue. The response to the THESES section has been particularly good: **Charlotte Cederbom**, **Sandro Guedes** and **Cornelia Spiegel** have sent in abstract of their Ph.D.-theses and **Eva Enkelmann** sent in the abstract of her recently finished masters thesis. The abstracts, reproduced on pages 3-5, demonstrate that track research is very much alive and covers methodical problems as well as applications to basement and sedimentary rocks and provenance analyses. An open position at the London fission-track lab and several meeting are announced on p. 5., in the POSITIONS and MEETINGS sections, but do not miss the announcement for the Cadiz workshop on p. 23. Less positive is that no-one felt inclined to submit a book review, although there are plenty of interesting and relevant books out there. I have reluctantly supplied the content of the BOOKS section in the hope that it will stimulate others to do better in the next issue. The regular ARTICLES can be called an unqualified success.

Professor **Vladimir Perelygin** and his colleagues report on a fascinating research project aimed at identifying tracks in meteoritic minerals produced by stopping or spontaneous fission of superheavy elements that, due to their relative stability, may have existed for some considerable time in the early solar system. Share the excitement on page 8 about how natural [fission] tracks can reveal much more about our universe than the age and cooling history of terrestrial rocks.

Meinert Rahn and his colleagues present a new putative age standard for both fission-track and U/Th-He dating on page 9. All who have recently tried to obtain standards or who have considered the question of the future of standards know how important this is. The proposed standard moreover seems to possess excellent qualities with respect to availability, mineral separation, mineral content, uranium content and independent age control. No lab can afford not to react to their article, the more so since their proposed standard is about half as old as the Fish Canyon /Durango tandem.

Apatite fission-track thermal history modelling is based on the implicit assumption that temperature is the only factor affecting track length reduction. Except for some early experiments by Robert Fleischer and his colleagues, there is little experimental evidence about the effects of pressure. On page 10, **Anke Wendt** and **Olivier Vidal** report preliminary results of extensive experiments aimed at quantifying fission-track annealing under pressure. Their startling results suggest that we ignore the effect of pressure at our peril.

I had the great pleasure of meeting **Mike Krochmal** and **Ian Larsen** in Heidelberg earlier this year. Whether we use Autoscan or a different system, we are all familiar with their stages, and I believe many will share my interest to know how they started and developed their product. Mike and the team at Autoscan obliged by writing a history of Autoscan. Page 14.

Tony Hurford's article addresses a broad range of problems related to thermal history analysis. I believe it will come as an immense relief to the methodically inclined, especially after the aborted attempt justly bemoaned by Kerry Hegarty [On Track 10/1, 2000], that someone with Tony's authority finally puts the question: "*do we really know what we are doing when we measure and interpret our data and promulgate our answers in terms of denudation amounts, sediment fluxes, basin inversion, tectonic movement, hydrocarbon maturity …?*" Well, … do we? It is doing an injustice to Tony's article to simply state that he identifies three problem areas: [1] intra- and inter-lab reproducibility of length measurements [see also Seward et al., On Track 10/2, 2000], [2] how to deal with the effects of chemical composition, even at the sub-microprobe level, and [3] in view of this, how to make sure that we have the appropriate annealing equations and modelling algorithm for the samples at hand. His article on page 16 is a must. Tony finishes by proposing an inter-laboratory initiative, aimed at making a start with solving these problems, that all of us, without exception, simply must support if we are ever to make progress!

Many of us are familiar with TRACKKEY, the versatile program developed by **István Dunkl** for calculating fission-track ages, distinguishing component populations, making radial plots and age distribution plots, …etc. On page 19, István discusses the use of additional parameters reflecting grain shape, colour, zoning …etc. and shows by way of two clear practical examples how they can be used to extract a maximum of information from single-grain fission-track counts.

Short Tracks

Noriko Hasebe moved last February from Kanazawa University, Japan, to the Department of Geological Sciences, at the University College London for a two year sabbatical. Her stay is funded by the Japanese Society for the Promotion of Science. Her research is concerned with zircon. Together with other members of the London Fission Track Group, Noriko will carry out experiments aimed at understanding the effects of radiation damage [mainly alpha-damage] on fission track [and probably U-Th/He] geochronology.

David Coyle, On Track's first editor and known and loved on at least three continents, informs us that "he is going to become an Apple Certified Cocoa trainer". So "if anyone needs help porting old Mac apps to the brave new/old world of Mac OS neXt", then Dave is the man to call. [David A. Coyle, Regional Manager, Software Development, Tensor Information Systems, Fort Worth, Texas, US, Email: david.coyle@tensor.com, Web: http://www.tensor.com]

Charlotte Cederbom defended her thesis in Gothenburg, Sweden, on March 13th. The opponent was Dr. Peter van der Beek from Grenoble. Charlotte went on to a three year post-doc position in Edinburgh. Her research project is part of the CRUST-initiative and aims to document the timing, magnitude and spatial extent of Caenozoic fault block uplift and erosion of the Atlantic margin in the UK and West Shetland sectors.

Sandro Guedes obtained his Ph.D. from the Gleb Wataghin Physics Institute, State University of Campinas, Brazil on April 5th. His research on the spontaneous-fission decay constant of ^{238}U was supervised by Professor Julio Cesar Hadler Neto.

Meinert Rahn writes that a new Ph.D. student, **Katharina Link**, has recently started at the University of Freiburg, Germany, with him and Prof. J. Keller. Katharina will work on the thermal and magmatic evolution of the Rhine Graben including fission track and (U-Th)/He dating of intrusive dike and graben shoulder samples. The investigations are part of a collaboration with the Basel fission track group of Bernhard Fuegenschuh and the (U-Th)/He lab of Rafael Pik in Nancy, France.

Cornelia Spiegel obtained her Ph.D. from the University of Tübingen, Germany, in January. Her research is concerned with the post-collisional exhumation history of the European Alps, mainly based on fission track dating of detrital zircons from the foreland basins.

Ed Sobel informs us that In the last year, there have been several papers suggesting new or revised ages for Fish Canyon Tuff and some other standards. He wants to know if anybody has discussed this from a fission-track point of view. Ed could not be persuaded to write a contribution for On Track on the subject, which is understandable considering his previous articles. Is anyone else interested? Ed further informs us that on August 1st a new law governing radiation safety went into effect in Germany. This seems to have been implemented to match a new European law which became effective in July. This new law has important consequences for importing radioactive material irradiated in the United States. European fission-track labs might want to ask their radiation safety officers about this topic. The relevant legislation [Adobe Acrobat .pdf-format; in German] can be downloaded at http://goanna.mpi-hd.mpg.de/fission/fission.html.

Theses

FISSION TRACK THERMOCHRONOLOGY APPLIED TO PHANEROZOIC THERMOTECTONIC EVENTS IN THE SWEDISH PART OF THE BALTIC SHIELD [Charlotte Cederbom, Department of Geology, Earth Sciences Centre, Göteborg University, Sweden.]

The Swedish part of the Baltic Shield is characterized by a Precambrian basement and a few remnants of Phanerozoic cover rocks. The Phanerozoic geological development in Sweden is therefore poorly established. A geological event known to have affected the Baltic Shield is e.g. the collision between Laurentia and Baltica resulting in the Caledonian Orogeny at ~400 Ma. Nevertheless, the former thickness and extent of the erosional deposits originating from the Caledonian thrust belt have been unknown and so also the Palaeozoic to Caenozoic thermotectonic history of southern Sweden. The fission track dating method is a useful method for investigating low-temperature events, and has been applied to apatite, zircon and titanite basement samples from southern and central Sweden. In addition, apatite samples from Finland have been analysed. The results reveal that the western part of central Sweden and southern Sweden were heated above at least 100°C, during the Phanerozoic, while the eastern part of central Sweden and Finland experienced reheating to temperatures below 100°C. Furthermore, three areas with significantly different trends among the fission track results have been discerned in southern Sweden. It is concluded that Caledonian foreland basin deposits were responsible for the extensive Palaeozoic heating event that affected Sweden and Finland. The sediments probably reached a thickness of at least 2.5 km in western and southern Sweden, and at least 1 km in the Åland Archipelago. The discrepancy between the fission track data in southern Sweden indicates that large-scale vertical tectonic movements within the basement were triggered by the load. Non-uniform exhumation of southern Sweden during the Carboniferous-Jurassic was accompanied by deposition offshore. The Cretaceous unroofing of the basement was followed by renewed covering. Modelling of apatite fission track data from southern Sweden suggests a temperature rise in the order of 20°C and 35°C along the southwest and the southeast coast respectively. It is interpreted as the result of covering of 650-1000 m thick deposits. The Caenozoic final exhumation of southern Sweden was most pronounced around the southern tip of Lake Vättern and along the southeast coast of southern Sweden. [Charlotte Cederbom]

TWO NEW DETERMINATIONS OF THE DECAY CONSTANT FOR SPONTANEOUS FISSION OF ^{238}U, λ_F, THROUGH FISSION-TRACK TECHNIQUES [DUAS NOVAS DETERMINAÇÕES DE CONSTANTE DE DECAIMENTO POR FISSÃO ESPONTÂNEA DO ^{238}U, λ_F UTLIZANDO-

SE TÉCNICAS DE TRAÇOS DE FISSÃ] [Sandro Guedes, Instituto de Física Gleb Wataghin, Universidade Estadual de Campinas, UNICAMP, Brazil.]

More than 50 determinations of the spontaneous fission decay constant of ^{238}U, λ_f, have been published and no agreement has been reached among them. Most of the obtained values are placed around two central values: 7.0 and 8.5 x 10^{-17} a^{-1}.

In this thesis, the published λ_f measurements have been analysed and the main systematic error sources have been identified. Concerning the Fission Track Method, neutron dosimetry rises as the main systematic error source. Two new determinations have been carried out through fission track techniques, avoiding the errors found in the previous measurements.

Thin films of natural uranium have been used as neutron dosimeters in the first determination. The value obtained in this experiment was $\lambda_f = (8.37 \pm 0.17) \times 10^{-17}$ a^{-1}. In the second experiment, infinite films, loaded with ^{242}Pu, have been used as sources of fission fragments in order to calibrate the detector used for collecting ^{238}U spontaneous-fission fragments. The value found was $\lambda_f = (8.7 \pm 0.4) \times 10^{-17}$ a^{-1}.

Both values agree between them and with the nominal value 8.5 x 10^{-17} a^{-1}. The derivation of a λ_f value from a measurement using fission-track techniques, but without neutron irradiation makes it more reliable. The fact that the two values are in agreement is an indicative that the dosimetry with thin uranium films yields coherent results. We believe this work has contributed to make the FTM, an independent method. [Sandro Guedes]

POST-COLLISIONAL EXHUMATION HISTORY OF THE CENTRAL ALPS: EVIDENCE FROM THE FORELAND BASIN SEDIMENTS [Cornelia Spiegel, Geologisches Institut Universität Tübingen, Germany.]

The Oligo-Miocene is an important period for the geomorphological evolution of the Alps. After the Eocene-Oligocene collision and nappe stacking the Central Alps started to develop a significant relief in Oligocene times. Miocene lateral extrusion caused an east-west stretching of more than 300 km and led to the collapse of the relief. This collapse is reflected by a drastic decrease of sediment accumulation rates in the foreland basins of the Central Alps at 21 Ma.

The aim of this study was a detailed reconstruction of the exhumation history and the surface evolution of the Central Alps in Oligo-Miocene times. Geochronological, geochemical and isotope studies on the foreland basin sediments give evidence for the first exposures of certain tectonic units and their cooling rates. Moreover, the paleodrainage system of the Central Alps in Oligo-Miocene times can be reconstructed.

To summarize, the following can be concluded: During Oligocene times only sedimentary cover nappes [flysch and carbonates] and basement nappes of the Austroalpine mega-unit were exposed on the northern flank of the Central Alps. The eroded part of the Austroalpine basement in the Central Alps consisted of large areas, which experienced only weak or even no Eo-Alpine metamorphic overprint. It was the direct western continuation of the Ötztal and Silvretta block of the western Eastern Alps. Austroalpine basement exposed on the southern flank of the Central Alps experienced slightly higher temperatures [~240-300°C] during Cretaceous metamorphism. The main drainage divide was situated north of a volcanic chain which was positioned in the area of the Periadriatic lineament. Contemporaneous with the collapse of the relief, units of the Penninic lower plate became exposed over large areas of the Central Alps [21 Ma]. While in the hinterland of the Kronberg-Gäbris and Hörnli fan only upper parts of the Penninic nappe pile were eroded, the Honegg-Napf and Pfänder system rooted in deeper levels of the Penninic sequence. Geochronological data reveal an average cooling rate of ~20°C/Ma in Late-Oligocene to Early Miocene times for these Penninic units. The Pfänder river system rooted in the Lepontine area of the Central Alps. The Pfänder fan itself was situated in the area of the recent Lake Constance. Therefore, the catchment area was similar to the present-day Rhine river and the Pfänder system might be called 'Paleo-Rhine'. In Middle Miocene times Lower Penninic units of the Lepontine Dome were exhumed to the surface, contemporaneously with the opening of the Tauern window in the Eastern Alps.
[Cornelia Spiegel]

THE TAN-LU FAULT ZONE AT THE EASTERN EDGE OF THE DABIE SHAN [EASTERN CHINA] - A VIEW FROM FISSION-TRACK THERMOCHRONOLOGY [Eva Enkelmann, Institut für Geologie der Technischen Universität Bergakademie Freiberg, Germany.]

This thesis utilizes apatite fission-track analysis to unravel thermal episodes within the Dabie Shan orogen and its foreland, the Yangtze foreland fold-and thrust belt. In the methodical part, three more or less independent methods for determining a fission-track age were compared: the absolute method, the Z-method, and the ζ-method. The three methods yield identical results within error. The absolute method is the most precise. Commonly cited limitations, i.e. inaccuracy in neutron fluence determination and imprecise knowledge of the fission decay constant, do not apply, if a number of precautions are observed. A comparison of different etching conditions demonstrated that distinctly stronger etching has no significant effect on the ζ-value. Confined track length measurements were performed on Cf-irradiated mounts and mounts used for fission-track dating. A comparison of their length distributions showed that after Cf-irradiation, the number of measurable confined tracks had increased more than tenfold.

Geological application of apatite fission-track thermochronology to the interior of Dabie Shan and the Yangtze foreland fold-and thrust belt indicates that the recorded thermal episodes relate to known geological events. All samples yielded Late-Cretaceous to Palaeogene ages. Cretaceous magmatism and accompanying metamorphism effectively reheated the Dabie basement units. The apatite fission-track data show that low-temperature thermochronometers are unable to record cooling after the Triassic-Jurassic ultrahigh-pressure orogeny and that provenance studies related to Triassic-Jurassic hinterland events are impossible. The regional distribution of the ages within the basement units can, on a first-order, be interpreted as a result of domal uplift or a domal thermal anomaly centred on the ultrahigh pressure units in eastern Dabie. The asymmetry of the uplift/anomaly is related to Late Cretaceous normal faulting along the Tan-Lu. The Xiaotian-Mozetang fault zone in northern Dabie, a major Early Cretaceous structure reactivating the Triassic-Jurassic orogenic belt, seems to have been inactive during the Late Cretaceous. Samples from north and south of the XMF yielded similar fission track ages. Several samples from the Dabie Shan and the Yangtze foreland fold-and thrust belt yielded Eocene ages (~40-50Ma). Modelling of these samples reveals enhanced cooling, requiring a tectonic and/or thermal event around 45 ± 10 Ma. This Caenozoic event may result from the combined effect of the Pacific subduction and the India-Asia collision. [Eva Enkelmann]

Positions

U/TH-HE DATING POSITION AT THE LONDON FISSION-TRACK LAB

A postdoctoral position will be available from early 2002 to run U/Th-He dating in the London fission-track Group at the University College London, working with Andy Carter, Tony Hurford, Kerry Gallagher [Imperial College] and Noriko Hasebe. A new Helium line is being constructed at UCL by Patterson Instruments and will be commissioned in spring 2002. The post is for two years, with a possible third year dependent on securing funds. Applicants should have experience in helium and noble gas mass spec operation and maintenance, and an interest in integrating the FT and U/Th-He methods. Contact Tony Hurford informally in first instance at: t.hurford@ucl.ac.uk.

[Tony HURFORD]

Meetings

EFTAN MEETING 22-23 NOVEMBER 2001

EFTAN is a federal organisation of European Fission Track groups. EFTAN was founded in 1992 with the purpose to promote fission track analysis in general and in Europe in particular. All European Fission Track groups can become a member. The network aims to promote communication between members, support European initiatives and collaboration, exchange of expertise and mobility between the groups.

Nine years ago, at the first and only official meeting held so far, I was appointed president of EFTAN and Günther Wagner vice-president. During the intervening period and at other meetings, workshops etc., members have been discussing with each other. Several members met at the Lorne meeting to discuss the possibility to organize a second EFTAN meeting.

I am pleased to announce that Günther Wagner and I have decided that the time has come to organise such a meeting. We propose to have this meeting during the second half of November 2001. The plan is to meet at Lautenbach in the Black Forest of Germany, the location of the first meeting. Suggestions for alternative venues are welcome. However, they should be inexpensive and the location should be central for the majority of fission trackers. We propose that the meeting should not last longer than two days. If participants could arrive before dinner time, we could start with the presentation and discussion during the first evening. The following day could be devoted to two sessions.

It is important that we know how many can participate and I would be grateful if you could reply expressing your interest in participating in the second EFTAN meeting. For the agenda of the meeting, we are interested in your input and ideas. They are most welcome. Please inform us of any points you think should be put on the agenda. I hope that you will support this initiative and that you have the opportunity to participate. Because of the arrangements concerning the hotel accommodation, discussion room … etc., we would appreciate it if you could respond as soon as possible. [Paul ANDRIESSEN]

EUROPEAN GEOPHYSICAL SOCIETY MEETING - EGS NICE 2002

The XXVII[th] General Assembly of the European Geophysical Society will be held in Nice, France, 22 - 26 April 2002. At the last two meetings I have been convenor of two sessions and although the final programme is not yet ready I will have the opportunity to promote fission-track research. If you are interested to present your research at an international congress you can submit your abstracts to one of the sessions I will convene. [Paul ANDRIESSEN]

JOINT MEETING OF THE EUROPEAN GEOPHYSICAL SOCIETY AND AMERICAN GEOPHYSICAL UNION - EGS/AGU NICE 2003

In 2003 EGS and AGU are planning to organize a joint congress in Nice and this will give us the opportunity to propose a symposium that is attractive for fission-track researchers from Europe and US. I am officer of the Solid Earth section of EGS and therefore I can promote such a symposium. I like to know what interest there is for such a symposium and I am looking for researchers from the US who would like to act as co-convenor for such a symposium. [Paul ANDRIESSEN]

Books

"A BEDSIDE NATURE - GENIUS AND ECCENTRICITY IN SCIENCE 1869-1953", edited by Walter Gratzer, presents a selection of reprints of Nature articles, published over a period of somewhat less than a century. Among other fascinating articles, there is one by Lise Meitner and Otto Frisch on the discovery of fission. The essential part of the article has however been edited out. A perusal of Volume 143 of Nature, lead to the discovery of the gems reprinted below that might shed some light on where the 'fission' in 'fission-track' and 'ion' in 'ion explosion spike' come from, and remind us of some of the scientific giants in whose footsteps we tread.

Some historians of science believe that Lise Meitner didn't receive due recognition for her discovery [see "LISE MEITNER: A LIFE IN PHYSICS" by Ruth Lewin Sime and "LISE MEITNER AND THE DAWN OF THE NUCLEAR AGE" by Patricia Rife]. It is a fact that Otto Hahn was awarded the 1944 Nobel Prize in chemistry for the discovery of fission. Although he had supported Lise Meitner, he later downplayed her involvement in the discovery. Hahn and Fritz Strassmann had discovered the formation of barium from neutron irradiated uranium but did not offer an explanation. Hahn sent a letter [December 19, 1938] to Lise Meitner, exiled in Sweden, describing his findings and asking: "Perhaps you can suggest some fantastic explanation," which she did, in collaboration with her cousin Otto Frisch. Niels Bohr seems to have been in no doubt in ascribing the discovery to Meitner and Frisch.

Disintegration of Uranium by Neutrons: a New Type of Nuclear Reaction

Lise Meitner and Otto Frisch [Nature 143, 1939, 239-240]

On bombarding uranium with neutrons, Fermi and collaborators [1] found that at least four radioactive substances were produced, to two of which atomic numbers larger than 92 were ascribed. Further investigations [2] demonstrated the existence of at least nine radioactive periods, six of which were assigned to elements beyond uranium, and nuclear isomerism had to be assumed in order to account for their chemical behaviour together with their genetic relations.

In making chemical assignments, it was always assumed that these radioactive bodies had atomic numbers near that of the element bombarded, since only particles with one or two charges were known to be emitted from nuclei. A body, for example, with similar properties to those of osmium was assumed to be eka-osmium [Z=94] rather than osmium [Z =76] or ruthenium [Z=44].

Following up an observation of Curie and Savitch [3], Hahn and Strassmann [4] found that a group of at least three radioactive bodies, formed from uranium under neutron bombardment, were chemically similar to barium and, therefore, presumably isotopic with radium. Further investigation [5], however showed that it was impossible to separate those bodies from barium [although mesothorium, an isotope of radium, was readily separated in the same experiment], so that Hahn and Strassmann were forced to conclude that isotopes of barium [Z=56] are formed as a consequence of the bombardment of uranium [Z=92] with neutrons.

At first sight, this result seems very hard to understand. The formation of elements much below uranium has been considered before, but was always rejected for physical reasons, so long as the chemical evidence was not entirely clear cut. The emission, within a short time, of a large number of charged particles may be regarded as excluded by the small penetrability of the 'Coulomb barrier', indicated by Gamov's theory of alpha decay.

On the basis, however, of present ideas about the behaviour of heavy nuclei [6], an entirely different and essentially classical picture of these new disintegration processes suggests itself. On account of their close packing and strong energy exchange, the particles in a heavy nucleus would be expected to move in a collective way which has some resemblance to the movement of a liquid drop. If the movement is made sufficiently violent by adding energy, such a drop may divide itself into two smaller drops.

In the discussion of the energies involved in the deformation of nuclei, the concept of surface tension has been used [7] and its value has been estimated from simple considerations regarding nuclear forces. It must be remembered, however, that the surface tension of a charged droplet is diminished by its charge, and a rough estimate shows that the surface tension of nuclei, decreasing with increasing nuclear charge, may become zero for atomic numbers of the order of 100.

It seems therefore possible that the uranium nucleus has only small stability of form, and may, after neutron capture, divide itself into two nuclei of roughly equal size [the precise ratio of sizes depending on finer structural features and perhaps partly on chance]. These two nuclei will repel each other and should gain a total kinetic energy of c. 200 MeV, as calculated from nuclear radius and charge. This amount of energy may actually be expected to be available from the difference in packing fraction between uranium and the elements in the middle of the periodic system. The whole 'fission' process can thus be described in an essentially classical way, without having to consider quantum-mechanical 'tunnel effects', which would actually be extremely small, on account of the large masses involved.

After division, the high neutron/proton ratio of uranium will tend to readjust itself by beta decay to the lower value suitable for lighter elements. Probably each part will thus give rise to a chain of disintegrations. If one of the parts is an isotope of barium [8], the other will be krypton [Z=92-56], which might decay through rubidium, strontium and yttrium to zirconium. Perhaps one or two of the supposed barium-lanthanum-cerium chains are then actually strontium-yttrium-zirconium chains.

It is possible [8], and seems to us rather probable, that the periods which have been ascribed to elements beyond uranium are also due to light elements. From the chemical evidence, the two short periods [10 sec. and 40 sec.] so far ascribed to ^{239}U might be masurium isotopes [Z=43] decaying through ruthenium, rhodium, palladium and silver into cadmium.

In all these cases it might not be necessary to assume nuclear isomerism; but the different radioactive periods belonging to the same chemical element may then be attributed to different isotopes of this element, since varying proportions of neutrons may be given to the two parts of the uranium nucleus.

By bombarding thorium with neutrons, activities are which have been ascribed to radium and actinium isotopes [8]. Some of these periods are approximately equal to periods of barium and lanthanum isotopes resulting from the bombardment of uranium. We should therefore like to suggest that these periods are due to a 'fission' of thorium which is like that of uranium and results partly in the same products. Of course, it would be especially interesting if one could obtain one of those products from a light element, for example, by means of neutron capture.

It might be mentioned that the body with the half-life 24 min [2] which was chemically identified with uranium is probably really ^{239}U and goes over into eka-rhenium which appears inactive but may decay slowly, probably with emission of alpha particles. [From inspection of the natural radioactive elements, ^{239}U cannot be expected to give more than one or two beta decays; the long chain of observed decays has always puzzled us.] The formation of this body is a typical resonance process [9]; the compound state must have a life-time of a million times longer than the time it would take the nucleus to divide itself. Perhaps this state corresponds to some highly symmetrical type of motion of nuclear matter which does not favour 'fission' of the nucleus.

[1] Fermi E., Amaldi F., d'Agostino O., Rasetti F., Segré E. [1934]. Proc. Roy. Soc., A, 146, 483.
[2] Meitner L., Hahn O., and Strassmann F. [1937]. Z. Phys., 106, 249.
[3] Curie I., and Savitch P. [1938]. C.R., 208, 906, 1643.
[4] Hahn O. and Strassmann F. [1938] Naturwiss., 26, 756.
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[6] Bohr N. [1936]. Nature, 137, 344, 351.
[7] Bohr N., and Kalckar F. [1937]. Kgl. Danske Vid. Selskab, Math. Phys. Medd. 14, Nr. 10.
[8] Meitner L., Strassmann F. and Hahn O. [1938]. Z. Phys. 109, 538.
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Physical Evidence for the Division of Heavy Nuclei under Neutron Bombardment

Otto Frisch [Nature 143, 1939, 276]

From chemical evidence, Hahn and Strassmann conclude that radioactive barium nuclei [atom number Z=56] are produced when uranium [Z=92] is bombarded by neutrons. it has been pointed out that this might be explained as a result of a 'fission' of the uranium nucleus, similar to the division of a droplet into two. The energy liberated in such processes was estimated to be about 200 MeV, both from mass defect considerations and from the repulsion of the two nuclei resulting from the 'fission' process.

If this picture is correct, one would expect fast-moving nuclei of atomic number 40 to 50 and atomic weight 100 to 150, and up to 100 MeV energy, to emerge from a layer of uranium bombarded with neutrons. In spite of their high energy, these nuclei should have a range in air of a few millimetres only, on account of their high effective charge [estimated to be about 20], which implies very dense ionisation. Each such particle should produce a total of about 3 million ion pairs.

By means of a uranium-lined ionisation chamber, connected to a linear amplifier, I have succeeded in demonstrating the occurrence of such bursts of ionisation. The amplifier was connected to a thyratron which was biased so as to count only pulses corresponding to at least $5\ 10^5$ ion pairs. About 15 particles per minute were recorded when 300 milligram of radium, mixed with beryllium, was placed one centimetre from the uranium lining. No pulses at all were recorded during repeated check runs of several hours total duration when either the neutron source or the uranium lining was removed. With the neutron source at a distance of four centimetres from the uranium lining, surrounding the source with paraffin wax enhanced the effect by a factor of two.

It was checked that the number of pulses depended linearly on the strength of the neutron source; this was done in order to exclude the possibility that the pulses are produced by accidental summation of smaller pulses. When the amplifier was connected to an oscillograph, the large pulses could be seen very distinctly on the background of much smaller pulses due to the alpha particles of uranium.

By varying the bias of the thyratron, the maximum size of pulses was found to correspond to at least 2 million ion pairs, or an energy loss of 70 MeV of the particle within the chamber. Since the longest path of a particle in the chamber was 3 centimetres, and the chamber was filled with hydrogen at atmospheric pressure, the particles must ionise so heavily that they can make 2 million ion pairs on a path equivalent to 0.8 cm of air or less. From this it can be estimated that the ionising particles must have an atomic weight of at least about seventy, assuming a reasonable connection between atomic weight and effective charge. This seems to be conclusive physical evidence for the breaking up of uranium nuclei into parts of comparable size, as indicated by the experiments of Hahn and Strassmann.

Experiments with thorium instead of uranium gave quite similar results, except that surrounding the neutron source with paraffin did not enhance, but slightly diminished the effect. This gives evidence in favour of the suggestion that also in the case of thorium some, if not all of the activities produced by neutron bombardment, should be ascribed to light elements. it should be remembered that no enhancement by paraffin has been found for the activities produced in thorium, except for one which is isotopic with thorium and is almost certainly produced by simple capture of the neutron.

Prof. Meitner has suggested another interesting experiment. If a metal plate is placed close to a uranium layer bombarded with neutrons, one would expect an active deposit of the light atoms emitted in the 'fission' of the uranium to form on the plate. We hope to carry out such experiments, using the powerful source of neutrons which our high-tension apparatus will soon be able to provide.

Disintegration of Heavy Nuclei

Niels Bohr [Nature 143, 1939, 330]

Through the kindness of the authors I have been informed of the content of the letters [1,2] recently sent to the editor of Nature by Professor Meitner and Dr. Frisch. In the first letter, these authors propose an interpretation of the remarkable findings of Hahn and Strassmann as indication for a new type of disintegration of heavy nuclei, consisting in a fission of the nucleus into two parts of approximately equal masses and charges with release of enormous energy. In the second letter, Dr. Frisch describes experiments in which these parts are directly detected by the very large ionisation they produce. Due to the extreme importance of this discovery, I should be glad to add a few comments on the mechanism of the fission process from the point of view of the general ideas, developed in recent years, to account for the main features of the nuclear reactions hitherto observed.

According to these ideas, any nuclear reaction initiated by collisions or radiation involves as an intermediate stage the formation of a compound nucleus in which the excitation energy is distributed among the various degrees of freedom in a way resembling the thermal agitation of a solid or liquid body. The relative probabilities of the different possible courses of the reaction will therefore depend on the facility with which this energy is either released as radiation or converted into a form suited to produce the disintegration of the compound nucleus. In the case of ordinary reactions, in which the disintegration consists in the scope of a single particle, this conversion means the concentration of a large part of the energy on some particle at the surface of the nucleus, and resembles therefore the evaporation of a molecule from a liquid drop. In the case of disintegrations comparable to the division of such a drop into two droplets, it is evidently necessary, however, that the quasi-thermal distribution of energy be largely converted into some special mode of vibration of the compound nucleus involving a considerable deformation of the nuclear surface.

In both cases, the course of the disintegration may thus be said to result from a fluctuation in the statistical distribution of the energy between the various degrees of freedom of the system, the probability of occurrence of which is essentially determined by the amount of energy to be concentrated on the particular type of motion considered, and by the 'temperature' corresponding to the nuclear excitation. Since the effective cross-sections for the fission phenomena seem to be about the same order of magnitude as the cross-sections for ordinary nuclear reactions, we may therefore conclude that for the heaviest nuclei the deformation energy sufficient for the fission is of the same order of magnitude as the energy necessary for the escape of a single nuclear particle. For somewhat lighter nuclei, however, where only evaporation-like disintegrations have so far been observed, the former energy should be considerably larger than the binding energy of a particle.

These circumstances find their straightforward explanation in the fact, stressed by Meitner and Frisch, that the mutual repulsion between the electric charges in a nucleus will, for highly charged nuclei, counteract to a large extent the effect of the short-range forces between the nuclear particles in opposing a deformation of the nucleus. The nuclear problem concerned reminds us indeed in several ways of the question of the stability of a charged liquid drop, and in particular, any deformation of a nucleus, sufficiently large for its fission, may be treated approximately as a classical mechanical problem, since the corresponding amplitude must evidently be large compared with the quantum mechanical zero-point oscillations. Just this condition would in fact seem to provide an understanding of the remarkable stability of heavy nuclei in their normal state or in the states of low excitation, in spite of the large amount of energy which would be liberated by an imaginable division of such nuclei.

The continuation of the experiments on the new type of nuclear disintegrations, and above all the closer examination of the conditions for their occurrence, should certainly yield most valuable information as regards the mechanism of nuclear excitation.

[1] Meitner L. and Frisch O.R. [1939]. Nature 143, 239.
[2] Frisch O.R. [1939]. Nature 143, 276.

Search for relatively stable superheavy elements in nature by fossil track studies of crystals from meteorites and the lunar surface

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The main aim of this paper is to report further investigations on the search and identification of relatively stable nuclei [$Z \geq 110$] of Super Heavy Elements [SHE] in Galactic matter by fossil track studies of non-conducting crystals from the surface of some meteorites and from lunar regolite rocks.

As predicted theoretically in the late 60's, superheavy nuclei in the region of proton numbers Z = 110-114 and neutron number N = 184 [double magic closed nuclear shells] can possess life times from 10^3 up to 10^9 years. Thus nuclei of SHE can survive in extraterrestrial rocks and produce tracks in the host crystals as a result of spontaneous fission, if their life time is more than 5×10^7 years. Nuclei of SHE are supposed to be the products of nucleosynthesis in explosive processes in our Galaxy [supernova r-process nucleosynthesis, and, especially, neutron star formation processes, etc.]. When these nuclei accelerated to relativistic energies in the Galaxy, they can produce extended trails of damage in non-conducting extraterrestrial crystals. To be registered in extraterrestrial crystals the life time of such SHE nuclei in the Galactic cosmic rays must exceed ~10^3 years.

To search for and to identify the superheavy nuclei in the Galactic cosmic rays it is proposed to use the ability of some extraterrestrial crystals [olivines, pyroxenes, phosphates] to store for many million years the trails of damage produced by fast $Z \geq 23$ nuclei coming to rest in the crystalline lattice. The track length of fast $Z \geq 23$ nuclei is directly proportional to Z^2. Thus, the nuclei of SHE will produce tracks that are 1.6-1.8 times longer than the tracks due to high energy Th-U nuclei in the galactic cosmic rays. For visualisation of these tracks inside the crystal volume the proper controlled annealing and chemical etching procedures must be used.

In our pervious study in 1980, the fossil tracks due to Th-U nuclei were first observed and unambiguously identified by calibration of the olivine crystals with accelerated U, Au and Pb-ions. The charge distributions and energy spectra of Z = 26-92 galactic cosmic ray nuclei were measured. The number of Th-U nuclei track measured in olivine crystals was in total more than 1600, as compared with the rest world statistic – 30 events [LDEF, HEAO-3, ARIEL-6 experiments on direct registration of $Z \geq 70$ cosmic ray nuclei tracks in satellite based detectors]. Five anomalously long tracks, which could not be attributed to Th-U nuclei, were also registered in this study. The goal of these track studies is the final unambiguous identification of $Z \geq 110$ nuclei in the Galactic cosmic rays.

The second approach to identify SHE nuclei in nature is to search for the tracks in extraterrestrial phosphates due to spontaneous fission of $Z \geq 110$ nuclei producing 2-pronged and 3-pronged fission fragment tracks, which differ significantly from the tracks due to the spontaneous fission of ^{238}U and ^{244}Pu nuclei. Extraterrestrial phosphate crystals [whitlocites, apatites and stanfilldites] will be investigated in these studies.

A new apatite and titanite standard for fission-track and (U-Th)/He dating

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All of us need standards. Lots of standards. I have heard rumours of some of us having gone to sample FCT and having come back with several old suitcases filled with rocks ...

Ideally, we want a standard, which contains the minerals of interest in large quantities. For [U-Th]/He dating, we also would love to have large grains, in order to minimize surface effects. Furthermore, we need to date our standard with other dating techniques, preferably by Ar/Ar. And we should be able to verify that the material has not undergone a complex time-temperature history after the start of track accumulation. And the investigated mineral grains should not be zoned, should be free of inclusions. And ... and ... and ... There is a long list of requirements, hard to cover by a single sample or locality. However, we might be in a position to offer a lithology able to deal with most of the requirements.

Next to the town of Freiburg, Germany, an extinct alkaline volcanic complex, the Kaiserstuhl, is located. At its northwest corner, the youngest extrusive phase has created a thick succession of lava flows and tuff layers. The phonolitic tuff t3 was dated with several methods. Kraml et al. [1996] produced Ar/Ar plateaus from single 0.5 to 2 mm sized clear sanidine crystals by incremental laser heating, and provided a cooling age of 16.2 ± 0.4 [2σ] Ma. These Ar/Ar ages are identical to an older K/Ar dating result by Lippolt et al. [1963]. Recently, the tuff has also been dated by the fission track technique on apatite, and by [U-Th]/He dating on apatite and titanite. Both apatites and titanites can be found in sufficient quantities in the 100-500 µm size range of the disaggregated rock. Disaggregation is done by simple washing and rubbing the collected tuff through a column of sieves, because most of the rock matrix is completely altered into clay minerals. For mineral separation, you therefore start by "washing, not crushing", which keeps the grains euhedral. The subsequent steps in mineral separation correspond to normal procedures, with the exception that apatites and titanites can also be gained from the fractions >300 µm. Suitable sanidine crystals are obtained by handpicking out of the 0.5-2 mm fraction.

Fission track dating of the apatites yielded an age of 16.8 [-1.2/+1.3] Ma [2σ, based on 20 crystals]. A mean fission track length of 15.17±0.18 [2σ] µm [n = 100] is in agreement with a very fast cooling and the absence of a later heating event. We admit that not all apatites are crystal clear like in Durango. But they are mostly euhedral, and therefore align perfectly for counting. A normal mount always contains more than enough large high-quality grains. Features that can be mistaken for tracks are absent. Single grain ages varied from 12.5 to 25.5 Ma in age, the U content varied from 13 to 72 ppm.

In addition, apatites and titanites were dated with the [U-Th]/He method. The mean age of six apatite mounts is 16.4±0.7 Ma [2σ]. The U concentration of the apatite subsamples varied from 25 to 33 ppm; the U/Th ratio showed a range of 0.10 to 0.23. Five titanite mounts were dated by [U-Th]/He, giving a mean age of 16.3±0.6 [2σ]. The U and Th concentrations were in the range 23-47 ppm and 63-80 ppm, respectively.

Within less than 0.5 standard deviations, all three methods provide the same result. The nearly perfect overlap between the three data sets is a good argument for the very simple thermal history of the tuff layer. The age of the proposed new standard is nearly identical to the Buluk tuff [Hurford and Watkins 1987], which is an approved zircon standard.

The new Limberg t3 standard provides material for apatite, titanite and sanidine, and the grain size is suitable for the fission track, laser single-grain Ar/Ar and [U-Th]/He methods. Our separation work has also shown the presence of low amounts of zircons in the tuff. However, these are most probably derived from crystalline basement fragments, which were transported from depth to the surface within the melt, and are not part of the phonolitic assemblage.

On the basis of our results, we propose the Limberg t3 tuff as a new age standard for the Ar/Ar method [sanidine], for fission dating [apatite and possibly titanite] and [U-Th]/He dating [apatite and titanite]. The consistent results obtained with three methods make it an attractive standard for studies on the low-temperature evolution of moderately to fast cooling settings.

Interested? Need a new standard? Or just another one to test? If yes, get your old suitcases ready ...

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Experimental evidence for the pressure dependence of fission track annealing in apatite

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INTRODUCTION

Apatite and zircon fission tracks analyses can provide information on the timing and the spatial variation of thermal histories as a function of the decay of U and of partial or total track annealing. The temperature at which fossil fission tracks in the apatite group minerals are annealed is not sharply defined but progressive, and depends on the mineral composition [e.g. Green et al., 1986; Carlson and Donelick, 1993], the cooling rate and possibly the symmetry group of the mineral [Kohn and Foster, 1996]. Annealing of fission tracks in minerals is described as a poorly understood diffusional-type process, which restores the damaged crystalline structure when thermally activated [e.g. Wagner and van den Haute, 1992; Gallagher et al., 1998].

The mean length of fossil fission tracks in apatite group minerals ranges from 14.5 µm to 15.5 µm [Gleadow et al. 1986]. Samples with mean track length in this range and narrow track length distributions are assumed to have experienced rapid cooling from temperatures above 100°C down to less than 60°C at the time indicated by the fission track age [Laslett et al. 1987]. Broad length distributions and shorter mean lengths suggest that the samples have experienced a more complex thermal history, spending a significant amount of time in the partial annealing zone [Gleadow et al., 1986].

We report and discuss experiments aimed at investigating the effects of other parameters such as hydrostatic pressure [P] and stress [σ], in addition to temperature [T], on the stability field of spontaneous fission tracks in apatites. This is motivated [1] by the fact that diffusional processes are expected to slow down under pressure, and [2] by the lack of experimental data of fission track fading under P and T.

The pressure dependence of diffusion has been studied, from the perspective of absolute reaction rate theory, e.g. in polycrystalline lead [Nachtrieb 1955; Hudson and Hoffman 1961], zinc [Lin and Drickamer 1954], uranium [Beyerler and Adda 1965] and olivine [Kohlstedt et al. 1980] [Figure 1]. These experiments revealed an approximately linear decrease of the logarithm of the diffusion coefficient D with increasing pressure. Assuming that similar mechanisms operate in fission track annealing, it is expected that the stability field of fission tracks widens with increasing hydrostatic pressure.

The only data on fading of spontaneous tracks under experimental pressures and temperatures date back to the work of Fleischer et al. [1965]. They studied fission track fading in tektites and zircon under pressure, temperature,

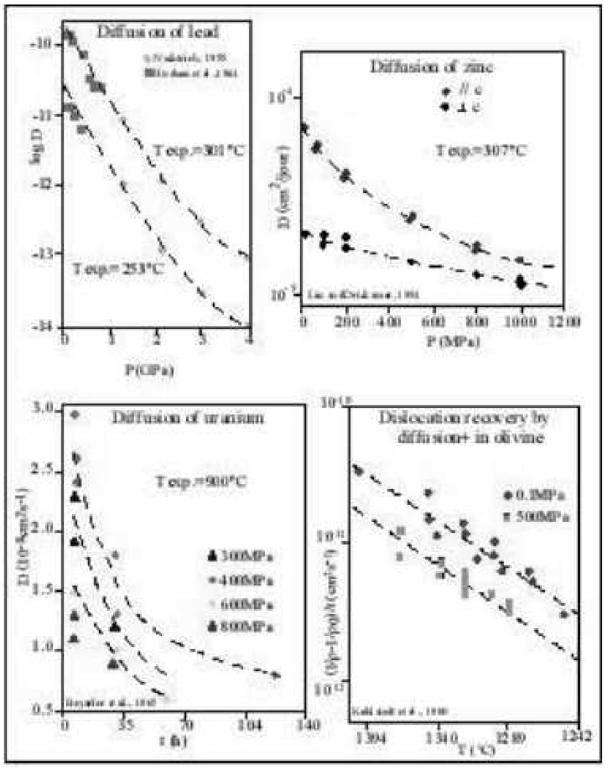

Figure 1. Pressure dependence of diffusion coefficients in lead, zinc, uranium and olivine.

plastic deformation, and ionising radiation. The tektites were annealed at pressures ranging from 0.1 to 6000 MPa and temperatures from 50 to 580°C [Figure 2]; the zircons were annealed at pressures from 0.1 to 8000 MPa at temperatures from 550 to 850°C; maximum annealing time was 167 hours [Figure 3].

In tektites, track fading in the high-pressure low-temperature run was observed to be independent of the annealing time [5 to 1000 minutes] and temperature [50 to 130°C]. The tracks were partially annealed at temperatures from 90 to 150°C the extent of annealing being independent of the annealing time. In the medium pressure [1000 -3000 MPa] and medium temperature range, tracks are stable during 1000 minutes at temperatures increasing from 130 to 250°C and 290 to 310°C. Fading becomes time-dependent above 310°C. At high temperatures and 200 MPa pressure tracks

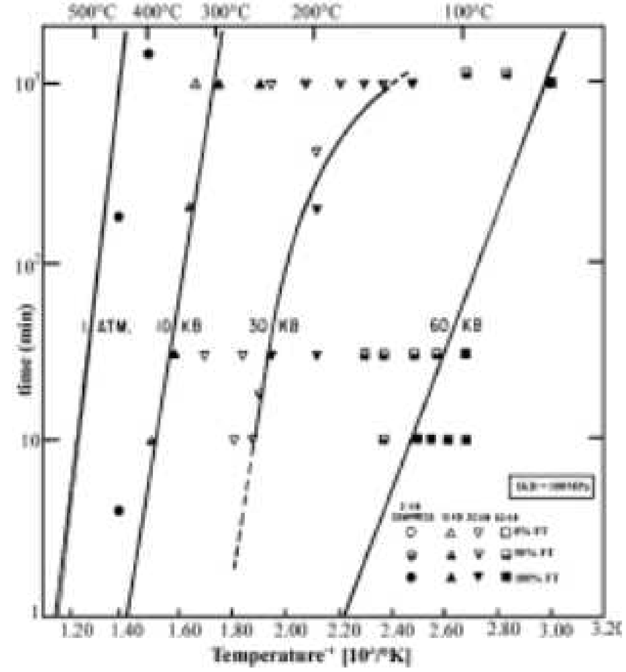

Figure 2. Fission-track stability in tektite as a function of pressure and temperature. Data from Fleischer et al. [1965].

remained unaffected. The runs at medium pressure showed a particularly complicated track fading pattern: total fading and partial fading do not constitute clearly separated data sets, but overlapped in some points. No information is given on fading tests at ambient pressure.

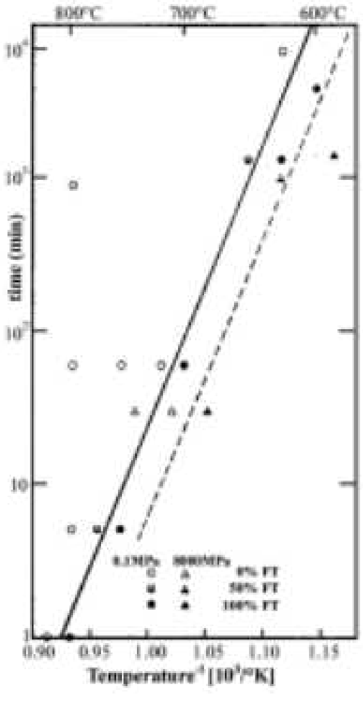

Figure 3. Fission-track stability in zircon as a function of pressure and temperature. Data from Fleischer et al. [1965].

In zircon, the high temperature ambient pressure run led to partial to total track fading; pressure produced similar fading behaviour at lower temperatures.

In general, these experiments seem to show that the application of hydrostatic pressure enhances the annealing of fission tracks. However, the experimental results are difficult to interpret since: [1] fission track densities were investigated qualitatively; [2] no information is given on the variation of the uranium content between samples which might introduce considerable errors in the experimental results; [3] the experiments performed under geologically relevant temperature-pressure conditions [up to 3000 MPa] do not provide a clear answer on the P dependency; [4] no experiments were performed which directly investigate the effect of temperature and ambient pressure compared to the effect of the same temperature at high pressure for constant time spans [$P_1 = 0.1$ MPa, $T_1 =$ constant, $t_1 =$ constant and $P_2 > 0.1$ MPa, $T_2 = T_1$, $t_2 = t_1$]. In addition, the experimental results seem to show that if pressure enhances the fading rate of fission track, then the processes which are involved during "annealing" are not governed by diffusion.

In order to obtain unambiguous data for spontaneous fission tracks, an experimental programme has been developed which allows a direct comparison of fission track behaviour at constant pressures, constant temperatures and constant times for different apatite compositions. The P-T coupling is representative of high pressure retrograde P-T paths. We are investigating latent and etched tracks by TEM and optical analyses of the annealed samples in comparison to the unannealed material. Here, we report the first results.

APATITES

Three single crystals [length up to 30 mm, diameter ca. 15 mm] of apatite of different provenance and chemical composition were used for the experiments: [1] yellow-green apatite from Durango [Mexico], [2] blue apatite from Sludjanka [Siberia] and [3] light blue apatite from Canada. Their fluor/chlorine ratios are as follows: Durango: F/Cl = 1:0.27; Sludjanka: F/Cl = 1:0.29; Canada: F/CL = 1:0.08. The crystals were cut into slices parallel to the c-axis in order to perform all experiments on sections with the same orientation from the same crystals. The slices were sealed in 2 cm long, 5 mm diameter gold capsules together with 2 ml of distilled water for the low pressures runs [100 MPa, 350 MPa] and dry in gold capsules for the medium pressure runs [600 MPa, 800 MPa]. For the high pressure runs at 2000 MPa, the crystal slices were directly included in salt cylinders of 15 mm length and 7 mm diameter.

EXPERIMENTS

Different apparatus were used for P-T experiments in different pressure intervals:

[1] Simple heating experiments at ambient pressures were performed in a furnace. The cumulative uncertainty on the temperature measured with a Pt/13%Rd thermocouple was 2°C. The heating rate was 15°C/min. Cooling to ambient temperature at the end of each run was achieved in 15 minutes.

[2] The experiments at pressures of 100 and 350 MPa were performed in horizontal, externally heated, cold seal pressure vessels. The confining pressures were built up with H_2O vapour and controlled with a Bourbon gauge to within 0.5 MPa. Temperatures were measured with a chromel-alumel thermocouple located at the hot end of the vessel, and controlled electronically to within 5°C. The heating rate was about 20°C/min and quenching of the capsules from

500°C to ambient temperature was achieved in 5 minutes before decompression. [Table 1].
[3] The high pressure runs at 600 and 800 MPa were performed in an internally heated pressure vessel. The confining pressures were built up with Argon gas and electronically controlled to within 1 MPa. The cumulative uncertainty on the temperature, measured with Pt/13%Rd thermocouples located at both ends of the pressure chamber, was 3°C. The temperature gradient in the pressure chamber was measured electronically and was less than 1°C. The heating rate was 20°C/min. Cooling to ambient temperature at the end of the runs was achieved in 1 minute before decompression. [Table 1].
[4] The ultrahigh-pressure runs at 2000 MPa were performed in a solid medium apparatus in which the confining pressures were built up by flowing salt. The heating rate was 15°C. The temperature, measured with Pt/13%Rhd was electronically controlled to within 2°C. Cooling to ambient temperature was achieved under pressure in about 90 minutes.

ANALYSES

The apatite sections were carefully taken out of their jackets. Most had remained intact and had not changed colour. They were cut into several oriented pieces. One was used for common fission track analyses, a second for high resolution transmission electron microscopy [HRTEM]. The fission track samples were embedded in epoxy and prepared as thin sections, avoiding heating above 35°C. A sufficient thickness of material was removed from the crystal surface in order to avoid interference from interactions between the confining medium [water, gas, salt] and the crystal. The fission track analyses were performed on spontaneous tracks in sections parallel to the c-axis after etching in HNO_3 /H_2O = 6.5/100 at room temperature for 40 seconds [e.g. Wagner and Van den haute, 1992, Hurford, 1990ab]. After etching, fission track densities, lengths and orientations were measured. Here, we concentrate on the fission track densities.

RESULTS

Altogether 50 successful experiments were performed from which we present here the first 17 results. The changes in fission-track densities as a function of pressure, temperature, time and chemical composition are shown in Figure 4. The final track densities are represented as percentages of the initial densities as a function of time in a simple XY-graph.

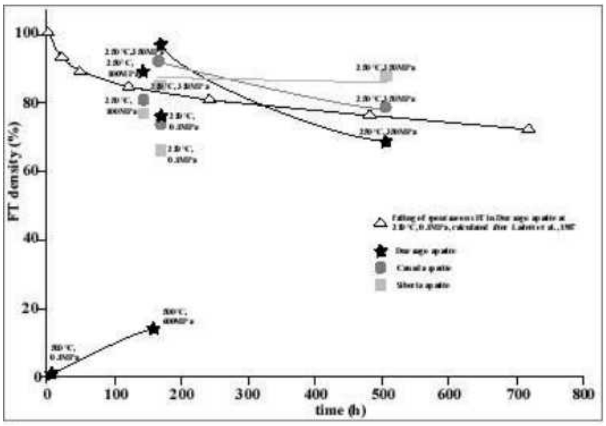

Figure 4. Experimental results on fission track densities after annealing at P and T.

It is clear that an increased pressure at constant temperature and a running time of one week increases the fission track stability in all three apatites. In the three week experiments, a decrease in fission track densities was observed compared to the densities after one week annealing. The average slope of the curves for the Canada and Siberia apatites suggests a constant rate of fading for longer time spans which is lower than the rate calculated for Durango apatite at 250°C and ambient pressure using the equations of Laslett et al. [1987]. The Durango sample showed stronger fading after three weeks than the two other samples. This is probably an artefact and related to the inhomogeneity of the uranium distribution in the Durango apatite which can amount to 30%. In addition, features similar to fission tracks were observed in apatites which were exposed to temperatures of 500°C at 600 MPa for one week. The same annealing at ambient pressure led to total fission track fading after several hours [Figure 4]. The distribution of track length versus orientation in an unannealed apatite and the HP-HT annealed Durango crystal are similar, suggesting that the observed features are normal fission tracks [Figure 5]. Anomalous fission track fading, as described by Jonckheere and Wagner [2000], can be excluded, since the HP-HT samples are free of fluid inclusions and tracks were observed in fracture-free areas. In general, we can conclude from these first experimental results that pressures increases the fission track stability considerably. Figure 6 shows two photomicrographs of annealed fission tracks in comparison with an unannealed sample.

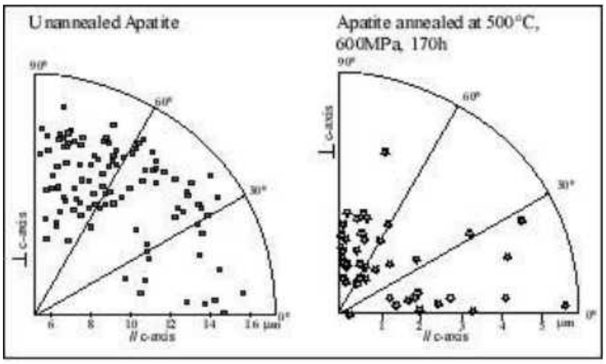

Figure 5. Projected fission-track length vs. angle to the c-axis in unannealed and [HP,HT] annealed apatite. In both experiments, track are longer parallel to the c-axis and shorter perpendicular to the c-axis as a result of anisotropy.

DISCUSSION

If fission tracks are "restored" by a diffusion-type mechanism, it seems that diffusion is less effective at high pressures, resulting in a shift of the fission track stability field to higher temperatures. This behaviour is known from diffusion processes in metals and some silicates [see Figure 1]. This allows us to describe fission track annealing as follows:

$$\rho_0 / \rho = - K \rho_0 t \exp [-[Q+PV]/kT] \qquad [1]$$

[Kohlstedt et al., 1980; Karato et al., 1981], wherein: ρ_0 = initial fission track density; ρ = final fission track density, K = constant, t = time, Q = activation energy, P = pressure, V = activation volume, k = Boltzmann's constant, T = temperature.

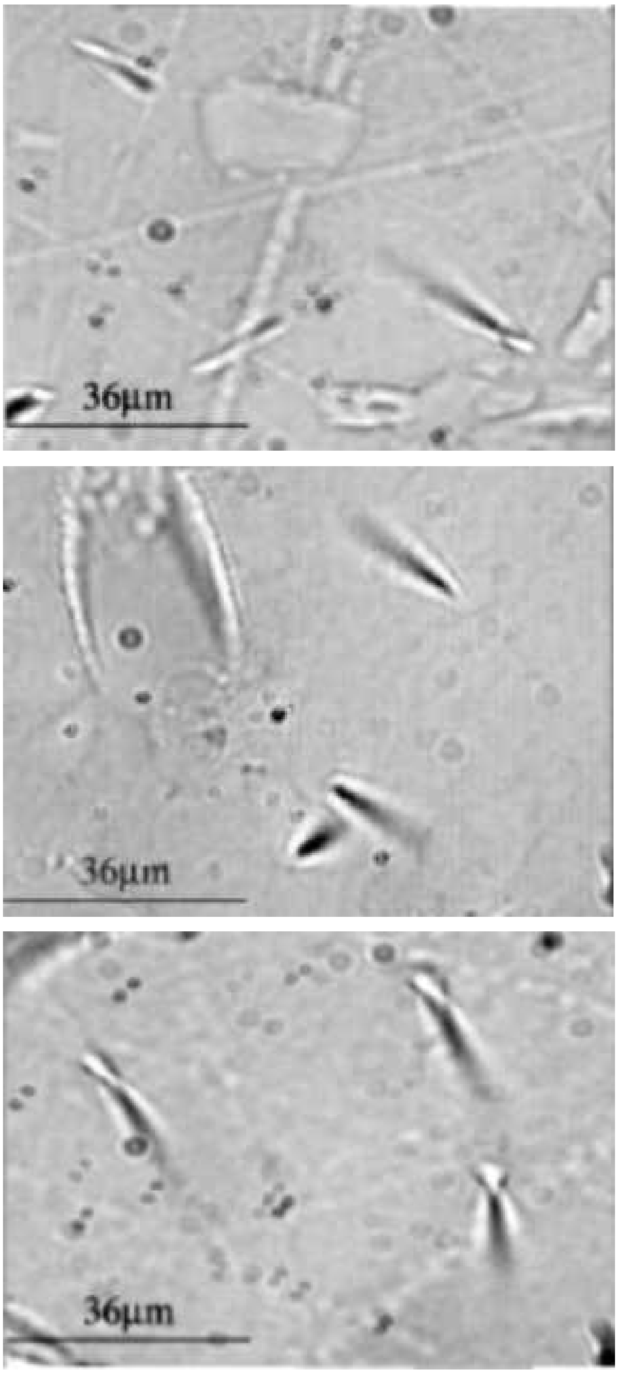

Figure 6. From top to bottom: unannealed Durango apatite; same crystal annealed for one week at [350 MPa, 250 °C]; same crystal annealed for one week at [600 MPa, 500 °C].

If the increased stability of fission tracks due to P-T coupling is confirmed by experiment, then important changes in the interpretation of fission track ages and in the derivation of exhumation paths are necessary for high pressure metamorphic rocks. If fission tracks have greater stability at increased pressure, then the closure temperature will be higher than the commonly accepted value [~ 100°C]. Examples of retrograde P-T-t paths describing this phenomenon are given in Figure 7. It can be seen that the classic stability field of fission tracks is narrower than the stability field derived from our experiments, leading to an overestimation of the closure ages during exhumation [red point in Figure 7].

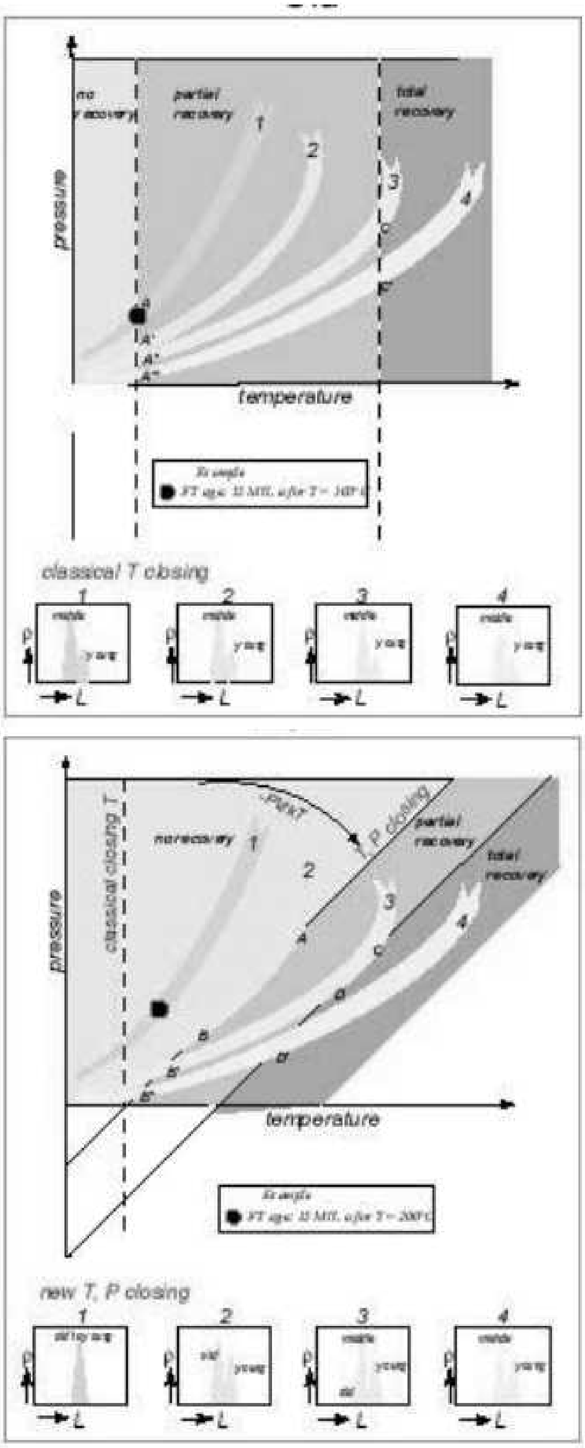

Figure 7. Examples of retrograde metamorphic paths and fission-track fading, using temperature-defined stabilities [top] and temperature-pressure defined stabilities [bottom]. The apparent closure temperature age becomes greater than the red closure pressure-temperature age. The track length distribution also changes when considering pressure-temperature dependent track stability.

The experiments show that fission tracks in minerals exposed at the Earth's surface can be inherited from greater depth without having been completely annealed at high temperatures. Therefore, a fission-track age can have a different meaning for high pressure metamorphic rocks characterized by a fast exhumation: either [1] it might describe the crystallisation conditions of the crystal or [2] it might describe a point of the retrograde metamorphic P-T-t path which can coincide with peak metamorphism. An experimental description of fission-track stabilities over a wide range of P-T coupling will lead to the complete reconstruction of the exhumation paths under which fission tracks completely anneal, partially anneal or not anneal at all.

CONCLUSION

The results presented here are preliminary and more work is needed. In particular, short and long-term experiments allowing an extrapolation of the experimental data to geological timescales as well as a quantitative comparison between the P-T dependent fading behaviour of spontaneous and induced fission tracks. As mentioned earlier, it is difficult to find a statistically representative number of horizontal confined fission tracks for the lengths measurements. Therefore we plan to irradiate our samples with Californium-fission fragments which will provide the possibility to analyse great numbers of confined tracks and will allow us to determine P-T fission track stabilities with great precision.

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Scanning through the ages

Mike Krochmal and the crew at Autoscan

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The whole thing started in about 1979, and is almost entirely Prof. Andrew J. Gleadow's fault. He had the bright idea that there must be a better way for Fission Trackers than to sit in dimly lit rooms for weeks or months on end, counting tracks manually to the accompaniment of the music of those little hand-clickers, writing down the numbers on bits of paper that get picked up by other people and scribbled on, and going cross-eyed looking for mica-side tracks that aren't there because the detector lost contact with the grain mount. Can't imagine why anyone would not enjoy that !

The first people to become involved were Dr. Peter Leigh-Jones and Dr. Leigh Fiddes, then working in the Department of Communication and Electronic Engineering at RMIT in Melbourne. These two bright lads had just given two papers at the IREECON [17th International Electronics Convention and Exhibition] in Sydney in 1979, called "A Microprocessor Controlled Precision Scanning System for Step and Repeat Exposure" and "A Computer Based Optical and Electron Beam Lithographic Facility". The equipment described, which was a scanning stage able to be driven over an area of 50 mm by 50 mm in steps of 0.5 micron, was designed around an M6800 microprocessor [hands up those who can remember those little beauties !] Peter and Leigh were certainly well qualified to put Andy's ideas into practice.

The initial systems built for fission track dating [both of which were installed at the University of Melbourne, one in 1981 and one in 1982] were designed around a modified stage of ample proportions supplied by Zeiss. Focus was achieved by means reminiscent of a screw-top jar, edge-driven by a stepper motor and the electronics were a sight to behold. By the time of the third system [South Korea in 1984], the stage was a custom-made model, and the electronics were wire-wrapped [the technology of promise at the time - whatever happened ?].

By the time system 6 was installed [again at the University of Melbourne, in 1984], Dr. Michael J. Smith had taken over the company, and had incorporated it officially as Autoscan Systems Pty. Ltd. This system was based on the first of the "only a mother could love it" AS1000 stages that were to be with us until 1993. Mike is a mechanical engineer, and designed and manufactured the first truly compact stage with integrated 3-axis motion, with the focus being independent of the microscope focus mechanism. That stage used dc motors for X and Y movement, but a stepper motor for focus. Any fission tracker who worked with that stage is able to give a good rendition of the slow, laboured grind of the focus stepper motor, but it did the job, and it did it well. Mike Smith was the first to represent Autoscan at a conference : the 4th International Fission Track Dating Workshop in Troy, NY, USA in 1984.

My first involvement with Autoscan was in 1986, when I represented Mike Smith at ICOG6 in Cambridge, UK. That was a memorable conference, and I have pleasant memories of passing under Newton's Bridge while punting on the Cam, and of the madrigals on the riverbank. I then spent a year working in the US, but acquired Autoscan Systems from Mike Smith when I returned in March 1988. By that time, Mike had sold nearly a dozen systems, and Autoscan was beginning to be a well-known name among fission trackers.

1988 was also the year of the 5th [6th?] International Fission Track Dating Workshop in Besançon, France. Again, this was a most memorable meeting and those who attended will no doubt have pleasant memories of the visit to the salt works and the hot-air balloon rides.

By the time of ICOG7 in Canberra, Australia in 1990, we already had 20 systems installed. We were lucky to be there at the time of the Floriade - another great experience. The 7th International Fission Track Dating Workshop was held in Philadelphia, PA, USA in 1992. Again, more excitement - we got to see the actual porch [with Coke machine] that was the location of filming for "Witness", a film about the Amish starring Harrison Ford and Kelley McGuire. And now we know where Philly cheese comes from.

In 1990, we successfully applied for a Federal Government R&D grant, which allowed us to develop a new generation of stages, as well as software which incorporated image processing. These systems, which are able to detect, characterise and re-locate the tracks left by alpha particles in CR39, were in demand by the radiation protection community and other disciplines. As a result of this new market opening for us, we became involved in some serious trading which resulted in installations in 14 countries by 1997. These activities prevented us from attending ICOG8 in Berkeley in 1994, the 8th International Fission Track Dating Workshop in Ghent in 1996, or ICOG9 in Beijing, China in 1998. But we did make the effort to come back to the fold in February of 2000, when Fission Track 2000 [the 9th International Conference on Fission Track Dating and Thermochronology] took place in Lorne, Victoria, Australia. It was a wonderful experience to be able to catch up with familiar faces from long ago [although some were sadly missed]. It also brought home to us again how lucky we are here in Australia, when it comes to our environment and places of natural beauty – it was with great pride that we joined the well-conducted conference tour along the Great Ocean Road and to the Twelve Apostles.

Over the years, we have had the odd bit of acknowledgment or two, such as receiving [among others] the coveted Qantas/Austrade Award for Export Excellence, being featured in major articles in various Australian Federal and State government publications, and getting our name in articles in overseas publications.

Well, where to from here ? Our systems have seen several total design overhauls and enhancements [stage and joystick hardware, software and electronics], and will no doubt see more. As of 2001, Autoscan has a consolidated presence in 20 countries across a broad range of scientific disciplines. The indications are that the technique of Fission Track Dating is not only well established, but on a growth curve and being recognised as a standard technique. After years of world-wide economic stagnation which have left their bitter mark on most areas of science [except the glamour areas of the International Space Station and the Human Genome Project], governments around the globe seem to be beginning to come to the realisation that without science and education, there is no future. In a world of instant gratification, the realities are beginning to dawn. Let us hope that this is the start of a new and lasting awareness, not a brief flicker of alertness followed by a relapse into deep sleep.

Our approach to our clients has been to encourage both positive and negative feedback, and to make appropriate changes to our product where necessary. From the feedback received, we know that the fission track community holds our company in high regard for the quality of its product and its after-sales service. The pricing of the product is the one element of our business which is sometimes questioned [as is the case with any product at any price]. The reality is that whoever said : "You get what you pay for" was quite right. We attempt to provide the best possible solution to the challenges faced by our clients at the best possible end price. But a commercial organisation cannot endure by selling its products at a loss. Doing this means doing a disservice not only to itself, but to the market: better products can only be generated by viable companies. Our history of 22 years of service to the fission track dating community attests to the fact that we are in this for the long haul.

In closing, I would like to thank Raymond Jonckheere for the opportunity to tell our story, and to our team at Autoscan, which includes Ian Larsen [our General Manager], Garey Laken [Technical Director], and our large and dedicated team of staff, contractors, external consultants and suppliers too numerous to mention, for getting us to where we are and keeping us there. Without a skilled, experienced, and harmoniously operating crew a ship is just so much flotsam in the water. And finally but most importantly, special thanks go to you, the users of our systems, for supporting us over the years. Without the scientific guidance we have had from all quarters of the fission track community to date, we would not be where we are today. Happy tracking.

Length measurement, annealing and kinetic models: are we still out to lunch[1] ?

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Some 20 years ago, Paul Green and I argued the case for standardisation of fission-track age measurement and calibration. After protracted and sometimes heated debate, the majority of workers in the fission-track game adopted a unified approach which has worked successfully for more than a decade [1,2]. The zeta calibration of Fleischer and Hart [3], together with the use of age standards, has given us all a common, if imperfect, baseline from which to work. Consensus in age calibration is one reason why the fission-track method has prospered, has found application in diverse areas of geoscience, and has given many of us research grants and jobs. The other reason is the realisation that fission-track age means little without the means to decipher the thermal record which it represents: track lengths must be measured. And interpreted. "*Aye, there's the rub"* - as Shakespeare put it [4]. To be blunt, do we really know what we are doing when we measure and interpret our data and promulgate our answers in terms of denudation amounts, sediment fluxes, basin inversion, tectonic movement, hydrocarbon maturity .... ? Conversations with colleagues, certain articles in recent issues of *On Track*, and some presentations at FT 2000 in Lorne, shout two things very loudly to me: firstly we have no effective standardisation of track length measurement; and secondly many of us are using interpretative approaches which are inappropriate to our methodology. Kerry Hegarty [5] rightly bemoaned the wasted opportunity of Lorne in that having got to the verge of admitting the problem, we "**walked off to lunch**".

Let us try and tease out some of the aspects where problems exist, and then search for some practical steps which we can take together. I don't claim these thoughts as necessarily original and whilst *de facto* they are aimed at apatite, they should be equally applicable to zircon and titanite.

Our effort in interpreting and giving geological sense to our data revolves around three basic elements:

• measurement and quantification of fission track annealing;

• description of fission track annealing [not the same as understanding it];

• use of the annealing description within a geological timescale.

Few of us have measured fission track annealing systematically; even fewer are able to formulate an algorithm to best describe annealing, or to write our own programme which uses that algorithm to predict the probable age and length. **But nonetheless almost all of us use such descriptions and programmes in geological applications**, and thereby hangs the problem of suitability and compatibility. Taking a northbound number 73 London bus from UCL to go to Trafalgar Square just because it is big and red and full of people could be foolish without checking its appropriateness: a 73 goes to Oxford Street not Trafalgar Square, and northbound is the wrong direction anyway. Similarly, how appropriate are the published measurements and descriptions of annealing to our own specific laboratories and techniques? Were the annealing data determined with identical revelation, observation, measurement, data selection and bias criteria as we use on our samples? Almost certainly not. As Geoff Laslett has underlined, to use the Laslett et al. [1987] [6] model generally for all apatite samples is flawed [he called it bad science]. Not only will the experimental parameters of the original annealing runs [7] and subsequent sample analysis in London or Tübingen or Arizona or wherever differ, but that annealing study was on an apatite of one composition [Durango], whilst we work daily with samples of differing compositions. And we have all learnt the *credo* that apatite annealing is dependant on composition.

So how do we respond? Usually by ignoring the problem - but knowing that we should do better, but being uncertain exactly how. It is unreasonable and impractical to consider that each of us establish our own set of annealing data on apatites of differing composition: it's long and painstaking work and few have risen [or been able to rise] to the challenge. Funding **is a problem** for most university-based groups where methodological work is frequently subordinated to geoscience applications, more likely to secure funding and personnel.

Similarly few workers have routine access to a electron probe to determine the composition of **all** the apatite grains analysed; sometimes one or two samples are measured in a study and the compositions assumed to be similar for other grains. Etch pit size can act as a proxy to composition [8], with Cl [or OH] rich apatites giving bigger pits. Infra-red spectra have also been suggested as indicative of composition [9]. But then assuming we have determined the composition of apatites from a North Sea borehole sandstone [or wherever], what do we do with our results? Data from apatites with compositions outside a defined range could be excluded from a sample set, perhaps to give a closer approximation to the Durango-annealing data used in Laslett et al. [1987]; but this results in a part, perhaps a key part, of the thermal history record being discarded.

Geotrack are different because they have made a major commitment of resources over many years to derive a multi-compositional annealing model which, so they tell us, has answered many of the questions most of the rest of us only whisper about. Yes, their model does remain unpublished but Geotrack is a commercial organisation whose daily bread comes from their efforts without the subsidy from, or liability to, the public purse enjoyed or endured by most of us. Conversely the rules of free and

[1] A case of *discussus interruptus* perhaps ?

open scientific publication advocate full accessible justification of cited theory and methodology. Geotrack's claimed success in deriving a deeper kinetic understanding should spur on other efforts to similar or parallel studies.

A notable dataset has been reported in the trilogy of papers published by Ray Donelick, Rich Ketcham and Bill Carlson which included a vast array of annealing results on apatites with a wide spread of compositions, a description of annealing and a predictive model using that description [10-12]. Experimental procedure was especially well controlled in these experiments and other influences considered. I suspect that most fission-track workers read at least part of these detailed papers, were highly impressed, but again thought "*how can I use these studies to improve work in my own laboratory?".*

We have similarly undertaken a large number of apatite annealing studies in London, in experiments headed by Jocelyn Barbarand and Andy Carter [13,14]. Rex Galbraith is formulating our annealing algorithm and, in time, we'll seek to patch that into our favoured predictive model, Kerry Gallagher's MonteTrax [15]. Details of these studies are in press and we aim to present some key findings in subsequent issues of *On Track*.

Since composition is seen as the all-important factor, let's consider one aspect briefly. Figure 1a shows the mean track lengths [MTL] measured for 13 apatites of differing composition annealed together at 320°C for 10h. A spread of MTL values is found, with a systematic decrease correlating with a decrease in chlorine content. However, 6 samples show no chlorine present in probe analysis and yet, exhibit a wide range of MTLs indicating differential annealing. Electron microprobe analysis using wavelength dispersive systems [WDS] has a detection limit of about 0.009 apfu [0.03 wt.%, 300 ppm] for chlorine [16] - some argue 200 ppm. Analysis of those 6 apatites using wet chemistry with a detection limit of ~16 ppm reveals a definite correlation between chlorine and track length [Figure 1b]. So chlorine appears to continue to exert an important influence at the sub-300 ppm level, below the limits detectable by electron probe - which gives us the problem of how to determine chlorine routinely in such common fluorapatites. This is not to exclude the possible effects caused by other substitutions: REEs especially are commonly cited in discussions over beer.

Such detail in annealing response is detected by very precise [and hopefully accurate] probe and wet chemistry analyses, and the measurement of a relatively small number of fission-track lengths. The subdivision of a fission-track dataset into bins determined by small differences in measured chemistry means that some data subsets can be very small. Three questions leap out. Firstly, what are the precision and accuracy of these fission-track measurements? Secondly, are these uncertainties factored into subsequent operations such as annealing algorithms and predictive thermal history modelling? And thirdly, given the level of these uncertainties, what robust comparison of data is there at the inter- and intra-laboratory analysis levels?

We've already noted the necessity for similar, ideally identical, techniques on project samples and on annealing calibration experiments. Distinct differences in length distributions also result according to whether TINTs or TINCLEs or a mixture are measured in a sample [10-12,17] this problem is exacerbated with higher levels annealing where

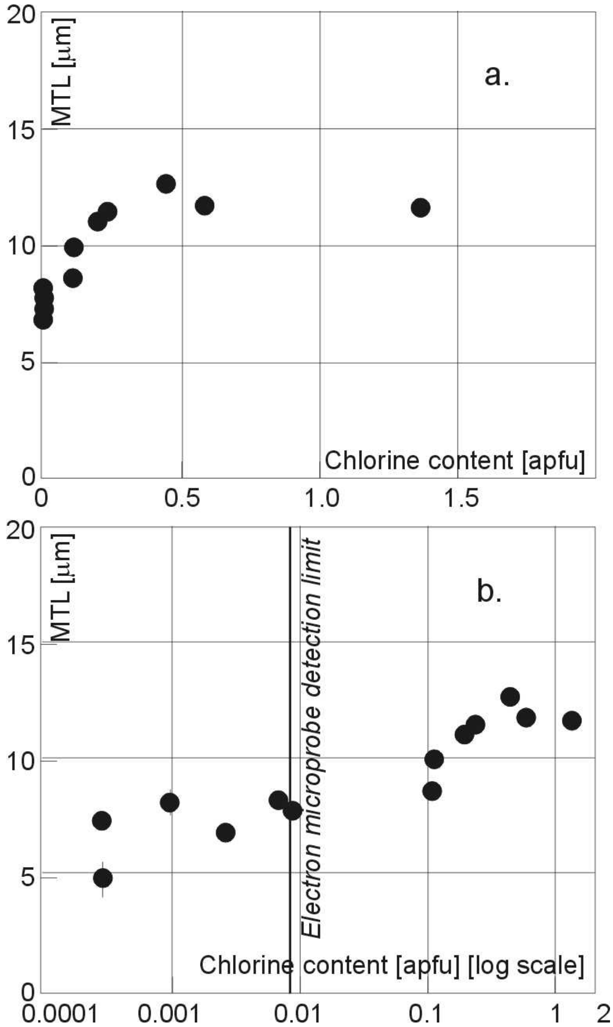

Figure 1. Comparison of measured mean track length for apatites of differing chlorine contents measures by [1.] electron microprobe and][b.] wet chemistry

there is a dependence of length on angle of the track to the c-axis. Di Seward and colleagues reported in the last *On Track* variation in results from etch times and operators. We have found similar differences between analysts: Figure 2 shows the length distributions measured by 5 people using identical observation conditions on a single fluor-apatite sample containing induced tracks annealed for 10h at 320°C. Both MTLs and length distributions show substantial variation which is a direct consequence of angular distribution bias: longer tracks parallel to the c-crystallographic axis are more readily identified and measured. Observers A, B, C and E found bimodal distributions with differing modes and spreads. Observer D found a unimodal distribution with very few short tracks at high angles to the c-axis.

These variations come from five experienced observers using the same microscope on the same sample. Add to this inter-laboratory differences in etching, dry *vs*. oil observation, total magnification, TINTs *vs*. TINCLEs, absolute calibration of length measurement, use of ^{252}Cf tracks to enhance confined track length numbers, consideration of track angle, cut-off point for short tracks .... Are any two fission-track workers doing things the same way? Almost certainly not. Dare I pose this question: could the variation introduced by differences in methodology approach the scale of differences resulting from compositionally-controlled annealing? So, potentially, we have two areas of variation instead of just one! Rather than cry into our pinot noir, or abandon the Axioplan in favour of the rejuvenated upstart [U-Th]/He, let us look at what we can do to advance the fission-track method which without a doubt can provide unique and valuable data for geoscience.

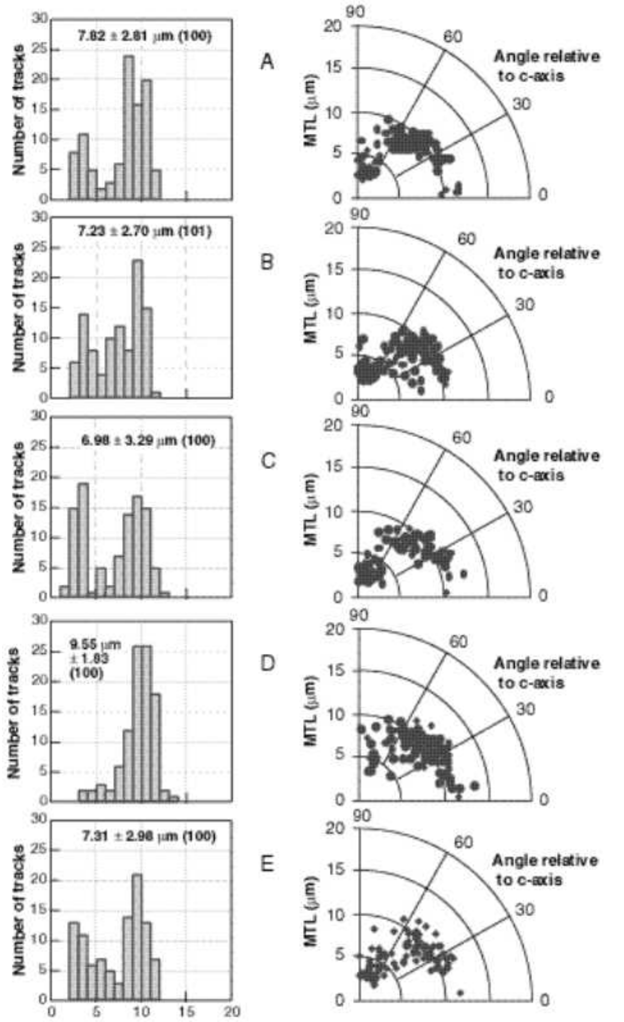

Figure 2. Comparison of measurements by five analysts upon a single apatite sample containing induced tracks annealed at 320 °C for 10h.

Most science, ours included, is an iterative process whereby we erect an hypothesis, however imprecise, and try to improve or replace it through testing, experimentation and discussion. It is not reasonable to suggest that until the model is perfected, nobody should measure a thermal history nor publish a fission-track paper nor yet complete their thesis. We are where we are. Without doubt we must improve our basic hypothesis: that means our annealing data, the annealing description, how we use that description both in terms of routine sample composition measurement and predictive modelling of thermal history. But in addition we must safeguard the results we are producing now against ill-defined or unrecognised uncertainty introduced by methodological differences and compositionally-controlled annealing differences. Are throw-away lines like *"the samples have broadly similar compositions to Durango apatite"* really sufficient to justify application of the Laslett et al. 1987 model?

A kinetic description of annealing behaviour for apatites of different composition is in the public domain [10-12], with our London studies en route; somehow we need to relate and calibrate these studies to our individual analysis methods in our own laboratories. We also need to formulate a more honest, more robust assessment of the uncertainties involved in the way we make track length measurements, which may mean bigger errors.

Zeta, as formulated for fission-track age analysis, includes factors for physical constants, reactor calibration, and personal methodology: I agree with Günther Wagner and Peter Van den haute [18] that deconvolution of zeta into the physical bits and a procedural factor Q should be a definite aim of the fission track community. There is obviously some sort of similar procedural factor for length analysis - let's call it L_Q for now, and it's a pretty complex beast involving all of the factors that I've mentioned above.

Here's a practical suggestion for a first step towards establishing a measure of inter-laboratory comparison, and defining our own L_Q: let each of us measure for ourselves, using our own methods and criteria, a few specific track-length distributions in the same samples. This isn't original but builds on the Loaded Dog experiment devised in Melbourne some years ago.

Suppose three c-axis parallel slices of an apatite crystal are distributed to each active laboratory for polishing, etching and measurement in their preferred way. Each slice would have been totally annealed and irradiated to induce a reasonable track density.

- Slice 1 could contain full-length induced tracks: this would represent the base-line for comparison of the most easily measured parameter.
- Slice 2 could contain induced tracks reduced to ~10 µm: this would test the level of angular bias in measurement.
- Slice 3 could contain a bimodal mixture of full-length and shortened tracks [double irradiation]: this would test for any sampling bias toward longer lengths.

Track densities might also be measured in each slice and the relation to lengths noted. There would be no right or wrong answers [who would dare claim absolute truth?], but we could measure the overall dispersion of values and each of us could assess our relative position. Anonymity would be kept throughout. A crucial factor is that such a study would permit direct comparison with annealing datasets: each worker could compare their results with those on an identical sample obtained by analysts who had published annealing data [i.e. Ray Donelick, the forthcoming London results, and possibly Geotrack].

Preparation of material for such a comparison would a major task, requiring large, reasonably homogeneous crystals. A large volume of apatite crystals separated from a single sample might be an acceptable alternative. Irradiation of large apatite masses will produce high activities. This is very much a first "back-of-the-envelope" attempt at defining areas of variation which might be usefully tested, but which keep within reasonable limits of material and manpower. Clearly apatites with a variety of compositions should be similarly compared, but this could be viewed as a second stage.

I would be pleased hear and circulate your comments, alternative ideas and constructive criticisms - contact me as above. Further, the London Group would be willing to undertake the preparation work for such a first inter-laboratory study and to co-ordinate / be a repository for the results.

Perhaps, as Kerry Hegarty said, we did miss a valuable opportunity at Lorne. Or perhaps we should be more positive and consider that Lorne represents to length analysis what the Pisa conference was to age calibration: a forum to raise awareness and focus all our minds about problems which we prefer not to face. Sure, there are major issues of annealing algorithms and predictive modelling still to address. But let's start with things we can achieve fairly readily and evaluate our analytical comparability.

I thank Andy Carter, Jocelyn Barbarand and Andy Gleadow for comments on and contributions to these thoughts - but accept full responsibility for any errors and omissions.

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An introduction to data handling with **TRACKKEY 4.1.** Additional parameters

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INTRODUCTION

TRACKKEY 4.1 provides a system for handling data from fission-track analyses with the external detector method. Its principal features will published in the near future [Dunkl, in press]. However, space limitations in the Computers and Geosciences Journal have prevented us from presenting the system in detail, and since submission of the manuscript [1999] several new modules have been added.

During routine microscopic observations we register three kinds of data for the individual crystals: spontaneous and induced track counts and the measured area. For simple samples this is sufficient, but in the case of provenance studies or multi-compositional apatites from igneous rocks, additional information may be of great importance, for example chlorine content or D_{par}, but also microscopic observations: shape, colour, zoning … etc. In these pages I present examples of samples containing different crystal populations and give some advice on the use of TRACKKEY version 4.1 for grouping.

Thanks to the numerous answers to my questionnaire concerning the computer settings used I was able to decide several things. The most important consequences are that the main window is larger, but that TRACKKEY 4.X runs only on monitors with 1024x768 pixels resolution or more. It has been compiled under 32 bits. Thus, it does not run under Windows 3.x but it can open and save long file names [it must be stressed that the use of extremely long names is discouraged].

DATA INPUT

There are nine fields for including additional information on the dated crystals [Figure 1]. The **CHLORINE**, **FLUORINE**, **D_{par}** and **LENGTH** fields are strictly numeric. The **SHAPE**, **COLOUR** and **ZONING** records can contain only one character. The content of the **SHAPE** record is coded **E**, **S**, **A** and **R** to denote euhedral, subhedral, anhedral and rounded crystals. The aim of this restriction is to simplify data selection and grouping, in particular in merged files. The **GOODNESS** and **COMMENT** fields can contain both numeric and text data.

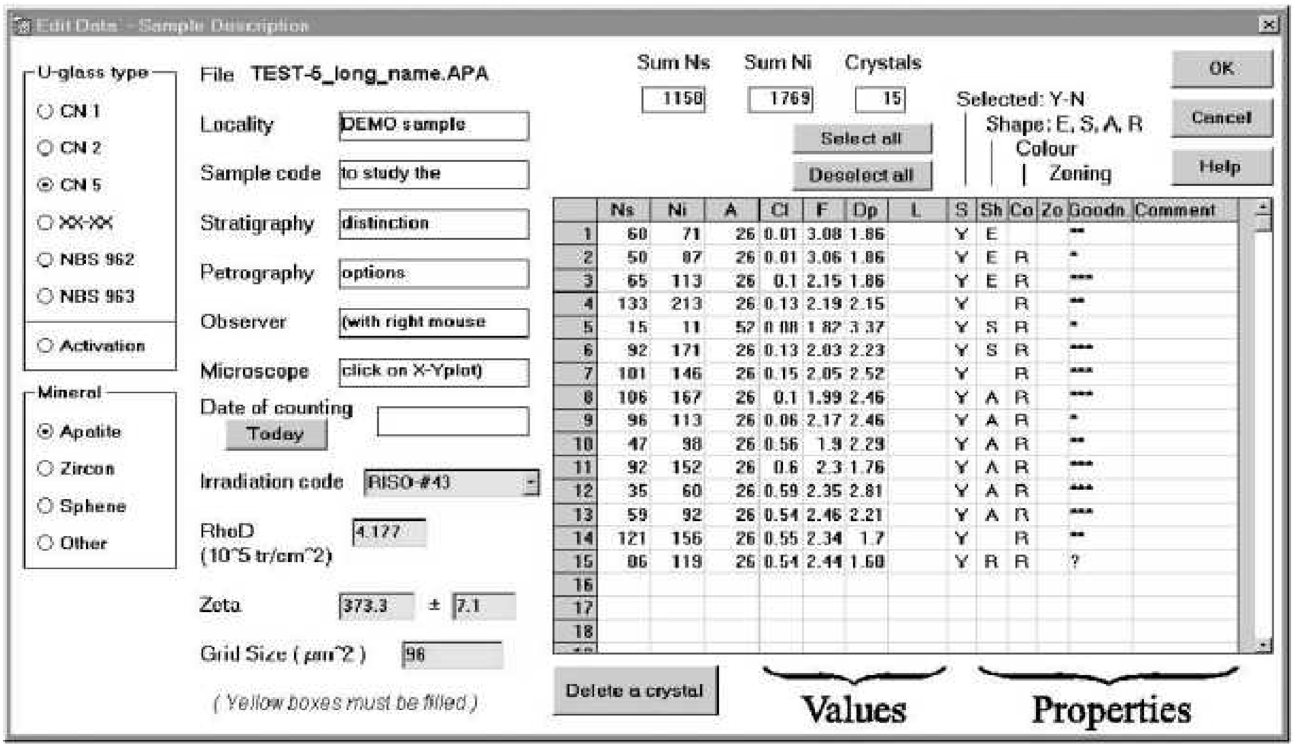
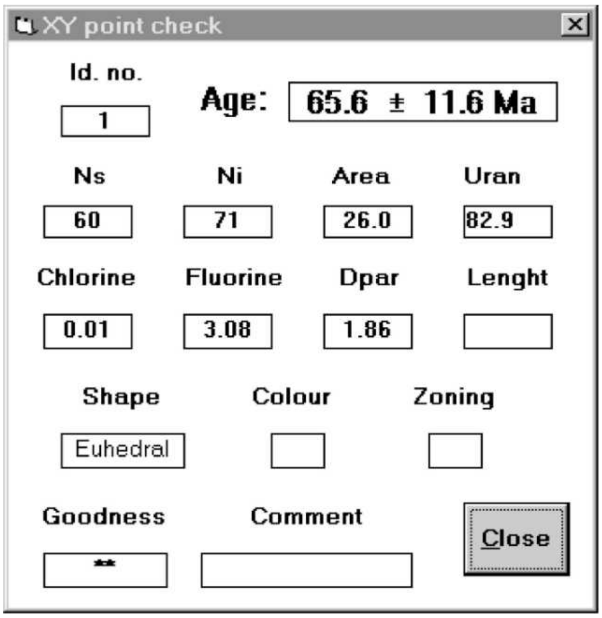


Figure 1. The extended EDIT DATA window. There are nine additional fields to store chemical composition and characteristic microscopic features besides N_S, N_I and Area.

Apart from the limitations of the **SHAPE** record, these nine fields can be used freely to register any kind of measured parameters. There is a further option: the selection-deselection toggle switch for the individual crystal data is also in this window [Figure 1].

The record of an individual grain [Figure 2] is displayed by a left mouse click on the data points in the X-Y plot of the **MAIN WINDOW**. A rapid check can throw light on why some data points are outliers [low counts, extreme composition or D_{par}, or comments made during microscopic observation].



The criteria for distinguishing grain populations can be selected in the **X-Y PLOT OPTION** window: right mouse click on the X-Y plot in the **MAIN WINDOW** [Figure 3]. At the left, the user can select the horizontal and vertical axes, at the right are the criteria for distinguishing grain populations. The **SYMBOLS ACCORDING TO VALUES** option splits the population in subpopulations at given cut-off values; the numerical parameters can be used for this. Sometimes splitting according to uranium content results in interesting grouping. Splitting according to the counted surface area can reflect errors in track counting or track registration in hard rocks but it can also have significance relating to provenance in detrital sediments.

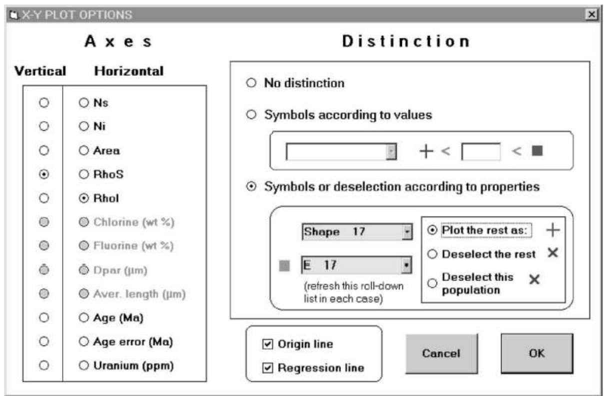


Figure 3. [above] The X-Y PLOT OPTIONS window. The disabled (grey) fields at the left indicate that such values are not present in this file. The distinction and deselection is also controlled from here; in case of deselection the plots will be redrawn and the statistical values recalculated.

Figure 2. [left] The X-Y POINT CHECK window displays all registered data of a crystal.

The **SYMBOLS AND DESELECTION ACCORDING TO PROPERTIES** option allows grouping of grains according to the text records. The upper drop-down list shows which property data are available, and for how many grains [Figure 4A]. The lower drop-down list presents the categories, both the restricted one about the shape and the user-defined text remarks [Figure 4B and 4C, respectively]. In addition to distinguishing subpopulations, deselection is also controlled from here. In case of deselection, the plots are redrawn and the statistical values are recalculated.

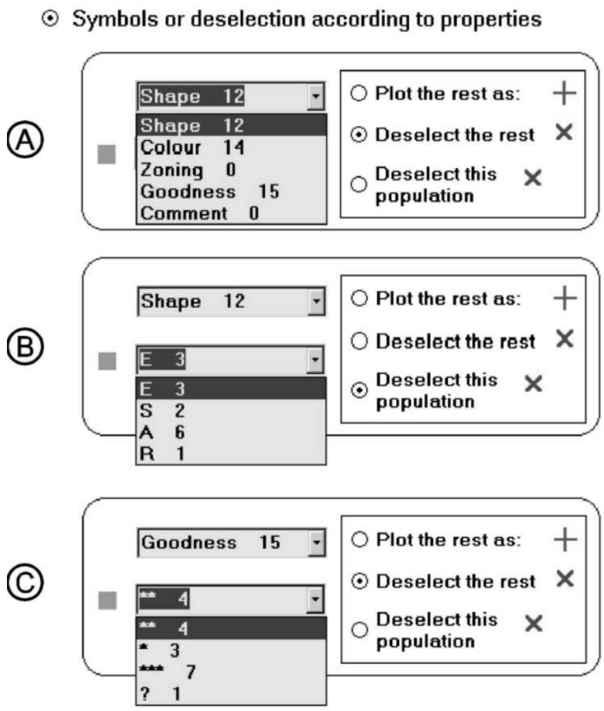


Figure 4. A part of the X-Y PLOT OPTIONS window. The selection for a distinctive plotting or rejection can be performed according to text data. (A): Number of unique values grouped by properties; (B) and (C): the lower roll-down list shows what kind of categories are registered and how many crystals fall into these categories (E, S, A and R characters representing euhedral, subhedral, ahedral and rounded grains, respectively).

EXAMPLE I

Figure 3 shows how the distinction is made on a sandstone sample which contains 17 euhedral zircon grains. These are plotted as squares in the MAIN WINDOW and the distinction is also indicated in its lower left corner [Figure 5]. The radial plot and the X-Y plot present a remarkable separation of the euhedral and the rounded zircon populations. It is also clear, that outside the ca. 50 Ma group of euhedral grains, there is a single euhedral crystal with a rather old age. How do we calculate the age for the younger euhedral population?

1] Right click on the X-Y plot and DESELECT THE REST option will leave only the euhedral grains.

2] X-Y POINT CHECK [left click on the old grain] shows that this outlier is the 45th grain.

3] A left click on the statistical data shows the data table. A double click on the SELECTED record of the 45th grain will deselect it.

Only the young euhedral grains are now still selected. The window shows the following results: 16 grains; central age: 53±3 Ma; chi-square probability: 80%. Thus, we can assume that this population derived from a single, probably volcanic source.

EXAMPLE II

An exceptional, but natural, sample, shows the scope of grouping according to numeric values such as chlorine, fluorine and uranium content. It is from a Triassic dike with many endogenous, igneous inclusions. The apatites are euhedral and columnar in the matrix and big and rounded in the inclusions. Microprobe analyses showed that their Cl and F contents are also different. Figure 6A indicates, that the Cl rich and Cl poor grain populations give similar central ages [192±17 and 198±18 Ma]. This implies that, although the samples underwent rejuvenation, the expected drift is not observable. Figures 6B and 6C carry a kind of petrogenetic meaning. Not only the Cl-content but also the U-content allows a clear distinction [Figure 6B]. Almost all Cl-rich crystals have a low U-content. The squares represent euhedral grains, the X-symbols rounded, anhedral ones. It is obvious from the plot, that not all the Cl-rich grains have euhedral shape. It is also possible to make a separation by the F-content [in this case splitting at F=2 wt.%]. It is noticeable from the plots that there is a grain that is at the same time rounded, Cl-rich, F-poor and U-rich. It belongs to neither of the two well-defined groups and represents a petrogenetic link between the two immiscible magmas.

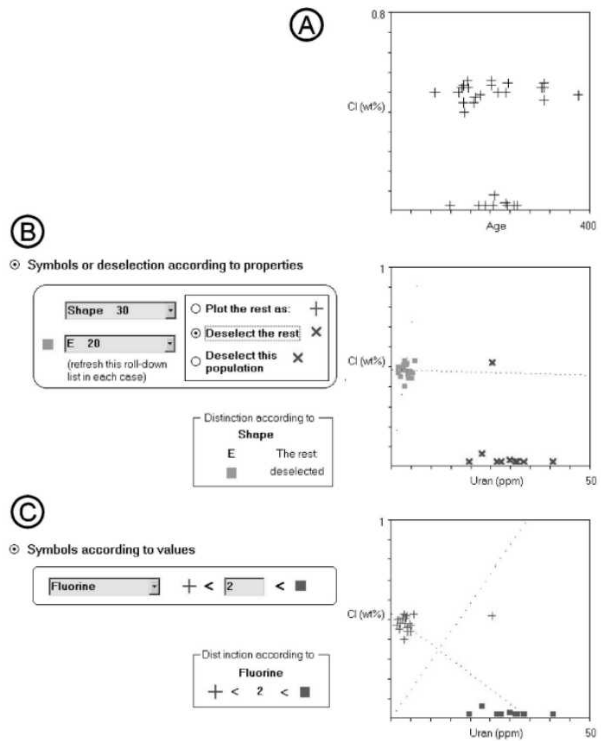


Figure 6. Multi-parameter evaluation of a composite sample. This figure is composed of extracted parts of the X-Y PLOT OPTIONS window (at the left, showing how the selection was made) and the X-Y plots are extracted from the MAIN WINDOW, to present how the separation looks like.

The distinct populations are also plotted in the DXF export file [MENU: FILE / EXPORT / DXF FILE], which can be imported as a vector graphic by nearly all drawing programs.

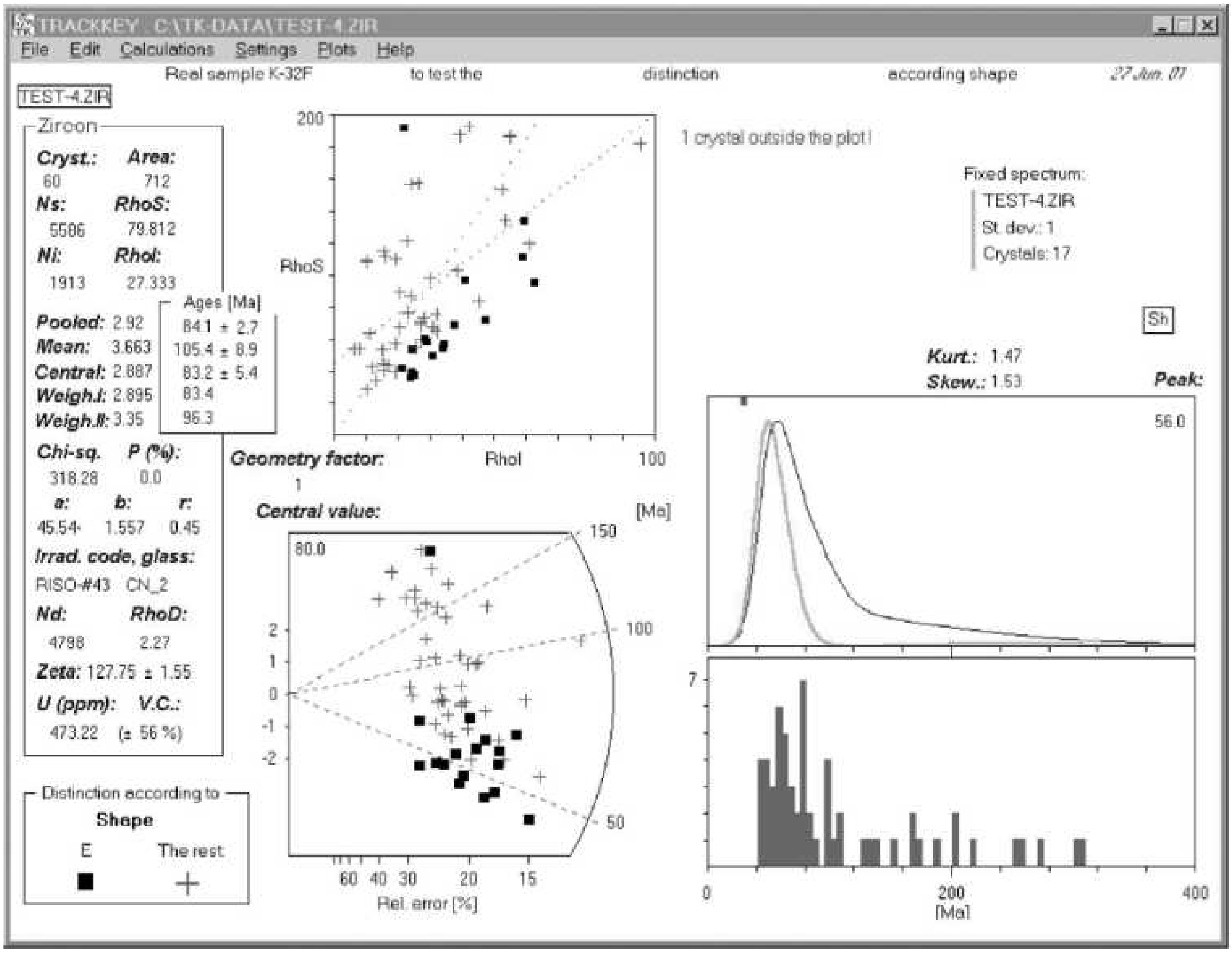


Figure 5. The euhedral grains are shown as squares in the MAIN WINDOW. The criterion used for the separation is in the bottom left corner of the window.

ADDITIONAL NEW FEATURES

The MAIN WINDOW indicates what kind of additional information is linked to the crystal data. The Sh symbol on the right side of Figure 5 indicate that this file contains data on shape. The existence of chlorine, fluorine, etc. data are also indicated here.

Several trackers use the external surface of the zircons for spontaneous track counting using a geometry factor of 1 instead of the 0.5 value [Gleadow, 1981]. This value can be modified at the SETTINGS menu and when it is not equal to 0.5 it is indicated in the MAIN WINDOW [see Figure 5, beside the χ^2-test] and also all age and zeta calculating windows and prints.

SOFTWARE AVAILABILITY

The program needs several DLL files which are not parts of the Windows operation system. Thus, each computer needs an installation procedure once. New versions of the EXE-file of the program can be run without reinstallation, only the old version of the executable should be replaced by the new one.

The set-up kit, a short instruction file for installation [READ_ME_TK_4.1.TXT] and the synthetic and natural example files used above [placed in the TK-DATA directory] are available on the IAMG anonymous ftp-site [http://www.iamg.org/] and from my web site [http://www.uni-tuebingen.de/geo/gpi/ag-frisch/mitarbeiter/dunkl/index.html]. It would be practical to send me an e-mail when you download. I can then inform TRACKKEY users about updates. The program is freeware but I would request that you cite the Computers and Geosciences paper.

ACKNOWLEDGEMENTS

I have received useful comments and suggestions from the Tübingen fission track group, in particular from Balázs Székely. Many thanks.

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CADIZ 2002

WORKSHOP ANNOUNCEMENT

Fission track analysis: theory and applications

UNIVERSITY OF CÁDIZ, 2002

General information

This workshop follows three meetings in 1997 (Bologna), 1998 (Florence), and 1999 (Chatillon). Cádiz (Spain) was proposed for the next meeting and dates were changed from 2001 to 2002 with the intention of holding the workshop between the 2000 Lorne meeting and the next international conference in 2004.

Dates

The provisional schedule is ***4 to 7 June 2002***. The final schedule will depend on the number of participants and presentations. A first circular will be sent via email by mid summer with information concerning the venue, registration fees, accommodation, publication of abstracts, deadlines, travel, … etc.

Excursions and other activities

A one-day field trip to the Ronda peridotite massif is programmed. The Ronda massif is situated 100 km west of Cádiz in the Betic internal zones, and is one of the most extreme examples of exhumation of mantle material from depths of probably more than 100 km to the surface. The field trip will probably take place on of June 5 or 6, in the middle of the workshop, thus giving the participants the opportunity to talk and exchange ideas in a more relaxed environment rather than in between presentations.

A visit to one of the many sherry wineries in the area will be organized for the participants and accompanying persons.

Publication

We are presently in negotiation with the Geological Society of Spain concerning the publication of extended abstracts in a new journal of the Society, called GEOTEMAS, which is dedicated to the publication of meeting proceedings. More information will be provided in the first circular.

Information

For any information or suggestions send an email to Luis Barbero (*luis.barbero@uca.es*)

Fission-Track Papers

The following is a list of recent and soon-to-be published fission track papers that were submitted by the authors for inclusion in this issue of On Track. With 278 entries, the list is extensive but still far from complete. It may however serve as a starting point for compiling a 'complete' list of fission-track papers. We would all agree that such a list has practical use as a reference to what is happening in fission-tracks or in your study area. This cannot be achieved without everyone's active co-operation. So, if you have or know of a paper that you would like to see listed in this section, please send the complete reference or a photocopy of the first page to the editor. We are also interested in non-fission-track papers that may be of interest to the fission-track community.

1998

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FT STAge Systems

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Outstanding Hardware:
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Fission Track Laboratories Using the System
(year installed; *adapted to a non-Kinetek stage)

- Stanford University, Stanford, California (1991)
- University of California, Santa Barbara, California (1992)
- ARCO Exploration and Production Technology, Plano, Texas (1992). Moved to University of Minnesota, Minneapolis, Minnesota, in 1999.
- Universität Bremen, Bremen, Germany (1993)
- E.T.H., Zürich, Switzerland (1993*)
- Kent State University, Kent, Ohio (1993)
- University of Wyoming, Laramie, Wyoming (1993)
- University of Arizona, Tucson, Arizona (1993)
- Max-Planck-Institut, Heidelberg, Germany (1993*)
- Union College, Schenectady, New York (1994)
- Monash University, Melbourne, Australia (1994*). Moved to University of Melbourne in 1999.
- La Trobe University, Melbourne, Australia (two systems, 1994*). Moved to University of Melbourne in 1999.
- University of Pennsylvania, Philadelphia, Pennsylvania (1995)
- Universität Tübingen, Tübingen, Germany (1995)
- Universidad Central de Venezuela, Caracas, Venezuela (1995)
- Brigham Young University, Provo, Utah (1995)
- Central Research Institute of the Electric Power Industry, Chiba, Japan (1995)
- Universität Salzburg, Salzburg, Austria (1996)
- University of Southern California, Los Angeles, California (1996)
- E.T.H., Zürich, Switzerland (second system, 1996*)
- Geologisk Centralinstitut, Copenhagen, Denmark (1996*)
- University of Waikato, Hamilton, New Zealand (1996*)
- Università di Bologna, Bologna, Italy (1997)
- Centro di Studio di Geologia dell'Appenno e delle Catene Perimediterranee, Florence, Italy (1997)
- University of Wyoming, Laramie, Wyoming (second system, 1997)
- Universität Potsdam, Potsdam, Germany (1997)
- Seoul National University, Seoul, Korea (1998)
- E.T.H., Zürich, Switzerland (third system, 1998)
- Universität Basel, Basel, Switzerland (1998)
- University of Florida, Gainesville, Florida (1998)
- Université Paris-XI, Paris, France (1998)
- Universität Graz, Graz, Austria (1998)
- Göteborgs Universitet, Göteborg, Sweden (1999)
- Universidad de Cádiz, Cádiz, Spain (1999)
- Universite Montpellier II, Montpellier, France (1999)
- Kurukshetra University, Kurukshetra, India (1999)
- Universität Tübingen, Tübingen, Germany, (second system, 1999)
- California State University, Fullerton, California (2000)
- Geoforschungszentrum, Potsdam, Germany (2000)
- Polish Academy of Sciences, Krakow, Poland (2000)

Further Information:
An early version of the system is described in a paper in Nuclear Tracks and Radiation Measurements, vol. 21, p. 575-580, Oct. 1993 (1992 Philadelphia Fission Track Workshop volume). For detailed information please contact: Dr. Trevor Dumitru, 4100 Campana Drive, Palo Alto, California 94306, U.S.A., telephone (auto-switching voice and fax line): 1-650-725-6155.

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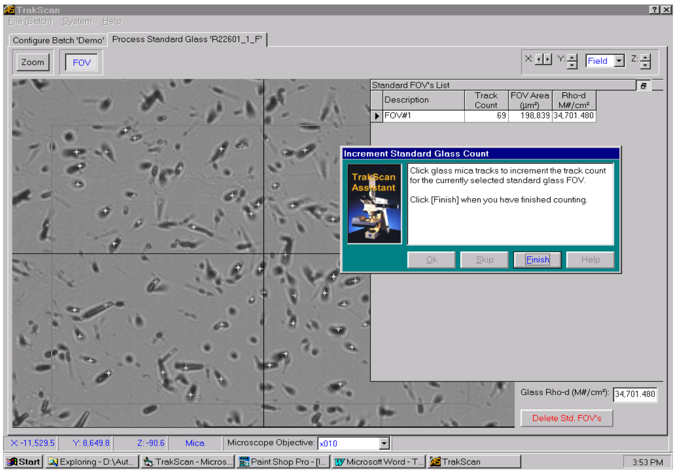

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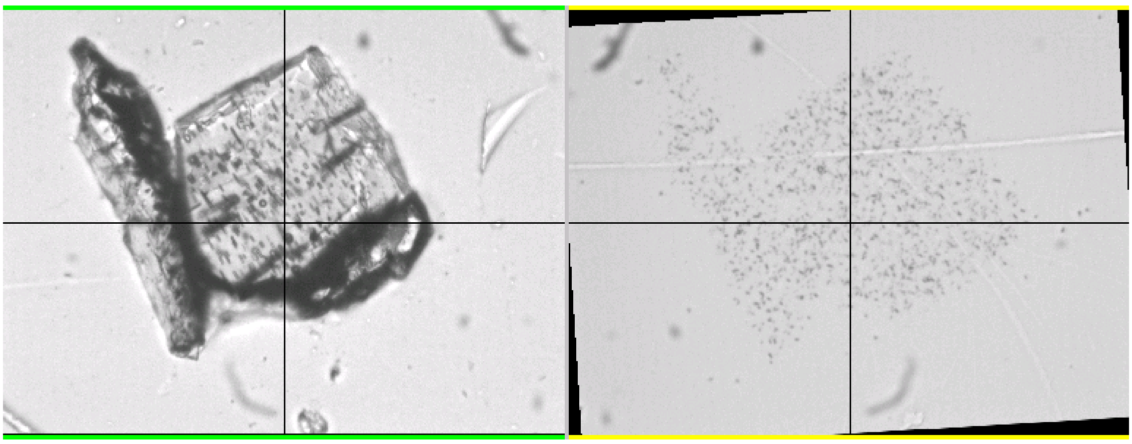

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Afterthoughts

Geologists inhabit scenes that no one ever saw, scenes of global sweep, gone and gone again, including seas, mountains, rivers, forests, and archipelagos of aching beauty, rising in volcanic violence to settle down quietly and forever disappear - almost disappear. [John McPhee]

The scientist does not study nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful. If nature were not beautiful, it would not be worth knowing, and if nature were not worth knowing, life would not be worth living. [Henri Poincaré]

Science is built up with facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house. [Henri Poincaré]

It is a capital mistake to theorise before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts. [Sir Arthur Conan Doyle]

The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them. [Sir William Lawrence Bragg]

Important - Urgent - Important - Urgent

On Track needs a new editor ! No-one has reacted to the invitation to take over the editorship for the next two issues of On Track. Individuals contacted privately by the present editor, have also all declined. Some have even resisted attempts at downright blackmail! On Track is in good health and I am certain that all its editors over its ten year existence will confirm that editing On Track is a rewarding job. A look at the contents of this issue will also convince anyone that On Track actually fulfils its function as a medium for unofficial scientific and other communications very well.

We all have other commitments, but the editorship of On Track need take up no more of your time than you are prepared to invest. There is no need to start from scratch. The next editor receives Microsoft Word [.doc] files of the previous issues, as well as .html-files of all the issues that have been published on the web, and up-to-date mailing and e-mail lists. The contents is supplied courtesy of your colleagues.

I have received promises for three major contributions for the next issue and will continue to collect anything submitted for On Track. Everything will be handed over to the first person to claim the editorship. Failing this, I will propose that a new editor is elected at the next meeting of EFTAN. I regret that this will favour European trackers, but it is the first and only meeting I can attend. If this fails, I undertake to put together the next issue, so that all those who have promised contributions of whatever nature are guaranteed their publication, but, at the latest in this issue, I will publicly designate the next editor, and send him/her all the necessary material. It is from then on a matter between him/her and the track community what happens next.

Important - Urgent - Important - Urgent

In theory there is no difference between theory and practice. But in practice there is. [Jan van de Snepscheut]

The only work that is degrading or derogatory is bad work, work that is done solely for what it will bring and not for the sake of the work itself. [Caroline Franklin]

He [...] persecuted time with hope, and finds no advantage in the process but only the losing of hope with time. [William Shakespeare]

And in the modesty of [...] duty I read as much as from the rattling tongue of [...] eloquence. [William Shakespeare]

He that of the greatest works is finisher oft does them by the weakest minister. [William Shakespeare]

And when I wander here and there, I then do most go right. [William Shakespeare]

Optimism is the faith that leads to achievement. Nothing can be done without hope. [Helen Keller]

Experience is the name so many people give to their mistakes. [Oscar Wilde]

Any approximation in physics is better than you should expect it to be. [Andrei Sakharov]

It is high time laymen recognised the misleading belief that scientific enquiry is a cold dispassionate enterprise, bleached of imaginative qualities, and that a scientist is a man who turns the handle of discovery: for at every level of scientific endeavour scientific research is a passionate undertaking, and the promotion of natural knowledge depends above all upon a sortie into what can be imagined, but is not yet known. [Peter Medawar]

If you need statistics to interpret the outcome of an experiment, you should start thinking of a better experiment. [Sir William Lawrence Bragg]

For every person who wants to teach there are approximately thirty who don't want to learn. [C. Sellar and R.J. Yeatman]

Talent is what you possess; genius is what possesses you. [Malcolm Cowley]

What lies behind us and what lies before us are tiny matters compared to what lies within us. [Ralph Waldo Emerson]

Education is what survives when what has been learnt has been forgotten. [Burrhus Frederic Skinner]

Academic politics is the most vicious form of politics, because the stakes are so low. [Wallace Sayre]

It is not so much where I go, as where I stand. [Clint Eastwood]

Men occasionally stumble over the truth, but most of them pick themselves up and hurry off as if nothing had happened. [Winston Churchill]

Call for Contributions

The next issue of On Track is scheduled for late December 2001 and we are looking for contributions. On Track welcomes contributions of virtually any kind, including scientific articles, news, gossip, job openings, descriptions of new lab techniques, reviews of useful products, ravings about what the other labs are doing wrong, meeting announcements, cartoons and descriptions of what you are doing in your research.

If you would like to contribute, please send the final document no later than **December 15, 2001**. If you intend to submit a substantial article, please let the editor know as soon as possible.

On Track includes a list of recent and forthcoming fission-track papers. If you know of a paper that was published recently or is in press and should appear in the list, please let me know so that it can be added to the list. Also, if you happen to change location due to a change in jobs or finishing off the thesis and graduating, please inform the editor.

On Track is also happy to print advertisements. Please contact the editor for advertising rates. On Track has remained free of charge and will continue to do so (at least for the near future). However, to save costs we generally mail only one copy per lab so please be sure to photocopy the lab copy and pass copies around your lab. If possible, we will also send out On Track electronically, so please make sure the editor has an up-to-date e-mail address for each person/lab.

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