On Track

The Newsletter of the International Fission-Track Community

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NEXT EDITOR:
Ed Sobel
Institüt für Geowissenschaften
Universität Potsdam
Postfach 601553
D-14415 Potsdam Germany
Phone: ++ 49 331 977 5403
Fax: ++ 49 331 977 5060
E-mail: sobel@rz.uni-potsdam.de

Editor's Notes

The past few months have seen a number of important meetings, most noteworthy of which was the fission-track workshop held in El Puerto de Santa Maria (Cadiz) in Spain. Although primarily intended as a European gathering, participants from Australia, North and South America gave the meeting a truly international flavour, and highlighted the need for regular dedicated workshops. In MAKING TRACKS IN THE MONASTERY Tony Hurford presents a review of the Cadiz workshop. I attended this meeting and thoroughly enjoyed the camaraderie and willingness to freely exchange knowledge and experiences. Such community spirit continues in this issue of On Track. First on offer are three new sources of software. From Australia we have an updated MacIntosh version of Rod Browns MacTrack program used by many to calculate and plot their age data. An alternative age calculation and plotting program, TrackKey, has been freely available for some time from Istvan Dunkl who now offers us another program for age component analysis. On the same theme Mark Brandon reports on an upgraded windows version of his BINOMFIT program.

There is widespread collaboration amongst the FT community but how much interaction is there with other branches of science? Raymond Jonckheere and Luis Chadderton in their article BACK TO BASICS highlight how little we (the FT community) have collaborated with physicists whose knowledge of complex atomic systems are key to advance understanding of track formation and behaviour, and ultimately future refinement of track annealing models. There is without doubt a strong case for going back to basics in track research and I would urge us all to take note of Raymond's plea.

An area where there is a history of cross disciplinary collaboration is landscape geomorphology. In his article entitled RIFTED MARGINS, FISSION TRACKS, AND LANDSCAPE EVOLUTION MODELS Peter van der Beek considers the role of low temperature thermochronology and looks at where future research is heading. Peter is uniquely placed in this regard since he has a foot in each camp - he runs a fission track laboratory and develops numerical models for landscape evolution. Numerical skills are not my strong point and if the truth be said nor is it for many and yet we routinely use statistical models whether for assessing the quality of our data, extracting age components, or modelling age and track length data. Annealing models have become an integral part of the data interpretation process and recently new descriptions have been published for different apatite compositions but we still lack a basic kinetic model built on sound physical processes. The closest to this is Carlson's model published in American Mineralogist back in 1990. In their article entitled CARLSON'S LAW: A FORMAL COMPARATIVE STUDY WITH RESPECT TO LASLETT'S LAW Radid et al, make a numerical comparison between Carlson's physical model and the widely used Laslett '87'.

I hope you find these articles informative and thought provoking. If there are issues arising from these articles or if you have general concerns that you want to sound out with the FT community there is the web-based fission-track discussion group FISSION-TRACK@jiscmail.ac.uk If you do not already belong to this group you can sign up at; http://www.jiscmail.ac.uk/lists/FISSION-TRACK.html

Finally,Ed Sobel has gallantly offered to take over editorship of On Track. So for the next issue, due in January, please forward him your news, gossip, address changes and most importantly, articles. Ed's email address is: sobel@rz.uni-potsdam.de

[Andy Carter]

Short Tracks

Cornelia Spiegel arrived at the University of Melbourne in April for two years of post-doctoral studies. Cornelia recently completed her PhD thesis on the exhumation history of the Central Alps, using detrital zircon fission track age data at the University of Tuebingen. Whilst at Melbourne Cornelia will be working on the low temperature annealing behaviour of apatite and on projects being undertaken by the Melbourne Group.

Robin Clayton has joined the London Group to run the (U-Th)/He facility. Robin is an isotope geochemist and has previously worked in Sweden and Germany

Matthias Bernet started a two-year postdoctoral position in June at University of Canterbury, New Zealand. Matthias completed his Ph.D. thesis in May at Yale University on the use of detrital FT thermochronology to study the exhumational history of the Alps. He was jointly supervised by Mark Brandon and John Garver (Union College). At Canterbury, he will work with Prof. Kari Bassett on the use of cathodoluminescence for provenance analysis.

Frank Pazzaglia and **Mark Brandon** will receive the 44th Kirk Bryan Award at the 2002 National Meeting of the Geological Society of America, in recognition of their paper: Pazzaglia, F.J., and Brandon, M.T., 2001, A fluvial record of long-term steady-state uplift and erosion across the Cascadia forearc high, western Washington State: American Journal of Science, v. 301, p. 385-431. The paper was note as an outstanding example of the integration of fluvial geomorphology and fission-track dating in the study of active tectonic processes.

The Special Issue of Tectonophysics entitled "Low temperature thermochronology: from tectonics to landscape evolution", edited by Barry Kohn and Paul Green appeared on 6 May, 2002 as Volume 349 (1-4). The volume contains 18 papers and arises from a selection of presentations made at the 9th International Conference on Fission Track Dating and Thermochronology held at Lorne. Titles of these papers are listed in the recent publications section.

Meetings

THE 10th INTERNATIONAL CONFERENCE ON FISSION TRACK DATING AND THERMOCHRONOLOGY will be hosted in Amsterdam, The Netherlands in 2004. The planned date for the conference is August 8-14th. More information will be given later on this year.

GEOLOGICAL SOCIETY OF AMERICA, ANNUAL MEETING DENVER October 27th-30th 2002. Topical session T111 is entitled DETRITAL THERMOCHRONOLOGY-DATING OF EXHUMATION AND LANDSCAPE EVOLUTION IN MOUNTAIN BELTS. Session convenors Matthias Bernet and Cornelia Spiegel

THE 21st INTERNATIONAL CONFERENCE ON NUCLEAR TRACKS IN SOLIDS will be held in New Delhi, India during October 2002. Further details can be obtained from;http://www.nsc.ernet.in/conf/icnts21/ntis21.main.html

AGU FALL MEETING 2002, SAN FRANSISCO
Special session T06 convened by Ed Sobel and Douglas Burbank is entitled -TOPOGRAPHY, EXHUMATION, AND OROGENIC STEADY-STATE. This session will examine the development of the steady-state orogen. How do we recognize a steady-state orogen at present or in the geologic record? What are the factors which favor or hinder the development of such an orogen? How do climate and lithology influence the time scale required to reach steady-state? We encourage submissions which focus on the topographic or exhumation history of an orogenic belt. Both numerical modelling studies of landscape development and field-based studies utilizing methods such as geomorphology, remote sensing, and thermochronology are appropriate. Contributions utilizing fission track data to address this topic are of particular interest!

Abstract submission deadlines are; 29 th August for abstracts not submitted electronically and 5th September for electronic submissions.
For further information contact the convenors:

Edward Sobel,
Institüt für Geowissenschaften, Universität Potsam, Postfach 601553, D-14415 Potsdam, Germany.
Email: sobel@rz.uni-potsdam.de
Telephone: (+49) 331-977 5403
Fax: (+49) 331-977 5060

Douglas Burbank,
Department of Geological Sciences, University of California, Santa Barbara, , Webb Hall Rm 2116, Santa Barbara CA 93106 USA
Email: burbank@crustal.ucsb.edu
Telephone: 805-893-2586

A GSA Penrose conference on **"Tectonics, Climate, and Landscape Evolution"** will be held on January 13-17, 2003, in Taroko National Park, Taiwan. Conveners are Sean Willett, (U Washington), Niels Hovius (Cambridge U), Mark Brandon (Yale U) and Don Fisher (Penn State U). The conference will be held in Taroko National Park, Taiwan. Cost of the five-day conference, including room and board, is expected to be less than $850. An optional four-day field trip will be offered from January 9-12, providing a full cross section across the Taiwan orogen. Cost for that trip is expected to be less than $500. We anticipate funds will be available to help subsidize the costs for graduate students.

Potential participants should send a letter of application before September 1, 2002, to one of the conveners, including a brief statement of interests and relevance of the applicant's work to the conference topic, as well as a short abstract of work to be presented at the meeting, if desired. Attendance is limited to 80 persons, although we hope to attract the participation of a broad range of earth and atmospheric scientists. Graduate students are encouraged to apply. Further information is available at ;
http://www.geosociety.org/profdev/penrose/03-taiwan.htm.

EVOLUTION OF THE EARTH'S SURFACE - A two day meeting at the University of Glasgow is to be held on April the 15th and 16th 2003 to consider the rates and timing of surface processes. The meeting will focus on the applications of mineralogical, chemical and isotopic techniques to understanding mechanisms and quantifying rates of denudation of the Earth's surface. The emphasis will be on understanding how processes operating at the present-day have moulded the surface of the Earth and how these processes operate on other planets, in particular Mars. The main themes are;

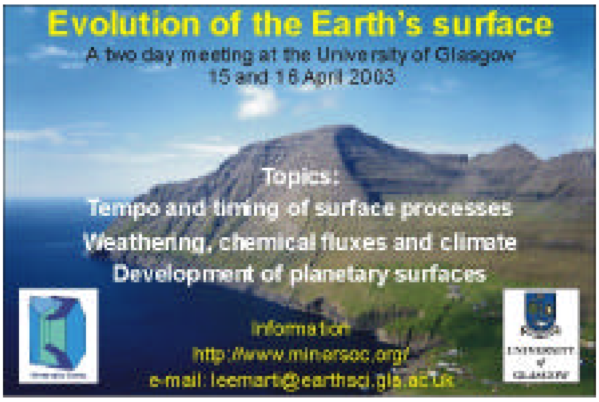
1. Tempo and timing of surface processes with emphasis on determining rates of uplift and erosion using low temperature thermochronometry techniques including;
   - Fission-track
   - (U-Th)/He dating
   - Cosmogenic isotopes
   - (Keynote speakers Tibor Dunai and Paul Bierman)
2. Weathering and global chemical fluxes
3. Development of planetary surfaces

Further information can be obtained from http://www.minersoc.org/ or by email: leemarti@earthsci.glas.ac.uk

IN APRIL 2003 EGS AND EGU will organise a combined conference in Nice, France. Several sessions are now being prepared that might be of interest for scientists using fission-tracks and other low temperature geochronological tools. If you are interested please visit the website;
http://www.copernicus.org/EGS/EGS.html

SECOND LATIN AMERICAN SYMPOSIUM ON NUCLEAR TRACKS, SAO PEDRO, BRAZIL, FEBRUARY 23-28, 2003. The first circular for this international meeting is now being distributed. The deadline for abstracts is 15th November 2002.

ITALIA 2004, 32ND INTERNATIONAL GEOLOGICAL CONGRESS, FLORENCE, ITALY, 20-28TH AUGUST 2004. The first circular for the 32nd IGC conference is now available with details on the web at http://www.32igc.org
Relevant symposia include Geomorphology, Geodynamics and Isotope Geochemistry. Those planning on attending should complete an electronic questionnaire on this website by August 31, 2002.



RIFTED MARGINS, FISSION TRACKS, AND LANDSCAPE EVOLUTION MODELS: A HAPPY "MENAGE A TROIS" ?

Peter van der Beek <pvdbeek@ujf-grenoble.fr>

Laboratoire de Géodynamique des Chaînes Alpines
Université Joseph Fourier
BP 53, 38041 Grenoble, France

Rifted continental margins have been in the picture of the fission-track community for nearly two decades, and a large number of studies have been devoted to studying the patterns of denudation on the rifted margins of all five continents. At the same time, numerical landscape evolution models have taken a lot of interest in the geomorphic development of rifted margins. These are the first structures where the different efforts of trying to understand the interplay between tectonic and erosional forcing on landscape development have been more or less integrated. In this modest contribution, I'll try to use the developments within both the fission-track and in the modelling communities that study rifted margins to illustrate how integration of fission-track data and numerical models can help us to understand landscape evolution, and what are the difficulties we face at present.

So, what's so interesting about rifted margins?

Good question … well, for one they are large structures and relatively simple ones as well. High-elevation rifted margins, which are the ones that interest us, are characterised by an upland region, an escarpment, and a coastal strip. The questions surrounding them are relatively simple: what is the tectonic significance of the escarpment, when did it form, do these margins necessarily indicate rift-related tectonic uplift, how do they evolve? Rifted margins do not show the tectonic complications (thrust sheets and so) on that characterise orogenic mountain belts. One can therefore hope that relatively limited databases (around 100 samples?) are representative of a relatively large area, although … see further for some examples where things may not be so simple and lateral variations in margin evolution may be important. Moreover, the amounts of denudation that characterise rifted margins are in the order of a few km and therefore well suited for studies using fission-track data, whereas in many active orogenic belts higher-temperature systems are required, apatite fission-track ages often being << 1 Ma. Finally, the interaction between tectonics and erosion on rifted margins is relatively simple: there may have been a pulse of syn-rift uplift, after which the response to denudation appears to be purely flexural isostatic. This makes the numerical models for landscape development on rifted margins relatively simple, compared to those used for compressional orogens (see, for instance, Beaumont et al., 2000).

Conceptual "models" of the early days: erosion cycles

Of course, we haven't started thinking about the evolution of rifted margins only 15 years ago. Already at the end of the 19th century, Eduard Suess and especially W.M. Davis proposed a theoretical framework in which the geomorphic development of rifted margins was to be cast for nearly a century. Within their concept of "erosion cycles", rifted margins (as all other parts of continental interiors) were suggested to evolve through pulses of rapid tectonic uplift followed by long periods of erosional downwearing and "aging" of the landforms. This would lead to the establishment of planation surfaces that could be dated by correlating them with offshore sequences or by directly dating deposits or alteration products associated with them. In the 1950's, South African Leister C. King adapted the Davisian ideas to involve the creation of planation surfaces through escarpment retreat rather than by downwearing. Although King vehemently attacked Davis in his writings, he really only suggested another mechanism by which planation surfaces would form and left the whole "erosion cycle" framework intact.

The paradigm of erosion cycles and planation surfaces has proved very influential and long-lived. The concept is still at the base of the geomorphic literature that is currently being embraced by geodynamicists studying vertical motions through time of regions like southern Africa and north-western Europe. However, although the existence of flat landscape elements that can locally be dated is not debated, the correlation of these remnants and the notion that they were initially horizontal (two necessary assumptions to use them to establish uplift and denudation chronologies) are pretty controversial. See Mike Summerfield's introduction to his "Geomorphology and Global Tectonics" book for a more detailed outline and critique of the erosion cycle approach.

What have fission tracks taught us?

The first fission-track studies of rifted margins, in the mid-1980's, focussed on the timing of margin uplift with respect to rifting, hoping to use the results as an argument in the "active vs passive" rifting debate that had been opened up in the 1970's by Burke and Sengör. These first studies in SE Australia and along the Red Sea showed that apatite fission-track ages were generally equal to or younger than rifting on the coastal strip seaward of the escarpment, and much older inland (Figure 1). This indicated that several km of denudation (and uplift?) had taken place since the onset of rifting on these margins, and therefore favoured a passive rifting mechanism. The fission-track data also clearly showed that the patterns of denudation at rifted margins are incompatible with the conceptual "rift margin monocline" model that was based on the correlation of planation surfaces inland and outboard of the escarpment with offshore sedimentary sequence boundaries (e.g., Brown et al., 2000).

Of course, once we started digging a bit further and more data came out, things became more complicated. First, not all rifted margins are so well-behaved. Extensive fission-track databases from SE Australia (Gleadow et al., 1996) and SW Africa (Brown et al., 2000) show significant lateral variations, with notably some inland regions that show young (syn-post rift) apatite fission-track ages. It is not very clear what these mean, other than some denudational response to tectonic reactivation of ancient crustal structures.

Secondly, as everybody knows by now (but it's still useful to repeat) … fission tracks do not record uplift but cooling! The fact that fission-track ages seaward of the escarpment are younger than rifting only shows that (presumably denudation-controlled) cooling of that region post-dates rifting. The mechanism driving denudation of the coastal strip is simply the increase in local relief imprinted by rifting; it does not require uplift of the margin at all. Flexural backstacking of the amount of overburden removed from the margin may indicate whether it has undergone rift-flank uplift (e.g., van der Beek et al., 1994) but these inferences depend strongly on the flexural model that is chosen. Actually, the fission-track data do not exclude pre-rift uplift provided it's wavelength was sufficiently long to not increase relief and denudation rates very much.

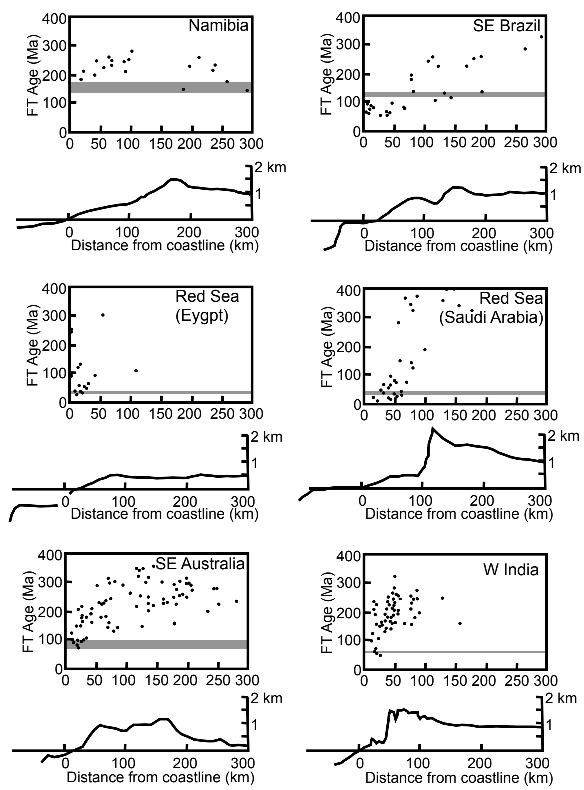


Figure 1. Topogaphic profiles and apatite fission track ages across six rifted margins. Yes, I know you've seen this figure a hundred times before … (this is Yanni Gunnel's version; Gunnell, 2000). The grey bars in the AFT age plots indicate the timing of break-up

Finally, in some regions the amounts of denudation inferred from the fission-track data have been in serious disaccord with the rates of landscape change inferred from geomorphologic studies. This point has notably raised a 10-year long controversy in SE Australia (see Kohn and Bishop, 1999, for a recent review). Of course, the amounts of denudation inferred from apatite fission-track data are dependent on the geothermal gradient which is usually (let's face it) guessed. On the other hand, the spatial and temporal scales to which the fission-track and the geomorphological studies pertain are often not the same, and the disagreement may have more to do with unwarranted extrapolation of results than with a real discrepancy.

Early studies suggested that the fission-track data could actually record syn-rift heating and post-rift cooling together with limited denudation. Several numerical analyses have, however, pointed out the impossibility of sufficiently heating the upper few km of crust in a rifted margin by lithospheric thinning or even magmatic underplating, so that this way out of the problem is not on. A question that is often overlooked though, is the nature of the overburden and its thermal conductivity, as well as the possibility that fluid flow systems have operated in the past and modified the thermal structure of the study area. In SE Australia for instance, there is an intriguing correlation between the youngest fission-track ages and the areas probably formerly covered by sediments …

In come the numerical models…

Since the conception of the first numerical models of landscape evolution in the early 1990's, they have been used to study the geomorphic development of rifted margins (e.g., Kooi and Beaumont, 1994; Tucker and Slingerland, 1994). They are therefore potentially of much use in sorting out the questions raised above, and on the other hand the large fission-track datasets that have been collected on different rifted margins can be useful to constrain these models.

Numerical landscape evolution models turn around three components: the initial and boundary conditions imposed by tectonics, a number of surface process algorithms, and a tectonic / isostatic response to erosion. The models that have hitherto been applied to rifted margins take a simple kinematic approach to the tectonic control; i.e. the pre-rift morphology and syn-rift uplift history are imposed on the model. Surface processes incorporated in the models usually are fluvial incision and transport, hillslope transport, and bedrock landsliding. These are cast in terms of numerical algorithms of varying complexity: a diffusion law is commonly used for hillslope transport; different mechanical and stochastic models exist for landsliding; and fluvial transport is often modelled using what is known as the "stream power" law. These laws are allowed to act on the initial landscape for a predefined period of time, and the isostatic response of the lithosphere to denudation may be included using simple flexural models. Predictions of landscape evolution models include the present-day morphology and drainage pattern but also the denudation history and every point in the model, and this is where the obvious link with fission-track data comes in.

A problem with these models is that the spatio-temporal scale on which erosional processes are observed is several orders of magnitude smaller than the scale on which the models predict landscape development to take place. There is thus a serious extrapolation problem (this should ring a bell to those involved in designing annealing algorithms). Moreover, the surface process algorithms are necessarily a gross simplification of the actual processes going on in nature and the laws are therefore difficult to calibrate. An analogy to this problem may be the well-know "effective elastic thickness" of the lithosphere used in flexural models: we all use it but we know that it is purely a model parameter, we can't go out in the field and actually measure "elastic thickness". The same is true for the parameters used in the surface process algorithms except that, in the case of the elastic thickness everybody agrees more or less on the theory behind the parameter, whereas this is not the case for the erosion laws. Especially for fluvial incision, there are at least six different algorithms around, and we are arguing which of these best describes the processes going on in nature.

Nevertheless, the numerical landscape evolution models can help us a lot in conceptualising what is going on at rifted margins and to interpret our fission-track datasets. An example of how apatite fission-track data and landscape evolution models can be combined to study the geomorphic development of rifted continental margins is provided by a recent study of the eastern margin of South Africa (the Drakensberg Escarpment). A fission-track database including samples from two boreholes (Brown et al., 2002) has shown that some 4.5 km of overburden has been removed from the coastal strip of this margin since break-up, with denudation rates peaking in the early-mid Cretaceous. The Swartberg borehole, located 50 km seaward of the Drakensberg Escarpment, records a phase of accelerated denudation from ~90–70 Ma B.P., much earlier than would be expected in the case of an escarpment retreating at a constant rate since break-up. Brown et al. therefore propose a model of landscape development in which any escarpment initiated at the coast was rapidly destroyed by rivers draining from an interior divide just seaward of the present location of the Drakensberg Escarpment. The present-day escarpment developed and became pinned at this divide. A numerical model was designed to try to simulate this behaviour and to understand what are the major controls on landscape development at this margin (van der Beek et al., 2002). The model results show that the pre-break-up topography of the margin has exerted a fundamental control on subsequent margin evolution (Figure 2): if the initial topography is a horizontal plateau, the margins evolves through escarpment retreat; if the pre-rift topography included an inland drainage divide, the initial plateau seaward of this divide will be rapidly degraded and a new escarpment develops at the location of the initial divide. Although the present-day morphologies predicted by both models are quite similar, the denudation histories at any point of the margin are very different (Figure 3) and it should be possible to discriminate between them using apatite fission-track thermochronology. In the SE African case, the data clearly favour the plateau degradation scenario; escarpment retreat plays a minor role in the evolution of the margin. Moreover, the models show that no large-scale uplift is required to explain the present-day morphology and denudation history of the margin: passive denudation with associated flexural isostatic rebound of a pre-existing ~2.5 km high plateau is sufficient. These model results are in agreement with previous modelling results from the SW African margin (Gilchrist et al., 1994) and SE Australia (van der Beek and Braun, 1999), which, however, did not explicitly take into account the fission-track database

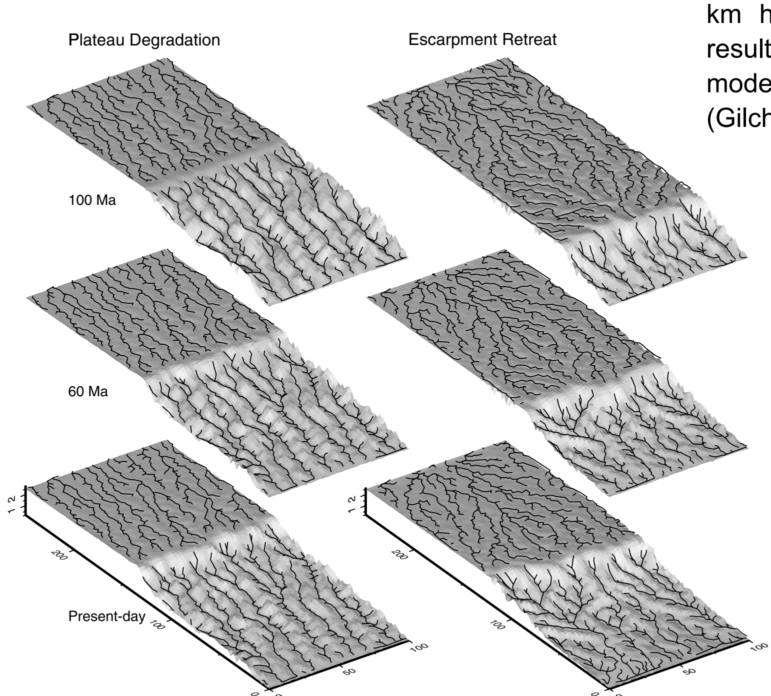


Figure 2. 3D plots of topography and drainage patterns predicted by the Plateau Degradation and Escarpment Retreat models, at 100 Ma, 60 Ma and the present-day. The models were designed to simulate the evolution of the SE African (Drakensberg Escarpment) margin. After van der Beek et al.(2002).

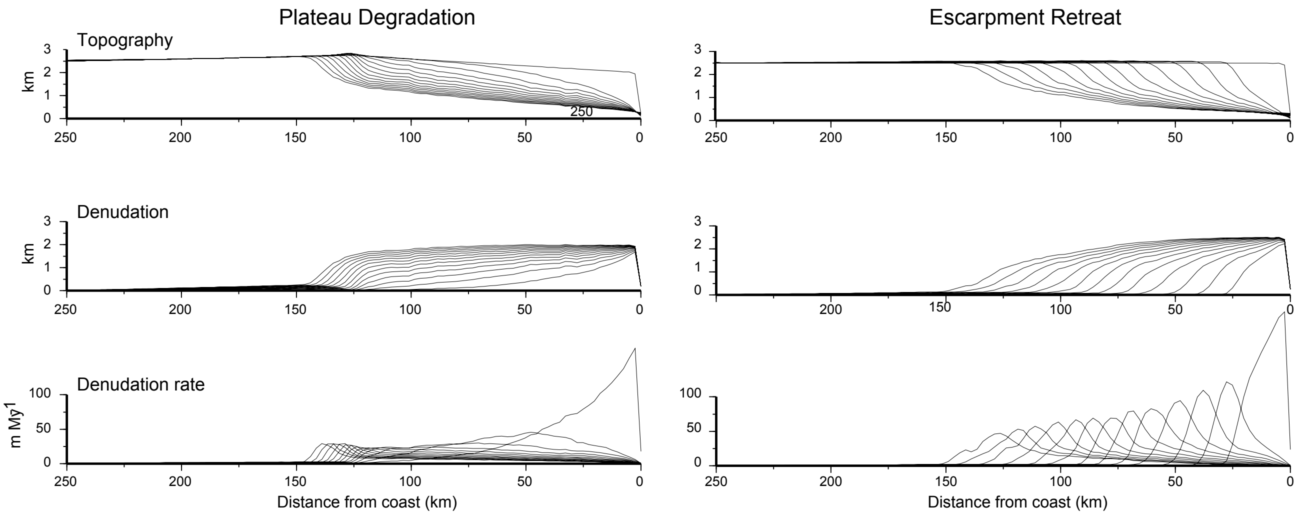


Figure 3. Evolution of strike-averaged topography, denudation, and denudation rates for the models shown in Figure 2. Profiles are shown at 10 m.y. intervals, from zero (start of model run) to 130 m.y. (present-day). Also after van der Beek et al. (2002).

Of course, there remain discrepancies between the inferences from the fission-track data and the outcomes of the geomorphic models. In general, the models have difficulty reproducing the amounts of denudation that are inferred from the fission-track data; they just about predict the minimum amount allowable by the data. Secondly, the landscape evolution models have a hard time reproducing the phases of accelerated denudation that are suggested by inverse modelling of the track length distributions. Of course, these problems can be partly attributed to the imperfections which still characterise the landscape evolution models: we really do not have a decent clue on how to incorporate lithological variations and, maybe more importantly, the effects of climate change through time into the models. However, we should also continue to look carefully at the interpretation of the fission-track data and all the steps that come between a fission-track age and length distribution and a denudation history (those nasty details like annealing algorithms and geothermal gradients), especially given the fact noted above that geomorphic estimates of denudation are also often somewhat lower than what a fission tracker would come up with. Here, the approach of simultaneously modelling data from a vertical (drill-hole?) profile to better constrain the denudation histories will probably become extremely useful, whatever Kit Johnson's car dealer may think of it.

What's in the future?

This question is answered in part by what I've written above: in order to efficiently use landscape development models and fission-track data together, we must continue to make progress both on the model and the data side. Concerning the models, we need to become more confident about the algorithms we use and find ways of calibrating the parameters that enter into them, so that we can attach some physical sense to their values. This will involve testing the models on well-constrained case-studies, probably on smaller scales than those that are of direct interest to fission-track thermochronology (let's say, the drainage basin as a characteristic spatial scale, and 10^5 years as a typical temporal scale). On the data side, we need to continue our search for methods that allow us to more confidently translate fission-track data into denudation rates, most notably try to get a better handle of spatial and temporal variations in geothermal gradients.

Two recent developments are particularly exciting: the combination of apatite fission-track data with (U-Th)/He and/or cosmogenic data, and the development of numerical models that take the transient disturbance of thermal structure into account. In southern Africa, the combination of apatite fission-track and cosmogenic data (Cockburn et al., 2000; Fleming et al., 1999) has clearly shown that short-term present-day rates of denudation and escarpment retreat (from the cosmogenic data) are an order of magnitude lower than those inferred from the fission-track data and have directly inspired the development of numerical models such as that shown in Figures 2 and 3 that try to explain these variations. Very recently, the first (U-Th)/He study of a rifted margin (Persano et al., 2002) has shown that (U-Th)/He ages from the coastal strip of SE Australia are nearly similar to apatite fission-track ages of the same samples, again lending support for models of margin evolution that include a rapid phase of plateau degradation in the first few tens of million years after break-up.

Finally, a new numerical model has recently been developed that fully takes into account the disturbance of the thermal structure of the crust by denudation and relief development (Braun, 2002). If we want to really compare predictions from landscape evolution models with existing thermochronological datasets, this is an indispensable step. As an example, Figure 4 shows (U-Th)/He ages predicted by escarpment retreat and plateau degradation models similar to those shown in Figures 2 and 3. The topographic evolution was exported from the *Cascade* landscape evolution model into the thermal model *Pecube*, which calculates the thermal evolution of the crust under an evolving topography. This was then used, together with a forward model of He ingrowth, to predict (U-Th)/He ages across the margin. Note the different patterns of ages that both models predict: the Escarpment Retreat model clearly shows ages decreasing from the coastline to the escarpment, because the peak of denudation migrates inland with the escarpment (e.g. Figure 3) whereas the Plateau Degradation model predicts less variation in the ages on the coastal strip which are all close to the age of break-up, as shown by the SE Australian data. Note also that the apatite fission-track age patterns predicted by these models differ much less, because samples are only exhumed from the apatite partial annealing zone in both cases. This example shows the importance of combining different thermochronological datasets to study rifted margin evolution and to constrain the numerical models.

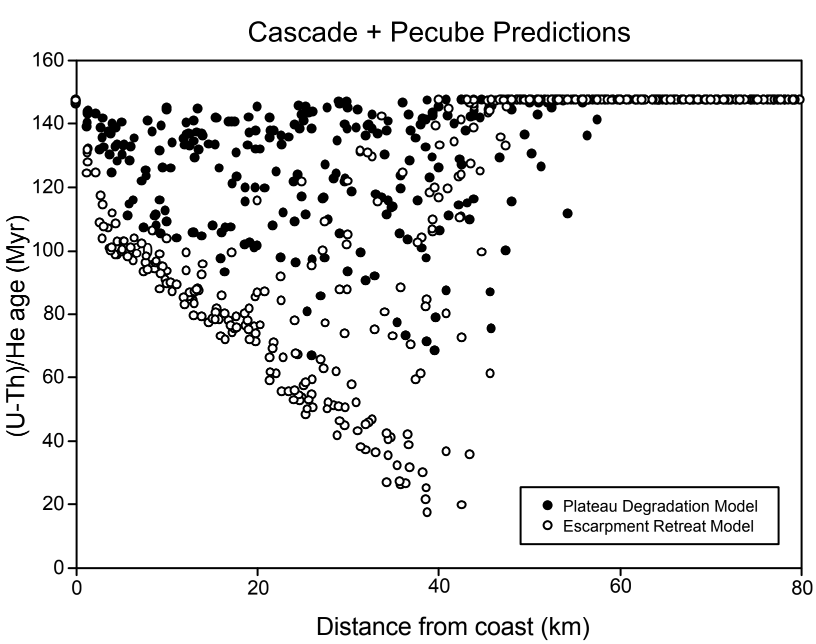


Figure 4. Distribution of (U-Th)/He ages across a rifted margin predicted by the Escarpment Retreat and Plateau Degradation models. The models that went into this calculation are comparable to those shown in Figures 2 and 3, except that they were designed to simulate the SE Australian margin: initial elevation at 1.5 km and rifting since 100 Ma. The present-day escarpment is located at ~50 km in both cases. After Braun and van der Beek (manuscript in preparation).

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SOFTWARE FOR TRACKERS

The following short articles describe new or improved software that are available free to the FT community, provided in the spirit of collaboration. Development of new statistical protocols is a major task and the added burden of writing and developing new software represents a significant amount of time investment. In addition to to the new software described below, several people have been providing free access to their modelling programs including Dale Issler AFTINV32 (On Track 1996 No.13), Kerry Gallagher with Monte Trax (On Track 1999 No. 19), and more recently Rich Ketcham and Ray Donelik's AFTSolve program that also comes with an excellent users guide. We should also not forget Rod Brown's Mac Track (now updated see article below) which has been in wide use for nearly ten years. Our sincere thanks go out to all of you past, present and hopefully, the future.

NEW SOFTWARE FROM TÜBINGEN:
A REVISED TRACKKEY AND A NEW PROGRAM FOR COMPONENT ANALYSIS

István Dunkl <istvan.dunkl@uni-tuebingen.de>

University of Tübingen, Germany

An improved version of **Trackkey** can now be downloaded from the following URL:

www.uni-tuebingen.de/geo/gpi/ag-frisch/mitarbeiter/dunkl/seiten/softwares.html

This new version (4.2) has been written to fix some minor bugs, calculate the "Dispersion", (you can create a compilation table from all your files) and improve the printer selection procedure.

PopShare

From the same website you can also download the PopShare program that was presented at the Cádiz meeting by István Dunkl and Balázs Székely.

POPSHARE is a Windows program for identification of components in mixed data. It uses the SIMPLEX method for the best-fit search. The user can select both the distribution type of the components and also the criterion of the best fit calculation.

POPSHARE is developed basically for identification of age components in single crystal data measured by fission-track geochronology on clastic sediments. However, a general application to treat any kind of data is also possible.

The recent version is only for beta test. The authors will prepare a more detailed description for the next On Track. Meanwhile on the homepage you will find a short guided tour on the usage and main functions of the program.

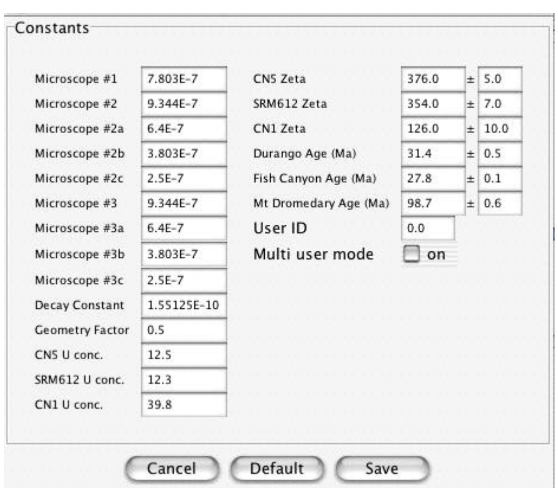
MAC TRACK X

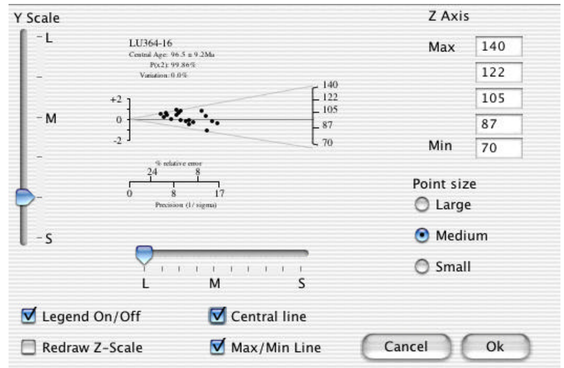
Thermochronology Group, School of Earth Sciences
The University of Melbourne

More than ten years ago Rod Brown wrote MacTrack, the fission track data reduction program for the Macintosh. Although many of us still use this version, some labs (including ours) are now starting to feel frustrated with its inability to run on more recent Operating Systems. So for all those people who are keeping that pre Power PC running in the corner of the lab just to use MacTrack - you can now throw it away and move up to MacTrack X.

MacTrack X has been completely rewritten using Java 2 (Version 1.3) so that it now runs on the modern Macintosh system (OS 10.0 and above, OS 9 does not support this version of Java). Theoretically, any computer that can run Java 2 can use MacTrack X (Windows, NT, Unix…) but in practice small changes might be needed to ensure complete compatibility. We don't routinely operate PCs so a compatible version has not been compiled. We will release a PC version when warranted – so ask and you may receive.

Most of the features found in the original MacTrack have been retained and improved (age, zeta, length and rhoD calculation, editing of data and images). However, others have now been added (multi user mode, sample locality map generation, summary tables, MonteTrax input files, preferences file, and a few additions designed for The University of Melbourne thermochronology group but others could be adapted for use elsewhere). The application is relatively small at 700 Kb. Some screen captures are shown below.

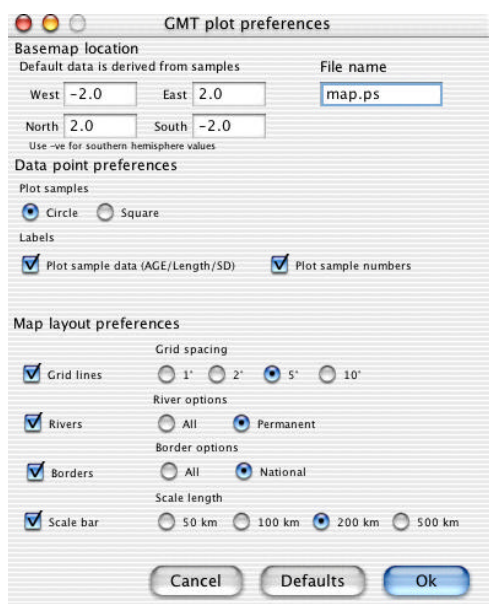




Copies of MacTrack X are available free for educational/research use and can be obtained by contacting Wayne Noble wpn@unimelb.edu.au (a commercial version is also available on request). We will maintain a list of people who are using MacTrack X and notify them as new updates are released. We will also deal with bugs or feature requests as time permits.

To use this release of MacTrack X you need an Apple Macintosh with Operating System 10.0 and above. A Java .jar file is available for users who wish to compile MacTrack X for other platforms – but this is completely untested. If you work with another system and are interested in MacTrack X send the details of your Operating System and we will try to compile a native version.

MacTrack X is written in Java so it has the potential to be expanded and incorporate other routines. It is also our intention to add (U-Th)/He thermochronometry data reduction capabilities in the near future.



DECOMPOSITION OF MIXED GRAIN AGE DISTRIBUTIONS USING BINOMFIT

Mark Brandon <mark.brandon@yale.edu>,

Department of Geology and Geophysics,

Yale University, P.O. Box 208109, New Haven, CT 06520-8109

Overview

This report describes BINOMFIT, a program for estimating components in a mixed distribution of fission-track (FT) grain ages. BINOMFIT has been around for some 10 years, but we have just finished building a Windows version that is much easier to use and provides extensive options for displaying and recording results. The program and source code (Visual Basic 6) are available, along with other FT programs, at www.geology.yale.edu/~brandon.

Introduction

A common problem in FT dating is the interpretation of discordant fission-track grain-age (FTGA) distributions. Discordance is defined when the variance of the grain ages is greater than expected for analytical error alone. The widely used χ^2 test provides the method for assessing if the distribution is "over-dispersed" relative to the expectation for count statistics for fission processes (Galbraith, 1981).

Most FT-chronologists use the central age (Galbraith and Laslett, 1993) to represent the "estimated age" of a discordant distribution. Implicit in this approach is that over-dispersion is due to random errors by the FT-chronologist and that such errors are approximately symmetrical around the expected count ratio. My experience with results from age standards suggests to me that most skilled FT-chronologists have a relative low error rate compared to the intrinsic variation due to fission processes. The implication is that discordance in FT dating is more commonly an indication of a mixed distribution rather than a poorly dated distribution.

Mixed distributions are expected for samples that have "detrital" FT ages, such as a sandstone with unreset zircon FT ages. In this case, the grain ages preserve information about the cooling history of the source region from which the zircons were eroded, assuming that the sandstone has remained cool enough after deposition to preserve those ages.

Discordance is also encountered in reset samples. In some cases, the discordance is taken as evidence for partial resetting, but the cause is more commonly due to differential resetting of grains with different annealing properties, due to variable composition in apatite or variable alpha-damage for zircon. Heterogeneous annealing is expected for reset sandstones given that the dated apatites and zircons are derived from a variety of sources (Brandon et al., 1998), but this result is also found in some plutonic rocks as well where one might expect that the dated mineral was more homogeneous (O'Sullivan and Parrish, 1995).

The central age is clearly not appropriate for mixed distributions, in that it provides only a simple average for all grains. A better approach is to decompose the FTGA distribution into a set of component distributions, and to interpret the FT results using the average ages for those components. Various methods are available for estimating components in a grain-age distribution (Seward and Rhoades, 1986; Galbraith and Green, 1990; Brandon, 1992; Galbraith and Laslett, 1993; Sambridge and Compston, 1994; Brandon, 1996).

In my experience, the best method for decomposing FT grain ages is the binomial "peak-fitting" method of Galbraith and Green (1990). The only program available for this method has been a DOS program, BINOMFIT, introduced by Brandon (1992). We have used this program extensively over the last 10 years and have found that it works very well for real FTGA distributions. A big advantage of the binomial peak-fitting method is that it provides a one-component solution that is equivalent to the pooled age. As a result, the calculation provides a seamless extension of the estimation method used for concordant FTGA distributions.

In formal terms, a mixed distribution is considered to be a mixture of a finite set of component distributions, or components. Such components will commonly appear as bumps or peaks in a histogram or probability density plot, but this need not be the case given that overlapping components may appear as only one peak. Nonetheless, the term peak has come to be used as an equivalent for component.

Galbraith and Laslett (1993) introduced the term “minimum age”, which can be loosely viewed as the pooled age of the largest concordant fraction of young grain ages in the FTGA distribution. They proposed a two-component mixture model for estimating the minimum age. Binomial peak fitting can also be used to estimate the minimum age of a distribution, while at the same time providing information about older components. The main requirement, however, is that peak fitting must be coupled with a test to find the maximum number of significant components in the distribution, as discussed below.

We have found that FT minimum ages are very useful in a variety of studies. For detrital zircon FT studies of volcanoclastic rocks, the minimum age is commonly a useful proxy for the depositional age of the rock (Brandon and Vance, 1992; Garver et al., 1999, 2000). Likewise, the minimum age for a tuff can remove biases due to older contaminant grains. For reset rocks, the minimum age represents the time of closure for that fraction of grains with the lowest retention for fission tracks, such as fluorapatites in apatite FT dating (e.g., Brandon et al., 1998) and radiation-damaged zircons in zircon FT dating (e.g., Brandon and Vance, 1992).

General Concepts for the BINOMFIT Program

It is useful to ask why the binomial distribution is important for this problem. The data we measure are spontaneous and induced track counts for each grain, designated as r_i and s_i with the index indicating the ith grain in a sample of i = 1 to N dated grains. The variables r_i and s_i are Poisson distributed, but they can be converted into a single binomial-distributed variable by the transformation r_i / (r_i + s_i) (Galbraith and Green, 1990). This variable can be approximated by a Gaussian distribution when values of r_i and s_i are large, which is commonly the case for zircon, which tends to have a high track density because of greater U content. However, as the cooling age and U content decrease, r_i and s_i get small. Thus, the Gaussian approximation tends to breaks down for young cooling ages, especially for apatites, which commonly have low U content. In these cases, decomposition methods based on the Gaussian distribution (e.g., GAUSSFIT by Brandon, 1992; MIX by Sambridge and Compston, 1994) will perform poorly. The binomial peak-fitting method provides unbiased estimates of peak ages for track counts of any size.

The binomial peak-fitting method is based on the maximum likelihood method, which means that the best-fit solution is determined by directly comparing the distribution of the grain data to a predicted mixed binomial distribution. This approach is a significant improvement over the convention least-square method, which requires more restrictive assumptions about the distribution of residuals.

A problem with all peak-fitting method is that the calculation requires an initial guess of the number and ages of the peaks in the distribution. The user specifies the number of peaks to be fit, and that number could be as large as the number of grains in the FTGA distribution. So we are left to ask, how many peaks are significant? The solution can also fail to converge given a poor initial set of peak ages used to start the solution.

BIONOMFIT provides an iterative search of peak ages and number of peaks to find an optimal solution. The procedure we use is an automated version of the *F*-test approach outlined in Brandon (1992). For this search, we consider a large set of trial solutions. The trick is to organize the search and to apply appropriate tests to find the best solution.

The quality of fit for each trial solution is scored using the χ^2 statistic, in a manner similar to the conventional χ^2 test. The strategy for the search is to consider successively larger number of peaks and to use a large number of initial guesses to ensure that for a specified number of peaks, we have found the best-fit solution. The initial guesses for peak ages are generated from the probability density plot for the FTGA distribution. The density plot is estimated using the method in Brandon (1996), and the first and second derivatives are used to find bumps and humps in the plot. The probability density at each candidate age is used to guess the potential size of the peak. We have tried an alternative approach, using evenly spaced ages, but the computation takes longer and does not provide any improvement in performance.

The next step is to iterate through an increasing number of peaks. The first iteration produces a single component age, with an age identical to the pooled age and a χ^2 value identical to that produced by the conventional χ^2 test. The next iteration finds a best-fit two component solution using all combinations of initial peaks as initial guesses. The best solution is the one with the lowest χ^2 value. We next consider a three-component solution, then a four-component solution, and on.

With each iteration, we use the *F* test to determine if the introduction of an additional component has produced a significant improvement in the χ^2 statistic (Brandon, 1992). In general, one will find that the χ^2 statistic gets smaller with the introduction of a new component. In part, this is due to the fact that the additional component provides the model with greater flexibility to fit the data. But we need to know if the improvement in fit is large compared with the expected random variability associated with measurements. In other words, we want to be assured that the additional peak is fitting signal and not just noise.

This question is nicely addressed by the *F* test. To explain, consider two solutions for *m* and *m*+1 peaks, and the quality of those fits, indicated by χ^2_m and χ^2_{m+1}. The *F* statistic is given by $F = (m+1)(\chi^2_m - \chi^2_{m+1})/\chi^2_m$. When *F* is large, then the improvement in fit associated with the additional peak is considered significant. The *F* distribution is used to assign a probability P(*F*), which is the probability that random variation alone could produce the observed *F* statistic. We consider P(*F*) < ~5% to indicate that the improvement in fit is significant. Thus, we can find the optimal number of significant peaks by adding peaks until we get a value of P(*F*)> ~5%.

Using BINOMFIT

The Windows version of BINOMFIT is written in Visual Basic v. 6.0. Most people will have to deal only with the executable program, but I am distributing the source code as well so that one can inspect the methods used in the program. You are free to modify the source code but please do not distribute the modified version without first consulting with me, in order to avoid confusion about different versions. Also I encourage queries about problems with the program and suggestions for improvements.

The executable version requires some supporting DLL and OCX files. These files are already loaded on many Windows systems since they are used by a variety of other programs. The Readme.txt file in the distribution package provides information for those of you that might be lacking the necessary support files.

Data files are constructed as simple text files. Make sure that the files are standard Windows-based ASCII files. If you are unsure about the provenance of a data file, then open the file in MS Word for Windows, edit out any offending lines or characters, and then save as Plain Text (*.txt). I recommend that the file extension be set to .FTA, .FTZ, etc. depending on the dated mineral. Note that the file extension may not be visible since the default option in newer versions of Windows is to hide the extension. You can change that option or just pay attention to the file type designation to see the extension.

Data files have the following format:

1) Line 1: Title for data set.
2) Line 2: This line is flagged by making the first value negative. All values on this line should be separated by commas.
    a. ZETA METHOD: Effective track density (tr/cm^2) and the relative standard error (%) for the fluence monitor, and the effective uranium concentration (ppm) of the monitor standard.
    b. Z METHOD: Enter line as: -1, 0, 0.
3) Line 3: All values should be separated by commas.
    a. ZETA METHOD: Zeta factor (yr cm^2/tr), standard error (yr cm^2/tr), counter square size (cm^2).
    b. Z METHOD: Z factor (yr), standard error (yr), counter square size (cm^2).
4) Line 4 and on: For each grain, enter the measured spontaneous and induced tracks, and the number of squares for the area counted. Data values can be separated by spaces or commas.

5) To merge another dataset, repeat lines 2 and on.

6) A semicolon in the first space marks the line as a comment. The program skips comments and blank lines.

The methods described here follow Hurford and Green (1983). The zeta method is the most widely used, but there are some cases where the method is needed (such as when an age standard is used as a fluence monitor). The program can handle up to 1000 grain ages, so size limitations should not be problem.

The program comes with some example data files. We focus here on MTTOM.FTZ, a detrital zircon FT sample from Mount Tom in the Olympics Mountains (Brandon and Vance, 1992). We start the program and use the file menu to open the data file. The program comes up with a window showing a list of initial guesses for peak ages. The user is free to remove (i.e., “uncheck”) specific peak ages from the list. The user then indicates the mode for the calculation. Automatic mode is as outlined above. Manual mode allows the user to specify a limited set of initial peaks ages, and to solve for that number of peaks only.

The automatic option is followed immediately by the best-fit solution (Figure 1). The best-fit peaks are reported by age, uncertainty, and size. The uncertainty for the peak age is given at 68% and 95% confidence intervals. The size of the individual peaks is reported as a fraction (in percent) and as a count (number of grains). Note that peaks sizes are constrained so that they all sum to 100%.

The “Grain Ages” plot (lower left in Figure 1) shows a vertical line for each grain age, organized according to its position in the file. The best-fit peak ages and 68% confidence intervals are plotted horizontally across the plot. The cursor can be used to find grains according to age and position in the file, by placing the cursor over the grain line and looking at the results in the status bar at the bottom of the program window. Right-clicking the cursor brings up a window where the user can remove the selected grain age or copy the plot to the clipboard, for pasting into another application.

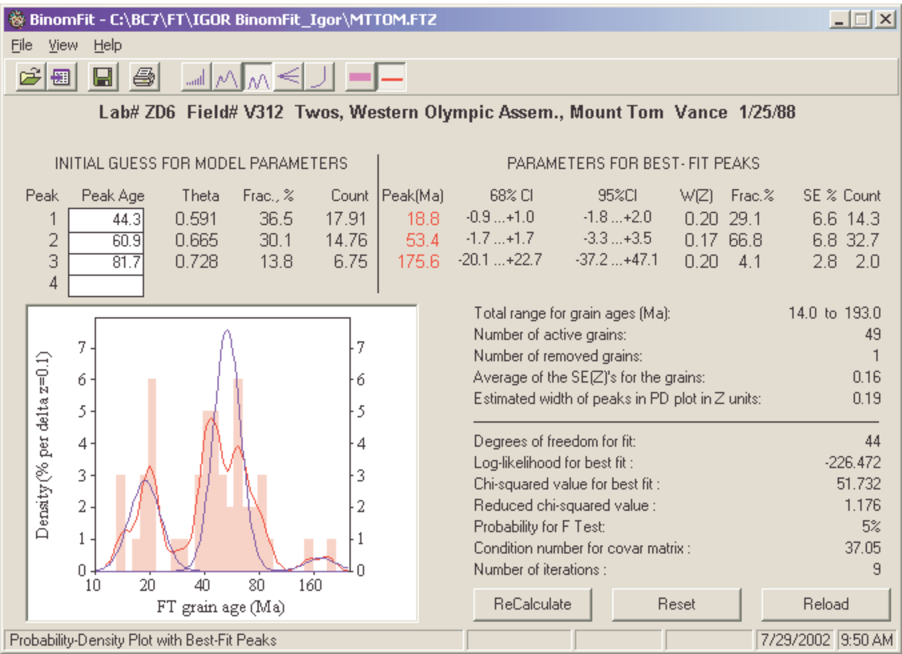


Figure 1. Best-fit solution for the Mount Tom zircon FT sample using automatic mode.

The toolbar or view menu can be used to select other reports on the data, including a probability density plot of the data and the best-fit peaks (Figure 2), a radial plot showing data and best-fit peaks (Figure 3), and a P(*F*) plot (Figure 4), which summarizes the results of the *F* tests used to determine the number of significant peaks.

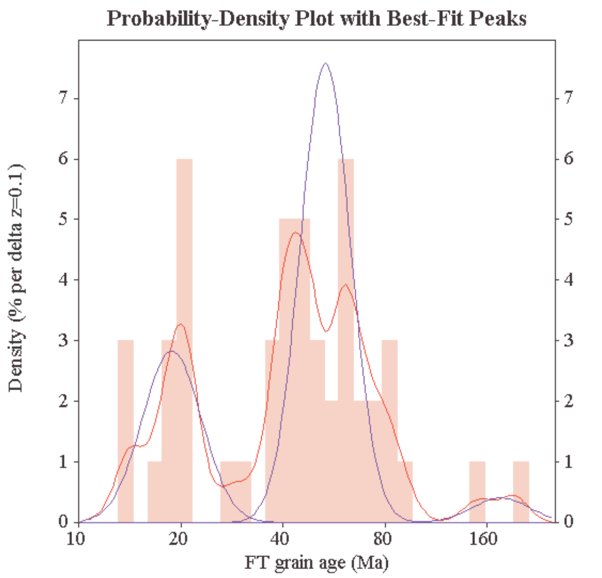


Figure 2. Probability density plot (red line) with best-fit peaks plotted using blue lines for the Mount Tom FT zircon sample. The histogram in the background is scaled to the same density as the density plot.

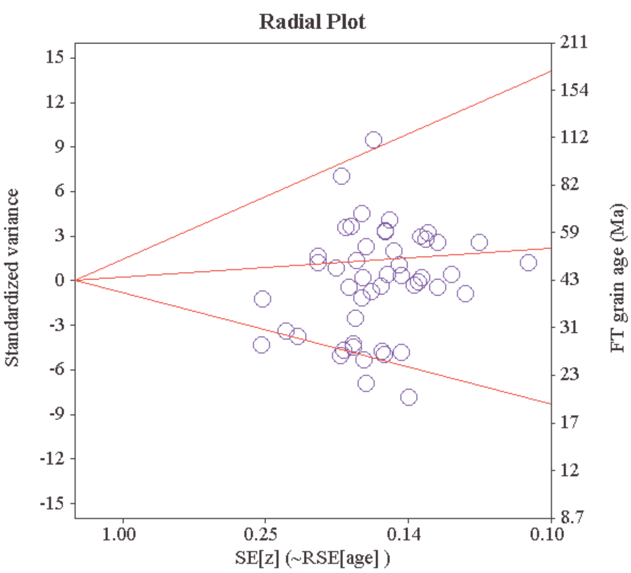


Figure 3. Radial plot for the Mount Tom FT zircon sample.

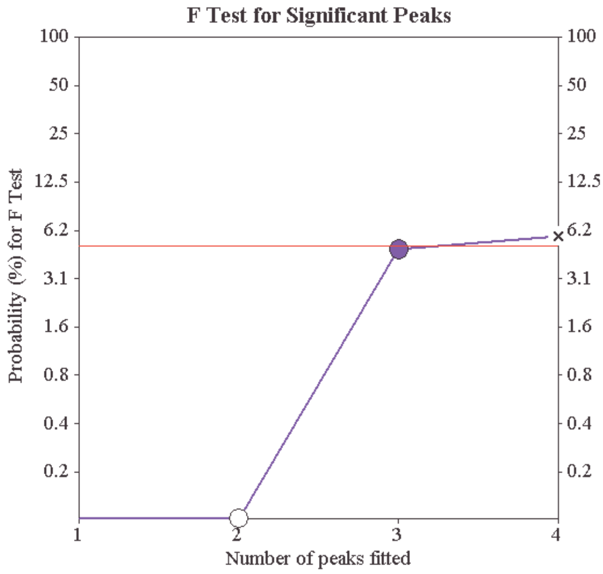


Figure 4. F test for Mount Tom zircon FT sample.

The P(*F*) plot is useful as a summary of the search, the details of which can be found in the Log File, available in the View menu. The peak search determined that the 3 peak solution was optimal, but note that the 4 peak solution failed by only a faction of a percent, with P(*F*) = 5.7%. Adding additional peaks manually indicates that the 5 peak solution has P(*F*) = 100%. Thus, we can say with confidence that the number of significant peaks is definitely more than 2 and less than 5. Note that this ambiguous result is unusual. More commonly, we find that P(*F*) rises rapidly across the 5% threshold.

The Print option in the File menu will send a full report of grain ages, best-fit solution and plots to a designated printer. The Save option in the File menu allows the user to save plot files, which can be imported into a graphics program (e.g., Excel, SigmaPlot) to prepare formal plots for publication. Plot files are available for probability density plots, radial plots, and P(*F*) plots. Data file can be saved as well, to account for when the file is modified in the program, due to removal of grain ages or merging multiple data files.

In closing, I note that the program presently lacks a Help file. I am hoping to have this available within the next couple of months. The program should be fairly intuitive for the average user.

Acknowledgment

This work has been supported by NSF grant OPP-9911925 to Brandon. Igor Boreyko of the Institute of the Lithosphere of Marginal Seas (Russian Academy of Sciences, Moscow) did the conversion into Visual Basic, under the guidance of Mark Brandon and Alex Soloviev. I thank Matthias Bernet, John Garver, Richard Stewart, and Massimiliano Zattin for help with testing the program.

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BACK TO BASICS?

RAYMOND C. JONCKHEERE[1] AND LEWIS T. CHADDERTON[2]

[1] Technical University and Mining Academy Freiberg, Bernhard von Cottastraße 2, Freiberg, Germany.
[2] Atomic and Molecular Physics Laboratories, Research School for Physics and Engineering, Institute for Advanced Studies, Australian National University, Canberra, Australia.

There are significant milestones in the development of fission-track dating and apatite temperature-time path modelling. Selection of apatite, track length measurements, use of confined tracks, application of external detectors, adoption of the -calibration, and the recognition of chemical composition effects are some of them. But the development of a practical algorithm for calculating thermal histories in the late eighties was probably the most significant breakthrough for apatite fission-track modelling. This was made possible by the use of empirical equations to describe isothermal annealing, and by adoption of the principle of 'equivalent time', permitting the big step to be made from constant to variable temperatures, and application of the corresponding annealing equations to 'real' geological situations. Never-theless a fundamental contradiction remains! Abandoning the search for a deeper understanding of track registration and recovery physics, in favour of empirical annealing equations, implied that we simply supposed a fission track, in our zeroth-order model, to be a complex and unspecified aggregate of unknown crystal defects. This *de facto* recognition of our inadequate understanding of the behaviour of a complex atomic physical system at the time was perfectly reasonable. The central principle of equivalent time, on the other hand, is derived from the 'independent pathway' hypothesis, which states that a fission track has no memory or identity apart from its etchable length. However different their histories, two tracks of the same length will show identical behaviour under the same conditions[1]. The 'independent pathway' hypothesis is as wide ranging in its implications[2] as it is beautiful in its simplicity[3]. But it does claim a fundamental understanding of fission tracks that is difficult to reconcile with an empirical approach[4]. And it must be argued in physics that no two *latent* tracks could possibly be identical, since the true compound ranges and the 'straggling' of fragments differ fundamentally due to the natural spread in both mass, energy and charge in fundamental binary fission.

Subsequent developments in apatite temperature-time path modelling have been characterised by the search for a better understanding of anisotropic and compositional effects, and the development of more efficient algorithms. This has, however, taken place within the framework of a self-contained empirical system disconnected from related fields. The result is a concept suspended somewhere between physics and geology, but lacking a bridgehead at either end. At the interface with physics, there is little more than a consensus that fission tracks are particle tracks produced by the fragments set free by nuclear fission of uranium. Indeed many physicists are even unaware that the geological etched fission track consists of two tracks – due to light and heavy fragments – and is therefore a sum of two etched 'ranges', each with an intrinsic deficit ('etched' as opposed to 'latent')[5]. At the interface with geology, there is a noticeable lack of resonance between fission-track annealing results and those obtained

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1 This formulaton is certainly not entirely supported by the experimental evidence. But for modelling purposes it suffices that the principle of equivalent time applies to the mean length of a statistically sufficient 'single-length' population of tracks (defined as a population with a common age and thermal history). A closer look at the principle of equivalent time in the context of general statistical validity would clearly be worthwhile.

2 In its less than rigorous formulation, the 'independent pathway' hypothesis can be interpreted to imply the identity of fossil and induced tracks of the same mean length. Herein lies the justification for applying annealing equations derived from experiments on induced tracks to the annealing of fossil tracks on a geological timescale.

3 Fission track annealing in general is described by: dl/dt = F(l, T( )), with l = length, t = time and 0 < < t (t=0 corresponding to a point in time before the onset of effective track accumulation), whereas fission-track annealing with equivalent time is simply described by: dl/dt = F(l, T(t)).

4 There is indeed experimental support for the principle of equivalent time within a limited range of lab annealing conditions but in our view this is not suffcient to warrant its applacation to annealing on a geological timescale.

5 A physicist's track is just that – one fragment – one trajectory – one track.

using independent, classical methods. This is sometimes interpreted as proof of the superior power of modern physical methods. We find some irony in this, because as the instances of unsuspected and uncorroborated kilometer-scale uplift in diverse tectonic settings worldwide accumulate, the gap between fission-track and classical geology widens, confusion increases and - let's face it - our confidence is the casualty!

It is futile to try to capture the moral high ground by criticising a system that others have struggled to construct. It is also too simple to wave the banner of interdisciplinary research in support of efforts to re-connect fission-track modelling with track physics and classical geology. The fact is that it is hardly likely that a new theoretical basis for fission-track modelling will be (re)constructed *ab initio* in the short term. However, a better understanding of the formation, structure and properties of fission fragment (and energetic heavy ion) tracks generally will *at least* set qualitative limits to the interpretation of our data, and could well lead us to those atomic scale processes which produce observed track changes over geological periods of time. It is also a fact that, although temperature-time path modelling has on occasion produced results that are not supported, or even in conflict with the independent geological evidence, this has not until now led us to question the principles of the method. Perhaps this is because contradictions are difficult to resolve. And absence of evidence for an event is never formal acceptable evidence against it. It is also much simpler to reconcile different geological interpretations than to question the physical method. But the geological evidence *does* itself set limits to the interpretation of our fission-track results.

We briefly discuss some aspects of apatite fission-track modelling which lie ill-at-ease with us. We ask questions and, where we can, we try to point a way.

Spikes

The ion explosion spike has long been the favoured geological track formation model. Of course we have been aware of the thermal spike, the thermalised ion explosion spike, core plasma, Orsay and CBK models – but have considered them less successful overall. Those who have taken an interest, will have accepted the correlation with $[dI/dx]_c$ and the distinction between insulators and conductors as arguments in favour of the ion explosion spike. Other explanations and the later demonstration of track registration in metallic glasses and metals, and non-registration in some insulators, have received less attention. The subject has grown complex, and we lost interest altogether when we opted for an independent empirical approach. The general feeling - who cares? - was understandable. If the geological community had waited for consensus about what a fission track is and how it is formed, there would be no apatite T(t)-path modelling today. But we *have* created a habit. The only model presented in fission-track texts is the ion explosion spike with, at most, a mumbled proviso leaving the distinct impression that it is more intended to cover the author against all eventualities than anything else. In the face of that, how many of us know whether the ion explosion spike is still considered a probable track formation mechanism by specialists?

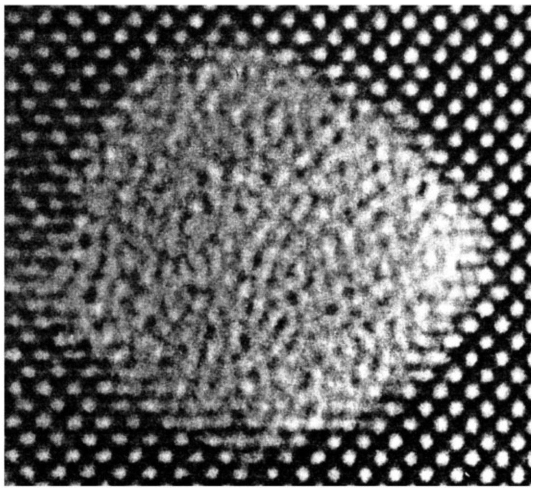

Figure 1. HRTEM micrograph of the cross-section of a 14 MeV/nucleon Pb-ion track in zircon (from: Bursill and Braunshausen 1991)

The ion explosion spike (like the spherical displacement spike in ion implantation) predicts a cylindrically depleted track core, surrounded by a region rich in point defects and a gradual transition from one to the other (like the depleted zone in a displacement spike (Chadderton 1965)). Assuming for a moment that the beautiful TEM cross-section of a 14 MeV/nucleon Pb-ion track in zircon (Bursill and Braunshausen 1991; Figure 1) is representative of a fission track, then we have an amorphous track core, surrounded by virtually intact lattice and a sharp boundary between the two, which is moreover more parallel to low-index planes than one could expect it to be. The Pb-ion track in zircon is, in this, as unlike an ion explosion spike track as a track can be. On the other hand, the core boundaries are reminiscent of the flat interfaces that develop between different phases in crystal growth, melting, dissolution, and, more familiar, in etching. Do we then accept, without further question, that here is a clear phase transition demarking a track, and arbitrarily extend that model to other minerals?

The point is that we do not know but that we could know if we cared enough about the physics of fission tracks. But does it matter? For many of us still, it is unimportant which is the real track formation mechanism. One hundred times the core diameter has been etched out before we even see a track under our optical microscopes. The opened channels we count and measure and the atomic scale physical structures that are latent fission tracks are, to all intents and purposes, different beasts. But for most of its life a fission track *is* the physical object. It is the latent track beast that responds to temperature, pressure, stress and how it does respond depends on what it is. The traditional view of annealing has been of a depleted cylinder being 'replenished' by the surrounding interstitial atoms moving back towards the core, over distances of several unit cells, through a more or less intact lattice. An amorphous thermal spike core, on the other hand, can be repaired by outward migration of the defects through a progressively less damaged matrix. Formation mechanism, track structure and annealing are closely related.

Track physics has also had its bumpy ride. Nevertheless the last decade has evidently seen *significant advances* in fundamentally understanding (largely due to the availability of GeV heavy ions, MeV cluster ions, artificial fragments etc.) the very nature of the primary beast (latent track). Instead of comparing this spike with that, that spike with this, it is now abundantly clear, and is rapidly becoming widely recognized, that we must to different degrees incorporate aspects of all the different spikes (thermal, Coulomb explosion, plasma, and so on) into one 'compound spike'. Such a simple step to reality! All those physical processes – direct heating due to Z_{eff}, charging, repulsion and then re-attraction of -electrons, added heating (and still more Z_{eff}) due to a transient plasma, formation of a protective (and neutralizing) electron sheath etc. – fused into one. Instead of comparing we now combine them. And it is suggested that we combine them according to simple rules associated first with the properties of the charged projectile (well understood for fission fragments) which do not change, and secondly (and much more importantly) with the unique atomistic properties of the target, especially defects. In this context we are obliged to note that all purely thermal spikes rely only on macroscopic averaged properties of heat conduction. Surface fission tracks are anomalous in every sense. The Coulomb explosion spike dominates everything, electrons and positive ions can escape into 'vacuum', there is loss of momentum, and therefore matter in electronic 'sputtering'.

But in annealing – in a general sense the inverse of registration – many different repair mechanisms are conceivable, that are not the reverse of those involved in track formation: recrystallisation of the original or precipitation of different, perhaps intermediate phases, randomly oriented in the core, and/or partially or completely epitaxial with sharp track walls. We have until now perhaps also tacitly assumed that one annealing mechanism, one track structure (and by implication one formation mechanism) will explain the different thermal stabilities of tracks in different minerals, their anisotropy and dependence on chemical composition, and unetchable gaps, better than any other. How much further would we be if the known track properties in apatite were anchored in a firm physical description for fragment stopping? And how much further still if we were to recall that phase changes are in practice brought about by the catalytic action of intrinsic point defects - defects unique to each specific mineral? In this scenario the simple phase change in zircon in Figure 1 becomes the exception, rather than the rule. Apatite is similarly "well-behaved".

Take your pick

There is perhaps one principle more engrained in geological fission track theory than the ion explosion spike - so fundamental that it doesn't even have a name. We call it the 'line-segment model', which states that a fission track of a given etchable length can be equated with a mathematical line segment of the same length. It not only explains the relationship between volumetric and surface track densities, but also dictates the anticipated linear relationship between track length and track density. There has been experimental confirmation, for a limited range of lengths, from annealing experiments on induced tracks, but does it also apply to fossil tracks? Well - yes and no! Gleadow and Duddy (1981) observed a different trend, characterised by a certain amount of length reduction without reduction of track density. Green

(1988) later re-normalised the track densities, and re-established the linear relationship. But this re-normalisation is based on the premise that there exists a linear relationship. If we were to start from a different premise, say that there is a certain amount of length reduction without a decrease of track density, then the re-normalisation of the track densities would be invalid, and the resulting, unaltered relationship would also confirm our premise. On formal grounds, the re-normalisation doesn't prove, nor does Green (1988) claim, that one is right and the other is wrong. But it does produce the same relationship for fossil as for the induced tracks, which is, moreover, in agreement with the line-segment model. It didn't have to be so, and the result is therefore inconclusive but not trivial. That may be, but here is a mathematical relationship, confirmed by experiments on induced tracks, and at least not in conflict with the data on fossil tracks. Nevertheless, we argue that there are two options. One, the line-segment model is correct and fossil and induced tracks anneal in the same manner. Two, fossil and induced tracks do not anneal in the same manner, which comes dangerously close to questioning the principle of equivalent time, and the line-segment model does not apply to fossil tracks.

But why make difficulties, and on this point? The usual commonplaces can make it sound like a noble enterprise, but the truth is that there is much to be gained. If the relationship proposed by Gleadow and Duddy (1981) is right, we do not have to invoke unidentified systematic errors, which happen to be the same magnitude as the length reduction, to explain why the independent fission track ages of age standards, and other samples of known age, agree with their reference ages, without length correction. This also applies to the Otway apatites: a length correction would make them ten percent older than the titanites. Even invoking unknown, or known, systematic effects, it still takes some explaining how the apatite ages can be older than the titanite ages. But Otway is not our immediate concern. If near-ambient temperature annealing of fossil tracks, over geological periods of time, is indeed not the same as laboratory annealing of induced tracks, then the borehole data tell us that a significant length reduction can take place at low temperatures. This is in fact not in conflict with a track recovery mechanism based on the physics of point defect activated diffusion - slow but relentless over time.

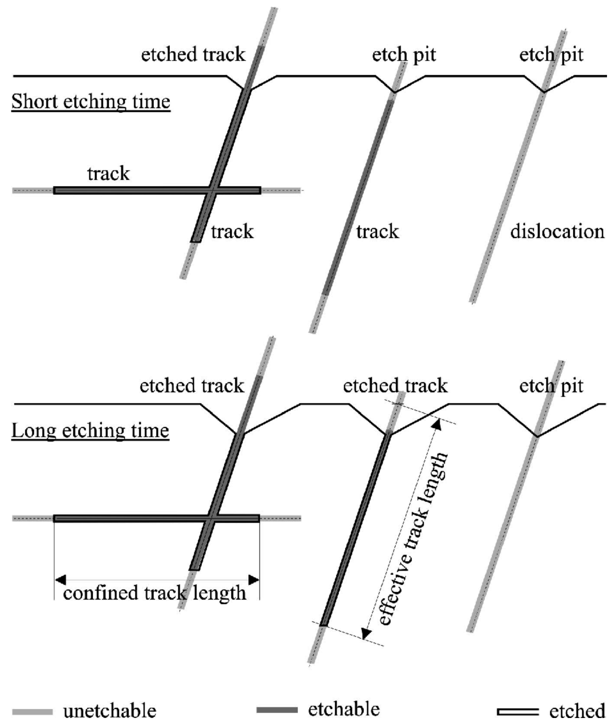

Figure 2. A hypothetical mechanism to account for the difference between the mean confined track length (l_{con}) and the density-effective mean length of surface-intersecting tracks (l_{eff}), proposed to explain the fact that $l_{eff} > l_{con}$ according to the calculated values for Durango apatite (spontaneous tracks: l_{eff} = 16.2 ± 0.3 m; induced tracks: l_{eff} = 16.9 ± 0.4 m; Jonckheere 1995).

Yet it is an unwelcome complication, and we would have to rethink the extrapolation of the laboratory-based annealing equations, though it would rid us of the world-wide recent exhumation in one stroke. With that gone, our fission-track results would at least now and again be in agreement with the independent geological evidence.

If there is a non-linear relationship between track length and track density, the line-segment model must be flawed. Gleadow et al. (1983) have shown one way in which this could be so. A second is illustrated in Figure 2. It is within the bounds of the accepted image of tracks. A track consists of a central etchable section, and unetchable sections at either end, where the damage is below the etching threshold[6]. If this damage is continuous

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[6] Here there are two physicist's tracks (one geologist's) with common origin, but only two ends. The physics argument would be contrary to the view that the unetched segments are of identical length due to an etch sensitivity arising out of (a) detailed track structure due to real differences in fundamental particle range and straggling, and (b) subsequent differences in the spatial density of point defects. These differences may be indistinguishable if there is initially a sharp crystal/amorphous interface, and certainly if a statistical average is taken over many measured lengths.

and sufficient to allow the formation of an etch pit, then the effective length is not the same as the etchable length. That ‘unetchable’ damage can nevertheless produce an etch pit is due to the fact that the formation of an etch pit is a result of the defect properties of the surface, not of the track (Jonckheere and Van den haute 1996). Even a dislocation, the minimal form of linear damage, produces an etch pit. Both mechanisms run into difficulties, and we support neither of them, but they do show that the line-segment model is not self-evident. As with the principle of equivalent time, we should know much more about track revelation before making such a claim.

Conclusion

The separation of fission-track modelling from physics has allowed us to construct a working geological tool, without much interference from physicists. It has remained comparatively simple and has not been seriously contested. It has remained in the hands of geologists and it has been successful. But how theoretically sound is it? We don’t know because we are disconnected from physics. How well does it work? There isn’t that much accord with the independent geological evidence to claim that the method has proved itself. What can we do? We can give it a nudge and see how it stands up; this is what we have attempted here. But we should consider going back to basics. The superstructure is fine but the foundations may not be solid. Reasearch on such fundamental questions must be interdisciplinary but not expensive: it is therefore not impossible to sell.

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MAKING TRACKS IN THE MONASTERY

A reflection on the ***European Workshop on Fission-Track Analysis*** held in Cádiz, Spain, June 2002.

Tony Hurford <t.hurford@ucl.ac.uk>

Dept. of Geological Science, University College London,
Gower Street, London WC1E 6BT, UK.

The former Cappuccino Monasterio San Miguel (built in 1733 and now a hotel) was the venue for the European ***International Workshop on Fission-Track Analysis: Theory and Applications*** between 3rd and 7th June 2002. Situated in the town of El Puerto de Santa Maria on the Bay of Cádiz, Andalucia, Spain, this workshop was organised by Luis Barbero (University of Cádiz) and was the successor to three meetings, initially Italian and subsequently more widely European, started by Gianni Zuffa in Bologna. The Cádiz workshop drew wider participation with colleagues from Australia and the United States joining the Eurozone (plus British, Swiss and Norwegian) trackers. This expansion was, perhaps, appropriate given the location: El Puerto de Santa Maria was the starting point for Christopher Columbus's epic voyage to the New World.

The themes of the Workshop centred around methods and applications, with keynote papers by Ulrich Glasmacher reconsidering formation and cooling ages from alpha-recoil tracks, and your present correspondent who endeavoured to review where we are with the FT method. Feeling a bit like an aged seer giving the state-of-the-nation talk, I commented (yes, yet again) on the lack of consensus and comparability in considering the compositional effects on annealing, reproducibility and standardisation of length measurement, and modelling of track-length data. Integration of FT and U-Th/He chronometry was noted as an exciting reality for constraining lower temperatures and this was ably demonstrated subsequently with papers on Swedish Precambrian basement (Charlotte Cederbom et al.), the Great Escarpment Development, SE Australia (Christine Persano et al.), the Aegean islands (Stephanie Brichau et al.), the Canadian Shield (Matevz Lorencak et al.) amongst others. It seems the application of U-Th/He apatite chronology is truly underway ..... what, I wonder, will the pitfalls be - if any? Combining the philosophy for interpreting FT data with the analytical skills of the noble gas experts may mean that potential problems will be averted. Let's hope so, because the helium method working in tandem with FT chronometry promises us much.

In the Alpine Chain session, Maria Laura Balestrieri and Max Zattin asked whether we need something more than AFT data to understand northern Apennine exhumation, citing new ZFT, AHe and ZHe data to define a more detailed pattern. Barbara Ventura and colleagues reported detail of post-Variscan exhumation of the Erzgebirge metamorphics and granites from borehole samples. Moving to the Andes, I was amazed at the number of people working there - just as well it's a big orogen! When teaching the Andes in undergraduate Global Tectonics classes I was always disappointed at the apparent dearth of detailed chronology: these research efforts can only serve to ameliorate that situation. A cornucopia of papers was presented by Alberto Adriasola Munoz (Southern Chilean Andes), Harold Ege et al. (Central Andean fold-thrust belt, S Bolivia), Kirsten Gräfe et al. (Southern Chile), Martin Wipf et al. (south central Peru), Richards Spikings et al. (Ecuador - FT and ^{40}Ar-^{39}Ar), Sarah Shoemaker (SW Mexico) and Stuart Thomson (Patagonian Andes).

The question ***"just how stable is stable?"*** (originally Rod Brown's I think) was revisited in southern Canada (Matevz Lorencak and colleagues), at the Laurentian margin (Ulrich Glasmacher et al.), in the East African/Antarctic orogen (by Joachim Jacobs et al.) and in Namibia (Matthias Raab and Rod Brown). In extensional settings thermochronology in the nearby Betics was discussed by our host Luis Barbero and colleagues, in the Basin and Range Province (Tim Carter et al.), Central Madagascar (B. Emmel et al.), on the East Greenland margin N of 72°N (Kirsten Hansen et al.), along the Ghana transform margin (Frank Lisker), and in SW Bulgaria (Alexandre Kounov).

Ever since our simplistic treatment of FT data from detrital grains (***Geol Mag***, **121**, 269, 1984) I've always been fascinated by the use of FT to identify detrital components and to determine provenance.

Istvan Dunkl and Balazs Székely discussed a more sophisticated analytical approach together with a very attractive on-screen visualisation of the procedure. Alexie Soloviev and John Garver presented Western Kamchatka results considering the possibility of its being a northern continuation of the Japanese Shimanto belt accretionary complex.

I've mentioned just some of the directions that research and the resulting presentations seem to be heading. Apologies to those whose names are not explicitly mentioned - I've not attempted to provide an all-inclusive listing of all presentations. Luis Barbero and Ferran Colombo provided an excellent volume of abstracts attractively produced as ***Geotemas*** Volume 4 by the Sociedad Geológica de Espana (ISSN 1576-5172). Luis may have spare copies for sale to those interested.

So what, Mr. Editor, were my lasting impressions of Cádiz? A change to the north European timetable for lunch and dinner to accommodate the Mediterranean siesta and lifestyle? Perhaps the visit to Terry's* Bodegas to see the making of sherry and brandy, and to taste the end-products? (*that's **not** Di Seward's husband's private booze supplier). Surely Thursday's magical mystery tour (with uncooperative coach drivers) to find the elusive Ronda peridotite definitely rated highly on entertainment value, affording some excellent opportunities for relaxed discussion of ideas and projects, if not for field geology!

We also discussed EFTAN (at some length! Ed.) - the rather moribund European Fission-Track Network, started some 10 years ago to facilitate cooperation between workers throughout 14+ European countries. Discussion about the future of the network revealed a series of specifically defined objectives: to facilitate the exchange of intellectual ideas, share common problems and seek solutions; to encourage human mobility (especially of young scientists) between research teams; and to advertise research funding opportunities, particularly between research groups. A new committee was elected (Balestrieri, Barbarand, Barbero, Carter, Glasmacher, Hurford) to take forward the stated aims. Further details can be found shortly at; http://www.eftan.ucl.ac.uk

There were some landmarks and details which I felt were significant:

- the challenge to our use of the x^2 test for datasets of 20-30 crystals (Balazs Székely)
- the widespread use of Rich Ketcham's AFT-Solve program for data interpretation
- the resurgence of titanite as an FT chronometer (Joachim Jacobs)
- the reconsideration of the similarity (or not) of spontaneous and induced track annealing (Jocelyn Barbarand)
- the continuing uncertainty about how to use the dependency of apatite FT annealing on composition in interpreting routine sample data. Barry Kohn described some interesting results from the Stillwater layered complex, where chlor-rich apatite resistance to FT annealing is not paralleled in He retention which remains similar irrespective of anion content.

But for me perhaps the most important thing was the enthusiasm for our subject which shone out in conversation and in the very high standard of oral and poster presentation, especially by the many research students in attendance. Also the open-forum discussions after each thematic session were very stimulating, with many people asking questions and offering comments in a constructive spirit and an easy and relaxed atmosphere. Well done to Luis Barbero and colleagues for the organisation - and to the all participants and contributors for their lively, instructional and challenging contributions, both formal and informal.

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- University of California, Santa Barbara, California (1992)
- ARCO Exploration and Production Technology, Plano, Texas (1992). Moved to University of Minnesota, Minneapolis, Minnesota, in 1999.
- Universität Bremen, Bremen, Germany (1993)
- E.T.H., Zürich, Switzerland (1993*)
- Kent State University, Kent, Ohio (1993)
- University of Wyoming, Laramie, Wyoming (1993)
- University of Arizona, Tucson, Arizona (1993). 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)
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- Universität Salzburg, Salzburg, Austria (1996)
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- E.T.H., Zürich, Switzerland (second system, 1996*)
- Geologisk Centralinstitut, Copenhagen, Denmark (1996*)
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- 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)
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- Universidad de Cádiz, Cádiz, Spain (1999)
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- 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)

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.

CARLSON'S LAW : A FORMAL COMPARATIVE STUDY WITH RESPECT TO LASLETT'S LAW

A. RADID *, J.C. MIELLOU*, A. CHAMBAUDET**

*Laboratoire de Mathématiques et Applications – Unité Mixte de Recherche 6632 C.N.R.S.,
**Laboratoire de Microanalyses Nucléaires Equipe d'Accueil 473 – LRC– CEA MO 7,
Faculté des Sciences et des Techniques, Université de Franche-Comté,
16 route de Gray, 25030 Besançon Cedex, France

INTRODUCTION

Here, we develop the results presented in Radid et al. (2002) for extending Laslett's law to Carlson's law, and give a new formulation of Carlson's law and compare it to a corresponding Laslett's situation.

First, we derive a Bertagnolli-kind of expression from the usual Carlson's law formulation. This gives rise to a Cauchy's problem for a first order differential equation, which is very similar to the equation derived from Laslett's law in Igli et al. (1999). We also recall that for thermal histories with a constant temperature, Carlson's law admits a formulation similar to a previous annealing Laslett's mathematical expression. This provides a homogeneous approach to the numerical methods applied to both these laws.

COMPARISON OF CARLSON'S AND LASLETT'S LAWS FOR TEMPERATURE VARIABILITY

Let us consider Carlson's law, which represents the mean length reduction of a population of fission tracks by:

$$l(t) = L - A\left(\frac{k}{h}\right)^n \left[\int_s^t \theta(\tau)\exp\left(\frac{-Q}{R\theta(\tau)}\right)d\tau\right]^n \qquad (1)$$

The function $t \to l(t)$ represents the mean length of a population of tracks at time t that were born at time s after an annealing thermal history, expressed by the function $\tau \to \theta(\tau) : \tau \in [s,t]$.

L is the initial mean length of the tracks, h the Planck's constant, k the Boltzman's constant, θ the absolute temperature, $[s,t]$ the annealing time interval, Q the activation energy of the atomic motions leading to defect cancellations, R the universal constant of any gas, n a strictly positive real number that is smaller than one (which describes the initial distribution of the radial defects) and A an empirical constant of the shortening of the axial length.

Let us note:

$$r(t) = \frac{l(t)}{L} \qquad (2)$$

We obtain:

$$r(t) = 1 - \frac{A}{L}\left(\frac{k}{h}\right)^n \left[\int_s^t \theta(\tau)\exp\left(\frac{-Q}{R\theta(\tau)}\right)d\tau\right]^n \qquad (3)$$

Where r represents the mean length shortening rate of the considered population of fission tracks, which satisfies:

$$\left(1 - r(t)\right)^{\frac{1}{n}} = \left(\frac{A}{L}\right)^{\frac{1}{n}} \frac{k}{h}\left[\int_s^t \theta(\tau)\exp\left(\frac{-Q}{R\theta(\tau)}\right)d\tau\right] \qquad (4)$$

Let us derive the two sides of the above relation with respect to time variable t. We obtain:

$$\frac{-1}{n}\left(1 - r(t)\right)^{\frac{1}{n}-1}\frac{dr}{dt} = \left(\frac{A}{L}\right)^{\frac{1}{n}} \frac{k}{h}\theta(\tau)\exp\left(\frac{-Q}{R\theta(\tau)}\right)$$

That is to say:

$$\begin{cases} \dfrac{dr}{dt} = -n\left(1 - r(t)\right)^{1-\frac{1}{n}} \left(\dfrac{A}{L}\right)^{\frac{1}{n}} \dfrac{k}{h}\theta(\tau)\exp\left(\dfrac{-Q}{R\theta(\tau)}\right) \\ r(0) = 1 \end{cases} \qquad (5)$$

Therefore, Carlson's Law reads:

$$\begin{cases} \dfrac{dr}{dt} = -r\alpha_0\big(r,\theta(t)\big)\exp\left(\dfrac{-Q}{R\theta(t)}\right) \\ \alpha_0\big(r,\theta(t)\big) = \dfrac{k}{h}\, n\left(\dfrac{A}{L}\right)^{\frac{1}{n}} \dfrac{1}{r(t)}\big(1-r(t)\big)^{1-\frac{1}{n}}\theta(t) \\ r(0) = 1 \end{cases} \quad (6)$$

This initial value problem is very similar to the one associated to Laslett's law, which reads:

$$\begin{cases} \dfrac{dr}{dt} = -r\alpha_0\big(r,\theta(t)\big)\exp\left(\dfrac{-B\big(r(t)\big)}{C\theta(t)}\right) \\ \alpha_0\big(r,\theta(t)\big) = C\exp(-A)\theta(t)\dfrac{1}{\big(r(t)\big)^b}\left(1-r(t)^b/b\right)^{1-a} \\ r(0) = 1 \end{cases} \quad (7)$$

where the constants a, b, must satisfy $a = \dfrac{1}{n},\ b = 1$ in order to better fit (6).

THE EXPRESSION OF CARLSON'S LAW UNDER A CONSTANT TEMPERATURE

If the temperature is constant, then the equation (1) becomes:

$$l(t) = L - A\left(\frac{k}{h}\right)^n \left[\int_0^t \theta \exp\left(\frac{-Q}{R\theta}\right) d\tau\right]^n \quad (8)$$

Which gives rise to:

$$\big(1 - r(t)\big)^{\frac{1}{n}} = \left(\frac{A}{L}\right)^{\frac{1}{n}} \frac{k}{h}\, t\theta \exp\left(\frac{-Q}{R\theta}\right)$$

Conversely, this implies that:

$$\ln(t) = \frac{1}{n}\big[\ln(1-r) + C\big] + \frac{Q}{R}\frac{1}{\theta}\ln(\theta) \quad (9)$$

with;

$$C = -\ln\left(\frac{A}{L}\left(\frac{k}{h}\right)^n\right) \quad (10)$$

It is worthwhile to note that Carlson (1990) p. 1136, established a comparison between expression (9) of Carlson's law and a previous annealing law written by Laslett for isothermal histories.

CONCLUSION

This comparison makes it possible to extend to Carlson's law the study performed in Radid et al. (2002) with respect to the approximation of the general thermal histories by using piecewise constant functions. The result is a new perspective for studying numerical methods for both Carlson's and Laslett's laws (this is in reference to our forthcoming paper (2002) entitled, "Some Comparative Numerical Experiments Concerning Two Standard Fission Track Thermal Annealing Laws").

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Reactor Watch

This section is concerned with reporting the lastest developments concerning reactor facilities If you hear of any new developments concerning reactors or are aware of reactors that may be suitable please contact the Editor of On Track to ensure the latest developments can be reported back to the Fission Track community.

Frank Lisker reports that the new German neutron source in Garching (FRM II) is expected to start working early next year with the possibility of providing irradiation services from mid 2003. This will be a 20 MW reactor with two rabbit loading systems. The facility will have a maximum neutron flux of 8×10^{14} n/cm^2s^{-1} with fast and epithermal components expected to be significantly <1%. Details about this reactor can be found on the web at

http://www.frm2.tu-muenchen.de/frm2/index_en.html

Frank also pointed out that there is another German neutron irradiation facility at the GKSS Forschungszentrum in Geesthacht which has a reasonably high flux (8×10^{13} n/cm^2s^{-1}) but unfortunately is not well thermalised with fast and epithermal components of 2.5% and 2.3% respectively.

Barry Kohn reports that excavations have begun at Lucas Heights for the new reactor intended to replace the ageing Hifar facility. This is good news. The bad news is that a fault was encountered during the excavations and the media have got hold of this. Consequently environmentalists have new ammunition with which to voice their opposition. The reactor people are now quite 'anxious' to have the history of this fault assessed. It has been examined and trenched by a group of geo-seismic people from New Zealand, where they have plenty of experience, at least with young tectonics. But the question that now needs clarification regards the 'timing' of fault movement. Investigations will probably require some AFT and/or (U-Th)/He work that will help to ensure the timely completion of the new reactor (or maybe not). Stay tuned!

Meanwhile a consultation is planned between the Geoscience community and the reactor people to determine specifications that best suite their needs. Although the reactor is already basically designed input from the geoscience community may influence some relatively minor engineering changes that will benefit a wider community of research based users.

John Garver mentions that the Oregon facility is now so heavily used by trackers that in order to cope with demand it is going to have to start using another position.

REACTOR INFORMATION CHARACTERISTICS	LUCAS HEIGHTS HIFAR X7 position	OREGON TRIGA Mark-II thermal column [inner face]	THETIS positions 6,7,8,15,16
Thermal fluence:	3 - 5.7 x 10^{12}	1.0 x 10^{11}	1.0 - 3.0 x 10^{11}
Epithermal fluence:		5.0 x 10^{08} [c]	0.6 - 4.3 x 10^{09}
Fast fluence:		5.0 x 10^{08}	0.8 - 5.0 x 10^{09}
Thermal /fast:		145 [b]	60 - 120
Thermal/epithermal:		200	70 - 160
Cd ratio for Au:	~125, ~98	14	
Cd ratio for Co:			
Radial gradient:		3%/cm	6% / cm
Axial gradient:	~ 5 %/cm		1% / cm
Foreigners ?	Yes	Yes	Yes
Price [nationals]	A$350 /can [?]	$ 200 (zr)	175 Euro /7h
Price [foreigners]	A$350 /can plus shipping	$ 400 (ap) plus shipping	175 Euro /7h incl. ship. [g]
Packing:	Ti cans [a] [supplied]	polyethylene	
Can size [mm] : [diam. x length]	20 x 50 (total glass in each can must not excede 15 grams)	23 x 90 price for 2 cans	19 x 70
Website	www.ainse.edu.au/		
E-mail Contact:	David.hurwood@ansto.gov.au		

REACTOR INFORMATION CHARACTERISTICS	VIENNA TRIGA Mark-II	PAVIA TRIGA Mark-II Lazy Susan Rot. spec. rack	PAVIA TRIGA Mark-II Thermal Column	KYOTO KUR
Thermal fluence:	1.0 x 10^{13}	1.0 x 10^{12}	3.8 x 10^{09}	4.0 x 10^{11}
Epithermal fluence:	[d]			6.0 x 10^{08}
Fast fluence:		9.0 10^{11}		8.0 x 10^{07}
Thermal /fast:		1.1		5000
Thermal/epithermal:				700
Cd ratio for Au:		6.5	31	~200 [f]
Cd ratio for Co:		48		
Radial gradient:				
Axial gradient:				
Foreigners ?	Yes	Yes	Yes [e]	No
Price [nationals]	Free	On demand		
Price [foreigners]	Variable, ± $80 /can	On demand		No commercial use
Packing:	plast. up to 80 h oth.: Al+quartz	plastic, Al can, glass, etc.	plastic, Al can, glass, etc.	plastic capsule
Can size [mm] : [diam. x length]	35 x 100	22.5 x 50	22.5 x 50	
Website				
E-mail Contact:				

TABLE 1: comparison of reactor parameters. Notes: [a] Mass of sodium containing glass must not exceed 15 g per can; total mass of can + contents must not exceed 55 g. Some users report problems with broken samples; [b] Extrapolated from 6" from face using 10%/cm gradient; [c] Measured 6" from face; [d] Epithermal neutron flux is high; induced Th-fission can be a problem; [e] thermal column is presently unavailable for FT-irradiations; [f] Cd-ratio is pers. com. [1988] Prof. M. Koyama to T. Tagami; [g] except by specialised transport.

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Fission-Track Papers

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

2000

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International Fission-Track Directory

This revised and extended International Fission-Track Directory is by no means complete or accurate. Although a number of people do not figure in the staff, e-mail or phone directories of the institutes under which they are mentioned, this has not been interpreted as a sign of non-existence, and they have for the moment been retained with their old affiliations. It would be much appreciated if you would let the editor know if your address has changed, or if people have joined or definitively left your lab, so that the directory can be updated.

Abbate, Ernesto
Dipartimento di Science della Terra
University of Florence
Via La Pira 4, 50121 Firenze, Italy
Phone: +39 55 275 7527
Fax: +39 55 218 628
E-mail: abbate@unifi.it
Web: steno.geo.unifi.it

Aizawa, Minoru
Department of Geology
Imperial College
Prince Consort Road, London SW7 2BP, UK
Phone: +44 171 594 6468
Fax: +44 171 594 6464
E-mail: m.aizawa@ic.ac.uk

Andriessen, Paul A.M.
Department of Isotope Geochemistry
Faculteit Aardwetenschappen
Vrije Universiteit Amsterdam
De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands
Phone: +31 20 4447340
Fax: +31 20 6462457
E-mail: andp@geo.vu.nl
Web: www.geo.vu.nl/~isotopen

Angelmaier, Petra
Institut für Geologie und Paläontologie
Eberhard Karls Universität Tübingen
Sigwartstrasse 10, D-72076 Tübingen, Germany
Phone: +49 7071 2975 240
Fax: +49 7071 5059
E-mail: petra.angelmaier@uni-tuebingen.de
Web: homepages.uni-tuebingen.de/petra.angelmaier

Armstrong, Phillip A.
Department of Geosciences
California State University
P.O. Box 6850 Fullerton, CA 92834-6850, USA
Phone: +1 714 278 3169
Phone: +1 714 278 7266
E-mail: parmstrong@fullerton.edu
Web: geology.fullerton.edu/index.htm

Arne, Dennis C.
Western Australian School of Mines
Curtin University of Technology
PMB22, Kalgoorlie WA 6430, Australia
Phone: +61 8 9088 6134
Fax: +61 8 9088 6140
E-mail: arned@wasm.curtin.edu.au
Web: www.wasm.curtin.edu.au/staff/Arne.html

Avé Lallemant, Hans G.
Department of Earth Science
Rice University
6100 Main St, Houston, TX 77005-1892, USA
Phone: +1 713 348 4880
Fax: +1 713 348 5214
E-mail: ave@rice.edu
Web: terra.rice.edu

Bal, K. D.
Fission Track Laboratory
Keshav Deva Malaviya Institute of Petroleum Exploration
Oil and Natural Gas Corporation
Dehradun, India
Web: www.ongcindia.com/r&d/oiis/kdmipe

Balcázar Garcia, Miguel
Departamento de Estudios del Ambiente
Instituto nacional de investigaciones Nucleares
Apartado Postal 18-1027,México, D.F. 11801, Mexico
E-mail: mbg@nuclear.inin.mx
Web: www.inin.mx

Baldwin, Suzanne
Heroy Geology Laboratory
Department of Earth Sciences
Syracuse University
Syracuse, New York 13244-1070, USA
Phone: +1 315 443 4920
Fax: +1 315 443 2619
E-mail: sbaldwin@syr.edu
Web: su-thermochronology.syr.edu

Balestrieri, Maria Laura
Dipartimento di Science della Terra
University of Florence
Via La Pira 4, 50121 Firenze, Italy
Phone: +39 55 275 7494
Fax: +39 55 218 628
E-mail: mlaura@geo.unifi.it
Web: steno.geo.unifi.it

Barbarand, Jocelyn
Jocelyn Barbarand
UMR OrsayTerre 8616
Université Paris-Sud
Bâtiment 504
91405 Orsay cedex, France
Tel: 00.33.1.69.15.48.68
Fax : 00.33.1.69.15.48.68
E-mail: barbaran@geol.u-psud.fr

Barbero González, Luis C.
Dipartimento Geologia
Facultad de Ciencias del Mar y Ambientales
Universidad de Cadiz
1150 Puerto Real, Cadiz, Spain
Phone: +34 956 470 864
Fax: +34 956 470 811
E-mail: luis.barbero@uca.es
Web: www2.uca.es/facultad/ciencias_mar

Batt, Geoffrey
Department of Geology
Royal Holloway
University of London
Egham Hill
Egham
Surrey TW20 OEX
Phone: +44 01784 443606
E-mail: g.batt@gl.rhul.ac.uk

Belton, Dave X.
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia
Phone: +61 3 8344 9669 /7675
Fax: +61 3 8344 7761
E-mail: d.belton@earthsci.unimelb.edu.au
Web: www.earthsci.unimelb.edu.au

Bergman, Steven C.
Department of Geological Sciences
Southern Methodist University
Dallas, Texas 75275-0395, USA
Phone: +1 214 768 1510
Fax: +1 214 768 2701
E-mail: scb@mail.smu.edu
Web: www.geology.smu.edu

Bernet, Matthias
Department of Geology and Geophysics
Yale University
210 Whitney Avenue, New Haven CT 6520, USA
Phone: +1 203 432 5686
Fax: +1 203 432-3134
E-mail: matthias.bernet@yale.edu
Web: www.geology.yale.edu/~mb324

Bigazzi, Giulio
Istituto di Geocronologia e Geochimica Isotopica
Consiglio Nazionale delle Ricerche
Area delle Ricerca di Pisa
Via G. Moruzzi, 1, 56124 Pisa, Italy
Phone: +39 50 315 2283
Fax: +39 50 315 2360
E-mail: g.bigazzi@iggi.pi.cnr.it, and iggi@iggi.pi.cnr.it
Web: www.area.pi.cnr.it/AREAEN/iggi.html

Blythe, Ann E.
Department of Earth Sciences
University of Southern California
Los Angeles, CA 90089-0740, USA
Phone: (213) 821-1094
Fax: (213) 740-8801
E-mail: blythe@earth.usc.edu

Boettcher, Stefan S.
Department of Geological Sciences
University of Texas at Austin
Austin, TX 78712, USA
Phone: +1 512 471 8547
Fax: +1 512 471 9425
E-mail: sboett@maestro.geo.utexas.edu
Web: www.geo.utexas.edu

Bojar, Ana-Voica
Insitut für Geologie und Paläontologie
Karl-Franzens Universität
Heinrichstraße 26, A-8010 Graz, Austria
Phone: +43 316 380 8727
Fax: +43 316 380 9871
E-mail: ana-voica.bojar@kfunigraz.ac.at
Web: www-ang.kfunigraz.ac.at/~bojar

Bondar, Julia
State Science Center of Environmental Radiogeochemistry
34 Palladin Avenue, 03142 Kiev, Ukraine
Fax: +380 44 451 02 36
E-mail: center@radgeo.freenet.kiev.ua

Bondarenko, Oleg
Radiation Protection Institute
53 Melnikova Street, Kiev 04050, Ukraine
Phone: +380 44 213 3502
Fax: +380 44 219 4900
E-mail: boa@rpi.kiev.ua

Boulyga, Sergei
Central Department for Analytical Chemistry
Research Centre Jülich
D-52425 Jülich Germany
Phone: +49 2461 613 291
Fax: +49 2461 612 560
E-mail: s.boulyga@fz-juelich.de

Boztug, Durmus
Jeoloji Mühendisli_i Bölümü
Mühendislik Fakültesi, Cumhuriyet Üniversitesi
58140 Sivas,Turkey
Phone: +90 346 219 1010
Fax: +90 346 219 1171
E-mail: boztug@cumhuriyet.edu.tr
Web: jeoloji.cumhuriyet.edu.tr

Brandon, Mark T.
Kline Geology Laboratory
Department of Geology and Geophysics
Yale University
P.O. Box 208109, 210 Whitney Avenue, New Haven, CT 06520-8109, USA
Phone: +1 203 432 3135
Fax: +1 203 432 3134
E-mail: mark.brandon@yale.edu
Web: www.geology.yale.edu/~brandon/

Brix, Manfred R.
Institut für Geologie, Mineralogie und Geophysik
Fakultät für Geowissenschaften
Ruhr-Universität Bochum
Postfach 102148, D-44721 Bochum, Germany
Phone: +49 2343 223 236
Fax: +49 2343 214 572
E-mail: manfred.r.brix@ruhr-uni-bochum.de
Web: www.ruhr-uni-bochum.de/hardrock/Mitarbeiter/brix.html

Brown, Roderick W.
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia
Phone: +61 3 8344 9868 /7675
Fax: +61 3 8344 7761
E-mail: rwbrown@unimelb.edu.au
Web: www.earthsci.unimelb.edu.au

Brunel, Maurice
ISTEEM GGP laboratory CC 058
Universite Montpellier II
1 Place E. Bataillon, 34095 Montpellier Cedex, France
Phone: +33 4 67 14 36 47
Fax: +33 4 67 14 42 53
E-mail: brunel@dstu.univ-montp2.fr
Web: www.dstu.univ-montp2.fr

Burchart, Jan
Institute of Geological Sciences
Polish Academy of Sciences
Zwirki i Wigury 93, 02-089 Warsaw, Poland
Web: www.pan.pl/english/index.html

Calmus, Thierry
Instituto de Geología
Universidad Nacional Autonoma de México
Apartado Postal 1039, Hermosillo, Sonora, 8300 Mexico
E-mail: tcalmus@servidor.unam.mx
Web: geologia.igeolcu.unam.mx/geol.htm

Carlson, William D.
Department of Geological Sciences
University of Texas at Austin
Austin, TX 78712, USA
Phone: +1 512 471 4770
Fax: +1 512 471 9425
E-mail: wcarlson@mail.utexas.edu
Web: www.geo.utexas.edu/faculty/carlson.htm

Carpéna, Joëlle
Commissariat Energie Atomique
Direction Energie Nucléaire
Centre d'Etudes de Cadarache
DED/SEP/Bâtiment 307, 13108 Saint Paul lez Durance CDX, France
Phone: +33 4 42 25 46 94
E-mail: carpe@bahia.cad.cea.fr
Web: www-cad.cea.fr/r10.htm

Carpenter, Stephen B.
Office of International and Academic Affairs
National Institute of Standards and Technology
100 Bureau Drive, Stop 1090 Gaithersburg, MD 20899-1090, USA
Phone: +1 301 975 4119
E-mail: b.carpenter@nist.gov
Web: www.nist.gov/oiaa/steve.htm

Carter, Andrew
Fission Track Research Group
Department of Earth Sciences
University College London
London WC1E 6B, UK
Phone: +44 20 7679 2418
Fax: +44 20 7813 2802
E-mail: a.carter@ucl.ac.uk
Web: www.fissiontrack.ucl.ac.uk/Personal/Andypage/AC.html

Carter, Tim J.
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia
Phone: +61 3 8344 7673 /7675
Fax: +61 3 8344 7761
E-mail: t.carter@pgrad.unimelb.edu.au
Web: www.earthsci.unimelb.edu.au

Cawley, Steve
BP-Amoco
Farburn Industrial Estate, Aberdeen AB21 7PB, UK
E-mail: cawleysj@bp.com

Cederbom, Charlotte
Department of Geology and Geophysics
University of Edinburgh
Edinburgh EH9 3JW, Scotland, UK
Phone: +44 131 6 508 524
Fax: +44 131 6 505 931
E-mail: cederbom@glg.ed.ac.uk
Web: www.glg.ed.ac.uk

Chadderton, Lewis T.
Research School of Physical Sciences and Engineering
Australian National University
Canberra, ACT, Australia
Phone: +61 2 6125 4542
Fax: +61 2 6125 0043
E-mail: Lewis.Chadderton@anu.edu.au
Web: wwwrsphysse.anu.edu.au/ampl/research/rad/index.html

Chambaudet, Alain
Laboratoire de Microanalyses Nucléaires
Université de Franche-Comté
16 route de Gray, F-25030 Besancon Cedex, France
Phone: +33 3 81 66 65 01
Fax: +33 3 81 66 65 22
E-mail: alain.chambaudet@univ-fcomte.fr

Chan, Roslyn
Minerals Division
Australian Geological Survey Organisation
P.O. Box 378, Canberra ACT 2603, Australia
Phone: + 61 2 6249 9371
Fax: + 61 2 6249 9930
E-mail: roslyn.chan@agso.gov.au
Web: leme.anu.edu.au

Clavero, Jorge
Servicio Nacional de Geologia y Mineria
Av. Sta. Maria 0104, Casilla 10465, Providencia, Santiago de Chile
Phone: +56 2 737 5050
Fax: +56 2 777 1906
E-mail: JClavero@sernageomin.cl
Web: www.sernageomin.cl/prototipo/index.htm

Cloos, Mark
Department of Geological Sciences
University of Texas at Austin
Austin, TX 78712, USA
Phone: +1 512 471 4170
Fax: +1 512 471 9425
E-mail: cloos@mail.utexas.edu
Web: www.geo.utexas.edu/faculty/cloos.htm

Coleman, Max
Research Institute for Sedimentology
The University of Reading
P.O. Box 227, Whiteknights, Reading, RG6 6AB, UK
Phone: +44 118 931 6627
Fax: +44 118 931 0279
E-mail: m.l.coleman@reading.ac.uk
Web: www.rdg.ac.uk/AcaDepts/sl/Sed/Staff/People/mlc1.html

Corrigan, Jeff D.
ARCO Exploration and Production
2300 W. Plano Parkway, Plano, TX 75075, USA
Phone: +1 214 509 4090
E-mail: dprjdc@arco.com

Coutand, Isabelle
Universitaet Potsdam
Institut für Geowissenschaften
Karl-Liebknecht-Str. 24-25
D-14476 Golm, GERMANY
Phone: +49-331-977-2483
Fax: +49-331-977-5060
Email: coutand@geo.uni-potsdam.de
http://www.uni-potsdam.de/u/Geowissenschaft

Crowhurst, Peter
CSIRO Petroleum Resources
P.O. Box 136, North Ryde NSW 1670, Australia
Phone: +61 2 9490 8666
Fax: +61 2 9490 8902
E-mail: p.crowhurst@dpr.csiro.au
Web: www.dpr.csiro.au/research/tbe.html

Crowley, Kevin, D.
Board on Radioactive Waste Management
National Research Council
2101 Constitution Avenue, Washington, DC 20418, USA
Phone: +1 202 334 3066
Fax: +1 202 334 3077
E-mail: kcrowley@nas.edu
Web: www4.nationalacademies.org/cger/brwmwebp.nsf

Currie, Lisel D.
Energy and Environment
Geological Survey of Canada
3303-33rd St., NW Calgary, Alberta, T2L 2A7, Canada
Phone: +1 403 292-7004
Fax: +1 403 292 4961
E-mail: lcurrie@nrcan.gc.ca
Web: www.nrcan.gc.ca/gsc/calgary/index_e.html

Danahara, Tohro
Kyoto Fission Track Co. Ltd.
44-4 Minamitajiri-cho, Kita-ku, Kyoto 603, Japan
Phone: +81 75 493 0684
Fax: +81 75 493 0741
E-mail: BYU02730@niftyserve.or.jp

Danisik, Martin
Institut für Geologie und Paläontologie
Eberhard Karls Universität Tübingen
Sigwartstrasse 10, D-72076 Tübingen, Germany
Phone: +49 7071 2975 240
Fax: +49 7071 5059
E-mail: martindanisik@yahoo.com
Web: www.uni-tuebingen.de/geo/gpi

de Bruijne, Karen
Department of Isotope Geochemistry
Faculty of Earth sciences
Vrije Universiteit Amsterdam
De Boelelaan 1085, Amsterdam 1081 HV, The Netherlands
Phone: +31 20 4447310
Fax: +31 20 6462457
E-mail: bruc@geo.vu.nl
Web: www.geo.vu.nl/~isotopen

De Corte, Frans
Institute for Nuclear Sciences
University of Gent
Proeftuinstraat 86, B-9000 Gent, Belgium
Phone: +32 9 264 6627
Fax: +32 9 264 6699
E-mail: Frans.Decorte@rug.ac.be
Web: allserv.rug.ac.be/~jddonder/AnalChem/incmain.htm#Home

De Graeve, Johan
Geologisch Instituut
Universiteit Gent
Krijgslaan 281 (S8), B-9000 Gent, Belgium
Phone: +32 9 264 4592
Fax: +32 9 264 4997
E-mail: Johan.Degrave@rug.ac.be
Web: allserv.rug.ac.be/~fmees/mineralogy.htm

de Paulo, Sérgio R.
Instituto de Ciências Exatas e da Terra
Universidade Federal de Mato Grosso
78060-900, Cuiaba, MT, Brazil
Instituto de Geociências
Universidade de São Paulo, São Paulo, SP, Brazil
E-mail: Iraesergio@uol.com.br
Web: www.ufmt.br/icet/icet.html
Web: www.igc.usp.br

De Wispelaere, Antoine
Institute for Nuclear Sciences
University of Gent
Proeftuinstraat, 86, B-9000 Gent, Belgium
Phone: +32 9 264 6627
Fax: +32 9 264 6699
E-mail: Antoine.Dewispelaere@rug.ac.be
Web: allserv.rug.ac.be/~jddonder/AnalChem/incmain.htm#Home

De Wit, M.C.J.
De Beers Consolidated Mines Ltd.
P.O. Box 7383, Centurion, 0046 Pretoria, South Africa

Dickin, Alan P.
School of Geography and Geology
McMaster University
Hamilton, Ontario L8S 4M1, USA
Phone: +1 905 525 9140 Ext. 24365
Fax: +1 905 522 3141
E-mail: dickin@mcmaster.ca
Web: www.science.mcmaster.ca/geology/dickin.html

Dodson, Martin H.
Department of Earth Sciences
University of Leeds
Leeds, LS2 9JT, UK

Dokka, Roy K.
Department of Geology
Louisiana State University
E235 Howe Russell Building, LSU Baton Rouge, Louisiana, 70803-4101, USA
Phone: +1 225 388 3353
Fax: +1 225 388 2302
E-mail: dokka@geol.lsu.edu
www.geol.lsu.edu/department/facilities/laboratories/tectonics/index.html

Donelick, Raymond A.
Donelick, Margaret B.
Donelick Analytical Inc.
1075 Matson Road, Viola, Idaho 83872-9709, USA
Phone: +1 208 875 2332
Fax: +1 208 875 8881
E-mail: donelick@apatite.com
Web: www.apatite.com

Dorighel, Olivier
Groupe de Géophysique Nucléaire
Université Joseph Fourier
Institut Dolomieu
15 Rue Maurice Gignoux, 38031 Grenoble Cedex, France

Duddy, Ian R.
Geotrack International Pty. Ltd.
37 Melville Road, West Brunswick, VIC 3055, Australia
Phone: +61 3 9380 1077
Fax: +61 3 9380 1477
E-mail: mail@geotrack.com.au
Web: www.geotrack.com.au

Dumitru, Trevor A.
Department of Geology and Environmental Sciences
Stanford University
Stanford, CA 94305-2115, USA
Phone: +1 415 725 1328
Fax: +1 415 725 2199
E-mail: trevor@pangea.stanford.edu
Web: pangea.Stanford.edu/structure/projects/fission_track.html

Dunai, Tibor J.
Department of Isotope Geochemistry
Faculty of Earth sciences
Vrije Universiteit Amsterdam
De Boelelaan 1085, Amsterdam 1081 HV, The Netherlands
Phone: +31 20 444 7398
Fax:. +31 20 646 2457
E-mail: dunt@geo.vu.nl
Web: www.geo.vu.nl/~isotopen

Dunkl, István
Institut für Geologie und Paläontologie
Eberhard Karls Universität Tübingen
Sigwartstrasse 10, D-72076 Tübingen, Germany
Phone: +49 7071 2974 703
Fax: +49 7071 5059
E-mail: istvan.dunkl@uni-tuebingen.de
Web: www.uni-tuebingen.de/geo/gpi/ag-frisch/mitarbeiter/dunkl/seiten/ft-group.html

Durrani, Saeed A.
School of Physics and Space Research
University of Birmingham
Birmingham B15 2TT, UK
Phone: +44 21 414 4691 /4655
Fax: +44 21 414 4693
E-mail: s.a.durrani@bham.ac.uk

Edwards, Michael
Tektonophysik - Institut für Geologie
Technische Universität Bergakademie Freiberg
Bernhard-von-Cottastrasse 2, D-09596 Freiberg, Germany
Phone: +49 3731 393 758
Fax: +49 3731 393 295
E-mail: edwards@geo.tu-freiberg.de
Web: www.geo.tu-freiberg.de/tektono

Elias, Jürgen
Institut für Geologie und Paläontologie
Eberhard Karls Universität Tübingen
Sigwartstrasse 10, D-72076 Tübingen, Germany
Fax: +49 7071 5059
E-mail: jnelias@med.uni-tuebingen.de
Web: www.uni-tuebingen.de/geo/gpi

Enkelmann, Eva
Institut für Geologie
Technische Universität Bergakademie Freiberg
Bernhard-von-Cottastrasse 2, D-09596 Freiberg, Germany
Phone: +49 3731 393 758
Fax: +49 3731 393 295
E-mail: e.enkelmann@mpi-hd.mpg.de
evaenkelmann@hotmail.com
Web: www.geo.tu-freiberg.de/tektono

Evarts, Russell C.
U.S. Geological Survey, MS-999
345 Middlefield Road, Menlo Park, CA 94025, USA
Phone: +1 650 329 4929
Fax: +1 650 329 4936
E-mail: revarts@usgs.gov
Web: www.usgs.gov

Fabel, Derek
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia
E-mail: d.fabel@unimelb.edu.au
Web: www.earthsci.unimelb.edu.au

Farley, Kenneth A.
Division of Geological and Planetary Sciences
California Institute of Technology
Caltech MS 170-25, Pasadena CA 91125, USA
Phone: +1 626 395 6005
Fax: +1 626 568 0935
E-mail: farley@gps.caltech.edu
Web: www.gps.caltech.edu/~farley/farley.htm

Fayon, Annia K.
Department of Geology and Geophysics
University of Minnesota-Twin Cities
108 Pillsbury Hall, 310 Pillsbury Drive SE, Minneapolis, MN 55455, USA
Phone: +1 612 626 9805
Fax: +1 612 625 3819
E-mail: annia@geolab.geo.umn.edu
Web: www.geo.umn.edu/orgs/whitney/DLW_postdoc.html

Feinstein, Shimon
Department of Geological and Environmental Sciences
Ben Gurion University of the Negev
P.O. Box 653, Beer Sheva 84105, Israel
Phone: +972 8 647 2622
Fax: +972 8 647 2997
E-mail: shimon@bgumail.bgu.ac.il
Web: www.bgu.ac.il/geol/index.html

Filip, Jiri
Institute of Geology
Academy of Sciences of the Czech Republic
Rozvojova 135, Prague 6 CZ 165 02, Czech Republic
Phone: +420 2 3308 7248
Fax: +420 2 3308 7111
E-mail: filip@gli.cas.cz
Web: www.gli.cas.cz

Fisher, David E.
Department of Geological Sciences
University of Miami
Miami, FL 33124-0401, USA
Phone: +1 305 284 3254
Fax: +1 305 284 4258
Web: www.as.miami.edu/geology

Fitzgerald, Paul G.
Heroy Geology Laboratory
Department of Earth Sciences
Syracuse University
Syracuse, New York 13244-1070 USA
Phone: +1 315 443 2871
Fax: +1 315 443 2619
E-mail: pgfitzge@syr.edu
Web: su-thermochronology.syr.edu

Fleischer, Robert L.
Department of Geology
Union College
Schenectady, NY 12308, USA
Phone: +1 518 388 6985
Fax: +1 518 388 6417
E-mail: fleischr@union.edu
Web: zircon.geology.union.edu/Fleischer.html

Fletcher, John M.
Departamento de Geología
Centro de Investigación Científica y de Educación Superior de Ensenada
Km 107 Carr. Tijuana - Ensenada. Ensenada, B.C., México
P.O. Box 430222, San Diego, CA 92143-0222, USA
Phone: +1 174 50 50 26031
Fax: +1 174 50 50 26021
E-mail: jfletche@cicese.mx
Web: geologia.cicese.mx/jfletche/jfletche.htm

Foland, Sara S.
Amoco Production Company
P.O. Box 800, Denver, CO 80201, USA
E-mail: sfoland@geosociety.org

Foster, David A.
Department of Geology
University of Florida
P.O. Box 112120, Gainsville, FL 32611-2120, USA
Phone: +1 352 392 2231
E.mail: dafoster@ufl.edu
Web: www.clas.ufl.edu/users/dfoster

Franks, Daniel
University of Queensland
St Lucia Brisbane QLD 4072, Australia
E-mail: danielfranks@hotmail.com

Fügenschuh, Bernhard
Geologisch Paläontologisches Institut
Universität Basel
Bernoullistrasse 32, Basel BS CH-4056, Switzerland
Phone: +41 61 267 86 10
Fax: +41 61 267 36 13
E-mail: bernhard.fuegenschuh@unibas.ch
Web: www.unibas.ch/earth/tecto/people/fuegenschuh.html

Galbraith, Rex F.
Department of Statistical Science
University College London
Gower Street, London, WC1E 6BT, UK
Phone: +44 20 7679 1859
Fax: +44 20 7383 4703
E-mail: rex@stats.ucl.ac.uk
Web:www.ucl.ac.uk/geolsci/research/fissiontrack/Personal/Rexpage/Rex.html

Gallagher, Kerry
Department of Earth Sciences and Engineering
Imperial College of Science, Technology and Medicine
Exhibition Road, London, SW7 2BT, UK
Phone: +44 20 759 46424
Fax: +44 20 759 46444
E-mail: kerry@ic.ac.uk; k.l.gallagher@ic.ac.uk
www.huxley.ic.ac.uk/research/Comp&Geophys/Geophys/maintext.php3

Ganzawa, Yoshiro
Hokkaido University of Education
1-2 Hachiman-cho, Hakodate, 040, Japan
Phone: +81 0138 41 1121
Fax: +81 0138 42 3982

Garver, John I.
Department of Geology
Union College
Schenectady, NY 12308-2311, USA
Phone: +1 518 388 6517
Fax: +1 518 388 6789
E-mail: garverj@union.edu
Web: zircon.union.edu/FT/FThome.html

George, Annette
University of Western Australia
Department of Geology and Geophysics
Nedlands WA 6907, Australia
Phone: +61 (08) 9380 1923
Fax: + +61 (08) 9380 1037
E-mail: ageorge@geol.uwa.edu.au
Web: www.geol.uwa.edu.au/~ageorge/ageorge.html

George, Pete
Department of Geological Sciences
University of Texas at Austin
Austin, TX 78712, USA
Web: www.geo.utexas.edu

Gibson, David
CRC LEME/AGSO
P.O. Box 378, Canberra ACT 2601, Australia
Phone: +61 2 6249 9748
Fax: +61 2 6249 9930
E-mail: dave.gibson@agso.gov.au
Web: leme.anu.edu.au

Gibson, Helen
Geotrack International Pty. Ltd.
37 Melville Road, West Brunswick, VIC 3055, Australia
Phone: +61 3 9380 1077
Fax: +61 3 9380 1477
E-mail: mail@geotrack.com.au
Web: www.geotrack.com.au

Giegengack, Robert
Department of Earth and Environmental Science
University of Pennsylvania
Philadelphia, PA 19104-6316, USA
Phone: +1 215 898 5191
Fax: +1 215 573 9145
E-mail: gieg@sas.upenn.edu
Web: www.sas.upenn.edu/earth/giegenga.html

Giles, Melvin R.
EPT-HM, Volmerlaan 8, Rijswijk, The Netherlands
E-mail: gilesm@siep.shell.com

Glasmacher, Ulrich
Forschungsstelle Archaeometrie
Heidelberger Akademie der Wissenschaften
Saupfercheckweg 1, 69117 Heidelberg, Germany
Phone: +49 6221 516 321
Fax: +49 6221 516 633
E-mail: ua.glasmacher@mpi-hd.mpg.de
Web: www.haw.baden-wuerttemberg.de

Gleadow, Andrew J. W.
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia
Phone: +61 3 8344 9866
Fax: +61 3 8344 7761
E-mail: gleadow@unimelb.edu.au
Web: web.earthsci.unimelb.edu.au/Gleadow/Gleadow.html

Gräfe, Kirsten
Geoforschungszentrum Potsdam
Telegrafenberg, Gebäude C122, D-14473 Potsdam, Germany
Phone: +49 331288 1315
Fax: +49 331288 1370
E-mail: graefe@gfz-potsdam.de
Web: www.gfz-potsdam.de/pb3/pb31/index-pb-en.html

Green, Paul F.
Geotrack International Pty. Ltd.
37 Melville Road, West Brunswick, VIC 3055, Australia
Phone: +61 3 9380 1077
Fax: +61 3 9380 1477
E-mail: mail@geotrack.com.au
Web: www.geotrack.com.au

Grimmer, Jens C.
Institut für Geologie
Technische Universität Bergakademie Freiberg
Bernhard-von-Cottastrasse 2, D-09596 Freiberg, Germany
Phone: +49 3731 394599
Fax: +49 3731 393597
E-mail: jens.grimmer@geo.tu-freiberg.de
Web: www.geo.tu-freiberg.de/tektono

Grist, Alexander M.
Department of Earth Sciences
Dalhousie University
Halifax, Nova Scotia, B3H 3J5, Canada
Phone: +1 902 494 2372
Fax: +1 902 494 6889
E-mail: agrist@is.dal.ca
Web: meguma.earthsciences.dal.ca/staff/grist.htm

Grivet, Manuel
Laboratoire de Microanalyses Nucléaires
U.F.R. des Sciences et des Techniques
Université de Franche-Comté
16 route de Gray, F-25030 Besancon Cedex, France
Phone: +33 3 81 66 65 01
Fax: +33 3 81 66 65 22
E-mail: manuel.grivet@univ-fcomte.fr
Web: www.univ-fcomte.fr

Guedes de Oliveira, Sandro
Departamento de Raios Cósmicos e Cronologia
Instituto de Fisica Gleb Wataghin
Universidade Estadual de Campinas
Caixa Postal 6165, CEP 13083-970 UNICAMP, Campinas, SP, Brazil
Phone: +55 19 788 5522
Fax: +55 19 788 5512
E-mail: guedes@ifi.unicamp.br
Web: www.ifi.unicamp.br/~turtelli/www0.htm

Guglielmetti, Alessandra
Instituto di Fisica Generale Applicata
Università degli Studi di Milano
Via Celoria 16, 20133 Milano, Italy
Phone: +39 02 266 6259
Fax: +39 02 266 5717
E-mail: guglielmetti@mi.infn.it
Web: albinoni.brera.unimi.it/istituto/istituto.htm

Gunnell, Yanni
Laboratoire de géographie physique
Universite Denis Diderot, Paris VII
1 Place Aristide Briand, 92195 Meudon Cedex, France
Phone: +33 1 4507 5552
E-mail: gunnell@paris7.jussieu.fr
Web: www.sigu7.jussieu.fr

Hadler Neto, Julio Cesar
Departamento de Raios Cósmicos e Cronologia
Instituto de Fisica Gleb Wataghin
Universidade Estadual de Campinas
Caixa Postal 6165, CEP 13083-970 UNICAMP, Campinas, SP, Brazil
Phone: +55 19 788 5522
Fax: +55 19 788 5512
E-mail: hadler@ifi.unicamp.br
Web: www.ifi.unicamp.br/~turtelli/www0.htm

Hansen, Kirsten
Geologisk Centralinstitut
Oster Volgrade 10, DK-1350, Kobenhavn K, Denmark
Phone: +45 31 42 18 94
Fax: +45 33 14 84 33
E-mail: kirstenh@geo.geol.ku.dk

Harrison, Mark T.
Department of Earth and Space Sciences
University of California, Los Angeles
595 Charles Young Drive East, Los Angeles, CA 90095-1567, USA
Phone: +1 310 825 7970
Fax: +1 310 825 2779
E-mail: tmh@argon.ess.ucla.edu
Web: www.ess.ucla.edu/faculty/harrison

Hasebe, Noriko
Department of Earth Sciences
Kanazawa University
Kanazawa, 920-1192, Japan
Phone: +81 76 264 5727
Fax: +81 76 264 5746
Web: earth.s.kanazawa-u.ac.jp/chronology/EnglishPage/indexE.html
London Fission Track Research Group
Research School of Geological Sciences
University and Birbeck Colleges
London WC1E 6B, UK
Phone: +44 207 679 7704
Fax: +44 207 813 2802
E-mail: hasebe@kenroku.kanazawa-u.ac.jp
www.ucl.ac.uk/geolsci/research/fissiontrack/Indexpage/index.html

Hashemi-Nezhad, Reza S.
Department of High Energy Physics
School of Physics, University of Sydney
A28 Sydney, NSW 2006, Australia
Phone: +61 2 9351 5964
Fax: +61 2 9351 7727
E-mail: reza@physics.usyd.edu.au
Web: www.physics.usyd.edu.au/hienergy/index.html

Hayashi, Masao
Kyushu Sangyo University
Fukuoka 813, Japan
Phone: +81 92 673 5883
Fax: +81 92 673 5899
Web: www.ip.kyusan-u.ac.jp/e/ksu-e.html

Hegarty, Kerry A.
Geotrack International Pty. Ltd.
37 Melville Road, West Brunswick, VIC 3055, Australia
Phone: +61 3 9380 1077
Fax: +61 3 9380 1477
E-mail: mail@geotrack.com.au
Web: www.geotrack.com.au

Hejl, Ewald R.
Institut für Geologie und Paläontologie
Universitat Salzburg
Hellbrunnerstraße 34/III, A-5020 Salzburg, Austria
Phone: +43 662 8044 5437
Fax: +43 662 8044 621
E-mail: ewald.hejl@sbg.ac.at
Web: www.sbg.ac.at/gew

Hendriks, Bart W.H.
Department of Isotope Geochemistry
Faculty of Earth sciences
Vrije Universiteit Amsterdam
De Boelelaan 1085, Amsterdam 1081 HV, The Netherlands
Phone: +31 20 4447397
Fax: +31 20 6462457
E-mail: henb@geo.vu.nl
Web: www.geo.vu.nl/~isotopen

Hill, Kevin C.
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia
Phone: +61 3 8344 9708 /7675
Fax: +61 3 8344 7761
E-mail: kevin.hill@unimelb.edu.au
Web: www.earthsci.unimelb.edu.au

Himeno, Osamu
Department of Mining Engineering
Kyushu Sangyo University
Hakozaki, Fukuoka 812-81, Japan
Phone: +81 92 642 3635
E-mail: himeno@mine.kyushu-u.ac.jp

Hobro, James W. D.
Bullard Laboratories, Department of Earth Sciences
University of Cambridge
Madingley RoadCambridge CB3 0EZ, UK
Phone: +44 1223 337 191
Fax: +44 1223 360 779
Email: hobro@esc.cam.ac.uk
Web: bullard.esc.cam.ac.uk/~hobro

Honda, Teruyyki
Atomic Energy Research Laboratory
Musashi Institute of Technology
Kawasaki 215, Japan
Web: atomsun2.atom.musashi-tech.ac.jp

Hoshino, Hidehiro
Kanazawa University
Kakuma town, Kanazawa City, Ishikawa Pref. Japan
E-mail: hide43@nihonkai.kanazawa-u.ac.jp

House, Martha
Division of Geological and Planetary Sciences
California Institute of Technology
Caltech MS 100-23, Pasadena CA 91125, USA
Phone: +1 626 395 6023
Fax: +1 626 568 0935
E-mail: mhouse@gps.caltech.edu
Web: www.gps.caltech.edu/%7Emhouse

Huigen, Yvette
Department of Isotope Geochemistry
Faculty of Earth sciences
Vrije Universiteit Amsterdam
De Boelelaan 1085, Amsterdam 1081 HV, The Netherlands
Phone: +31 20 4447397
Fax: +31 20 6462457
E-mail: huiy@geo.vu.nl
Web: www.geo.vu.nl/~isotopen

Hungerbühler, Dominik
Department Erdwissenschaften
ETH-Zentrum
CH-8092, Zurich, Switzerland
Web: www.erdw.ethz.ch

Hulver, Michael L.
Saudi Aramco
Box 9279, Dhahran 31311, Saudi Arabia
E-mail: hulverml@mail.aramco.com.sa
Web: www.saudiaramco.com

Hurford, Anthony J.
London Fission Track Research Group
Department of Earth Sciences
University College London
London WC1E 6B, UK
Phone: +44 20 7679 7704
Fax: +44 20 7813 2802
E-mail: t.hurford@ucl.ac.uk
Web:www.ucl.ac.uk/geolsci/research/fissiontrack/Indexpage/index.html

Indrelid, Sarah
Petroleum Development Oman
E-mail: sarah.sl.indrelid@pdo.co.om
Web: www.pdo.co.om

Iriarte, Sergio
Servicio Nacional de Geologia y Mineria
Av. Sta. Maria 0104, Casilla 10465, Providencia, Santiago de Chile
Phone: +56 2 737 5050
Fax: +56 2 777 1906
E-mail: SIriarte@sernageomin.cl
Web: www.sernageomin.cl/prototipo/index.htm

Issler, Dale R.
Natural Resources Canada
Geological Survey of Canada
3303-33rd St., NW Calgary, Alberta, T2L 2A7, Canada
Phone: +1 403 292 7172
Fax: +1 403 292 5377
E-mail: dissler@nrcan.gc.ca
Web: www.nrcan.gc.ca/gsc/calgary/index_e.html

Ito, Hisatoshi
Central Research Institute of Electric Power Industry
1646 Abiko, Abiko city, Chiba, 270-1194, Japan
Phone: +81 471 82 1181 ext. 8525
Fax: +81 471 83 3182
E-mail: ito_hisa@criepi.denken.or.jp Web: criepi.denken.or.jp; wwwsoc.nacsis.ac.jp/jseg/index-e.html

Iunes, P.J.
Departamento de Raios Cósmicos e Cronologia
Instituto de Fisica Gleb Wataghin
Universidade Estadual de Campinas
Caixa Postal 6165, CEP 13083-970 UNICAMP, Campinas, SP, Brazil
Phone: +55 19 788 5522
Fax: +55 19 788 5512
E-mail: iunes@ifi.unicamp.br
Web: www.ifi.unicamp.br/~turtelli/www0.htm

Iwano, Hideki
Kyoto Fission Track Co. Ltd.
44-4 Minamitajiri-cho, Kita-ku, Kyoto 603, Japan
Phone: +81 75 493 0684
Fax: +81-75 493 0741
E-mail: BYU02730@niftyserve.or.jp

Jacobs, Joachim
Fachbereich 5, Geowissenschaften
Universität Bremen
Postfach 330440, D-28334 Bremen, Germany
Phone: +49 421 218 3993
Fax: +49 421 218 3995
E-mail: jojacobs@geopol.uni-bremen.de
Web: www.joachimjacobs.de/index.htm

Johnson, Kit
London Fission Track Research Group
Department of Geological Sciences
University College London
London WC1E 6B, UK
Phone: +44 20 7594 6542
Fax: +44 20 7594 6464
E-mail: k.johnson@ic.ac.uk

Jolivet, Marc
Division of Earth Sciences
University of Glasgow
The Gregory Building, Lilybank Gardens, Glasgow, G12 8QQ, Scotland, UK
Phone: +44 141 330 2783
Fax: +44 141 330 4817
E-mail: marc.jolivet@earthsci.gla.ac.uk
Web: www.earthsci.gla.ac.uk/staff/jolivet.html

Jonckheere, Raymond
Geologie Tektonophysik
Technische Universität
Bergakademie Freiberg
Bernhard von Cottastraße 2
D-09599 Freiberg (Sachsen)
Deutschland.
Tel. : +49 3731 393813
Fax : +49 3731 393597
Email: raymond.jonckheere@geo.tu-freiberg.de
Web: r.jonckheere@mpi-hd.mpg.de

Juez-Larre, Joaquim
Department of Isotope Geochemistry
Faculty of Earth sciences
Vrije Universiteit Amsterdam
De Boelelaan 1085, Amsterdam 1081 HV, The Netherlands
Phone: +31 20 444 7395
Fax: +31 20 646 2457
E-mail: juej@geo.vu.nl
Web: www.geo.vu.nl/~isotopen

Kamp, Peter J.J.
Department of Earth Sciences
University of Waikato
Private Bag 3105, Hamilton 2001, New Zealand
Phone: +64 7 838 4876
Fax: +64 7 856 0115
E-mail: p.kamp@waikato.ac.nz
Web: sci.waikato.ac.nz/cgi-bin/dynapage.pl?pagename=erth

Keay, Sue
Department of Earth Sciences
University of Queensland
St Lucia, Brisbane QLD 4072, Australia
Phone: +61 7 3365 8248
Fax: +61 7 3365 1277
E-mail: s.keay@earth.uq.edu.au
Web: www.earth.uq.edu.au

Ketcham, Richard A.
Department of Geological Sciences
University of Texas at Austin
Austin, TX 78712, USA
Phone: +1 512 471 0260
Fax: +1 512 471 9425
E-mail: richk@maestro.geo.utexas.edu
Web: www.geo.utexas.edu/scientist/ketcham.htm

Kelley, Shari A.
Department of Earth and Environmental Sciences
New Mexico Institute of Mining and Technology
801 Leroy Place, Socorro, NM 8780, USA
Phone: +1 505 661 6171
E-mail: sakelley@ix.netcom.com
Web: www.ees.nmt.edu/faculty/kelley.html

Kendrick, Dan
Department of Earth Sciences
La Trobe University
Bundoora, VIC 3083, Australia
Phone: +61 3 479 1273
Fax: +61 3 479 1272
E-mail: geordk@luff.latrobe.edu.au
Web: www.latrobe.edu.au/pesa/Research-ltu/Irian.html

Kim, Joong Wook
Department of Science Education
Taegu National University of Education
Daemyung-2 Nam-gu, Taegu, 705-715, Korea
Phone: +82 53 620 1343
Fax: +82 53 620 1340
E-mail: jwkim@taekyo.taegu-e.ac.kr
Web: soback.kornet.net/~jwkim5/g-hi.html

Kohn, Barry P.
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia
Phone: +61 3 8344 7217 /7675
Fax: +61 3 8344 7761
E-mail: b.kohn@unimelb.edu.au
Web: www.agcrc.csiro.au/people/KohnBarry

Koshimizu, Satoshi
Yamanashi Institute of Environmental Sciences
5597-1 Kenmarubi, Kamiyoshida, Fujiyoshida, Yamanashi
403-0005 Japan
Phone: +81 555 72 6194
Fax: +81 555 72 6206
E-mail: koshi@yies.pref.yamanashi.jp
Web: www.yies.pref.yamanashi.jp/eigo/english.htm

Kounov Alexandre
Geology Institute
ETH-Zentrum
Sonneggstrasse 5, 8092, Zurich, Switzerland
Phone: +41 1632 3639
Fax: +41 1632 1080
E-mail: Kunov@eurasia.ethz.ch
Web: www.erdw.ethz.ch

Kowallis, Bart Joseph
Department of Geology
Brigham Young University
Provo, UT 84602, USA
Phone: +1 801 378 2467
Fax: +1 801 378 2265
E.mail: bkowallis@byu.edu; bart_kowallis@byu.edu
Web: geologyindy.byu.edu/faculty/bjk

Krochmal, Michael
Autoscan Systems Pty. Ltd.
P.O. Box 112, Ormond, VIC 3204 Australia
Phone: +61 39 596 8065 /8092
Fax: +61 39 596 8369
E-mail: autoscan@autoscan.com.au
Web: members.ozemail.com.au/~autoscan/index.html

Krummei, Gerhard
Geological Society of Australia Incorporated
Victoria Division
GPO BOX 2355, Melbourne Vic 3001, Australia
Web: www.vic.gsa.org.au

Laken, Garey
Autoscan Systems Pty. Ltd.
P.O. Box 112, Ormond, VIC 3204 Australia
Phone: +61 39 596 8065 /8092
Fax: +61 39 596 8369
E-mail: autoscan@autoscan.com.au
Web: members.ozemail.com.au/~autoscan/index.html

Lal, Nand
Department of Earth Sciences
Kurukshetra University
Kurukshetra 136119, India
Phone: +91 1 744 20410
Fax: +91 1 744 20277

Lange, Jan-Michael
Museum für Mineralogie und Geologie
Staatliche Naturhistorische Sammlungen Dresden
Königsbrücker Landstraße 159, D-01109 Dresden, Germany
Phone: +49 351 892 6403
fax: +49 351 892 6404
E-mail: lange@snsd.de
Web: www.snsd.de

Larsen, Ian
Autoscan Systems Pty. Ltd.
P.O. Box 112, Ormond, VIC 3204 Australia
Phone: +61 39 596 8065 /8092
Fax: +61 39 596 8369
E-mail: autoscan@autoscan.com.au
Web: members.ozemail.com.au/~autoscan/index.html

Laslett, Geoff
CSIRO Mathematical and Information Sciences
Private Bag 10, Clayton South MDC Vic 3169, Australia
Phone: +61 3 9545 8018
Fax: +61 3 9545 8080
E-mail: geoff.laslett@cmis.csiro.au
Web: www.cmis.csiro.au/Geoff.Laslett/index.htm

Lee, Yong I.
School of Earth and Environmental Sciences
Seoul National University, Korea
E-mail: lee2602@plaza.snu.ac.kr
Web: sees.snu.ac.kr/bken/index.html

Lewis, Cherry L.E.
History of Geology Group
The Geological Society of London
Wells Cottage, 21 Fowler Street, Macclesfield, Cheshire
SK10 2AN, UK
Phone: +44 1625 260049
Fax: +44 1625 523690
E-mail: clelewis@aol.com
Web: www.geolsoc.org.uk

Lim, Hyoun Soo
School of Earth and Environmental Sciences
Seoul National University, Korea
E-mail: limhs@plaza1.snu.ac.kr
Web: sees.snu.ac.kr/bken/index.html

Link, Katharina
Institut für Mineralogie, Petrologie und Geochemie
Albert-Ludwigs-Universität
Albertstrasse 23b, 79104 Freiburg, Germany
Phone: +49 761 203 6425
Fax: +49 761 203 6396
E-mail: kalink@uni-freiburg.de
Web: www.uni-freiburg.de/minpet/welcome.html

Linn, Jon
Technical Applications and Geographic Information Systems Unit
West Virginia Department of Environmental Protection
10 McJunkin Rd, Nitro, WV 25143, USA
Phone: +1 304 759 0519
Fax: +1 304 759 0565
E-mail: jlinn@crimson.osmre.gov
Web: www.dep.state.wv.us/ito/tagis.html

Lisker, Frank
Fachbereich 5, Geowissenschaften
Universität Bremen
Postfach 330440, D-28334 Bremen, Germany
Phone: +49 421 218 3994
Fax: +49 421 218 3993
E-mail: flisker@uni-bremen.de Web: www.palmod.uni-bremen.de/FB5/agpolar/englisch/index1.htm

Liu, Shunsheng
Changsha Institute of Geotectonics
Academia Sinica
Changsha 410013, Hunan Province, PR China
Phone: +86 731 885 9165
Fax: +86 731 885 9137
E-mail: liuss@ms.csig.ac.cn
Web: www.csig.ac.cn

Lopez, Arturo
Departamento de Estudios del Ambiente
Instituto nacional de investigaciones Nucleares
Apartado Postal 18-1027,México, D.F. 11801, Mexico
E-mail: arturo.lopez@mpi-hd.mpg.de
Web: www.inin.mx

Lorencak, Matevz
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia
Phone: +61 3 8344 9669 /7675
Fax: +61 3 8344 7761
E-mail: m.lorencak@pgrad.unimelb.edu.au
Web: www.earthsci.unimelb.edu.au

Lovering, John
School of Earth Sciences
University of Melbourne
66A Molesworth Street, Kew Victoria 3101, Australia
phone: +61 3 9853 2868
Fax: +61 3 9853 3640
E-mail: fitzlove@alphalink.com.au

Lutz, Timothy M.
Department of Geology and Astronomy
West Chester University
West Chester, PA 19383, USA
Phone: +1 610 436 3498
E-mail: tlutz@wcupa.edu
Web: geology.wcupa.edu

Märk, E.
Hohrere technische Bundeslehr- und Versuchsanstalt
Anichstrasse 26-28
A-6020 Innsbruck, Austria

Märk, T. D.
Abteilung für Kernphysik und Gaselektronik
Institut für Experimentalphysik
Leopold Franzens Universität
A-6020 Innsbruck, Austria

Mahon, Keith I.
Exxon Production Research Company
P.O. Box 2189, Houston, TX 77252-2189, USA
Phone: +1 713 965 7036
Fax: +1 713 965 2779
E-mail: kmahon@dialaccess.com

Maksaev, Victor
Department of Geology
University of Chile
Casilla 13518, Correo 21, Santiago de Chile
Phone: +56 2 678 4112
Fax: +56 2 696 3050
E-mail: vmaksaev@tamarugo.cec.uchile.cl
Web: www.cec.uchile.cl/~geologia

Marshallsea, Susan
Geotrack International Pty. Ltd.
37 Melville Road, West Brunswick, VIC 3055, Australia
Phone: +61 3 9380 1077
Fax: +61 3 9380 1477
E-mail: mail@geotrack.com.au
Web: www.geotrack.com.

Maze, Will B.
Exxon Production Research
P.O. Box 2189, Houston, TX 77252-2189, USA
Phone: +1 713 965 7223
Fax: +1 713 965 7951

McCorkell, Robert
CANMET, Mineral Technology
Energy, Mines and Resources
555 Booth Street, Ottawa, Ontario K1A 0G1, Canada

McCulloh, Thane H.
7136 Aberdeen, Dallas, TX 75230, USA
Phone: +1 214 691 6809

McInnes, Brent
CSIRO Exploration and Mining
P.O. Box 136, North Ryde NSW 1670, Australia
Phone: +61 2 9490 8597
Fax: +61 2 9490 8921
E-mail: b.mcinnes@dem.csiro.au
Web: www.dem.csiro.au

Miller, Elizabeth L.
Department of Geology and Environmental Sciences
Stanford University
Stanford, CA 94305-2115, USA
Phone: +1 650 723 1149
E-mail: miller@pangea.stanford.edu
Web: pangea.Stanford.EDU/structure/projects/fission_track.html

Miller, Jack A.
Department of Earth Sciences
University of Cambridge
Downing Street, Cambridge CB2 3EQ, UK
Phone: +44 1223 337 184
Fax: +44 1223 333 450
E-mail: jam2@esc.cam.ac.uk
Web : www.esc.cam.ac.uk

Moore, Marilyn
Geotrack International Pty. Ltd.
37 Melville Road, West Brunswick, VIC 3055, Australia
Phone: +61 3 9380 1077
Fax: +61 3 9380 1477
E-mail: mail@geotrack.com.au
Web: www.geotrack.com.au

Mora, Jorge
Escuela de Geologia, Minas y Geofisica
Facultad de Ingenieria
Universidad Central de Venezuela
Caracas, Venezuela
Web: www.ing.ucv.ve/depgeo.htm

Moser, Franz
Institut für Geologie und Paläontologie
Eberhard Karls Universität Tübingen
Sigwartstrasse 10, D-72076 Tübingen, Germany
Phone: +49 7071 2975 240
Fax: +49 7071 5059
E-mail: franz.moser@uni-tuebingen.de
Web: homepages.uni-tuebingen.de/franz.moser

Most, Thomas
Institut für Geologie und Paläontologie
Eberhard Karls Universität Tübingen
Sigwartstrasse 10, D-72076 Tübingen, Germany
Phone: +49 7071 2975 240
Fax: +49 7071 5059
E-mail: thomas.most@uni-tuebingen.de
Web: homepages.uni-tuebingen.de/thomas.most

Murakami, Masaki
Department of Geology and Mineralogy
Division of Earth and Planetary Sciences
Graduate School of Science, Kyoto University
Sakyo-ku, Kyoto 606-8502, Japan
E-mail: s30x1176@ip.media.kyoto-u.ac.jp
Web: terra.kueps.kyoto-u.ac.jp/index_eg.html

Murphy, John M.
Department of Geology and Geophysics
University of Wyoming
P.O. Box 3006, Laramie WY 82071, USA
Phone: +1 307 766 5435
Fax: +1 307 766 6679
E-mail: geojm@uwyo.edu
Web: home.gg.uwyo.edu

Murrell, Glen
Department of Isotope Geochemistry
Faculty of Earth sciences
Vrije Universiteit Amsterdam
De Boelelaan 1085, Amsterdam 1081 HV, The Netherlands
Phone: +31 20 444 7310
Fax:. +31 20 646 2457
E-mail: murg@geo.vu.nl
Web: www.geo.vu.nl/~isotopen

Murtazaev, Khatam
General Physics Sub-Faculty
Khujand State University,
735700, Khujand, Tajikistan
Phone: (+992 3422) 53212, 23775
E-mail: murtaza@hotam.khj.td.silk.org
murtaza@khj.tajik.net

Naeser, Chuck
Naeser, Nancy
U.S. Geological Survey
926a National Center, Reston, VA 20192, USA
Phone: +1 703 648 6964 (C)
Phone: +1 703 648 5328 (N)
Fax: +1 703 648 6953
E-mail: cnaeser@usgs.gov (C)
nnaeser@usgs.gov (N)
Web:greenwood.cr.usgs.gov/capabilities/gronemtrac/geochron/fission/contacts.html

Neumann, Reinhard
Materials Research
Gesellschaft für Schwerionenforschung
Planckstrasse 1, D-64291 Darmstadt, Germany
Phone: +49 6159 71 2172
Fax: +49 6159 71 3266
E-mail: r.neumann@gsi.de
Web: www-wnt.gsi.de/mr

Nishimura, Susumu
Department of Geology and Mineralogy
Division of Earth and Planetary Sciences
Graduate School of Science, Kyoto University
Sakyo-ku, Kyoto 606-8502, Japan
Phone: +81 75 753 4150
Fax: +81 75 753 4189
Web: terra.kueps.kyoto-u.ac.jp/index_eg.html

Noble, Wayne P.
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia
Phone: +61 3 8344 9788 /7675
Fax: +61 3 8344 7761
E-mail: w.noble@earthsci.unimelb.edu.au
Web: www.earthsci.unimelb.edu.au

Oddone, Massimo
Dipartimento di Chimica Generale
Università degli Studi di Pavia
Viale Taramelli, 12, 27100 Pavia, Italy
Phone: +39 382 507 334
Fax +39 382.528 544
E-mail: oddone@ipv36.unipv.it
Web: chifis1.unipv.it/genchem.htm

Ohira, Hiroto
Department of Geoscience
Shimane University
1060 Nishikawatsu, Matsue 690-8504, Japan
Phone: +81 852 32 6465
Fax: +81 852 32 6469
E-mail : ohira@riko.shimane-u.ac.jp
Web: terra.riko.shimane-u.ac.jp

Olesch, Martin
Fachbereich 5, Geowissenschaften
Universität Bremen
Postfach 330440, D-28334 Bremen, Germany
Phone: +49 421 218 3940
Fax: +49 421 218 3993
E-mail: olesch@geopol.uni-bremen.de
Web:www.palmod.unibremen.de/FB5/agpolar/englisch/index1.htm

Omar, Gomaa I.
Department of Earth and Environmental Science
University of Pennsylvania
240 South 33rd Street, Philadelphia, PA 19104-6316, USA
Phone: +1 215 898 6908
Fax: +1 215 898 0964
E-mail: gomar@sas.upenn.edu
Web: www.sas.upenn.edu/earth/omar.html

Ono, Masako
Department of Earth and Planetary Materials Science
Faculty of Science, Hokkaido University
Kyoyo-chigaku, N17-W8, Kita-ku, Sapporo, 060, Japan
Phone: +81 11 716 2111 ext. 5309
Fax: +81 11 736 3290
E-mail: mo@epms.hokudai.ac.jp
Web: www.ep.sci.hokudai.ac.jp/epms/index_e.htm

Osadetz, Kirk
Energy and Environment
Geological Survey of Canada
3303-33rd St., NW Calgary, Alberta, T2L 2A7, Canada
Phone: +1 403 292 7022
Fax: +1 403 292 7159
E-mail: kosadetz@nrcan.gc.ca
Web: www.nrcan.gc.ca/gsc/calgary/index_e.html

O'Sullivan, Paul B.
1521 Pine Cone Road
Moscow, ID 83843
USA
Phone: (208) 892 1493
Fax: (208) 875-8881
E-mail: OSullivan@apatite.com

Pagel, Maurice
Laboratoire de Géochimie
Faculté des sciences d'Orsay
Université Paris Sud XI
Bâtiment 504, F-91405 Orsay-Cedex, France
Phone: +33 1 6915 6755
Fax: +33 1 6815 4882
E-mail: pagel@geol.u-psud.fr
Web: geosciences.geol.u-psud.fr/recherch/weblab/pagel.html

Pagliuca, Renato
Dipartimento di Scienze della Terra
Università degli Studi di Pavia
Via Ferrata 1, 27100 Pavia, Italy
Phone: +39 382 505 839
Fax: +39 382 505 890
E-mail: ullayu@tin.it
Web: manhattan.unipv.it

Pain, Colin
Cooperative Research Centre for Landscape Environments & Mineral Exploration (CRC LEME)
GPO Box 378
Canberra, ACT 2601
Australia
Tel: (02) 6249 9469 - International: 61 2 6249 9469
Fax: (02) 6249 9930 - International: 61 2 6249 9930
Mob: 0409 225 008 - International: 61 0409 225 008
Email: Colin.Pain@ga.gov.au
Web: http://leme.anu.edu.au/staff/pain.html

Pan , Yun
Department of Geological Sciences
State University of New York at Albany
DEAS - ES351, Albany, NY 12222, USA
E-mail: ypan@spsu.edu; ynatl@bellsouth.net

Parand, Simon
Geological Survey of Iran
Meraj Blvd., Azadi Sq., P.O. Box 13185-1494 Tehran, Iran
Fax: +98 21 600 9338
Web: www.gsi-iran.org

Paul, Tracy A.
Department of Chemistry
Arizona State University
Tempe, AZ 85287-1404, USA
E-mail: agtxp@asu.edu

Pengji, Zhai
Institute of High Energy Physics
Academia Sinica
P.O. Box 2732, Beijing 100080, PR China
Web: www.ihepa.ac.cn

Perelygin, Vladimir P.
Flerov Laboratory of Nuclear Reactions
Joint Institute for Nuclear Research
Post Office Box 79, 101 000 Moscow, Russia
Phone: +7 096 216 2102
Fax: +7 096 216 5955
E-mail: pergam@cv.jinr.ru
Web: sungraph.jinr.dubna.su/cap/index.html

Perez De Armas, Jaime G.
Department of Earth Science
Rice University
6100 Main St, Houston, TX 77005-1892, USA
Phone: +1 713 348 4880
Fax: +1 713 348 5214
E-mail: jaime@rice.edu
Web: terra.rice.edu

Petford, Nick
Centre for Earth and Environmental Science Research
School of Earth Sciences and Geography
Kingston University
Penrhyn Road, Kingston on Thames, Surrey, KT1 2EE, UK
Phone: +44 208 547 7518
Fax: +44 208 547 7497
E-mail: n.pet@kingston.ac.uk
Web: www.king.ac.uk/geog

Poupeau, Gerard R.
Centre de Recherche Physique Appliquée à l'Archéologie
Université Michel de Montaigne Bordeaux III
Maison de l'Archéologie, Esplanade des Antilles, 33607 Pessac, France
Phone: +33 5 5712 4547
Fax: +33 5 5712 4553
E-mail: gerard.Poupeau@montaigne.u-bordeaux.fr
Web: www.montaigne.u-bordeaux.fr/Rech/page12.html

Prashad, Rajinder
Fission Track Laboratory
Keshav Deva Malaviya Institute of Petroleum Exploration
Oil and Natural Gas Corporation
Dehradun, India
Web: www.ongcindia.com/r&d/oiis/kdmipe

Price, P. Buford
Department of Physics
University of California
Berkeley, CA 94720, USA
Phone: +1 510 642 4982
Fax: +1 510 643 8497
E-mail: bprice@uclink4.berkeley.edu; price@lbl.qov
Web: physics.berkeley.edu/research/price

Puch, Thomas
Institut für Geologie und Paläontologie
Karl-Franzens Universität
Heinrichstraße 26, A-8010 Graz, Austria

Qvale, Henning
Institute for Energy Technology
P.O. Box 40, N 2007, Kjeller, Norway
Phone: +47 6380 6122
Fax: +47 6381 5553
E-mail: hq@varney.ife.no
Web: www.ife.no/english

Raab, Matthias
Göttinger Zentrum für Geowissenschaften
Georg-August-Universität Göttingen
Goldschmidtstrasse 3, D-37077 Göttingen, Germany
Phone: +49 551 399 707
Fax: +49 551 399 700
E-mail: mraab@gwdg.de

Meinert Rahn
HSK
5232 Villigen-HSK
Switzerland
phone:++41 56 310 39 03
fax: ++41 56 310 49 03
E-mail:rahn@hsk.psi.ch

Ramachandran, T.V.
Environmental Assessment Division
Bhabha Atomic Research Center
Mumbai 400 085, India
E-mail : tvr@apsara.barc.ernet.in

Ratschbacher, Lothar
Tektonophysik - Institut für Geologie
Technische Universität Bergakademie Freiberg
Bernhard-von-Cottastrasse 2, D-09596 Freiberg, Germany
Phone: +49 3731 393 758
Fax: +49 3731 393 295
E-mail: lothar@geo.tu-freiberg.de
Web: www.geo.tu-freiberg.de/tektono

Ravenhurst, Casey E.
Department of Geology and Geography
University of Massachusetts
Amherst, MA 01003, USA
E-mail: cravenhu@geo.umass.edu
Web: www.geo.umass.edu

Rawling, Tim
Australian Crustal Research Centre
Monash University
Wellington Road, Clayton VIC 3800, Australia
Fax: +61 3 9905 5062
E-mail: timr@mail.earth.monash.edu.au
Web: www.earth.monash.edu.au/agcrc/people/tim_rawling

Raza, Asaf
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia
Phone: +61 3 8344 9977 /7675
Fax: +61 3 8344 7761
E-mail: asaf@unimelb.edu.au
Web: www.earthsci.unimelb.edu.au

Rebetez, Michel
Laboratoire de Microanalyses Nucléaires
U.F.R. des Sciences et des Techniques
Université de Franche-Comté
16 Route de Gray, 25030 Besancon Cedex, France
Phone: +33 3 81 66 65 01
Fax: +33 3 81 66 65 22
E-mail: michel.rebetez@univ-fcomte.fr
Web: www.univ-fcomte.fr

Redfield, Thomas F.
Technical Exploration Services
5 Frost Court, Mill Valley, CA 94941, USA

Reinecker, John
Institut für Geologie und Paläontologie
Eberhard Karls Universität Tübingen
Sigwartstrasse 10, D-72076 Tübingen, Germany
Fax: +49 7071 5059
E-mail: john.reinecker@gpi.uni-karlsruhe.de
Web: www.uni-tuebingen.de/geo/gpi

Reiners, Peter
Department of Geology
Washington State University
Pullman, WA 99164-2812, USA
E-mail: reiners@wsu.edu
Web: www.wsu.edu/~reiners

Rielly, Jane
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia
Phone: +61 3 8344 7673 /7675
Fax: +61 3 8344 7761
E-mail: j.rielly@pgrad.unimelb.edu.au
Web: www.earthsci.unimelb.edu.au

Riley, Brook
Department of Geological Sciences
University of Texas at Austin
Austin, TX 78712, USA
Fax: +1 512 471 9425
E-mail: bcdr@mail.utexas.edu
Web: www.geo.utexas.edu

Ring, Uwe
Institut für Geowissenschaften
Johannes Gutenberg Universität
Becherweg 21, D-55099 Mainz, Germany
Phone: +49 6131 392 2164
Fax: +49 61 31 392 4372
E-mail: ring@mail.uni-mainz.de
Web: www.uni-mainz.de/~ring

Roden-Tice, Mary, K.
Center for Earth and Environmental Science
State University of New York Plattsburgh
101 Broad Street, Plattsburgh, NY 12901, USA
Phone: +1 518 564 2019
Fax: +1 518 564 3152
E-mail: mary.rodentice@plattsburgh.edu
Web: faculty.plattsburgh.edu/mary.rodentice

Ruiz, Geoffrey
Institute of Geology, Department of Earth Sciences
ETH Zürich
Sonnegstrasse 5, CH-8092 Zurich, Switzerland
Phone: +41 1632 37 02
Fax: +41 1632 10 80
E-mail: ruiz@erdw.ethz.ch
Web: www.erdw.ethz.ch

Saini, Hari Singh
Department of Radiometric Dating
Birbal Sahni Institute of Palaeobotany
53 University Road, Lucknow 226 007, India
Web: www.bsip-india.org

Sandhu, Amanjit
Environmental Sciences, Physical Sciences Division
University of Toronto
Scarborough Campus, 1265 Military Trail, Scarborough, ON M1C 1A4, Canada
Fax: +1 416 287 7279
E-mail: amanjitsandhu@usa.net
Web: glacier.scar.utoronto.ca

Schäfer, **Thorsten**
Fachbereich 5, Geowissenschaften
Universität Bremen
Postfach 330440, D-28334 Bremen, Germany
Phone: +49 421 218 3994
Fax: +49 421 218 3993
E-mail: postgrad@geopol.unibremen.de
Web: www.palmod.uni-bremen.de/FB5/agpolar/englisch/index1.htm

Schierl, Heimo
Institut für Geologie und Paläontologie
Universitat Salzburg
Hellbrunnerstraße 34/III, A-5020 Salzburg, Austria
Phone: +43 662 8044 5437
Fax: +43 662 8044 621
Web: www.sbg.ac.at/gew

Schuller, Volker
Institut für Geologie und Paläontologie
Eberhard Karls Universität Tübingen
Sigwartstrasse 10, D-72076 Tübingen, Germany
Phone: +49 7071 2975 240
Fax: +49 7071 5059
E-mail: volker.schuller@uni-tuebingen.de
Web: www.uni-tuebingen.de/geo/gpi/ag-frisch/mitarbeiter/schuller

Schwab, Martina
Institut für Geologie und Paläontologie
Eberhard Karls Universität Tübingen
Sigwartstrasse 10, D-72076 Tübingen, Germany
Phone: +49 7071 2974 703
Fax: +49 7071 5059
E-mail: martina.schwab@uni-tuebingen.de
Web: www.uni-tuebingen.de/geo/gpi/index.html

Schwabe, Erika
Heroy Geology Laboratory
Department of Earth Sciences
Syracuse University
Syracuse, New York 13244-1070 USA
Phone: +1 315 443 3828
Fax: +1 315 443 3363
E-mail: eschwabe@syr.edu
Web: su-thermochronology.syr.edu

Sekyra, Gerd
Institut für Geologie und Paläontologie
Universitat Salzburg
Hellbrunnerstraße 34/III, A-5020 Salzburg, Austria
Phone: +43 662 8044 5437
Fax: +43 662 8044 621
Web: www.sbg.ac.at/gew

Sélo, Madeleine
Laboratoire de Minéralogie
Museum d'Histoire Naturelle
61 Rue Buffon, 75231 Paris Cedex 05, France
Fax : +33 1 40 79 35 24
E-mail: selo@mnhn.fr
Web: www.mnhn.fr/mnhn/mineralogie

Seward, Diane
Institute of Geology, Department of Earth Sciences
ETH-Zentrum
Sonneggstrasse 5, 8092, Zürich, Switzerland
Phone: +41 1 632 3675
Fax: +41 1 632 1080
E-mail: diane.seward@erdw.ethz.ch; diane@erdw.ethz.ch
Web: www.erdw.ethz.ch

Shane, Phil
School of Environmental and Marine Sciences
University of Auckland
Tamaki, Private Bag 92019, Auckland, New Zealand
Phone: +64 9 373 7599 ext. 6821
Fax: +64 9 373 7042
Web: sems.auckland.ac.nz

Siddall, Ruth
Fission Track Research Group
Department of Earth Sciences
University College London
London WC1E-6B, UK
Phone: +44 20 7679 2758
Fax: +44 20 7813 2802
E-mail: r.siddall@ucl.ac.uk
Web:www.ucl.ac.uk/geolsci/research/fissiontrack/Personal/Ruthpage/RS.html

Singh, Gurinder
Department of Physics
Guru Nanak Dev University
Amritsar 143005, India

Sobel, Edward
Institut für Geowissenschaften
Universität Potsdam
Postfach 60 15 53, D-14415 Potsdam, Germany
Phone: +49 331 977 5403
Fax: +49 331 977 5060
E-mail: sobel@rz.uni-potsdam.de
Web: www.uni-potsdam.de/u/Geowissenschaft/Personal/Sobel/Sobel.html

Sohrabi, Mehdi
Radiation Protection Department
Atomic Energy Organization of Iran
P.O. Box 14155-4494, Tehran, Iran
Fax: +98 21 690 6095
Email: aeoicom@dci.iran.com

Soloviev, Alexie
Institute of the Lithosphere of Marginal and Inland Seas
Russian Academy of Sciences
Staromonetny per. 22, Moscow, 109180, Russia
Web: isir.ras.ru/en

Sorkhabi, Rasoul B.
Geology and Geochemistry Section
Technology Research Center
Japan National Oil Corporation
2-2 Hamada, 1-Chome,Mihama-ku, chiba-shi 261-0025, Japan
Phone: +81 43 276 4420
Fax: +81 43 276 4062
E-mail: rasoul@jnoc.go.jp
Web: www.jnoc.go.jp/english

Spiegel, Cornelia
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia

Spikings, Richard
Section des Sciences de la Terre
University of Geneva
13 Rue des Maraichers
1211 Geneva 4, Switzerland
Phone: Lab +41 22 702 6639
Office +41 22 702 6826
Fax: +41 22 320 5732
E-mail: Richard.Spikings@terre.unige.ch

Stapel, Gerco
Department of Isotope Geochemistry
Faculty of Earth sciences
Vrije Universiteit Amsterdam
De Boelelaan 1085, Amsterdam 1081 HV, The Netherlands
Fax:. +31 20 646 2457
E-mail: stag@geo.vu.nl
Web: www.geo.vu.nl/~isotopen

Steckler, Michael S.
Lamont-Doherty Earth Observatory
Columbia University
Palisades, NY 10964, USA
Phone: +1 914 365 8479
Fax: +1 914 365 8179
E-mail: steckler@ldeo.columbia.edu
Web: www.ldeo.columbia.edu

Stiberg, Jan-Petter
Fission and Vision AS
Ammerudgrenda 271, 0960 Oslo, Norway
E-mail: fission@online.no

Stockli, Daniel
Division of Geological and Planetary Sciences
California Institute of Technology
Mail Stop 100-23, Pasadena, CA 91125, USA
Phone: +1 626 395 6177 /6007
Fax: +1 626 683 0621
Email: stockli@gps.caltech.edu
Web: www.gps.caltech.edu

Stockmal, Glen S.
Institute of Sedimentography and Petroleum Geology
Geological Survey of Canada
3303-33rd Street, N.W., Calgary, Alberta T2L 2A7, Canada
Phone: +1 403 292 7173
Fax: +1 403 292 5377
E-mail: gstockma@nrcan.gc.ca
Web: www.nrcan.gc.ca/gsc/calgary/staff/stockmal_e.html

Stone, John
Department of Geological Sciences
University of Washington
P.O. Box 351310, Seattle Washington 98195-1310, USA
Phone: +1 206 685 9514
Fax: +1 206 543 3836
E-mail: stone@geology.washington.edu
Web: www.geology.washington.edu/faculty/stone-bio.html

Storzer, Dieter
Laboratoire de Minéralogie
Museum d'Histoire Naturelle
61 Rue Buffon, 75231 Paris Cedex 05, France
Fax : +33 1 40 79 35 24
E-mail: storzer@mnhn.fr
Web: www.mnhn.fr/mnhn/mineralogie

Stump, Edmund
Department of Geological Sciences
Arizona State University
Box 871404, Tempe, AZ 85287-1404, USA
Phone: +1 480 965 3971
Fax: +1 480 965 8102
E-mail: ed.stump@asu.edu
Web: geology.asu.edu/people/faculty/stump/index.html

Stüwe, Kurt
Institut für Geologie und Paläontologie
Karl-Franzens Universität
Heinrichstraße 26, A-8010 Graz, Austria
Phone: +43 316 380 5682
Fax: +43 316 380 9870
E-mail: kurt.stuewe@kfunigraz.ac.at
Web: wegener.kfunigraz.ac.at

Sumii, Tomoaki
Geochemistry Department
Geological Survey of Japan
1-1-3 Higashi, Tsukuba, 305, Japan
Phone: +81 298 54 3558
Fax: +81 298 54 3533
E-mail: sumii@gsj.go.jp
Web: www.aist.go.jp/gsj/dgc/chemtop.htm

Summerfield, Michael A.
Department of Geography
School of Earth Sciences
University of Edinburgh
Edinburgh EH8 9XP, UK
Phone: +44 131 650 2519
Fax: +44 131 650 2524
E-mail: mas@geo.ed.ac.uk
Web: www.geo.ed.ac.uk/home/geoghome.html

Suzuki, Masao
Rikkyo University
34-1 Nishi Ikebukuro, 3-Chome, Toshima-ku,
Tokyo 171, Japan
Web: www.rikkyo.ne.jp/~koho/englishpages.htm

Suzuki, Tatsuo
Department of Geology
Faculty of Education
Kagoshima University
Korimoto 1-20-6, Kagoshima 890-0065, Japan
Phone: +81 99 285 7807
Fax: +81 99 285 7807
E-mail: t_suzuki@edu.kagoshima-u.ac.jp
Web: www.edu.kagoshima-u.ac.jp/english.html

Tagami, Takahiro
Department of Geology and Mineralogy
Kyoto University
Kitashirakawa Oiwakecho, Sakyo-ku, Kyoto, 606-8502,
Japan
Phone: +81 75 753 4153
Fax: +81 75 753 4189
E-mail: tagami@terra.kueps.kyoto-u.ac.jp
Web: www.kueps.kyoto-u.ac.jp/~tagami/

Talbot, James
K/T GeoServices Inc.
P.O. Box 126, Argyle, TX 76226-0126, USA
Phone: +1 214 403 6342
Fax: +1 940 387 9980
E-mail: james@ktgeo.com
Web: www.ktgeo.com/tCI.html

Tamanyu, Shiro
Geothermal Resources Research Group
Institute for Geo-resources and Environment
National Institute of Advanced Industrial Science and Technology
Central 7, 1-1-1 Higashi, Tsukuba, 305-8567, Japan
Phone: +81 298 61 3941 /3737
Fax: +81 298 61 3717
E-mail: s.tamanyu@aist.go.jp
Web: unit.aist.go.jp/georesenv/English/index.html

Tello Sáenz, Carlos A.
Departamento de Raios Cósmicos e Cronologia
Instituto de Fisica Gleb Wataghin
Universidade Estadual de Campinas
Caixa Postal 6165, CEP 13083-970 UNICAMP, Campinas, SP,
Brazil
Phone: +55 19 788 5522
Fax: +55 19 788 5512
E-mail: saenz@ifi.unicamp.br
Web: www.ifi.unicamp.br/~turtelli/www0.htm

Thomson, Stuart
Institut für Geologie, Mineralogie und Geophysik
Fakultät für Geowissenschaften
Ruhr-Universität Bochum
Postfach 102148, D-44721 Bochum, Germany
Phone: +49 234 32 23236
Fax: +49 234 32 14572
E-mail: stuart.n.thomson@ruhr-uni-bochum.de
Web: homepage.ruhr-uni-bochum.de/Stuart.N.Thomson/Index.html

Tingate, Peter
National Centre For Petroleum Geology and Geophysics
Thebarton Campus
University of Adelaide
Adelaide SA 5005, Australia
Phone: +61 8 8303 4296
Fax: +61 8 8303 4345
E-mail: peter.tingate@adelaide.edu.au
Web: www.ncpgg.adelaide.edu.au/staff/peter_tingate.htm

Tonk, Christian
Museum für Mineralogie und Geologie
Staatliche Naturhistorische Sammlungen Dresden
Königsbrücker Landstraße 159, 01109 Dresden, Germany
Phone: +49 351 892 6424
fax: +49 351 892 6404
E-mail: tonk@snsd.de
Web: www.snsd.de

Toro Villegas, Gloria E.
Departamento de Geologia
Escuela de Administración, Finanzas y Tecnologías
Universidad EAFIT
A.A. 3300, Medellin, Colombia
Phone: +57 4 26 60 500 Ext. 352
E-mail: gtoro@eafit.edu.co; gtoro@sigma.eafit.edu.co
Web: www.eafit.edu.co/departamentos/geologia

Trautmann, Christina
Materials Research
Gesellschaft für Schwerionenforschung
Planckstrasse 1, D-64291 Darmstadt, Germany
Phone: +49 6159 71 2716
Fax: +49 6159 71 3266
E-mail: c.trautmann@gsi.de
Web: www-wnt.gsi.de/mr

Trautwein, Britta
Institut für Geologie und Paläontologie
Eberhard Karls Universität Tübingen
Sigwartstrasse 10, D-72076 Tübingen, Germany
Phone: +49 7071 2974 702
Fax: +49 7071 5059
E- mail: britta.trautwein@uni-tuebingen.de
Web: www.uni-tuebingen.de/geo/gpi/ag-frisch/mitarbeiter/trautwein

Van den haute, Peter
Geologisch Instituut
Universiteit Gent
Krijgslaan 281 (S8), B-9000 Gent, Belgium
Phone: +32 9 264 4592
Fax: +32 9 264 4984
E-mail: peter.vandenhaute@rug.ac.be
Web: allserv.rug.ac.be/~fmees/mineralogy.htm

van der Beek, Peter
Labo de Géodynamique des Chaînes Alpines
Observatoire des Sciences de l'Univers Grenoble
Université Joseph Fourier
Maison des Géosciences, BP 53, 38041 Grenoble, France
Phone: +33 476 514 062
Fax: +33 476 514 058
E-mail: pvdbeek@ujf-grenoble.fr
Web: www.univ-savoie.fr/labos/lgca/perso/cherc/pvand/pvand.htm

Van der Wateren, F. M.
Department of Isotope Geochemistry
Faculteit Aardwetenschappen
Vrije Universiteit Amsterdam
De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands
Fax: +31 20 646 2457
Web: www.geo.vu.nl/~isotopen

Vasconcelos, Paulo
Department of Earth Sciences
University of Queensland
St Lucia, Brisbane QLD 4072, Australia
Phone: +61 7 3365 2297
Fax: +61 7 3365 1277
E-mail: p.vasconcelos@earth.uq.edu.au; paulo@bgc.org
Web: www.earth.uq.edu.au

Ventura, Barbara
Fachbereich 5, Geowissenschaften
Universität Bremen
Postfach 330440, D-28334 Bremen, Germany
Phone: +49 421 218 3994
Fax: +49 421 218 3993
E-mail: bventura@geopol.uni-bremen.de
Web:www.palmod.unibremen.de/FB5/agpolar/englisch/index1.htm

Vidal, Olivier
Laboratoire de Géodynamique des Chaînes Alpines
Université Joseph Fourier, Maison des Géosciences
1381 Rue de la Piscine, 38400 St-Martin d'Hères, France
Phone: +33 4 76 63 59 24
Fax : +33 4 76 51 40 58
E-mail : Olivier.Vidal@ujf-grenoble.fr
Web:www.univsavoie.fr/labos/lgca/perso/cherc/ovid/ovid.htm

Viola, Giulio
Department of Geological Sciences
University of Cape Town
7701, Rondebosch, Cape Town, South Africa
Phone: +27 21 650 2928
Fax: +27 21 650 3783
Email: gviola@geology.uct.ac.za
Web: www.uct.ac.za/depts/geolsci

Virk, H. S.
Department of Physics
Guru Nanak Dev University
Amritsar 143005, India

Wadatsumi, Kiyoshi
Department of Geosciences
Osaka City University
3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558 Japan
Phone: +81 6 605 2593
Fax: +81 6 605 3071
E-mail: h1602@ocugw.cc.osaka-cu.ac
Web: www.sci.osaka-cu.ac.jp/geos/english/geoeng.html

Wagner, Martin
Institut für Petrographie und Geochimie
Universität Karlsruhe
Kaiserstrasse 12, D-7500 Karlsruhe, Germany

Wagner, Günther A.
Max-Planck-Institut für Kernphysik
Postfach 103980, D-69029 Heidelberg, Germany
Phone: +49 6221 516 289
Fax: +49 6221 516 633
E-mail: g.wagner@mpi-hd.mpg.de
Web: www.mpi-hd.mpg.de/english/index.html

Walgenwitz, Frederic
CSTJF Elf Aquitaine Production
Avenue Larribau, 64018 Pau Cedex, France
E-mail: frederic.walgenwitz@elf-p.fr

Walker, J. Douglas
Department of Geology
University of Kansas
120 Lindley Hall, Lawrence, KS 66045-2969, USA
Phone: +1 785 864 2735
Fax: +1 785 864 5276
E-mail: jdwalker@ukans.edu
Web: www.ukans.edu/~geology

Walker, Robert M.
McDonnell Center for Space Sciences
Physics Department
Washington University
1 Brookings Drive, St. Louis, MO 63130-4899, USA
Phone: +1 314 935 6257
Fax: +1 314 935 4083
E-mail: brw@wuphys.wustl.edu
Web: www.physics.wustl.edu/fac/walker.html

Wallace, Wesley K.
Department of Geology and Geophysics
University of Alaska
Fairbanks, AK 99775-5780, USA
Phone: +1 907 474 5386
Fax: +1 907 474 5163
E-mail: wes.wallace@gi.alaska.edu
Web: www.gi.alaska.edu/tsrg/people/wallace

Walter, Robert
Institute of Human Origins
1288 Ninth Street, Berkely, CA 94709-1211, USA
Phone: +1 510 525 0500
Fax: +1 510 525 0668
E-mail: bwalter@iho.org

Wang, Shicheng
Institute of High Energy Physics
Chinese Academy of Sciences
P.O. Box 2732, Beijing 100080, P.R. China
E-mail: wangshch@ihepa.ac.cn
Web: www.ihep.ac.cn/english/index.htm

Waraich, R. S.
Fission Track Laboratory
Keshav Deva Malaviya Institute of Petroleum Exploration
Oil and Natural Gas Corporation
Dehradun, India
Web: www.ongcindia.com/r&d/oiis/kdmipe

Watanabe, Hiroaki
Department of Earth Sciences
Kanazawa University
Kanazawa, 920-1192, Japan
Fax: +81 76 264 5746
E-mail: hiro741@kenroku.kanazawa-u.ac.jp
Web: earth.s.kanazawa-u.ac.jp/chronology/EnglishPage/indexE.html

Watanabe, Koichiro
Department of Mining
Faculty of Engineering
Kyushu University
36 Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan
Phone: +81 92 642 3634
E-mail: wat@mine.kyushu-u.ac.jp
Web: www.eng.kyushu-u.ac.jp/index-e.html

Weber, Ursula D.
School of Earth Sciences
University of Melbourne
Parkville, Victoria 3010, Australia
Phone: +61 3 8344 9669 /7675
Fax: +61 3 8344 7761
E-mail: u.weber@pgrad.unimelb.edu.au
Web: www.earthsci.unimelb.edu.au/~udw

Westgate, John A.
Environmental Sciences, Physical Sciences Division
University of Toronto
Scarborough Campus, 1265 Military Trail, Scarborough, ON M1C 1A4, Canada
Phone: +1 416 287 7234
Fax: +1 416 287 7279
E-mail: westgate@scar.utoronto.ca
Web: glacier.scar.utoronto.ca

Willet, Sean D.
Department of Geological Sciences
University of Washington
P.O. Box 351310, Seattle Washington 98195-1310, USA
Phone: +1 206 543 8653
Fax: +1 206 543 3836
E-mail: swillett@u.washington.edu
Web: www.geology.washington.edu/~willett

Wu, Qianhong
Changsha Institute of Geotectonics
Academia Sinica
Changsha 410013, Hunan Province, P.R. China
Phone: +86 731 885 9165
Fax: +86 731 885 9137
E-mail: wqh@ms.csig.ac.cn
Web: www.csig.ac.cn

Wyatt, Bruce
Stockdale Prospecting Ltd.
60 Wilson Street, Box 126, South Yarra, Vic 3141 Australia
Fax: +61 8 9378 0020
Email: bruce@spl.oz.au

Xu, Ganqing
Department of Earth Sciences
University of Waikato
Private Bag 3105, Hamilton 2001, New Zealand
Phone: +64 7 838 4024
Fax: +64 7 856 0115
E-mail: xu1@waikato.ac.nz
Web: sci.waikato.ac.nz/cgi-bin/dynapage.pl?pagename=erth

Yamada, Ryuji
Nagaoka Institute of Snow and Ice Studies
National Research Institute for Earth Science and Disaster Prevention
9400082 Suyoshi, Nagaoka, Niigata, Japan
Phone: +81 258 35 7522
Fax: +81 258 35 0020
E-mail: ryamada@nagaoka.bosai.go.jp
Web: www.bosai.go.jp/ad/Eng/division.htm

Yamashita, Tohru
Kyoto Fission Track Co. Ltd.
44-4 Minamitajiri-cho, Kita-ku, Kyoto 603, Japan
Phone: +81 75 493 0684
Fax: +81-75 493 0741
E-mail: BYU02730@niftyserve.or.jp

Yang, Tsanyao Frank
Department of Geology
National Taiwan University
245 Chou-shan Road, Taipei 106-17, Taiwan
Phone: +886 2 2369 5568
Fax: +886 2 2363 6095
E-mail: tyyang@ccms.ntu.edu.tw
Web: www.gl.ntu.edu.tw/english_mode

Yegingil, Zehra
Physics Department
Cukurova University
P.O. Box 171, 01330 Adana, Turkey
E-mail: zehra@cu.edu.tr
Web: www.cu.edu.tr/fakulteler/fef

Yoshioka, Tetsu
Kyoto Fission Track Co. Ltd.
44-4 Minamitajiri-cho, Kita-ku, Kyoto 603, Japan
Phone: +81 75 493 0684
Fax: +81-75 493 0741
E-mail: BYU02730@niftyserve.or.jp

Yuan, Wanming
Institute of High Energy Physics
Chinese Academy of Sciences
P.O. Box 2732, Beijing 100080, P.R. China
E-mail: yuanwm@ihepa.ac.cn
Web: www.ihep.ac.cn/english/index.htm

Yuexing, Feng
Department of Earth Sciences
University of Queensland
St Lucia, Brisbane QLD 4072, Australia
Fax: +61 7 3365 1277
E-mail: feng@earthsciences.uq.edu.au
Web: www.earth.uq.edu.au

Zattin, Massimiliano
Dipartimento di Scienze Geologiche
Universita di Bologna
Via Zamboni 67, 40127 Bologna, Italy
Phone: +39 51209 4579
Fax: +39 51209 4522
E-mail: zattin@geomin.unibo.it
Web: www.geomin.unibo.it

Zeitler, Peter K.
Department of Earth and Environmental Sciences
Lehigh University
31 Williams Drive, Bethlehem, PA 18015, USA
Phone: +1 215 758 3671
Fax: +1 215 758 3677
E-mail: peter.zeitler@lehigh.edu
Web: www.ees.lehigh.edu

Zentilli, Marcos
Department of Earth Sciences
Dalhousie University
Halifax, Nova Scotia, B3H 3J5, Canada
Phone: +1 902 494 3873
Fax: +1 902 494 6889
E-mail: marcos.zentilli@dal.ca
Web: meguma.earthsciences.dal.ca/staff/zentilli/zentilli.htm

Zhao, Yunlong
Beijing Geological Research Institute of Nuclear Industry
P.O.Box 9818 Beijing, P.R. China
Fax: +86 010 6491 7143
Web: www.cnnc.cn.net

Zhou, Zuyi
Department of Marine Geology and Geophysics
Tongji University
1239 Siping Road, 200092 Shanghai, China
Phone: +86 21 6598 2358
Fax: +86 21 6502 6278
E-mail: zzydmg@tju.ihep.ac.cn
Web: www.tongji.edu.cn/lib_english/enindex.htm

Zuffa, Gian Gaspare
Dipartimento di Scienze Geologiche
Universita di Bologna
Via Zamboni 67, 40127 Bologna, Italy
Phone: +39 51209 4540
Fax: +39 51209 4522
E-mail: zuffa@geomin.unibo.it
Web: www.geomin.unibo.it

Zwingmann, Horst
CSIRO Petroleum Resources
P.O. Box 136, North Ryde NSW 1670, Australia
Phone: +61 2 9490 8666
Fax: +61 2 9490 8902
E-mail: h.zwingmann@dpr.csiro.au
Web: www.dpr.csiro.au/research/tbe.html

Afterthoughts

A Ronda Ronda the garden like a teddy bear ....*(adapted from an old English nursery rhyme)*

Call for Contributions

The next issue of On Track is scheduled for January 2003 and we are looking for contributions. On Track welcomes contributions of virtually any kind, including scientific articles, news, gossip, job openings, descriptions of new lab techniques, reviews of useful products, ravings about what the other labs are doing wrong, meeting announcements, cartoons and descriptions of what you are doing in your research.

If you would like to contribute, please send the final document no later than **Dec 31, 2002**. If you intend to submit a substantial article, please let the editor know as soon as possible.

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

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Send contributions to:

Ed Sobel
Institüt für Geowissenschaften,
Universität Potsdam,
Postfach 601553,
D-14415 Potsdam
Germany
Phone:++ 49   331977 5403
Fax:++ 49 331 977 5060
E-mail: sobel@rz.uni-potsdam.de