On Track

The Newsletter of the International Fission-Track Community

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Editor's Notes

I am delighted to announce that OnTrack is back on track again.

Shortly after the 10th International Conference on Fission Track Dating and Thermochronology in Amsterdam in 2004, four manuscripts were submitted to OnTrack. Big thanks to the authors for their contributions and for their patience in particular.

Because of the forthcoming European Conference on Thermochronology (ECTC) in Bremen, Germany (30/7 - 4/8), I was trying to get this issue out as soon as the program had been finalised by the ECTC-committee. Despite the very short notice, my call for contributions in early May received a magnificent response from many people in the fission track community. Comprising 74 pages, this seems to be the largest OnTrack ever.

In this issue you will find details for the forthcoming ECTC and the Goldschmidt conferences, directly followed by nostalgic images from our past meeting in Amsterdam. OnTrack always encourages PhD students to tell us about their research. Commencing on page 13 seven students give us insight into *their* exciting projects, and most of them are in the first half of their candidature. I know that there are many more students in the community, and hopefully you will see the seven abstracts as an encouragement to write your own two paragraph project description for the next issue. From my personal point of view PhD students should start very early in their career to become visible in the scientific community. OnTrack is a great platform to start with, followed by conferences, workshops, etc. The better you are known for your research the better are your chances for a smooth transition into a post-doctoral position in a different research group. I encourage every student to use this opportunity and publish early versions of your work, and hope that supervisors encourage their students too. You will see it is a very beneficial exercise.

Three recent PhD theses give an overview of their base and applied research, demonstrating that basic assumptions should always be questioned.

In the article section Paul Green responded immediately to a heated (and ongoing) discussion in Amsterdam about the variability of track annealing behaviour in apatite, and outlines recommendations to integrate chlorine measurements. István Dunkl sent three articles, where he: a) invites researchers to participate in an interlaboratory comparison of U and Th measurements on gem-quality apatites; b) introduces his new program to test for outliers in datasets, and c) provides new features, tricks and tips for the use of Trackkey, a program to calculate fission track ages. A new research reactor in Germany commenced operations in 2004. Heiko Gerstenberg gives us great insight into the irradiation facility in Garching.

An amazing number of at least 324 fission track and U-Th/He papers has been published over the last three years.

Also, many people have moved in the last three years and it was quite a challenge to keep track of everybody. Therefore the fission track directory is almost up to date, and I believe that with combined forces and lot of chatting in Bremen we may have it as close as it gets in the next issue.

[Matthias Raab]

Short Tracks

Joachim Jacobs was appointed in late 2005 as a Professor of Structural Geology/Tectonics at the Department of Earth Science at the University of Bergen, Norway. He has already established a new fission track laboratory.

David Belton, formerly a member of Professor Andrew Gleadow's Fission Track Research Group at the University of Melbourne, has recently taken up a position with the Australia's national research organisation CSIRO. Within the Division of Exploration and Mining, David is now responsible for the operation of the nuclear microprobe. This role is based in the School of Physics at the University of Melbourne – so the move hasn't dramatically changed his travel arrangements! David continues aspects of his research in thermochronology as well as collaborative efforts with Professor Gleadow's group. Delegates to the upcoming ECTC Conference in Bremen might be interested to know that David will also be representing Alphachron – through which CSIRO and Patterson Instruments have commercialised the provision of (U-Th)/Helium analytical equipment.

Michael Krochmal from Autoscan Systems and **Matthias Raab** are building the first complete electronic archive of OnTrack. Many old versions only exist as hardcopies, and with the help of our intern Ute Eckardt, who scanned the early versions of OnTrack, we are now having a complete set of issues available. The archive is available on: http://www.autoscan.com.au/download.html. Whoever wants to mirror this archive is invited to download all issues from Mike's webpage or contact either of us for a CD.

Forthcoming Meetings

European Conference on Thermochronology

July 30 – August 04, 2006
Bremen, Germany

The European Conference on Thermochronology 2006 will take place at Bremen (Germany). The meeting begins on Sunday afternoon July 30 and lasts till Friday afternoon August 04. The Conference is hosted in the lecture theatre of the GEO building, domicile of the Earth Science Department of the Universität Bremen. Registration for conference participants and accompanying persons is open on Sunday afternoon from 15:00 to 20:00 at the GEO building, where the Icebreaker Party will be organized to welcome the delegates.

The scientific program is planned as a series of single sessions and includes oral presentations and posters. Methodological aspects of low-temperature thermochronology will be discussed on Monday July 31, while the geological interpretation of thermochronological data within long-term landscape evolution studies will be the focus during the following days. Posters will be presented on Tuesday, August 01 afternoon. A Round Table discussion, a field trip and the conference dinner are also part of the program (see below). The abstracts will be published as a volume of the "Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften". Moreover, it is considered to publish a selection of conference papers in a special issue of a leading international journal.

Conference language is English. Both Information to the Scientific Program (changes to the Program, details for oral and poster presenters, awards) and General Information (registration, internet access, social program, accompanying persons, eating, travel/accommodation) can be obtained from the 3rd Circular. To download the 3rd Circular and the latest version of the Scientific Program, and for further information and update please check: http://www.geopol.uni-bremen.de/ectc.htm or contact the ECTC2006 Organising Committee (ectc2006@uni-bremen.de).

The scientific program is published below:

Welcome Address		
Time: 8:30–9:00		
Session 1: Methods I		
Chair: G.A. Wagner		
Time	**Authors**	**Title**
9:00–9:30	**Gleadow, A.**, Gleadow, S., Belton, D., Kohn, B., Krochmal, M. & Brown, R.	**Coincidence Mapping^{TM} - a breakthrough strategy for the automatic counting of fission tracks in natural minerals**
9:30–9:50	**Marpu, P.R.**, Gloaguen, R. & Jonckheere, R.	Automatic identification of fission tracks using object-based image analysis
9:50–10:10	**Sobel, E.R.** & Seward, D.	Influence of etching conditions on apatite fission track etch pit diameter
10:10–10:30	**Ketcham, R.A.**, Carter, A., Donelick, R.A., Barbarand, J. & Hurford A.J.	An apatite fission-track calibration for all etching protocols: can we all get along now?
Coffee Break		
Time	**Authors**	**Title**
11:00–11:20	**Gerstenberg, H.** & Li, X.	Irradiation facilities at the *Forschungsneutronenquelle* Heinz Maier Leibnitz (FRM II)
11:20–11:40	**Hasebe, N.**, Ito, K., Carter, A., Hurford, A. & Arai, S.	LA-ICP-MS FT dating: zircon and volcanic glass
11:40–12:00	**Weber, U.D.**, Prowatke, S., Glasmacher, U.A., Ludwig, T. & Wagner, G.A.	Apatite fission track dating: determination of the ^{238}U-content using Secondary Ion Mass Spectrometry (SIMS)
12:00–12:20	**Suzuki, T.**	An absolute approach to fission track dating
12:20–12:40	**Foeken, J.P.T.**, Stuart, F.M., Dobson, K.J., Persano, C. & Vilbert, D.	A diode laser system for heating minerals for (U-Th)/He chronometry
Lunch		
Session 2: Methods II		
Chair: G. Bigazzi		
Time	**Authors**	**Title**
14:00–14:30	**Garver, J.I.**	**The significance of radiation damage in zircon for fission track dating**
14:30–14:50	**Dobson, K.J.**, Stuart, F.M., Dempster, T.J. & Hinton, R.	U and Th zonation in Fish Canyon Tuff zircon: implications for use as a zircon (U-Th)/He mineral standard
14:50–15:10	**Weise, C.**, Jonckheere, R. & Ratschbacher, L.	Annealing of heavy-ion tracks in monazite
15:10–15:30	**Stübner, K.**, Jonckheere, R. & Ratschbacher, L.	Helium diffusion in apatite assessed by Elastic Recoil Detection Analysis (ERDA) and implications for (U-Th)/He dating
15:30–15:50	**Spiegel, C.**, Kohn, B., Donelick, R., Belton, D., Raza, A. & Gleadow, A.	The effect of long-term low-temperature exposure on fission track stability and helium diffusion: constraints from deep sea drillings
Coffee Break		
Time	**Authors**	**Title**
16:20–16:40	**Belton, D.X.**, Gleadow, A.J.W. & Kohn, B.P.	A universal annealing model: the chlorine-compesated solution
16:40–17:00	**Zattin, M.**, Bersani, D. & Carter, A.	Raman microspectroscopy: a non-destructive tool for routine calibration of apatite composition for fission-track analyses
Round Table		
Chair: A. Hurford		
Time	**Speakers**	**Topics**
17:00–18:30	**Andriessen, P.A.M.**	Initiative for European thermochronology network
	Glasmacher, U.A.	TOPO-EUROPE
	Jonckheere, R.	Etching protocol
	Raab, M.J.	OnTrack

Session 3: Asia		
Chair: L. Ratschbacher		
Time	**Authors**	**Title**
9:00–9:30	**Carter, A.** & Foster, G.	**Improving source characterisation through combined fission track and Sm-Nd-Rb-Sr and Lu-Hf-U-Pb analysis on single detrital apatite and zircon grains**
9:30–9:50	**Khattak, N.U.**, Akram, M. & Khan, M.A.	Recognition of emplacement time of the Loe-Shilman Carbonatite Deposit from NW Pakistan: constraints from apatite fission-track dating
9:50–10:10	**Thiede, R.C.**, Arrowsmith, J.R., Bookhagen, B., McWilliams, M., Sobel, E.R. & Strecker, M.R.	Timing of dome formation in the Tethyan Himalaya, Leo Pargil (NW India)
10:10–10:30	**Campanile, D.**, Brown, R., Stuart, F., Widdowson, M. & Bishop, P.	The post break-up evolution of the Western Indian high elevation passive margin
Coffee Break		
Time	**Authors**	**Title**
11:00–11:20	De Grave, J., **Van den haute, P.**, Buslov, M.M. & Dehandschutter, B.	Thermotectonic evolution of the Teletskoye graben, northern Siberian Altai-Sayan Mountains, by means of multi-method chronometry
11:20–11:40	**Zhou, Z.**, Ding, R., Xu, C., Liu, Y., Cheng, H. & Xu, F.	Modelling of low-temperature exhumation rate in Dabie Shan based on (U-Th)/He and fission-track thermochronological data
11:40–12:00	Liu, S., Weber, U., Xu, Z.-Q., **Glasmacher, U.A.** & Wagner, G.A.	The Dabie Shan-Sulu Connection, China: Cause of strong East-West topography change as revealed by low temperature thermochronological data
12:00–12:20	**Tagami, T.**, Murakami, M. & Nagahara, K.	Probing fault zone heterogeneity on the Nojima fault: constraints from zircon fission-track analysis of borehole and trench samples
Lunch		
Session 4: Gondwana		
Chair: J. Jacobs		
Time	**Authors**	**Title**
13:30–14:00	**Lisker, F.**, Läufer, A.L.	**The home of the *break in slope* buried: the Cretaceous Victoria Basin between Antarctica and Australia**
14:00–14:20	**Emmel, B.**, Jacobs, J., Dasszinies, M.C. & Crowhurst, P.	Combined apatite fission-track and single grain apatite (U-Th)/He ages – a possibility to identify thermal overprinted crustal segments in Dronning Maud Land (East Antarctica)
14:20–14:40	**Raab, M.J.**, Brown, R.W. & Gleadow, A.J.W.	New sub-surface insights into the structural evolution of the Drakensberg Escarpment, South Africa
14:40–15:00	**Persano, C.**, van der Beek, P., Braun, J. & Balestrieri, M.L.	The Eritrean high elevation passive margin: is the escarpment retreating or is the plateau degrading?
15:00–15:20	**Daszinnies, M.C.**, Emmel, B., Jacobs, J., Grantham, G. & Wartho, J.-A.	Karoo age rift flank uplift and its implication for Gondwana rifting: constraints from $^{40}Ar/^{39}Ar$ hornblende, biotite and titanite fission track analyses in northern Mozambique
Coffee Break		

Session 5: Posters		
Time: 16:00–18:00		
Poster #	**Authors**	**Title**
1.	Alvarez-Marron, J., **Glasmacher, U.A.**, Menéndez, R., Marquínez, J. & Fernández, S.	Thermochronology of selected Variscan basement rocks in the Western Cantabrian Mountain Range
2.	Balestrieri, M.L., Abbate, E., **Bigazzi, G.** & Omer El Bedri Ali	Low-temperature thermochronology as a tool for reconstructing scarp evolution along Red Sea margins: preliminary apatite fission-track data from the Sudan coastal strip and continental interior and comparison with data from the contiguous Eritrea margin
3.	**Bauer, F.**, Glasmacher, U.A., Reiners, P., Bechstädt, T., Förster, A.	Low-temperature thermochronology, uplift and denudation history of the East African Rift system with special emphasis to the Ruwenzori Mountains (Uganda)
4.	**Bauer, F.**, Glasmacher, U.A., Reiners, P., Zühlke, R.	The Sabiñánigo delta complex: coupled basin and delta evolution of the Jaca Basin, Northern Spain – a thermochronological approach
5.	**Bermúdez, M.** & Alson, P.	*P*-partition and Methodology Alternating Proposal (MAP): new statistic-mathematical methodology that involves uranium densities to estimate ages of rocks by means of fission track dating
6.	**Carrapa, B.** & DeCelles, P.G.	Detrital apatite fission track thermochronology of the Argentine Puna: implications for early plateau development
7.	**Carrière, K.L.**, Glasmacher, U.A., Wagner, G.A. & Bechstädt, T.	Neoproterozoic to Holocene tectonothermal evolution of the southern Cantabrian Mountains, NW Spain as revealed by apatite fission tracks
8.	**Deeken, A.**, Sobel, E.R., Coutand, I., Haschke, M., Riller, U. & Strecker, M.R.	Construction of the southern Eastern Cordillera, NW-Argentina: from early Cretaceous extension to middle Miocene shortening, constrained by apatite fission track thermochronometry
9.	**Del Rio, P.**, Barbero, L., Stuart, F. & Casas, A.	Timing of tectonic uplift in the Sierra de Cameros (Iberian Range, Spain): constraints from fission track analysis and (U-Th)/He geochronology in apatites
10.	Emmerich, A., Bechstädt, T., **Glasmacher, U.A.** & Zühlke, R.	Modelling the basin history of the SW Dolomites with apatite fission tracks (Upper Permian to recent, Northern Italy)
11.	Faundez, V., Hervé, F., Stöckhert, B., **Brix, M.R.**	Post-Jurassic tectonic evolution of the western part of the Antarctic Peninsula: thermochronologic constraints from apatite and zircon fission track analyses – a progress report
12.	**Franco, A.O.B.**, Hackspacher, P.C., Hadler Neto, J.C., Saad, A.R., Guedes, S. & Iunes, P.J.	Apatite fission track thermochronology in southern Brazil: Cretaceous–Tertiary evolution in Ponta Grossa Arch and its relationship with the South Atlantic rift
13.	Glasmacher, U.A., **Krochmal, M.**, Bauer, F., Dreyer, C., Dowsey, G., Repenning, C., Warter, V., Hackspacher, P.	Reliability of confined fission-track length measurement with the new Autoscan automated 3-axis high precision stage
14.	**Heberer, B.**, Behrmann, J.H. & Rahn, M.	Reaction of an upper plate to varying subduction regimes – concept and initial results from the Southern Chile Trench
15.	**Juez-Larré, J.** & Andriessen, P.A.M.	The break-up of the Pangea megacontinent: erosional, geothermal and climatic implications in Western Europe
16.	**Krugh, W.C.**, Densmore, A.L. & Seward, D.	Displacement and denudation patterns from a linked normal fault array, Wassuk Range (Nevada, USA)
17.	**Lisker, F.** & Brown, R.	Segmentation and spatial variation of rifting of the Lambert Graben, Antarctica
18.	**Lisker, F.**, Läufer, A.L., Olesch, M., Rossetti, F. & Schäfer, T.	The denudation history of the Outback Shoulder of northern Victoria Land (Antarctica): a key to the evolution of the Transantarctic Basin
19.	**Rahn, M.K.**	Can we define the end of Molasse sedimentation? – A concept and first results from dating Hegau tuffs and volcanogenic layers in the uppermost Swiss Molasse sediments
20.	**Reinecker, J.**, Spiegel, C., Glotzbach, C., Rahn, M. & Frisch, W.	Investigating isotherm perturbation: 1. The Lötschberg transect (Switzerland)
Poster #	**Authors**	**Title**

21.	**Spiegel, C.**, Kohn, B.P., Belton, D.X. & Gleadow, A.J.W.	Cooling history of the Kenya rift valley flanks: implications for Late Cenozoic climate change in East Africa
22.	**Spiegel,C.**, Sachsenhofer, R., Danišík, M. & Privalov, V.	Thermal evolution of an intracratonic rift basin: the Donbas foldbelt, Ukraine
23.	**Swift, D.A.**, Persano, C., Nienow, P.W., Dowdeswell, J.A. & Evans, J.	Investigating rates and patterns of late Neogene denudation using detrital apatite fission track thermochronometry: Kangerlussuaq, East Greenland
24.	**Timar-Geng, Z.**, Henk, A. & Wetzel, A.	The influence of convective heat transport on the interpretation of fission-track data – numerical models and case studies
25.	Ullrich, A., **Glasmacher, U.A.**, Miletich, R. & Kohn, B.P.	High pressure effects on fission-track formation in apatite
26.	**Ventura, B.**, Lisker, F., Ehling, B.-C., Kopp, J. & Zeh, A.	From the NW Saxo-Bohemian Massif to the southern margin of the Northeastern German Basin: apatite fission track thermochronological constraints on Late Cretaceous tectonic inversion
27.	**Wölfler, A.**, Danišík, M., Dunkl, I., Dekant, C. & Frisch, W.	Exhumation and thermal history of the Kreuzeck basement complex (Eastern Alps) as inferred from apatite fission track and apatite (U-Th)/He thermochronometry
28.	**Wüthrich, E.**, Seward, D. & Dimov, D.	Preliminary thermochronological data on the tectonic evolution of the Bulgarian Rhodope
29.	**Xu, C.H.**, Mansy, J.L., van den haute, P., Guillot, F., Zhou, Z.Y., De Grave, J. & Selen, N.	Apatite fission-track thermochronology of Paleozoic rocks in the Ardenne
30.	**Zentilli, M.**, Grist, A.M. & Williamson, M-C.	Paleothermal effects of salt diapirs detected by apatite fission track thermochronology and (U-Th)/He dating

Session 6: Europe I		
Chair: L. Barbero		
Time	**Authors**	**Title**
9:00–9:30	Gibson, M., Sinclair, H.D., Lynn, G.J. & **Stuart, F.M.**	**Last to post-orogenic exhumation of the Pyrenees, Western Europe**
9:30–9:50	**Fellin, M.G.**, Vance, J.A., Garver, J.I. & Zattin, M.	Long low-temperature thermal histories and zircon fission-track annealing: a case study from Corsica
9:50–10:10	**Kuhlemann, J.**, van der Borg, K., Bons, P.D., Danišík, M. & Frisch, W.	Erosion rates on subalpine paleosurfaces in the western Mediterranean by in-situ ^{10}Be concentrations in granites: implications for surface processes and long-term landscape evolution in Corsica (France)
10:10–10:30	**Persano, C.**, Stuart, F.M., Barfod, D.N., Bishop, P. & Dempster, T.J.	Tertiary denudation of Scotland during impact of the proto-Iceland plume from low temperature thermochronometry
Coffee Break		
Time	**Authors**	**Title**
11:00–11:20	**Dobson, K.J.**, Stuart, F.M., Dempster, T.J., Persano, C. & Bell, B.R.	The timing and mechanisms of post rift denudation within the Palaeogene Hebridean Igneous Province: a multiple thermochronometer study
11:20–11:40	**Dreyer, C.**, Glasmacher, U.A., Bauer, F., Stockli, D., Weber, U. & Wagner, G.A.	Cretaceous to Paleogene temperature and exhumation history of the Odenwald revealed by apatite fission-track and (U-Th)/He data
11:40–12:00	**Ventura, B.**, Lisker, F. & Kopp, J.	Varying denudation and uplift pattern across the Elbe Fault System, East Germany
12:00–12:20	**Wauschkuhn, B.**, Jonckheere, R., Renno, A. & Ratschbacher, L..	Methodical limits of the apatite fission-track-temperature-time-path-modelling: borehole data from the *Kontinentale Tiefbohrung (KTB)*
Lunch		

Session 7: Europe II		
Chair: D. Seward		
Time	**Authors**	**Title**
13:30–14:00	**Barbarand, J.**, Cathelineau, M., Carter, A., Fourcade, S., Pagel, M. & Zeyen, H.	**Uplift and erosion of western Europe: what might be the role of hot fluid circulation?**
14:00–14:20	**Cederbom, C.**, Schlunegger, F., van der Beek, P. & Sinclair, H.	Climate versus tectonically driven Pliocene uplift of the European Alps: new fission track data from the North Alpine Foreland Basin
14:20–14:40	**Glotzbach, C.**, Spiegel, C., Rahn, M. K., Reinecker, J. & Frisch, W.	Investigating isotherm perturbations: 2. The Gotthard transect (Switzerland)
14:40–15:00	**Malusà, M.G.**, Zattin, M., Andò, S., Garzanti, E. & Vezzoli, G.	Erosional patterns constrained by fission-track grain-age distributions of detrital apatites: preliminary results from the Po River modern sands
15:00–15:20	**Boztuğ, D.**, Tichomirowa, M., Jonckheere, R., Harlavan, Y. & Bombach, K.	^{207}Pb/^{206}Pb, K/Ar and fission-track geothermochronology of the S-I-A-type granitoids revealing the continent-oceanic island arc and continent-continent collision stages of the Neo-Tethyan convergence system in central Anatolia, Turkey
Coffee Break		

Session 8: From fission track dating to landscape evolution		
Chair: R.W. Brown		
Time	**Speakers**	**Topic**
15:50–16:50	**Garver, J.I.,** **Van den haute, P.,** **Kohn, B.P.**	A short history of fission track research
Laudations		

Session 9: America		
Chair: M.R. Brix		
Time	**Authors**	**Title**
9:30–10:00	**Kohn, B.**, Gleadow, A., Kohlmann, F., Belton, D., Osadetz, K. & Brown, R.	**Low temperature thermochronology on cratons: rechecking the rules of the game**
10:00–10:20	**Thomson, S.N.**, Tomkin, J.H., Brandon, M.T. & Reiners, P.W.	Does glacial erosion control the height of mountains? Using thermochronology to find an answer in the Patagonian Andes
10:20–10:40	**Juez-Larré, J.**, Dunai, T.J. & González, G.	Subduction dynamics and climate change along the Andean margin of Chile, assessed by low-temperature thermochronology and cosmogenic nuclides
10:40–11:00	**Montario, M.J.**, Garver, J.I. & Reiners, P.W.	(U-Th)/He dating of fission-track-dated zircon with an example from Peru
Coffee Break		
Time	**Authors**	**Title**
11:30–11:50	**Hackspacher, P.C.**, Saad, A.R., Saenz, C.T. & Hadler Neto, J.C.	Constraints on the evolution of the Cenozoic continental rift system of SE-Brazil: fission track on apatite and zircon
11:50–12:10	**Riley, B.C.D.** & Garver, J.I.	Controls on low-temperature resetting of natural damaged detrital zircons: case study from Arizona
12:10–12:30	**Min, M.**, Ratschbacher, L., Jonckheere, R., Enkelmann, E., Tichomirowa, M., Bachmann, R., Nelson, B., Martens, U., McWilliams, M. & Weber, B.	Long-term evolution of continental transform fault zones: thermochronology along the northern Caribbean plate boundary (Guatemala-Honduras)
Closing Ceremony		

16th Annual V.M. Goldschmidt Conference 2006

27 August - 1 September 2006

Melbourne Exhibition and Convention Centre,
Melbourne , Australia

The Goldschmidt Conference has a number of sessions related to thermochronology under the Themes 7 and 10. The most relevant sessions amongst them are listed below. The full scientific program is available under www.goldschmidt2006.org.

Theme 7: Geochemical constraints on timescales and mechanisms of tectonic processes

S7-02: Up and down: Geochemical constraints on paleotopography and tectonic geomorphology
Convenors:
Matt Kohn
Barry Kohn

Topography reflects the complex interplay between tectonic and climatic processes, so topographic changes have fundamental influences on regional climate, flora and fauna, erosion, and structural and sedimentation styles. In addition, topography is a direct reflection of the internal force balance of an orogenic system, so paleoelevation histories can discriminate between competing orogenic models. In this symposium, we invite contributions that use geochemical proxies of paleoelevation to investigate a large range of geologic, climatic, and tectonic processes, e.g. thermochronology and exhumation histories, stable isotopes and plateau/range heights, atmospheric thermodynamics and paleoaltimetry, cosmogenic radionuclide exposure dating of slowly eroded surfaces, and the interplay among climate, erosion and topography.

S7-03: Fast and furious versus slow and steady: rates of geological processes
Convenors:
Gordon Lister
Simon Turner

Speakers in this session will be able to address the myriad questions that surround the issues of gradual versus episodic evolution in Earth process. Presentations will range from discussions as to the rate of evolution of landforms, the rate of magma formation, differentiation, degassing and emplacement, how fast can deformation and metamorphism take place, and how fast can rocks cool. Can vastly different processes be synchronized on a planetary scale? What does this imply in terms of System Earth? Many different isotopic systems can be utilized to address the questions that are of interest.

S7-06: Fault systems: their geochronology and geochemistry
Convenors:
Mike Cosca (mcosca@unil.ch)
Institute of Mineralogy and Geochemistry, University Lausanne
Simon Kelley (s.p.kelley@open.ac.uk)
Department of Earth Sciences, The Open University

Fault systems are ubiquitous features of the Earth's lithosphere and play critical roles in the exhumation of deeply buried crust, fluid transport, and the development of local and regional topography. This symposium is intended to highlight recent geochemical and geochronological advances in our understanding of the varied geological processes associated with deep and shallow fault systems. We invite contributions from a broad subject range that includes, for example, radiogenic and cosmogenic dating of mylonites, pseudotachylytes, extensional detachments, fault scarps and gouges, and the geochemistry and isotopic signatures of fault systems associated with oil and mineral deposits.

Theme 10: Surface processes, low temperature systems and landscape evolution weathering

S10-01: Geochemistry, chronology and global consequences of terrestrial weathering

Convenors:
Paulo Vasconcelos
Jerome Gaillardet

Distinct experimental approaches – the mineralogical and isotopic composition of marine sediments, and the age and rate of formation of weathering profiles on continental landscapes – reveal variations in the intensity of weathering processes through time. This session will examine compatibilities and discrepancies between the two approaches; it will explore new approaches suitable for investigating changes in weathering rates; and it will scrutinize the causes and consequences of varying weathering rates through time.

S10-02: Low temperature thermochronometry: models, methods and applications

Convenors:
Roderick Brown
Andrew Gleadow
Cornelia Spiegel

Rapid progress is being made in extending the reach of low temperature thermochronometry through the development of new analytical protocols for new minerals (Fe-Mn oxides, zircon etc) and in more sophisticated models, both for calculating cooling ages and for converting the ages (including track lengths and diffusion data) into thermal history information. We invite papers on any aspect of lowtemperature

thermochronometry especially those reporting new analytical procedures. Papers on novel applications and/or which use an intergrated approach to inverse modelling of diverse thermochronometry data are also particularly encouraged.

S10-03: Terrestrial cosmogenic nuclides: surface process rates and/or dates?
Convenors:
Tibor Dunai
Fin Stuart
Derek Fabel

In-situ produced cosmogenic isotope abundance measurements have enabled acompletely new approach to studying the Earth's surface environment. Advances insample preparation, measurement protocols and analyses of new isotopes in a widerrange of materials are producing larger data sets with more precision and more rapidly.These data offer opportunities for more sophisticated and ambitious applications which are driving development of more complex interpretive strategies and models. The resultant range of quantitative constraints on near surface earth processes now extends well beyond the exposure age, versus steady state erosion rate, options. The aim of this session is to discuss these recent developments, encompassing all aspects of measuring and applying cosmogenic isotope abundances to studying the Earth's surface evolution. We particularly encourage presentations on theoretical and practical issues related to studying catchment scale processes, and sampling and analytical strategies involving stable and/or radionuclides enabling extension to longer time scales.

Past Meetings

Every good meeting needs a good finale. The pictures below are a courtesy of Roderick Brown - who is also responsible for the captions - and Michael Krochmal. Enjoy reminiscent memories of the 10^{th} International Conference of Fission Track Dating and Thermochronology in Amsterdam in summer 2004:

Iconic Amsterdam

Stewart Clark, Simon Holdsworth, Justine Tinker, Kate Dobson, Daniel Campanile, Darrel Swift

Three ‘old hands’;Andrew Gleadow, Ed Sobel and Trevor Dumitru

Günther Wagner and Gulio Bigazzi

Three more ‘old hands’; Paul Green, Paul Andriessen and Mike Krochmal

Margaret and Ray from A to Z

Canal boat trip

Paul Green surprised that Paul Andriessen has turned down a second glass of red!

Glasgow stalwarts; Simon Holdsworth (who's actually from Birmingham), Cristina Persano, Darrel Swift and Stewart Clark

Paul Green supervising Rod Brown attempting to count to ten.

Jurgen Foeken and Cristina Persano

Kate and Callum

Günther Wagner and Andy Gleadow

Günther Wagner's assessment of the success of the Amsterdam meeting!

Current PhD Studies

Perturbation of isotherms below topography: constraints from tunnel transects through the Alps

Christoph Glotzbach, supervised by John Reinecker & Cornelia Spiegel, Universität Tübingen, Germany

The effect of perturbation of near surface isotherms by topography has been described early in the 20th century. The magnitude of perturbation depends on several parameters: exhumation rate, geothermal gradient, wavelength and amplitude of topography, and finally on the age of surface relief change. Recently, a number of studies were pursued to quantify the effect of topography on low temperature isotherms using analytical calculations of a simplified topography. Modelling results suggests that in rapidly exhuming areas low-temperature thermochronologic data are affected by the perturbation of near surface isotherms. Thus, resulting exhumation rates deduced from age elevation profiles may be overestimated.

Our study aims to directly measure the perturbation of isotherms under a given framework of denudation rate, topographic wavelength, relief amplitude, and geothermal gradient by applying low-temperature thermochronology (zircon fission track, apatite fission track and (U-Th)/He analysis). We sampled three tunnel transects through the Alps (Gotthard and Mont Blanc road tunnels and Lötschberg railway tunnel), as well as their corresponding surface lines. All transects are situated in areas with high local relief and present-day uplift rates between 0.7 and 1.5 mm/y. Thermochronological analysis will be complemented by steady state and time variable 3-D thermal modelling. This will allow comparing different model-scenarios with the measured age patterns, and testing paleotopographic reconstructions of the investigated areas. Additionally, our study aims to quantify the perturbation-induced overestimation of exhumation rates inherent to different dating techniques in orogenic settings, and thus to provide correction factors.

Low Temperature Thermochronology of the Krishna-Godavari Basin, India and its Hinterland

Himansu S. Sahu, supervised by Matthias Raab and Andrew Gleadow, The University of Melbourne, Australia

In an attempt to bring additional and robust tools towards hydrocarbon exploration, the current study focuses on the application of low temperature thermochronology (AFTT and U-Th/He dating technique) to understand the hydrocarbon habitat in the Krishna-Godavari basin, India and, to generate a picture of the landscape evolution in its hinterland through geological time. We are collaborating with ONGC (Oil and Natural Gas Corporation of India), which has provided 153 borehole samples (both onshore and offshore) from 10 different wells. In addition to that, 49 surface samples have been collected from the different areas of the hinterland giving special attention on the past tectonic activities and present drainage pattern in the area.

A combination of organic maturity data (Vitrinite Reflectance) and the analysis of low temperature thermochronology data will allow the identification of significant heating episodes in the past in which rocks reached palaeotemperatures which might have been higher than their present temperatures in the basin. It will quantify the effects of these palaeothermal episodes and the timing of cooling from maximum palaeotemperatures. Thus a thorough understanding of the thermal history of the basin as well as hydrocarbon habitat will be achieved.

The results of the low temperature thermochronology analysis on hinterland rock types will provide information on the amount of denudation through geological time as well as the sediment types being discharged into the basin. Models on mass balancing will incorporate the removal of crustal material from the continent and its redistribution onto the continental shelf, taking the volume of sediment deposited offshore into account.

Neogene Extensional Deformation in Northern Baja California, Mexico: Implications from Combined Low-Temperature Thermochronology and Structural Studies

Christian Seiler, supervised by Andrew Gleadow and Chris Wilson, The University of Melbourne, Australia

The Gulf of California provides the unique opportunity to investigate the transition from continental break-up to the development of passive continental margins. Despite its exemplary characteristics for many of the more evolved passive margins around the world, the complex evolution of this highly oblique rift-drift system is still poorly understood. The interaction between time, temperature and strain localization plays a central role in the evolution of the incipient margin adjacent to the Gulf of California and needs to be resolved in further detail if we are to understand when, where and how extensional deformation occurred.

Using the powerful combination of both the fission track and (U-Th)/He thermochronometers in conjunction with structural geology, the project focuses on mapping and structural work in a highly extended portion of the rift system as well as the acquisition and interpretation of a regional low-temperature thermochronological dataset in an area where other timing constraints on extensional deformation are scarce.

Modelling the architecture of coupled denudation-sedimentation systems in Australian sedimentary basin evolution

Stefan Frei, supervised by Andrew Gleadow, Barry Kohn and Matthias Raab, The University of Melbourne, Australia

Most of the coastal regions of the Australian continental landmass are passive margins and as they developed during and after Gondwana break-up, accumulated an enormous amount of onshore and offshore sediments. Some of these areas now host prolific hydrocarbon deposits and are therefore of economic importance. As the burial history of sedimentary basins is the controlling factor of the thermal maturation process, an understanding of the sources of sediment supply through time and their interactions with basin architecture and stratigraphy potentially provide important insights into basin evolution and the hydrocarbon systems they contain.

The aim of this PhD project is to provide a capability to map out the source regions for large sedimentary accumulations and to better understand the basin architecture and evolution of important hydrocarbon-bearing environments. Using low–temperature thermochronology, particularly the fission-track method, this technique presents a new perspective on sedimentary basin evolution by investigating the timing, magnitude and patterns of erosion in the basinal hinterland regions and revealing the course of broad-scale drainage patterns in the evolving landscape. The study will focus mainly on the southeastern and northwestern regions of Australia.

New Approaches to Low-Temperature Thermochronology

Steven Spencer, supervised by Andrew Gleadow, Barry Kohn, The University of Melbourne, Australia, and Shengbiao Hu, Chinese Academy of Sciences, Beijing.

This project aims to identify and characterise potential causes of excessively old apatite He ages, which are substantially older than their coexisting FT ages. Such ages have been attributed to different causes and some of these have been further tested, but this study in particular, evaluates the potential for alpha particles to be implanted into apatite grains 'in situ' by decay in high U- and Th-bearing neighbour minerals.

In addition, a combined apatite fission track and (U-Th)/He thermochronometry study has been undertaken on the eastern North China Craton (NCC). Basement samples were collected from the Shandong Province, south of the Bohai Basin, as a transect across the >2000km long, NE-SW trending Tan-Lu Fault and from a vertical profile at Mount Taishan. The eastern NCC margin has experienced predominantly compressive tectonic activity since the Palaeozoic with rifting dominating in the Cenozoic. This study will elucidate the timing of uplift and denudation associated with the interplay of regional compressional and rifting episodes, which have impacted the later stage tectonic evolution of the continental margin.

The post break-up margin evolution of northern Namibia (Kaokoveld)

Fernanda F. Luft, supervised by Matthias Raab and Barry Kohn, The University of Melbourne, Australia,

The Kaoko Belt in northern Namibia is a typical transpressional orogen characterised by km-scale NNW structures generated during the Late Neoproterozoic collision between Congo and Rio de La Plata cratons. These old regional structures (i.e. Purros Mylonite Zone, Khudobib and Sesfontein Thrust, and Ambrosiusberg Fault) have been reactivated during the Phanerozoic and played an important role in the tectonic evolution of the Kaoko Belt and influenced the sedimentary history of the Namibe and Walvis basins.

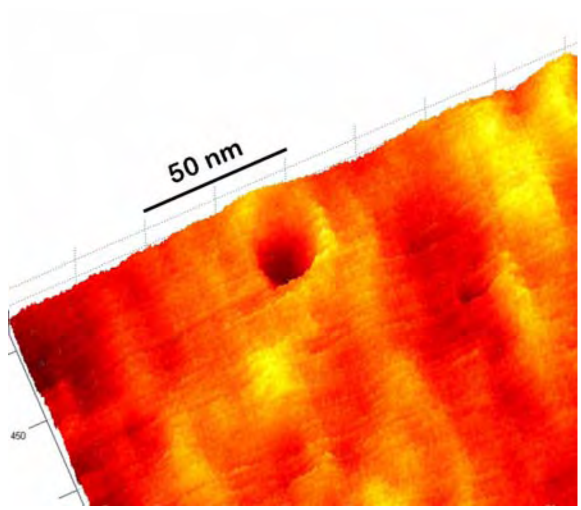
This project aims to investigate the denudation and structural history for this belt since continental break-up (ca 130 Ma). It will provide crucial information on plate readjustments and the effects on passive margin evolution. 75 basement samples, collected in transects orthogonal to the structural trend of the Kaoko Belt, will be analysed by apatite fission track and (U-Th)/He dating. This aims to enhance our understanding of the low temperature denudation history for the study area with a particlular emphasis on: 1. Significant structural offsets related to extensional and post-rifting tectonics, 2. potential application in petroleum exploration in the adjacent offshore basins

Low-temperature thermochronology of the northern Canadian shield, and new insights into fission track behaviour in solids

Fabian Kohlmann, supervised by Barry Kohn, Andrew Gleadow and Matthias Raab, The University of Melbourne, Australia

The project comprises two parts. One part, carried out in collaboration with the Geological Survey of Canada, aims to reconstruct the low temperature thermal history of the Slave-Rae craton in the Northwest Territories, Canada, principally using a combination of (U-Th)/He and fission track thermochronology. Particular attention will be given to kimberlite fields and different dyke swarms intruding the shield. The study will test quantitatively the paradigm of long-term craton stability and the recently proposed mechanism of radiation-enhanced annealing.

Another part of the project will investigate the formation of fission tracks in solids, using an Atomic Force Microscope (AFM), an instrument which is able to image the surface of minerals down to the atomic scale. The AFM approach aims to obtain new insights into fission track development in different minerals and their etching behaviour close to the nanoscale. In work so far, fission tracks were implanted in mica and fluorapatite using a 50μCi 252Cf source and imaged with an AFM. Preliminary data in mica suggests that unetched fission track openings form crater-like structures on the mineral surface with diameters between 16-28 nm. Some openings have a pronounced raised rim that probably represents a region of strained lattice around the track core.



3D-AFM image of an unetched fission track in mica

Recent PhD Theses

CALIBRATION OF THE FISSION-TRACK METHOD AND APPLICATION IN CENTRAL CHINA

EVA ENKELMANN

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This thesis deals with the determination of independent fission-track ages, i.e. ages that are not calibrated against the reference ages of age standards. Recent methodical advances imply that problems related to the value of the fission-decay constant and neutron fluence measurements need not remain obstacles to establish an independent fission-track method, provided that sources of systematic error related to the track counting can be accounted for. The proposed z_0-factor (GQR; Jonckheere, 2003) was determined for apatite using three different approaches; calculation, experiment and based on age standards. The results are consistent and consequently endorse the validity of the individual applied calibration approaches. The independent fission-track ages (f-ages) of the apatite age standards show that the ages of the accepted standards (DUR; FCT) are consistent with their reference ages but that those of the proposed age standards (MTD; LIM) are not. The latter are therefore not recommended for calibration. The f-, Z-, and z- ages of samples dated in the course of geological investigations are consistent and agree within their 1s errors. The fact that the f-ages agree with their Z- and z-ages is, however, inconsistent with the ~10 % length reduction of confined spontaneous tracks in the accepted standards; the same applies for the agreement between the independent ages obtained on accepted age standards. It is concluded that these results indicate that ~10 % reduction of the spontaneous track-lengths in FCT and DUR has no measurable effect on their fission-track ages. The calibration approach is extended to titanite, which presents the specific problem that the track etching and counting efficiencies depend on the accumulated radiation damages. The experimental calibration approach leads to a significant overestimation of GQR, because it requires prior annealing of the titanite. The GQR-values determined on the basis of age standards (FCT; MTD) are, however, consistent with the calculated value. The GQR-value determined on the proposed Limberg t3 standard is different, probably not because of an invalid reference age but due to numerous defects and dislocations that obstruct track counting. The fact that identical GQR-factors were obtained on standards of different age and uranium content suggests that a single Z-, z- or GQR-value is appropriate for dating titanites within a broad range of densities. An improved equation for calculating the uranium concentration in thick samples using external fission-track detectors is proposed and tested on standard uranium glasses (CN-5; IRMM-540R) and apatite samples (Durango; horse tooth) in which the uranium content was also determined with independent methods (INAA; ENAA; TIMS). The results show that accurate measurements with the fission-track method are possible within a broad range of uranium concentrations and that uranium determinations based on standards are only accurate if the standard and sample are made of the same material.

The Tibet Plateau is the result of the Cenozoic India-Asia collision that doubled the crust underneath Tibet and elevated the topography to 4-5 km. The area north of the Indian indenter can be mainly attributed to north-south convergence; however, east of the longitude of the eastern Himalayan syntaxis, high topography extends far beyond the eastern margin of India. This thesis also deals with the application of the fission-track method to study the exhumation processes in time and space in the eastern Tibet Plateau and the Qinling and to test the existing models of Plateau formation. Late Cretaceous to Miocene ages indicate a phase of very slow exhumation (<0.02 mm/a) and reflect tectonic quiescence and peneplanation, followed by more rapid exhumation (>0.2 mm/a) since the middle Miocene. Westerly younging ages across west-northwest dipping faults indicate out-of-sequence thrusting within the Longmen Shan belt and the Min Shan. Rapid exhumation is estimated to start at 18-11 Ma in the Min Shan area; the other areas of eastern Tibet give lower (7, 10, and 11 Ma in central eastern Tibet) or upper limits (13 and 30 Ma in southeastern Tibet) for the onset. Denudation was significant ≤10 km along the Longmen Shan, Min Shan and in the central Plateau, but the areas north and south of the Longmen Shan were denuded little, likely due to younger uplift. Cretaceous to Eocene ages indicate continuous cooling and slow denudation in the northern and eastern Qinling, which contrasts with rapid cooling at the end of the thermal history in the southwestern Qinling. There, the rapid cooling started at ~9–4 Ma, a few million years later than in the eastern Tibetan Plateau. A compilation of major Cenozoic faults in the eastern Tibetan Plateau and the Qinling, and their kinematic and dynamic characterization show that deformation in the Qinling is dominant strike-slip. Sinistral and dextral strike-slip boundaries, active at the end of the deformation history, bounding the area of rapid Late Cenozoic cooling identified by apatite fission-track thermochronology, outline an area of eastward rock flow.

THE LOW-TEMPERATURE THERMOCHRONOLOGY OF CRATONIC TERRANES

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Cratonic terranes present many problems for geologists attempting to define those regions of the continental crust that are the core of today's continents. Inherent in the term is the great passage of time, and typically, the term defines consolidated Archaean or Proterozoic crust (Park and Jaroszewski, 1994). Cratons are further distinguished on the basis of tectonic activity. Marshak and his colleagues (1999) suggest that the lack of penetrative deformation or metamorphism is a useful definition but they further narrow this with the restriction of a Precambrian timeframe. Central to either view is the assumption of stability and perhaps senescence. And, since many aspects of geological research involve the detection of stratigraphic, structural or mineralogical change, stability implies a lack, or at least a minimum, of change. Thus the absence of these traditional markers of geological evolution or change, related to these processes, presents significant challenges in the study of cratons. This is particularly so in shield areas - those cratons with exposed basement rocks.

The purpose of this thesis is to investigate key aspects of landscape evolution in two regions, central Australia and southern Africa, where models have been espoused, arguing for extraordinary surface stability or alternatively a simple erosional history or pediplanation. Contemporary thermochronological techniques now permit us to investigate these regions in previously unavailable detail.

The primary technique used in this work was apatite fission track analysis and an introduction to the fundamentals of the method are given in Chapter 1. The theoretical and practical aspects of the fission track method provided the basis for an innovative approach presented in Chapter 2. TASC is a scheme for analysing the raw fission track data so as to extract additional information about the rock's thermal history prior to undertaking traditional inverse modelling techniques. This method (recently described by the author in Ehlers et al., 2005) proved to be a powerful complement to the routine fission track analysis undertaken as part of the Australian and African case studies.

Although first proposed for geological use in the 1960's, the fission track technique really only gained serious application following technical and theoretical breakthroughs in the 1980's. Since then, growing understanding of the processes of annealing and how they might be modelled has allowed the technique continue developing. Chapter 3 is a discussion of this topic that expands on material previously published by the author and colleagues (Gleadow et al., 2002) and presents additional new work. Nevertheless, despite its wide application in tectonic and basin studies amongst others, there remain many improvements to be made and problems to be solved. As part of this project, research into several areas presented opportunities to contribute toward improvement in the apatite fission track technique, with the potential to aid the study of cratonic terranes.

The chlorine content of apatite has a profound influence on the sensitivity of the mineral for recording thermal events. Few current annealing models are capable of comprehensively addressing the variation of chlorine and other trace elements that appear to play a role in the annealing process. This issue is addressed in Chapter 4 where a universal annealing model is proposed to deal with the wide chemical variability observed in real apatites. For this theme, a fresh consideration of the empirical mathematical models was undertaken and all the published annealing data was considered.

Modern inverse modelling is based on a series of robust, but nonetheless empirical, equations that have withstood the test of time. However, with the aim of developing a more realistic and thus predictive model, Chapter 5 introduces an alternative, physico-chemical to modelling the thermal annealing of fission tracks. This work attempts to draw firmer links between the processes of fission track formation, the mechanics of diffusion and the predicted response to variable temperature regimes.

The first of the case studies is presented in Chapter 6 and is a comprehensive investigation of the long-term landscape evolution of the Davenport Ranges in the central Australian Craton. The study employs traditional petrographic methods as well as thermochronology and combines cosmogenic isotope analysis in an assessment of early landscape models. This chapter expands on work previously published by the author and co-workers (Belton et al., 2004) and has implications for our understanding of landscape evolution in the broader context of the Australian Craton.

In order to maximise temperature sensitivity in slow cooled terranes, the relatively new thermochronological technique of (U-Th)/Helium analysis of apatite was trialed on a suite of central Australian samples. The inconclusive results of this experiment prompted an investigation into the possible causes, and an important baseline study was conducted (Chapter 7). The study has implications for routine application of this new thermochronometer in cratonic and other terranes. More importantly the research identified a potential new thermochronometer with an even greater temperature sensitivity and near surface application for use in future landscape studies.

Chapter 8 documents a larger, craton-wide study of the Mesozoic to recent landscape evolution of the Zimbabwe Craton. This work builds on material presented in earlier chapters and provides a broader view of the nature of crustal cooling, structural reactivation and landform development in the cratonic setting of southern Africa

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COOLING HISTORY AND RELIEF EVOLUTION OF CORSICA (FRANCE) AS CONSTRAINED BY FISSION TRACK AND (U-TH)/HE THERMOCHRONOLOGY

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The island of Corsica in the Western Mediterranean represents an excellent study area for studying the processes of cooling, exhumation, and relief formation. In a relatively small area, two distinct principal domains are distinguished: (i) Alpine Corsica, a complex nappe stack dominated by metamorphic rocks of oceanic origin; and (ii) Variscan Corsica, a well-exposed Variscan crystalline basement made up mainly of unmetamorphosed granitoid rocks. Geodynamic evolution is characterized by Mesozoic extension, followed by middle Late Cretaceous to Eocene shortening, resulting in Alpine collision when the Alpine nappes were thrust onto the Variscan basement. In the Oligocene, the tectonic regime changed from a compressional to extensional, which led to collapse of the Alpine wedge, rifting leading to ocean spreading, and drifting of the Corsica-Sardinia block away from the European mainland. From the geomorphological point of view, Variscan Corsica represents an outstanding ridge-and-valley structure with peaks exceeding 2000 m in elevation, and with paleosurface remnants of unknown age preserved at elevations between 200 and 2300 m.

The aim of this study is to investigate the thermal and exhumation history and relief evolution of Corsica, and to constrain the age of paleosurface remnants through the use of zircon fission track (ZFT), apatite fission track (AFT) and (U-Th)/He dating techniques. Previous thermochronological studies focused on investigating the inversion of the Alpine wedge in NE Corsica, whereas the major part of Variscan Corsica is virtually unexplored. This study concentrates specifically on these regions with the highest relief and paleosurface remnants.

Altogether 3 ZFT, 67 AFT and 40 (U-Th)/He analyses were performed on samples from the Variscan basement and Eocene flysch sediments. The data published in other studies were carefully revised according to strictly defined criteria and fully integrated into our dataset.

ZFT analyses from the central part of the Variscan basement yield ages between 159.2±9.8 and 144.6±10 Ma. These ages record a thermal event related to the Jurassic opening of the Ligurian-Piedmont Ocean. Data from other studies suggest that the ZFT system in the eastern margin of Variscan Corsica was partially reset during Eocene metamorphism, and that during the Cretaceous there was no thermal event affecting Variscan Corsica. In Alpine Corsica, ZFT data together with 40Ar/39Ar data bracket the time of tectonic denudation of Alpine units between ~33 and 19 Ma.

AFT data range from 105.3±7.2 to 16.4±1.4 Ma. AFT ages from Eocene flysch are all completely reset. Based on the AFT data and thermal modeling results, the cooling history of Corsica can be reconstructed as follows: after the Jurassic thermal event related to opening of the Ligurian-Piedmont Ocean, the basement was cooling to near-surface temperatures where it remained until the Early Paleocene. Since the Late Paleocene, the basement was progressively buried below sediments of the foreland basin, and later during Eocene collision it was partly covered by Alpine nappes. At the end of the Eocene, all of Variscan Corsica had been covered by a thick pile of rocks, leading to a total reset of the AFT system in the major part of the basement. In the Oligocene, after tectonic reorganization, the basement started to exhume, which led to the removal of the thick cover from the top of the basement. The removal of the cover occurred by erosional denudation in most of Variscan Corsica, as well as by tectonic denudation in the NE part of the island. AFT ages from the NW part of the basement record an Early Miocene thermal event associated with the opening of the Ligurian-Provençal Ocean.

(U-Th)/He analyses of 12 samples from nine different paleosurface remnants yielded ages between 22.1±0.9 and 16.0±2.3 Ma. There are no obvious differences in He age between different paleosurface remnants, although the vertical distance in some cases is more than 1600 m. This indicates that all paleosurface remnants in Corsica have their origin in one single paleosurface. Segmentation of the paleosurface and differential uplift of individual blocks happened after the time of cooling through the temperature zone sensitive to the (U-Th)/He system. The age of the paleosurface formation is bracketed between ~120 and 60 Ma, based on FT data, thermal modeling results and considering stratigraphic and structural data. During Eocene collision, the paleosurface was buried by a thick flysch pile and was thus protected from destruction. In the Oligocene, the paleosurface started to exhume and the cover was removed. During the Miocene rotation, the paleosurface was cut by faults, and at ~17 Ma the region was uplifted by differential block movements, creating relief and inducing valley incision. This event can be viewed as the onset of peneplain destruction that occurred mainly by fault-induced valley incision and widening.

The data presented in this study bring new understanding of the thermal, tectonic and morphological evolution of Corsica and provide new insight into the geodynamic evolution of the Western Mediterranean realm. Moreover, it is shown that after proper revision, it is possible to integrate several, otherwise contradicting, FT datasets.

MEASURING WT% CL TO ASSESS AND ALLOW FOR VARIATION IN FISSION TRACK ANNEALING RATES BETWEEN DIFFERENT APATITE SPECIES

PAUL F. GREEN

Geotrack International, 37 Melville Road, Brunswick West, Victoria 3055, Australia (submitted 10/04)

Introduction

During discussion at the 10th International Conference on Fission Track Dating and Thermochronology, held in Amsterdam, August 8th-14th 2004, a growing acceptance of the variability in annealing behaviour of different apatite species, often within a single sample, led to contemplation of the way that such variation can be incorporated into routine application of apatite fission track techniques. Two basic approaches were espoused, one in which the differential annealing kinetics are explained in terms of chlorine content (an approach “championed”, if you will, by yours truly), and an alternative approach in which etch pit sizes are used to monitor these effects (favoured by Ray Donelick and co-workers). As a result of an (almost) impromptu discussion session chaired in highly capable fashion by Barry Kohn, the suggestion arose that the rival camps might set out protocols by which their favoured approaches could be implemented in routine application. With this in mind, the aim of this contribution is to outline some recommendations for routine integration of wt% Cl measurements with the more usual measurements of fission track age and track length data.

Background / Historical review

Studies of apatite fission track parameters in subsurface samples of volcanogenic sandstone from the Otway Basin in Southeastern Australia (Gleadow and Duddy, 1981) provided the first systematic evidence that apatite grains within a single rock sample could show a significant variation in the degree of annealing (i.e. age and/or length reduction). Since all the apatite grains within a single sample shared a common volcanic origin, and had undergone the same thermal history, an increasing dispersion in fission track ages downhole must clearly reflect differences in annealing rates which must be due to variation in composition and/or structure between the different apatite grains.

Green et al. (1985, 1986) subsequently reported that within one particular sample, from a present-day temperature of ~95°C, the fission track age measured in individual apatite grains correlated closely with the chlorine content of that grain, such that grains containing 0 wt% Cl were totally annealed (i.e. gave a zero age) while grains containing ~2 wt% Cl or above still retained fission

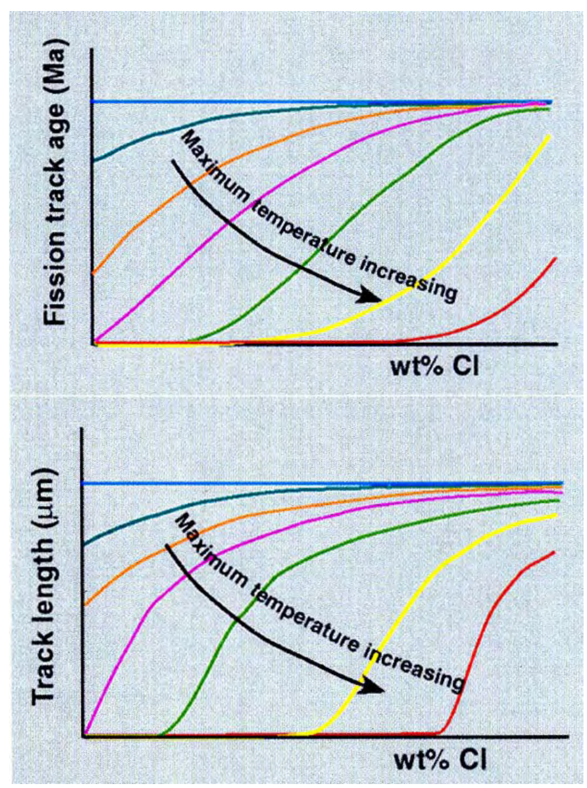

Figure 1: Patterns of fission track age and length expected in detrital apatites within sedimentary rocks currently at their maximum post-depositional temperature.

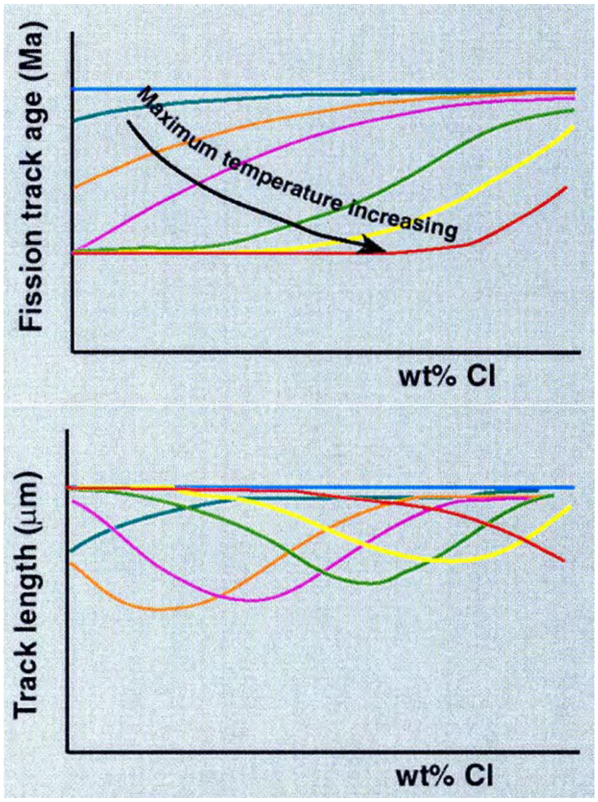

Figure 2: Patterns of fission track age and length expected in detrital apatites within sedimentary rocks which have been hotter inthe past.

track ages close to the depositional age of the host sediment (i.e. these grains had undergone very little annealing). Peter Tingate made the original measurements at the University of Melbourne as part of his PhD study. Peter's role in this is often overlooked, so we should acknowledge it here.

More recent laboratory studies have confirmed the existence of differences in annealing sensitivity linked to apatite composition. While such studies have consistently shown that wt% Cl exerts the dominant control (e.g. Barbarand et al. 2003; Ravenhurst et al., 2003), elements such as Sr, Mn and Fe have also been suggested as causing differences in annealing rates (Burtner et al., 1994; Carlson et al., 1999), although Crowley et al. (1991) reported that a Sr-rich apatite and a fluorapatite showed similar sensitivities. Other workers have suggested a possible role of rare earth elements (e.g. Carpena, 1998; Barbarand et al. 2003).

But no evidence has yet been reported for the systematic influence of any element other than Cl in natural data, and the influence of these other elements seems to be sub-ordinate to that of Cl. In contrast, a number of recent sedimentary basin studies have consistently illustrated the systematic effect of Cl on annealing sensitivity (e.g. Argent et al., 2002; Crowhurst et al., 2002; Green et al., 2002; Green, 2004).

Routine implementation of wt% Cl measurements

Geotrack's in-house approach involves measurement of wt% Cl on every apatite grain in which either age or track length data are measured. Data are then allocated into compositional groups, and apatite grains in each group are treated as separate (but not independent) systems characterised by their own specific annealing

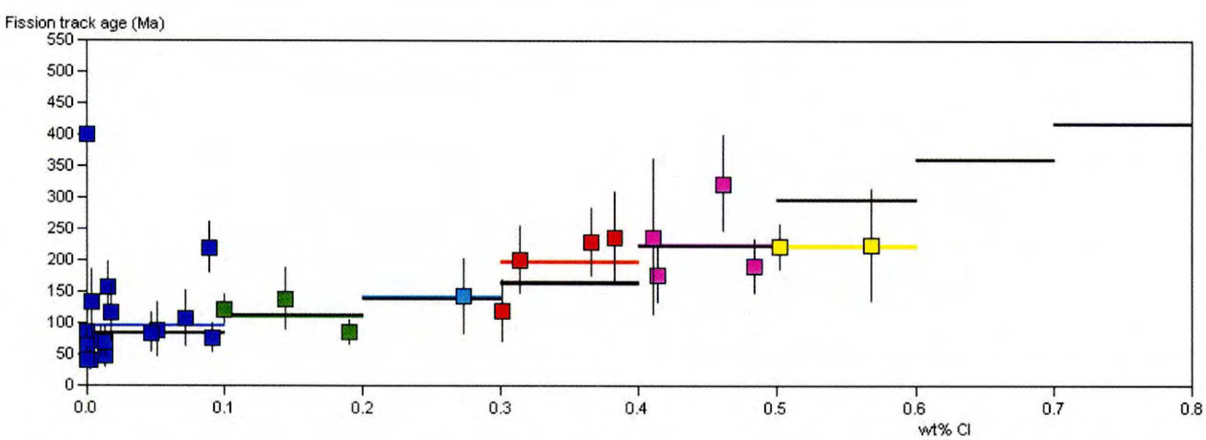

Figure 3: Fission track age vs wt% Cl in detrital apatites from a Triassic sandstone outcrop in NE England. Each square represents the fission track age measured in an individual apatite grain, with colours dividing the data into groups for analysis. The horizontal black lines show the predictions of the best-fit thermal history.

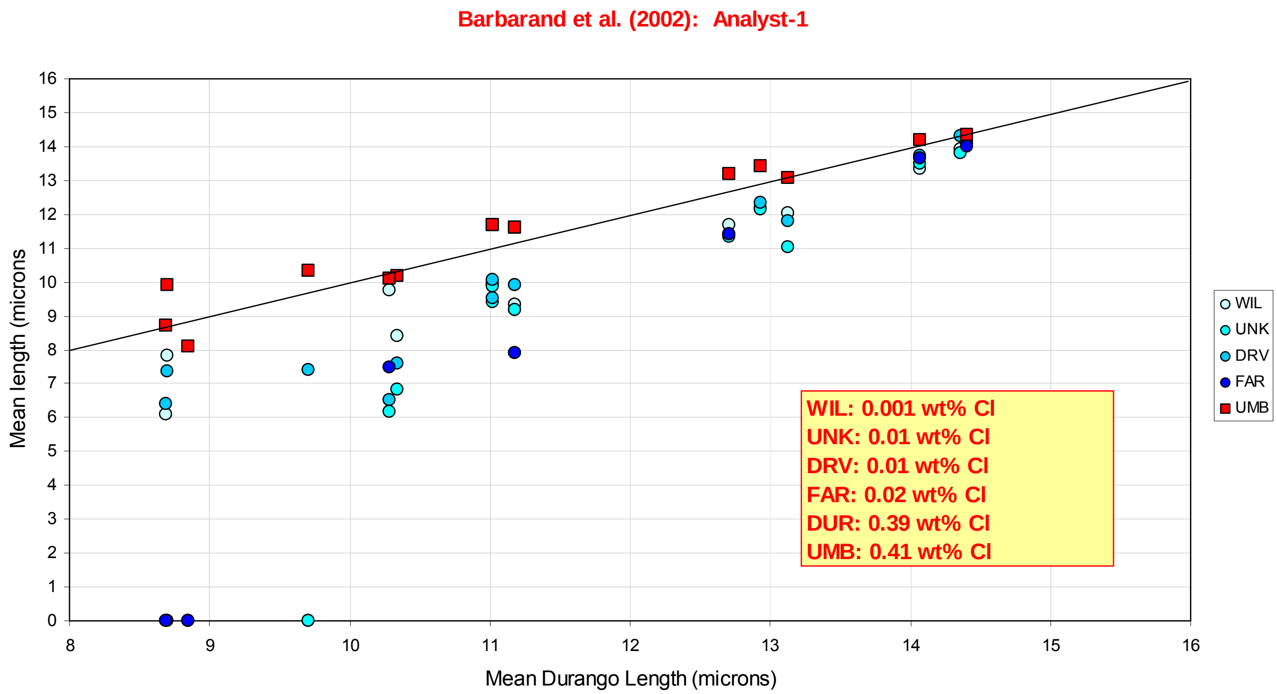

Figure 4: Mean track length in various annealed low-Cl apatites (from Barbarand et al. 2003) plotted against the mean length in Durango apatite from the same annealing run. The diagonal black line defines the 1:1 relationship. Mean track lengths an apatite containing 0.41 wt% Cl are close to the value measured in Durango apatite, whereas mean lengths in low-Cl apatites are always less than in Durango, by a substantial amount which increases as the degree of annealing (length reduction) increases).

constants. Using our proprietary "multi-compositional" annealing kinetic model which incorporates the differential effect of Cl on kinetics, we model expected parameters in each compositional group and compare these with the observed parameters in each group. The modelling approach is essentially identical to that described by Green et al. (1989), but using a number of parallel systems rather than a single mono-compositional system. Using maximum likelihood theory similar to that employed by Gallagher (1995) in MonteTrax, we can define the range of thermal histories which give predictions that are consistent with the measured parameters and their variation with wt% Cl within 95% confidence limits (and of course the best-fit history). There are a variety of ways this problem can be approached, but the important thing for this discussion is that the variation in annealing kinetics with wt% Cl should be taken into account.

Someone pointed out during the discussion in Amsterdam that this is all very well but there is no annealing model currently available that embodies the differential effect of wt% Cl. But in fact, the laboratory annealing data reported by Carlson et al. (1999) and Barbarand et al. (2003) for a variety of apatites provide a useful basis for erecting such a model. The key to this is the approach described by Ketcham et al. (1999) (which is similar to our own approach), where the degree of annealing in different apatites can be inter-calibrated such that predictions for one composition can be immediately converted to equivalent values for other compositions. In this way, for example, the predictions of the Laslett et al. (1987) model could be easily converted to apatites of other Cl contents using those recently published experimental data.

Even without using a multi-compositional model for fully quantitative interpretation, the variation of annealing rates with wt% Cl could still be utilised in qualitative fashion to extract useful information. Patterns of single grain age vs wt% Cl within individual samples are very much like Ar release spectra, and contain information on the degree of annealing. For example, in a sandstone that is currently at its maximum post-depositional paleotemperature, we would expect to see patterns like those shown in Figure 1, whereas in a sandstone that has been hotter in the past, expected patterns are rather different (Figure 2). So this type of data can be very useful in qualitative terms in understanding the thermal history of a sample.

Measuring wt% Cl on any individual grains that stand out as obviously inconsistent with other grains from the same sample provides a basis for

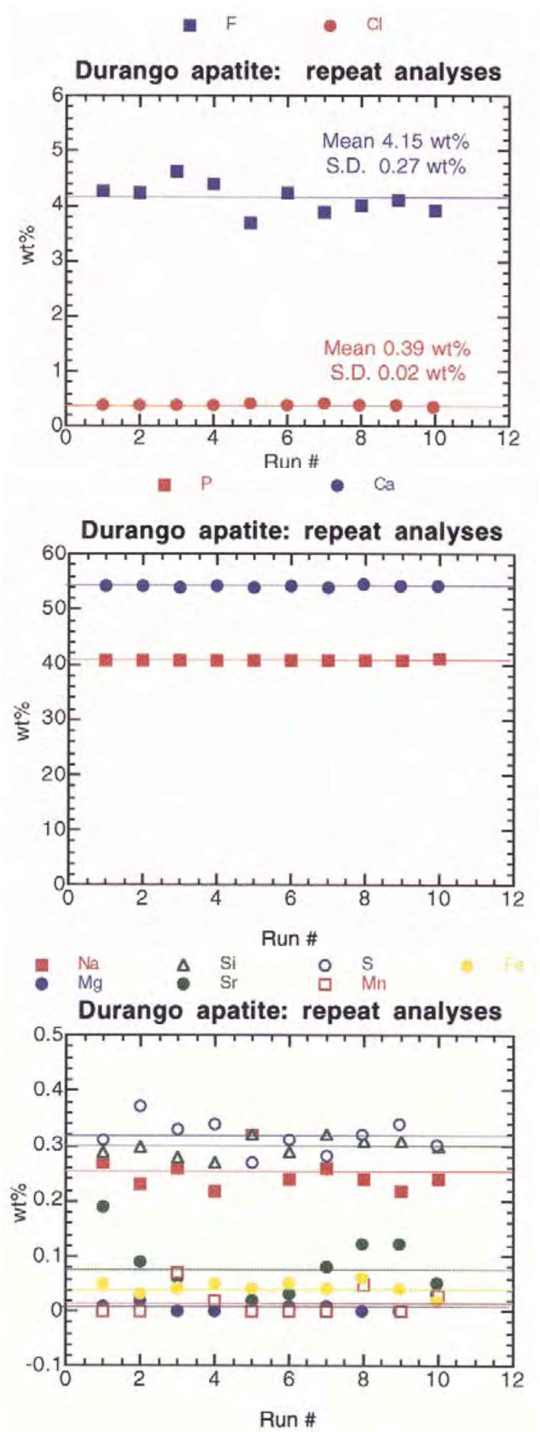

Figure 5: Repeated measurements of various elements at a single site within a slab of Durango apatite, using conditions decribed in the text. These results show no systematic shift with time, emphasising that judicious choice of analytical conditions can eliminate spurious effects that can be caused by intense beam currents focussed in a small area.

identifying and excluding possible contaminants (and/or grains dominated by second order controls on annealing). Figure 3 shows an example of data in apatites from a Triassic sandstone from NE England. The two grains containing between 0.0 and 0.1 wt% Cl with older ages are clearly aberrant, and can be excluded from further analysis.

A number of people have commented to us that they don't see any relationship between fission track age and wt% Cl in their own data. It's important to remember that such a relationship is only to be expected in samples which have been heated to the temperature range in which the differential effect of the range of Cl contents within the sample is maximised (as in the above sample). This is typically ~90 to 120°C, depending on the specific mix of chlorine contents. Even then, a clear relationship will only emerge if the time of cooling is sufficiently different to the time at which track retention began.

But even at lower temperatures the differential effect in the degree of track length reduction is significant, as shown in Figure 4. For annealing runs where the mean length measured in Durango apatite is 14 microns, mean lengths in the more F-rich (i.e. low Cl) apatites are around 13 microns, while where the mean length in Durango is 13 microns the values in the low-Cl apatites are between 11 and 12 microns. In contrast, an apatite containing 0.41 wt% Cl (similar to the value in Durango apatite) gives very similar mean lengths to the values in Durango. This emphasises the greater sensitivity of the low-Cl apatites, compared to Durango (so next time you hear someone refer to Durango as a fluor-apatite, be sure to correct them!).

The obvious effect of this is that applying models based on Durango apatite to data dominated by more sensitive (i.e. low Cl) apatites will require erroneously high paleotemperatures to produce a given degree of annealing, in turn implying unreasonably high amounts of erosion etc. As I suggested in Amsterdam, I believe this is a major contributor to the "anomalous Late Miocene cooling" effect often seen in MonteTrax solutions derived using the Laslett et al. (1987) annealing algorithm. Use of a modified model appropriate to the F-rich apatites, based on a conversion using the data in Figure 4, should reduce much of this "anomalous cooling", and should provide more realistic results using data from basement samples which are commonly (but not always!) dominated by Cl contents close to zero.

Practical issues

<u>Measurement of Cl</u>: We routinely measure only wt% Cl in every grain that is analysed for either age or

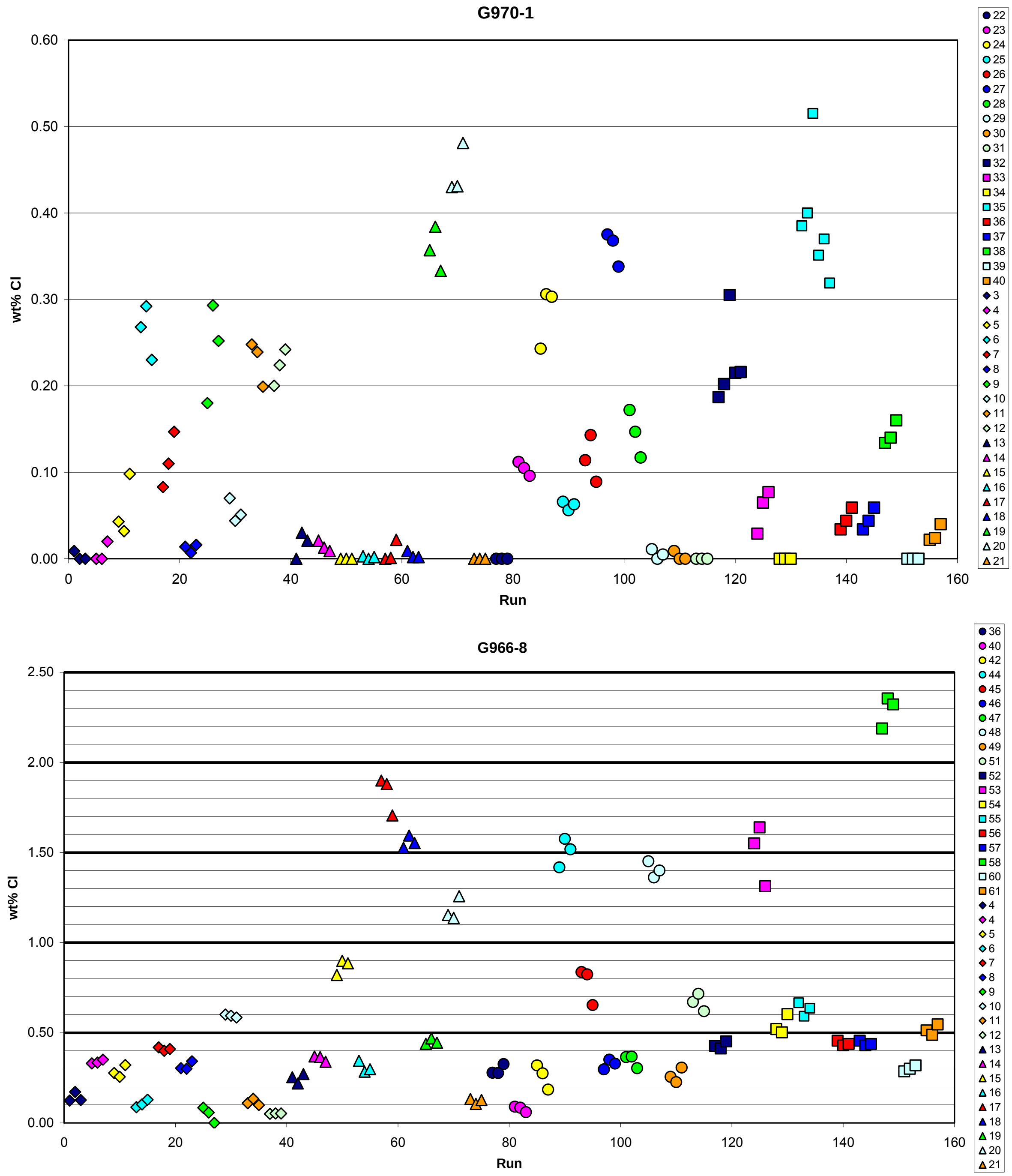

Figure 6: To test the uniformity of Cl in typical detrital apatites, we measured three (more, occasionally) 20 µm spots within each grain in two samples chosen at random from samples currerntly being processed. Results are grouped by colour and symbol for each grain, and emphasise the lack of significant Cl heterogeneity in the great majority of grains, with results in most cases falling within a single division of 0.1 wt% width, as employed in routine interpretation.

length. Chlorine contents are measured using a fully automated Jeol JXA-5A electron microprobe equipped with a computer controlled X-Y-Z stage and three computer controlled wavelength dispersive crystal spectrometers, with an accelerating voltage of 15kV and beam current of 25nA. The beam is defocussed to 20 µm diameter to avoid problems associated with apatite decomposition (see below), which occur under a fully focussed 1 - 2 µm beam. The X-Y co-ordinates of analysed apatite grains within each grain mount are transferred directly from the Autoscan Fission

Track Stage System to a file suitable for input into the electron microprobe (we can do that for "Trevor stages" too). The system is semi-automated, so that after the location of each grain is verified optically the stage shifts to each grain in turn and analyses for Cl. As we have three detector channels, we also monitor Ca and P count rates, as an additional check. Cl count rates from the analysed grains are converted to wt% Cl by reference to those from a Durango apatite standard (Melbourne University Standard APT151), analysed at regular intervals. This approach implicitly takes into account atomic number absorption and fluorescence matrix effects, which are normally calculated explicitly when analysing for all elements. A value of 0.43 wt% Cl is used for the Durango standard, based on repeated measurements on the same single fragment using pure rock salt (NaCl) as a standard for chlorine.

This approach gives essentially identical results to Cl contents determined from full compositional measurements, but has the advantage of reducing analytical time by a factor of ten or more. Measuring full compositions would be time prohibitive. We routinely make just a single 30 second measurement in each grain, with every measurement broken up into three sequential 10 second intervals . Monitoring the consistency of counts in each of the three intervals provides an additional check on beam stability etc.

Mobilisation of F: Stormer et al. (1993) showed that electron microprobe measurements in apatite could be severely affected by beam effects producing diffusion of fluorine within the apatite, leading to erroneous results. To illustrate that these effects can be eliminated by judicious choice of analytical conditions, Figure 5 shows the results of repeated determinations of various elements in a slab of Durango apatite, using our standard measuring conditions (15kv accelerating voltage, 25nA beam current, 20µm beam spot) and a longer than usual counting time of 6 minutes, in order to obtain good statistics for fluorine.

These measurements were all made on exactly the same spot, without moving the beam between measurements. Clearly there is no change in the resulting compositions over the total run time of one hour, showing that the effects reported by Stormer et al. (1993) can be eliminated by suitable choice of beam spot size, current etc. Indeed, such effects have been well known for over 30 years, and measuring conditions adopted for routine use since the late 1960's in the University of Melbourne, and more recently in our own electron microprobe facility, have been designed specifically to avoid these effects.

Non-uniformity in Cl: At the Amsterdam Conference, Andy Carter showed some results suggesting this could be a major effect in common apatites. And in conversation, many people have expressed the opinion that apatites are likely to be non-uniform. In contrast, we have never seen any evidence of major differences in wt% Cl within individual apatite grains. But to test this possibility more rigorously, we recently measured three spots within each grain in two samples selected at random. The results are shown in Figure 6. In my view, this is pretty convincing evidence that there isn't much variation in wt% Cl within any of these grains. The gridlines in these plots divide the data into 0.1 wt% Cl divisions, in exactly the way that we routinely split our data, and in most cases, all three measurements fall well within a single group.

Choice of group size: As above, we routinely divide the data into 0.1 wt% divisions. This is partly for simplicity, and partly because this is somewhat larger than the typical resolution of probe measurements. A third reason is that this seems to provide a convenient level of discrimination between differential annealing effects, as illustrated for example by Figure 3.

As before, a range of alternative approaches to this problem would be possible, e.g. a logarithmic division, involving break down 0.0-0.1 wt% Cl into finer divisions. This could be considered particularly beneficial since Barbarand et al. (2003) suggested that significant differences exist in annealing properties between apatites within the 0.0 to 0.1 wt% Cl range. But experience suggests that the temperature differential corresponding to variation within this interval is only a couple of degrees over geological timescales, so we see no practical reason to pursue any finer division of the data. The case study of data from Taranaki Basin Fresne-1, reported by Crowhurst et al. (2002), and further examples on our website (www.geotrack.com.au) further illustrate this point.

Second order effects: There is no doubt that other elements (Sr, Mn, CO_2, REE, OH?) also influence fission track annealing rates in apatite, as demonstrated by the laboratory annealing results reported by Carlson et al. (1999) and Barbarand et al. (2003), but no evidence of systematic effects similar to Cl have as yet been shown. In routine implementation, analysis of data as a function of wt% Cl allows those few grains which don't follow the trend with Cl to be identified and eliminated (see Crowhurst et al. 2002, and Figure 3, above).

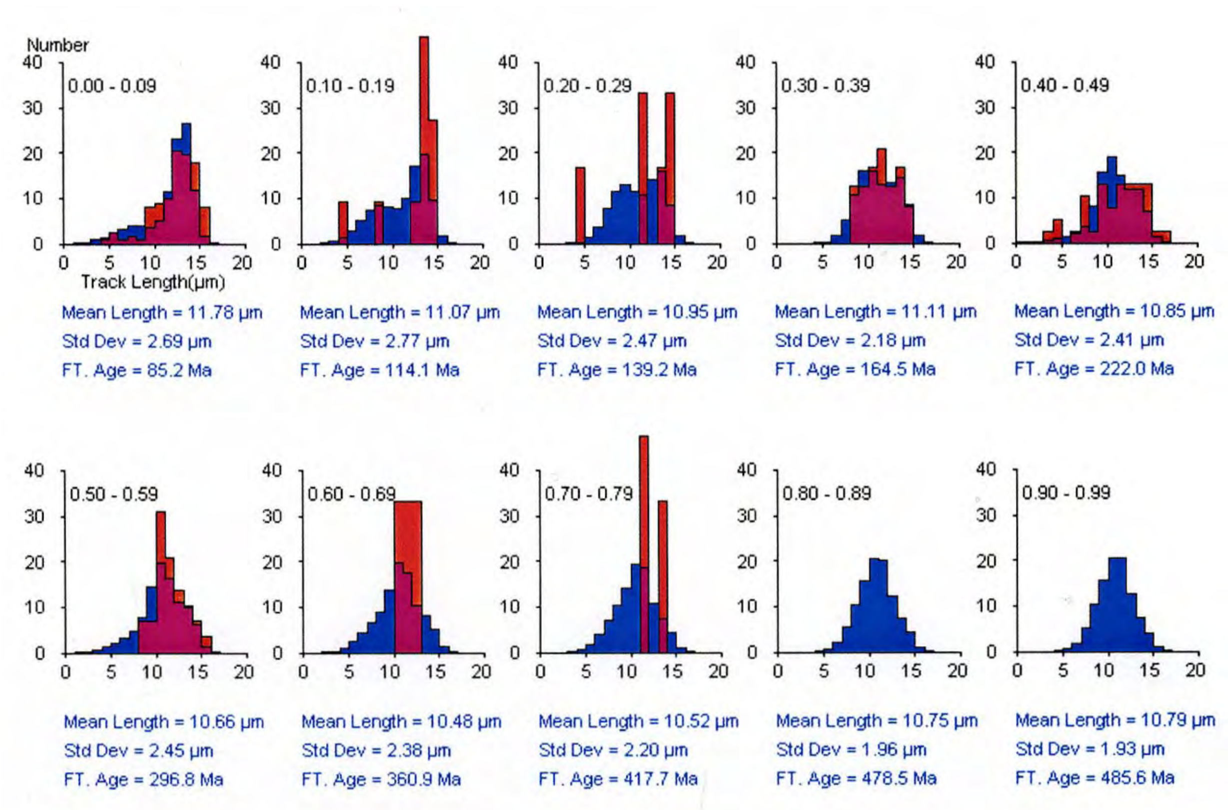

Figure 7: Track length distributions in different compositional groups within the Triassic sandstone from which the fission track age vs wt% Cl data were shown in Figure 3. Red histograms show measured data. Blue distributions show the distributions predicted by the best-fit thermal history.

Why should we worry about wt% Cl?

One obvious reason for worrying about it is accuracy – using a model based on a single composition to extract thermal history information will only provide accurate answers if applied to data in grains of the same composition.

But another important but more subtle reason is that compositional effects can introduce severe biases into data, which might not be obvious at first sight. One example might be of a sediment which has been heated to say 110°C and then cooled to lower temperatures fairly recently. Most of the F-rich grains will have been totally annealed and contain low spontaneous track densities (young ages), while the more Cl-rich grains will have undergone only partial age reduction. Since the F-rich grains tend to be the most common (in most cases), the age data would most likely be dominated by these grains, while the track lengths would come dominantly from the more Cl-rich grains which will have much older ages and therefore much higher spontaneous track densities. Treating all grains as equivalent in this case will inevitably distort the data to such a degree that any interpretations are meaningless.

If any further illustration is required of the need to pay explicit attention to compositional effects, Figure 7 shows the track length distributions in different compositional groups from the same Triassic sandstone sample for which the age vs wt% Cl data are shown in Figure 3.

Figure 7 shows how the data in various compositional groups undergo a transition from limited annealing of tracks formed up until the paleo-thermal maximum in grains containing high Cl contents to almost total annealing of the corresponding tracks in grains containing 0.0 wt% Cl. The track length distribution passes from a unimodal distribution in high Cl apatites through bimodal forms in intermediate compositions with shorter and longer tracks easily resolved, to a unimodal distribution with a small tail to shorter lengths in the most sensitive apatites. This is very reminiscent of the patterns of variation identified in

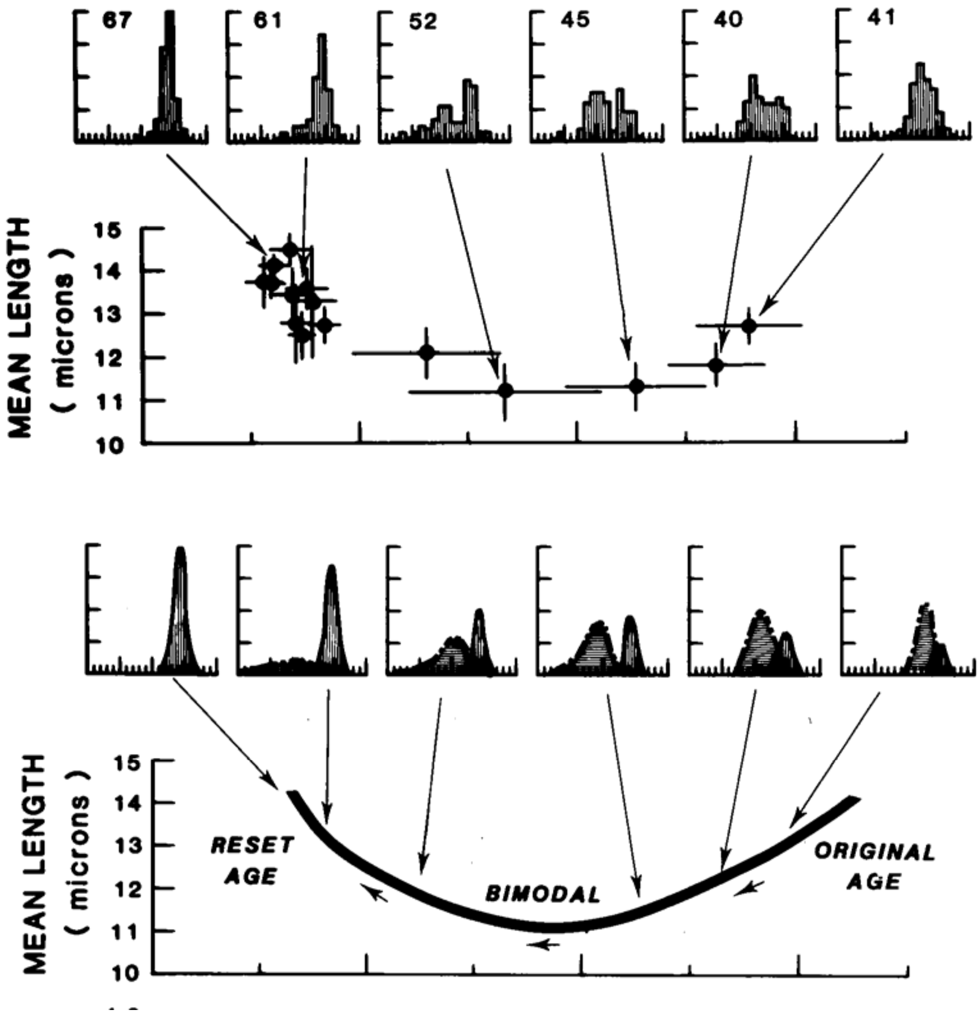

Figure 8: Relationships between mean track length and fission track age in apatites from a suite of outcropping Paleozoic basement samples from the UK Lake District (from Green, 1986). The track length distributions show the same systematic change as the fission track age is reduced that is seen in compositional groups within the single sample illustrated in Figure 7. For these outcrop samples, the differences largely represent differences in maximum paleotemperature, but in Figure 7 the differences are induced purely by differential annealing, with all grains having reached the same maximum paleotemperature.

a batch of outcrop samples from the English Lake District (Green, 1986), as illustrated in Figure 8.

The point here is that everyone would surely agree that there is no way that all the outcrop samples in Figure 8 could be treated as identical and given a common interpretation. But in the same way, it is equally inadmissible to treat all of the compositional groups within the Triassic sandstone sample in Figures 3 and 7 as identical (even though they do share an identical history).

The future

Quantitative definition of the influence of wt% Cl on annealing kinetics has to be a major direction of future research in the fission track community, if accurate results are to be obtained. Almost 20 years after it was first reported (Green et al., 1985), the influence of Cl on annealing kinetics is still largely ignored in the majority of studies, and it is time that the “head in the sand” attitude adopted in many quarters since that time was replaced by a more rigorous approach.

Another major subject for future research should be identification of second order controls. These undoubtedly exist, as discussed earlier, but a systematic influence of elements other than chlorine in "real data" has yet to be demonstrated.

Closing remarks

I've made the case here for using wt% Cl from electron microprobe analyses as the best indicator of differential annealing, and hopefully provided some practical suggestions regarding how it could be routinely implemented. At Geotrack we prefer this approach over the use of etch pit size, for a variety of reasons (but that's a separate issue for another day). But whatever your preference, one thing is clear – any route you take to dealing with differential annealing is better than ignoring it! And our commercial colleagues in Idaho are to be congratulated on their efforts in this direction. It's time for everyone else to join in!

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CALL FOR INTERLABORATORY COMPARISON OF U & TH MEASUREMENTS IN SUB MG APATITE SAMPLES

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The (U-Th)/He thermochronology needs precise determination of uranium and thorium in single grain accessory apatite crystals. Their weight is usually between 10 and 50 µg and the amount of actinide elements range from 0.01 to 10 ng in a single crystal. The low weigth, the low actinide concentrations and the chemical behaviour of thorium (tendency to adsorb) cause difficulties in these measurements. The Durango apatite is the most widely used age standard, however, only few actinide concentrations have been published so far. The reported Th/U ratios vary between 7.7 and 25. This broad range of the Th/U ratios is mainly due to the different origins of the aliquots (different mines, crystals and perhaps also zoning within the crystals). Hence, we can hardly estimate the consistency of the trace element analytical techniques used in different laboratories. Thus Tibor Dunai recommended already at the East Kilbride He-meeting in May 2004 to distribute an apatite powder for an inter-laboratory crosscheck.

We have performed homogeneity tests on several gem-like apatite crystals using CL imaging, (sensitive for manganese, and the main lanthanides), ICP-MS (28 elements in 52 isotopes), electron microprobe (quantitative traverses, 18 elements) and fission track mapping of uranium (laser ICP-MS mapping, IR spectroscopy and halogen determinations are also planned for the near future). The most homogeneous material contains low amounts of fluide inclusions, relatively few cracks and it is available in the form of several cm sized euhedral crystals (AS-16). This apatite was chosen as test material No.1 and we got a proper mass (over 4.5 kg) of more-or-less gem quality crystals from one locality. We perform a careful selection and pulverisation of ca. 100 g and we will start to distribute the 0.5 g aliquots of AS-16 in January or in February 2005. In order to detect a possible systematic deviation of methods/laboratories we plan to distribute a second material. This showed less perfect results in the homogeneity tests. However the significance of the inter-laboratory comparison will be increased by using two materials. None of these materials come from Durango.

The suggested amount taken for an analysis is 10 mg because (i) this relatively high amount will minimize the weighting error and (ii) this amount will assure the representativeness of these rather homogeneous solids. After the dissolution it is requested to take for analysis an aliquot of the solution corresponding to 15 µg apatite what is the average weight of an accessory apatite crystal.

We plan to present the results in the following, splitted form:

Table 1: Person or group & affiliation

Table 2: Method (icp-ms or other); with/without isotope dilution; acid composition and concentration; ml used for analysis; with/without ion-exchange; U, Th and Ca in ppm [solid]; blanks; special comments.

There will be no link between the tables and only one of us (ID) will handle the original raw data of the participants. The relation between the results and laboratories will be kept absolutely confidential. Further on the brand of instruments used for analysis will not be presented in order to keep the anonymity of the laboratories.

The results of the homogeneity tests of the gem-like apatite species and the compilation of their geochemical (and partly crystallographical) survey will be published only after the end of this proposed inter-laboratory comparison. The homogeneity of some of the tested crystals is rather promising; thus we hope that at the end of this survey we will be able to issue a new standard for electron microprobe as well as SIMS and Laser-ICP-MS.

Contact us in case of interest and we will mail an aliquot soon.

DO I NEED TO AVERAGE ALL MY ZETAS? — OUTLIER TEST BY OUT?LIER

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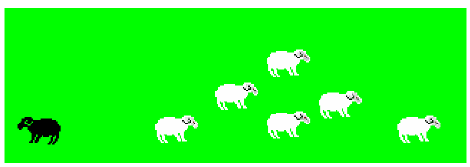
http://www.sediment.uni-goettingen.de/staff/dunkl/ (submitted 9/12/2004)

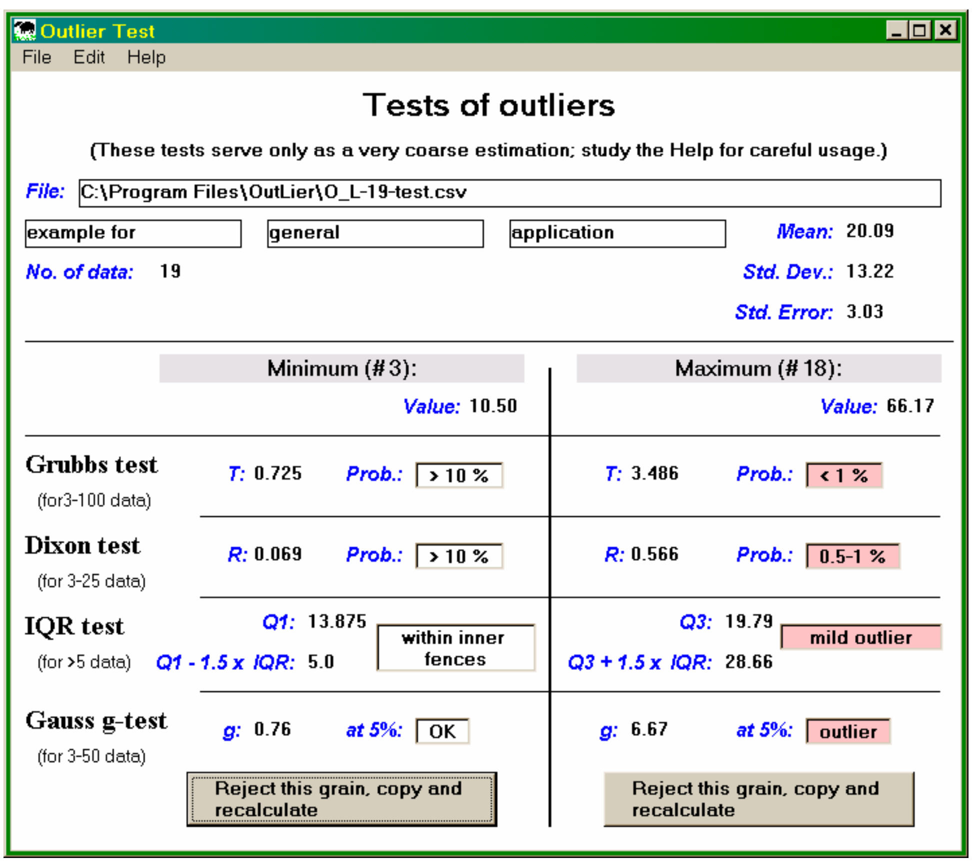
Windows program for testing outliers in data sets having normal or "close-to-normal" distribution, and low number of observations

It is always a dilemma: can we reject the "not nice" results or not? Which criterion can be used? For example in case of zetas if one value is far from all the other: is it necessary to include it in the averaging always, or not, or can we reject a measured values at all? I have compiled in this version of Out?Lier four widely used tests which may give some more exact approaches in these questions.

These tests are probably not useful to judge the rejection of a single grain FT age within an EDM sample (grain age population). In the majority of the samples the single grain ages follow some oblic distribution (lognormal, gamma or beta). Thus the usage of these tests - which are based on normal distributions - would give false results.

The main window:





1. Specifications

1.1. Hardware: Min. 200 MHz .

1.2. Operating system: Tested on WinMe, Win2000 and XP.

1.3. Decimal setting in operating system: DOT (Control Panel/Regional Options: "UK" or "US"; Decimal symbol: "."). Unfortunately the comma as decimal symbol makes troubles (sorry for .fr, .it, .de, .sk and .hu users)

1.4. Maximum of data: 300.

1.5. Input

1.5.1. From comma delimited text files

Order the data in maximum three columns (see an example in the table below; suggested software: any spreadsheet calculator, e.g. Excel, Grapher or Origin). First line: three cells for the description of sample locality, measuring conditions, etc. The first record must contain something.

All other lines:

1st cell: data (obligatory, must be a number)

2nd cell: standard deviation of the data (can be empty, but it is practical to save this value, if the file will be opened by other statistical software).

sample ID	text	text
13.76	3.28	data ID
17.2	2.35	data ID
10.5	2.69	data ID
14.55	4.84	data ID
-15.29	2.73	data ID

sample ID	**Some identification of the sample; obligatory, text or number**
	Data; obligatory, continuous, only numbers
	Error of the data; recommended, type when available
	Comments and data identification; can be empty, but do not use comma

3rd cell: ID of data point (can be empty)

Export the table as 'Comma delimited' or as 'Comma Separated Variables' text file (extension: '.csv').

1.5.2. Paste from the clipboard

Copy an individual, continuous column or a complete block with numbers only, having no empty cells, and paste it into the running Out?Lier.

OK

13.76
17.2
10.5
14.55
15.29

OK

13.76	14.55
17.2	15.29
10.5	13.15

FALSE

13.76	14.55
17.2	15.29
10.5	13.15
	35.65

1.6. Output

The results of the tests are presented on screen and can be copied to the clipboard in table form. Paste these data into a spreadsheet calculator program.

2. Usage

2.1. Purpose

These four tests are used to detect outliers in univariate data sets. Tested samples are usually repeated measurements performed in similar conditions. The supposed reason of the aberrant behavior of an outlier is related to some non-systematic, unknown, technical factor that added the unexpected deviation to the scatter of the data which is typical for the given measurement.

2.2. What are the results?

The program shows the results of four most commonly used outlier tests developed for low number of observations. The T, R, Qx and g values are calculated by testing the minimum and maximum values of the sample. These values are compared with the critical values of the tables (or test algorithms). The tables of critical values are listed below. The results of the tests are in framed text fields in the main window of the program.

In the Grubbs and Dixon tests the 'Prob.' values indicate the probability that the tested data belongs to the supposed normal distribution determined by the whole population. Below 5% the pink coloring warns to the low probability. The Grubbs and Dixon tests have complex tables with critical values, thus the results can be expressed by probability ranges (e.g. P=5-7.5%). The IQR test has three categories at P=5%: 'within inner fences' = no outlier, 'mild outlier' and 'extreme outlier'. The Gauss g-test has only two categories: 'OK' and 'outlier' at P=5%.

2.3. What is important to consider?

Normality

These tests are developed to detect outliers in samples having normal distributions. If the investigated sample has some other, especially asymmetric distribution (e.g. lognormal), then these tests give false results!

Very low number of observations

I have serious doubts on the usage of these tests when the number of observations is below 10. Each test somehow requires the empirical distribution of the data and relates the most extreme value(s) to some parameter of the distribution. If the number of observations is very low (e.g. below 5) then the model is poorly constrained and the estimation is rather approximate.

Data with different precision

If the elements of the data set are determined by very different precision, then the application of the tests need special care. End-member of such a population can be just a consequence of lower precision resulting from the given measurement.

When real outlier --> then few

If more than 20% of elements of the sample is identified as 'outlier' then (1) assumption on the normality of the distribution was not appropriate, and/or (2) quality of data is not proper, and/or (3) tested sample is composite in character, the elements were derived from two or more independent populations.

2.4. Summary

- All statistical tests can be just a very coarse approximation when the number of observations is low.

- Handle the results of the tests only as suggestions; consider rejection only when the population fulfils the requirements of 2.3.

- A really good reason to remove data from the data set exists only when some independent sign or evidence (e.g. technical problem) is known on the given data having 'aberrant behavior'.

- If the four tests do not give consistent results then it is worth to study the equations of the tests and trace the reason of the inconsistency. In these cases the rejection of the tested data can be problematic.

3. Equations of the tests

3.1. Grubbs test

The test is based on the difference of the mean of the sample and the most extreme data considering the standard deviation (Grubbs, 1950, 1969; DIN 32645; DIN 38402).

The test can detect one outlier at a time with different probabilities (see table below) from a data set with assumed normal distribution. If n>25 then the result is just a coarse approximation.

$$T_{\max} = \frac{x_n - X_{mean}}{s} \qquad T_{\min} = \frac{X_{mean} - X_1}{s}$$

where

x_i or x_n = the suspected single outlier (max or min)

s = standard deviation of the whole data set

X_{mean} = mean

3.2. Dixon test

The test is based on the differences between the data members at the tails of the sample (Dixon, 1953). The test detects one outliers at a time (see the table of critical values below). Normal or close-to-normal distribution of the sample is required.

$$r_{min} = \frac{x_2 - x_1}{x_n - x_1} \qquad r_{max} = \frac{x_n - x_{n-1}}{x_n - x_1} \qquad \text{when n = 3 to 7}$$

$$r_{min} = \frac{x_2 - x_1}{x_{n-1} - x_1} \qquad r_{max} = \frac{x_n - x_{n-1}}{x_n - x_2} \qquad \text{when n = 8 to 10}$$

$$r_{min} = \frac{x_3 - x_1}{x_{n-1} - x_1} \qquad r_{max} = \frac{x_n - x_{n-2}}{x_n - x_2} \qquad \text{when n = 11 to 13}$$

$$r_{min} = \frac{x_3 - x_1}{x_{n-2} - x_1} \qquad r_{max} = \frac{x_n - x_{n-2}}{x_n - x_3} \qquad \text{when n = 14 to 25}$$

where

x_i or x_n = minimum and maximum of the sample

$$g = \frac{x_{extr} - \overline{x}}{s}$$

where

X_{extr} = extreme value of the sample
$\overline{X}$ = the mean of all other data
s = standard deviation of all other data

3.3. IQR (interquartile range) test

The test is based on the difference between the first and third quartile of the sample (Q1 and Q3). If the most extreme data has 1.5 times IQR distance from the next quartile then it is considered as 'mild outlier'; if the distance is over 3 times IQR then it is considered as 'extreme outlier'.

3.4. Gauss g-test

The test is based on the difference between the suspicious extreme value and the mean and standard deviation calculated from the rest of the sample (Szalma, 1984).

4. The tables of critical values

Are in the Help of the program.

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Acknowledgements

The program was tested and the description was improved by Martin Danišik and Balázs Székely.

AUTOSCAN

Versions of Trakscan packages supplied by Autoscan Systems Pty. Ltd.

Autoscan Systems now supplies 4 versions of the Trakscan package :

A. Trakscan DeLuxe (based on Zeiss microscope)
This new version of Trakscan contains a number of significant improvements over its predecessor. It is based on the formidable Zeiss Axio Imager microscope:
1. The use of a very high-resolution colour digital camera and two monitor screens of matching resolution exploits the human brain's superior object detection and discrimination mechanism.
2. The incorporation of highly accurate external linear sensors allows our stages to achieve excellent positioning accuracy.
3. The new features of on-screen track counting and track length measurement have been made possible through the use of highly accurate imaging components : the microscope, camera and monitor screens.
4. The timing of our new version has been fortuitous : at this time Carl Zeiss (the foremost manufacturer of optical research microscopes) has decided to no longer manufacture or supply the drawing tubes (which were previously used in conjunction with our Trakscan programs and digitiser tablets to measure track lengths).
5. The use of two monitor screens in the latest version of our Trakscan software allows simultaneous viewing of both the grain and mica mounts (with a corresponding increase in usable image size), or simultaneous viewing of the camera image and the program control screen (thus enhancing program usability).
6. Our latest version of Trakscan is supplied with EasyLength, a new facility that allows the user to quickly assess the usability of specific mounts without going through the usual file housekeeping procedures. EasyLength also incorporates a useful graphing facility that provides instant feedback about the quality of the results obtained.
7. The Trakscan DeLuxe package incorporates a Zeiss Axio Imager microscope which has been configured to optimise the utility of this package for FTD work, but also incorporates optical components which facilitate a broad range of microscopic applications. It represents the absolute state-of-the-art in Zeiss microscopes at this time.

B. Trakscan Professional (based on Zeiss microscope)
This version contains most of the useful features of the DeLuxe version, but with some modifications to bring it into the range of a lower budget. It is based on a modified version of the Zeiss Axio Imager:
1. A specially configured Zeiss Axio Imager microscope, with most of the features of the DeLuxe microscope, but some economies in objective technology. This version of the Zeiss Axio Imager has been specially configured to maximise its usefulness for FTD work.
2. A monochrome high-resolution digital camera, which retains the crispness and detail of the DeLuxe version, but without the addition of colour information.
3. Standard motor shaft encoders on the stage. While these are not as accurate as the external linear position sensors, they still provide positioning repeatability of the order of 2 microns in X and Y, with positioning repeatability of the order of 0.2 microns in Z.
4. On-screen track counting and length measurement are still incorporated, thus providing a convenient and accurate method of carrying out these functions.
5. The EasyLength package is included.

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C. Trakscan DeLuxe (based on Olympus microscope)
This version is based on the popular Olympus BX51 microscope:
1. The use of a very high-resolution colour digital camera and two monitor screens of matching resolution exploits the human brain's superior object detection and discrimination mechanism, when aided by colour.
2. The incorporation of highly accurate external linear sensors allows our stages to achieve unprecedented positioning accuracy.
3. The new features of on-screen track counting and track length measurement have been made possible through the use of the highly accurate imaging components : the camera and monitor screens. This was not a practical method with previously available imaging technology.
4. The use of two monitor screens in the latest version of our Trakscan software allows simultaneous viewing of both the grain and mica mounts (with a corresponding increase in usable image size), or simultaneous viewing of the camera image and the program control screen (thus enhancing program usability).
5. Our latest version of Trakscan is supplied with EasyLength, a new facility that allows the user to quickly assess the usability of specific mounts without going through the usual file housekeeping procedures. EasyLength also incorporates a useful graphing facility that provides instant feedback about the quality of the results obtained.
6. This Trakscan DeLuxe package incorporates an Olympus BX51 microscope which has been specially configured to optimise the utility of this package for FTD. It represents the state-of-the-art in Olympus microscopes at this time.

D. Trakscan Professional (based on Olympus microscope)
This version contains most of the useful features of the DeLuxe version which is based on the Olympus BX51 microscope, but with further modifications to bring it into the range of a lower budget. It was specially configured to cater for the market segment which prefers to use a digitiser and drawing tube for counting and measuring tracks:
1. A specially configured BX51 microscope as above, but with a drawing tube to allow the use of a digitiser tablet for counting and length measurement of fission tracks.
2. A monochrome high-resolution digital camera, which retains the crispness and detail of the DeLuxe version, but without the addition of colour information.
3. A single high-resolution monitor screen.
4. Standard motor shaft encoders on the stage. While these are not as accurate as the external linear position sensors, they still provide positioning repeatability of the order of 2 microns in X and Y, with positioning repeatability of the order of 0.2 microns in Z.
5. A digitiser tablet for counting and measuring of fission track lengths. This method is preferred by some operators, who believe that the live view through the microscope afford a better means of visual discrimination between fission tracks and other mineral features.
6. The EasyLength package is included.

All of the above versions are supplied with our popular high-performance 3-axis AS3000i/f stage (supplied complete with EL300 electronic controller, JS300 joystick, universal power supply and all necessary connecting cables). The systems are also supplied with a suitable state-of-the-art computer package, which runs the Trakscan program under a current version of Windows.

We look forward to once again meeting our FTD friends at the European Conference on Thermochronology in Bremen, Germany (30 July-04 August 2006).

We would be delighted to assist you in deciding on the best package for your particular needs. Please contact us at Autoscan Systems Pty. Ltd.

Note : The product names above are trade names of their respective owners.

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NEW FEATURES, TRICKS AND TIPS FOR THE USE OF TRACKKEY (TK-NEWS NO. 3. — FOR VERSIONS 4.2.F AND 4.3)

ISTVÁN DUNKL

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The purpose of Trackkey is to calculate and visualize the single grain ages measured by the external detector method. In the last time I have made some improvements and here I would like to complete the former descriptions of this software (Dunkl, 1991; 1992). At the daily work by data made in different systems the file conversion is a really nerve-racking and unnecessary amusement. That is why the new TK versions contain more import and export filters to help the users and achieve more flexibility. Another issue is the type of the distribution of the single grain ages. It is especially important at the identification of age components at the age-provenance studies of siliciclastic rocks. A new plot of TK (Pearson type distribution) may help us for the better understanding.

Running on MAC: Frank Lisker runs without hindrance Trackkey on MAC with a PC emulation. Citation from his letter of 31/8/2004: A comprehensive overview about Windows emulation programs is given at *http://emulation.net/windoze/*. The easiest, smoothest running, most distributed (and most expensive) one is "Virtual PC" (current version: 6.1). Trackkey works excellently on this platform, and the respective files can be transferred straightly from and to the Mac disc. The only alternative I tested is "MacBochs", a rather intricate freeware which can be downloaded from *http://bochs.sourceforge.net/*.

Import: Trackkey uses a double file system. The **data files** (with extension: .APA and .ZIR) contain the counting data, irradiation code, chemical, Dpar & morphological information of the crystals and some optional data on the locality, petrography etc. The Nd of the irradiation, the name and U content of the monitoring glass and the zetas (+errors) are stored in one or more "user defined" **setting file(s)**. Thus, at the opening of fission track data files of other systems, some data of the setting file must be added for the proper calculations.

BinomFit-import: At the import of a data file with .FTZ or .FTA extension (Brandon, 1992) Trackkey can calculate the age, but can not extract the (i) type of U glass, (ii) the number of tracks on detector (Nd), (iii) the code of irradiation and (iv) the standard deviation of zeta. A warning message appears, and for the fast usage these values are temporarily supposed (for example glass name: "unknown", irradiation code: "# phantom" and standard deviation of zeta: 10).

MacTrack-import: The first problem is that the text exported MacTrack files have .TXT extension and that should make confusion: not all .TXT files can be imported in this way. At the import Tracckey can not extract the type of the U glass and the code of irradiation; thus the running of the program is stopped and the user is asked to specify these data.

Paste from Clipboard: If the user stores the counting data in a spreadsheet calculator (e.g. in an Excel table) then the new "Paste" function can be useful for a rapid conversion of the data to the Trackkey system (menu: File/New and press the Paste button for more guidance). By this function the user can paste from the clipboard the Ns, Ni and Area columns in the table of the Edit Data window.

Export: A part of the export files help at the presentation of results in tables and drawings and an other part of the export files help at the communication with other systems (e.g. AFTSolve and Binomfit).

New extension of "Grain-age files": The grain-age files contain the calculated ages of the grains (Trackkey data files contain only the rough counting data). Formerly both AFTSolve and Trackkey used the ".AGE" extension, but the two file types had basically different formats. In the latest TK versions the extension of the grain-age files has changed to ".GRA" to avoid confusions with Richard Ketcham's file system.

DXF (AutoCad) export: These export files contain the most important plots in vector graphic form. These files of .DXF extension can be imported and further edited by many graphical software.

AFTInv export: These files are used for modelling program of Dale Issler and they contain both track counts and lengths. Thus before the export the user must load a length file.

Copy results to clipboard: The calculated results can be placed on the clipboard in two formats.

"Menu: Edit / Copy All Results to Clipboard" will result in a table with 34 columns. This complex data record can be useful for an update of the user's internal data base, but too complex to insert in a report or publication as it is. The "Copy Selected Results" option will place on the clipboard the data, which are recommended by the IUGS (Hurford, 1990). The order of columns (see Table 1) is a little bit different from Tony's sequence, but contains all necessary data used in the tables of publications. For the N values square bracket is used because the normal bracket () has an assigned meaning in Excel.

File	Locality	Code	Strat.	Petrogr.	Cryst.	RhoS	[Ns]	RhoI	[Ni]	RhoD	[Nd]	Chi-sq. P (%)	Disp.	Central Age	±	1s
Pop-293.zir	Kallis	Gö-11	Mioc 2	sandst	50	66.53	[2531]	55.33	[2105]	4.54	[4798]	65	0.09	32.4	±	3.4

Table 1: Summary table placed on the clipboard (track densities are 105 tracks per cm2)

Length files: The latest TK versions can open both AFTSolve (Ketcham et al., 2000) and Dumitru's stage files (Dumitru, 1993) containing track length data.

Chi-square age: There was an interesting discussion at the Amsterdam meeting on the possible treatment methods of partly reset detrital apatite ages in sandstones. One possibility would be to apply the chi-square age (Brandon, 1992) that aims to identify a population at the youngest part of the single grain age distribution, where the chi-square value guarantees the homogeneity of this population. Using TK the isolation of this population is rather simply:

1. Menu: Plots / Spectrum Plot Options / Fix Actual Spectrum.
2. Menu: Calculations / Chi-square Age.
3. The appearing table shows the single grain ages in increasing order. The eighth column indicates the chi-square value computed from the first n single grain ages.
4. By selection of the grain population having chi-square value more than 1 % TK can calculate the so-called chi-square age and draws this population on the age spectrum plot.

Bar plot: The latest version can draw bar plot with ages below 1 million year; the only restriction is the maximum number of bins. It is limited to 250, because when the bins are too narrow then they can be simply invisible on the screen.

Type of distribution: There is rather robust method for the graphical estimation of the type of the distribution just using its kurtosis and skewness (beta1 and beta2). Trackkey contains a new module to plot the projection point of the data on a diagram showing major distribution types (Menu / Plots / Pearson Distribution). The disadvantage of this method is that it requires relative high number of data. There is a very simple empirical test to check how reliable are the beta values: the user can reject the latest 1.2...5 grains and observe the drift of the recalculated projection point on the plot. The distribution types of Pearson family are plotted on Fig. 1. A detailed analysis on the distribution of single grain ages is in preparation (comes maybe in the next OnTrack).

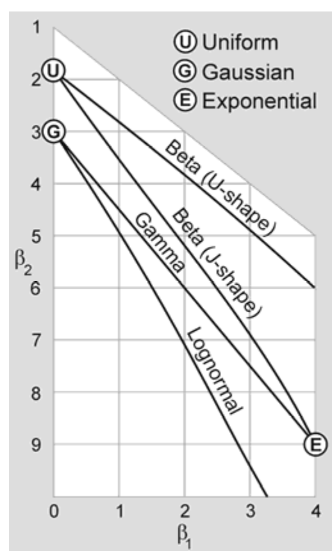

Figure 1: Distribution types of Pearson family

Goodness measure of the grains (e.g. PMA): The individual counts in the grains contain always some extra-Poissonal error. This comes mainly form the heterogeneous uranium distribution of the dated phases (see details in Green, 1981). We suggested a method and apply the "Proportion of Measurable Area" to characterize somehow the goodness of the dated grains (PMA; Dunkl and Székely, 2004). This is a number between 10 and 100. The latest TK version presents on the main window the average of the "goodness" estimations if they are performed on all grains. If the user applies some other numeric parameter and type these numbers into the "Goodness" column (the last but one) of the data table in the "Edit Data" window then their average will appear on the main window.

Calculation of uranium content: Former TK versions did not consider the different ranges of the fission track particles in glass and in the dated minerals. The new TK-BASE.SET setting file contains computed and the recommended values thanks to the letter communications of Eva Enkelmann and Raymond Jonckheere of 25/10/2004 and according to Jonckheere (2003) further considering the densities of the different materials (see Help on the window Settings / Uranium calculation).

Online Help: In the Help menu the user can develop an on-line connection to the Trackkey homepage and it hopefully help to check the latest version and visit the online help pages.

Example files: By upgrade delete the old example files from your machine, download the new set of files, and place them in the root of drive c (into the C:\TK-DATA directory). The new example files have speaking names and they will help to test the new functions (e.g.: binomfit-example, composite-file, distinction, L-Dumitru-s-stage, L-in-AFTSolve-format, MACTracks-example, test-activation, test-euhedral-population, with-PMA).

Suggestions, problems and points to be discussed:

- Independently of Trackkey I recommend the usage of *Total Commander* *(http://www.ghisler.com)*. It is similar to the former Norton Commander. File operations are much more transparent and very easy with such a system having always two lists by side than using "My computer" which shows only one list. Very useful function of it is the F3 function key that shows the content of the files promptly. Of course the unzipping and installation of TK is also very fast and simple with it.

- It is recommended to show the extensions of the files in your system. It can make serious troubles and wasting of time if you store the results of a sample in more files having the same file name (which is logic) and different extension/format. Thus it is worth to show the extension and for this to disable the following option: My computer / Tools / Folder Options / View / Hide file extensions for known file types.

- Unfortunately TK runs precisely only when the decimal setting of your Windows is dot (Control Panel / Regional Options: UK/US; Decimal Symbol: . dot!). This is an obscure history, sorry.

There are two points where we need some discussion and agreement for the proper und uniform presentation of FT data (and also for further upgrade of Trackkey):

- How to present the zero-track grains on the age spectrum? If a grain have zero spontaneous track then the zero FT age can be plotted by the bar diagram, but the zero age also involves zero s.d. and this makes impossible to draw a Gauss curve from this grain data. Thus, if a sample contains such grains the bar plot and the age spectrum show different characters. Ann Blythe suggested to apply one spontaneous track for such grains just to calculate some s.d. and draw the age spectrum. I was thinking also in this way and speculating even to apply 1/2 track. If someone has a concrete idea and can argue exactly how many virtual tracks can we apply for this computing then I would be happy to receive suggestions. If I will not get any constraints then the 4.3 version (see below) will perform the computing the age spectra with 1/2 track.

- If several samples can be added (as the sample localities are very close, or the ages are identical, etc.) and these mounts were irradiated with identical fluent (same irradiation package, close position) then the situation is easy: Menu / File / Combine Files / Load Another Data File. However, if the mounts were irradiated in different conditions (having different RhoD) we have to export them as "grain-age file" and later amalgamate those files. In this case only the mean age is calculated from the grain-age files. The Ns and Ni numbers can not be used for the computing of pooled and central ages as the grains experienced different irradiations. What to do in these cases? Can we normalize the Ni counts at all and when yes then how? The question is especially sharp when the individual samples pass the chi-square test, but for the amalgamated sample we still do not have the procedure and convention how to calculate the pooled or central age. I would be grateful if we achieve some wise convention for these cases.

Upgrade: The actually downloadable 4.2.f version contains all the above listed new functions. However, if you have no serious trouble with your running TK version I suggest to wait a few weeks with the download and upgrade because the coming 4.3 version will contain some more import/export filters (e.g. for the new stage software of Trevor Dumitru, for AFTINV of Dale Issler and for the new AFTSolve of Rich Ketcham). I will launch version 4.3 as soon as I get the example files with the new formats.

Steps of upgrade

(i) It is recommended to perform the installation of the latest version of TK into a new directory (e.g. Program Files\Trackkey.43).

(ii) Copy the existing personal setting files (having .SET extension e.g. myzircon.set) from the old program directory into the new TK directory. In this way the new version will use all your pre-set values (zetas, Nd numbers, graphical settings, etc.).

(iii) For the correct calculation of the uranium content modify some constants in all your personal setting files: Menu / Settings / Uranium calculation / Zeta method / Apatite = 0.945; Zircon = 0.797; Sphene = 0.935. If you install TK first time you can skip steps (ii) and (iii); in this case just create the personal setting files by modification of TK-BASE.SET.

(iv) Pull an icon from the new TK directory to the Desktop and delete the old icon to avoid confusion.

I am open for suggestions and ready for further upgrades.

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IRRADIATION FACILITIES AT THE FORSCHUNGSNEUTRONENQUELLE HEINZ MAIER LEIBNITZ (FRM II)

H. GERSTENBERG, X. LI

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In Garching near Munich, Germany, the Technische Universität München operates the Forschungsneutronen-quelle Heinz Maier-Leibnitz (FRM II), a 20 MW research reactor which had been taken in operation in 2004 and which is open for scientific research since April 2005.

The central component of the reactor is the single cylindrical fuel element – the so called compact core - containing approximately 8 kg of highly enriched uranium. The reactor core is embedded in a large (≈ 13 m³) cylindrical tank containing heavy water, which serves for the reflection and the moderation of the fission neutrons. The most important advantage of this design is that the maximum of the thermal neutron flux density is located within the moderator tank but outside the fuel element in an area which is accessible for scientific installations. Although the reactor has clearly been optimized for neutron beam tube experiments it offers several irradiation devices. Among those the pneumatic rabbit device, the hydraulic rabbit device and in particular the so-called fishing line setup, i.e. a very simple purely mechanical irradiation device, are regarded to be suitable for the irradiation of fission track specimens.

The pneumatic rabbit device is made up of 6 independent irradiation channels, using carbon dioxide instead of air as process gas in order to avoid the disturbing production of Ar-41. Due to its individual vertical position within the moderator tank each channel offers a specific neutron spectrum. The available thermal neutron flux densities in the pneumatic rabbit device range between 4.8E12 cm-2s-1 and 7.3E13 cm-2s-1, the corresponding ratio of thermal/fast neutron flux density covers values between 1300 and 67000. The neutron flux parameters for all of the channels are shown in detail in Table 1. They have been evaluated by means of the irradiation of Al:Au (0.1%), Al:Co (1%), Zr and Ni flux neutron monitors and subsequent gammaspectrometric analysis.*

The main field of operation of the pneumatic rabbit device is the low dose irradiation of small

Irradiation Position	Φ_{th} ($cm^{-2}s^{-1}$)	Φ_{epi} ($cm^{-2}s^{-1}$)	Φ_f ($cm^{-2}s^{-1}$)
Channel 1	3.5×10^{13}	9.6×10^{09}	2.0×10^{09}
Channel 2	1.5×10^{13}	4.8×10^{09}	4.3×10^{08}
Channel 3	5.0×10^{12}	1.4×10^{09}	7.1×10^{07}
Channel 4	6.8×10^{13}	3.3×10^{11}	4.3×10^{10}
Channel 5	3.9×10^{13}	1.4×10^{10}	5.1×10^{09}
Channel 6	7.0×10^{12}	1.8×10^{09}	1.5×10^{08}

Table 1: Neutron flux densities in the pneumatic rabbit device

Irradiation Position	Φ_{th} ($cm^{-2}s^{-1}$)	Φ_{epi} ($cm^{-2}s^{-1}$)	Φ_f ($cm^{-2}s^{-1}$)
Channel 1 - Pos. 1	1.3×10^{14}	2.6×10^{11}	3.9×10^{11}
Channel 1 - Pos. 2	9.3×10^{13}	9.9×10^{10}	2.0×10^{11}
Channel 2 - Pos. 1	1.1×10^{14}	7.5×10^{10}	2.1×10^{11}
Channel 2 - Pos. 2	7.7×10^{13}	3.9×10^{10}	1.0×10^{11}

Table 2: Neutron flux densities in the hydraulic rabbit device (4 most intense channels)

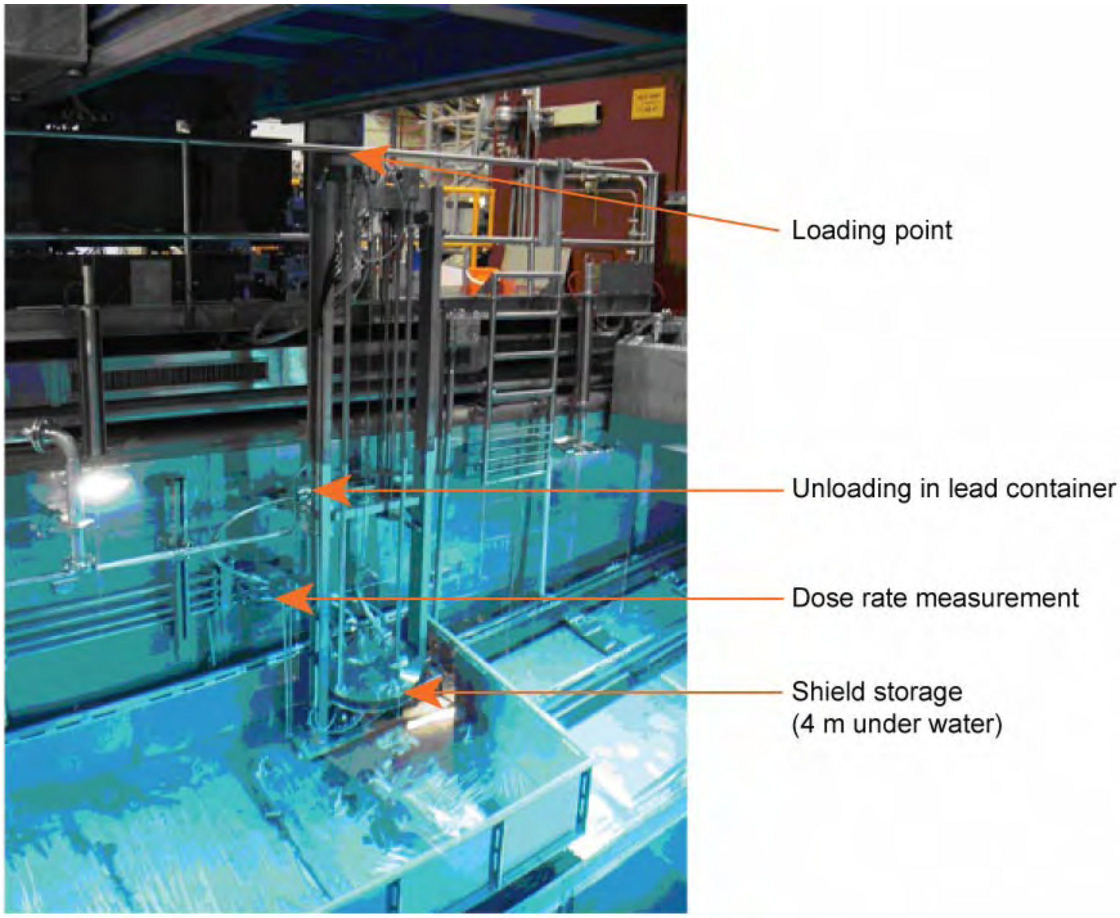

Figure 1: Loading and unloading device of the hydraulic rabbit device

samples typically for activation analysis. In principle, nonetheless, it is also suitable for fission track applications. The polyethylene (PE) rabbits used for the transport of the specimens into and out of the irradiation positions, however, restrict the maximum sample size to a cylinder of 14 mm in diameter and 60 mm in length and the mass of the specimens to 10 g. It is again due the use of PE as rabbit material that the integrated thermal neutron fluence is limited to approximately 2E17 cm-2. On the other hand the rather short transportation time of only about 1 s within the moderator tank allows meeting the required neutron fluence very precisely.

In contrast the hydraulic rabbit device - being based on the pool water driven transport of specimens between the loading/unloading position in the reactor building (see Fig 1) and the irradiation position of the facility - is primarily suited for long term irradiations. It exhibits 2 independent channels both of which can be loaded by up to 5 irradiation capsules at the same time. The irradiation capsules are made from high purity AlMg3 which allows them to be irradiated for several days in high thermal neutron flux densities of up to 1.3E14 cm-2s-1. The neutron flux parameters for the 4 most intense irradiation positions are given in Table 2. In order to avoid their direct contact with the reactor pool water the specimens in the hydraulic rabbit device are additionally contained in a water tight inner Al capsule which allow maximum specimen dimensions of 24 mm in diameter and 55 mm in height. The homogeneity of the neutron flux density along the axis of the irradiation capsule is well below 10%.

For the irradiation of fission track specimens, unfortunately, the hydraulic rabbit device, suffers from the problem of a too high thermal neutron flux density leading to requested irradiation times of only few seconds which due to the low transport velocity of the water driven system can not be achieved reliably. In the past this problem has been overcome by carrying out the irradiations at low reactor power of only typically 250 kW thus prolonging the irradiation times by a factor of 80. The results gained from this irradiation technique apparently met the needs of the involved geologists almost perfectly. The situation, however, is unsatisfying in the respect that an irradiation at the required low rector power is only possible during the start of the reactor after an exchange of the fuel

Figure 2: Fishing line irradiation device at the Forschungsneutronenquelle Heinz Maier-Leibnitz **(FRM II)**

element or a maintenance period which under the assumption of a regular reactor operation means only 5 times per year.

As a consequence from the above situation an irradiation device was needed which allows the irradiation of medium sized specimens in a moderate, to the highest extent possible pure thermal neutron field and provides at the same time short transportation times into and out of the irradiation position. For this purpose the so called fishing line irradiation setup was designed, built and licensed by the regulator. The irradiation position of this device is located in a light water filled vertical thimble in the moderator tank which can be top loaded from the reactor handling bridge. Its distance to the fuel element (center to center) is exactly 1 m. Vertically the standard irradiation position is the mid plane of the reactor fuel element. The corresponding thermal neutron flux density is approximately 1.1E13 cm-2s-1 , the ratio of thermal/fast neutron flux densities is far above 1000. Again the homogeneity of the thermal neutron field in the irradiation position is in the range of a few percent with respect to the volume of the specimen.

The irradiation technique is very simple. The specimen is contained in an AlMg3 container which is connected by means of a Nylon line to a coil being mounted on the handling bridge of the reactor. From this position the irradiation technician lowers the specimen into the irradiation position or pulls it out in the same manner after the completion of the irradiation by mechanically winding or unwinding the Nylon line from the coil (see Fig. 2). Using this device irradiations requiring neutron fluences in the range of 1E15 – 1E17 cm-2 can be done within minutes at full rector power. On the other hand the transfer time of the specimens into and out of the irradiation position is only few seconds; thus the target neutron fluence can be met reliably. Finally in case of an even considerably lower required neutron fluence the irradiation position can easily be shifted out of the mid plane of the fuel element and after a neutron flux density measurement a less intensive irradiation position may be defined keeping the irradiation times in the range of minutes at the same time.

In summary the Forschungsneutronenquelle Heinz Maier-Leibnitz (FRM II) is able to provide a considerable range of irradiation tools also for geological applications. In the collaboration with external researchers the irradiation service of the FRM II does not only perform the irradiation itself but provides an activation and dose rate calculation for each specimen and offers assistance in the transportation of activated specimens back to the customer.

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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 Inc., 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). Moved to Syracuse University, Syracuse, New York, in 2000.
•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)
•Universite 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)
•University of Glasgow, Glasgow, Scotland (two systems, 2001)
•Yale University, New Haven, Connecticut (2001)
•Université Joseph Fourier, Grenoble, France (2001)
•Universität Bremen, Bremen, Germany (second system, 2002)
•Université des Sciences et Technologies de Lille, Villeneuve d'Ascq, France (2002)
•University of Kansas, Lawrence, Kansas (2003)

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

Fission-Track Papers 2003-2006

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Call for Contributions

The next issue of OnTrack is scheduled for early in 2007 and we are (always) looking for contributions. OnTrack welcomes contributions of virtually any kind, including:

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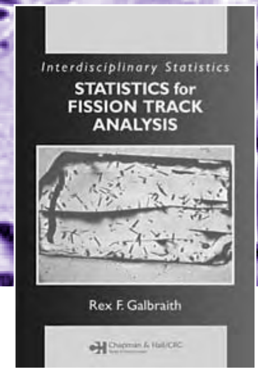

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