On Track

The Newsletter of the International Fission-Track Community

May 1997, Volume 7, Number 1, Issue 14

Editor: *Danny Stockli*

Department of Geological and Environmental Sciences,
Stanford University, Stanford, California 94305-2115 USA
(danny@pangea.stanford.edu)

In this Issue:

One copy per lab; please copy and distribute

On Track is a biannual newsletter of the international fission-track community. It is printed in the months of May and November. The views expressed in On Track are those of the authors and do not necessarily reflect those of the fission-track community or the editor(s) of On Track.

On Track will remain free, at least for the near future. However, to save costs we generally mail only one copy per lab so please be sure to pass On Track around your lab.

Printing and mailing costs for this issue of On Track were paid for by a monetary donation from Donelick Analytical, Incorporated and paid advertisements. Standard prices for full, half, and quarter page advertisements are US$ 200, US$ 100 and US$ 50, respectively. There is no charge for "short" ads by non-commercial entities (e.g., universities). Send inquiries concerning On Track to the next editor.

PREVIOUS EDITORS:
Dave Coyle (1990-91), La Trobe University
Trevor Dumitru (1991-92), Stanford University
Rasoul B. Sorkhabi (1992-93)Arizona State University
Dennis Arne (1993-94) Dalhousie University
Richard J. Weiland (1994-95) U of Texas, Austin
Ruth Siddall (1995-96) University College London

CURRENT EDITOR:
Danny Stockli (1996-97)
Department of Geological and Environmental Sciences
Stanford University
Stanford, California 94305-2115,
U.S.A.
Tel/Fax.: 415-725-6155
E-mail: danny@pangea.stanford.edu

NEXT EDITOR:
Paul O'Sullivan (1997-98)
School of Earth Sciences
La Trobe University
Bundoora, Victoria 3083
Australia
Tel. (03) 9479-3517
Fax. (03) 9479-1272
E-mail: pos@mojave.geol.latrobe.edu.au

Editor's Notes

In this issue, **Tracker** presents statistical insights into the topic of negative association between uranium concentration and track densities. This is a problem that was indirectly brought up by Ann Blythe in her article on the compositional influence on zircon annealing (OT, Nov 1996). It seems that zircon fission-track dating continues to be a red hot topic. In that context, **Meinert Rahn** presents new results regarding the temperature range of the zircon partial annealing zone. Time really seems to fly! **Ruth Siddall** refreshes our memories of the 1997 fission-track workshop in Gent. Once again we would like to thank **Franz De Corte** and **Peter Van den Haute** for the excellent organization of the workshop and their hospitality. **Maria Laura Balestrieri** and others present a new potential standard for dating glass, and **Ray Donelick** discusses the controversial topic of apatite fission-track annealing kinetics. In More Short Tracks (p. 20), **Paul Green** describes the move of Geotrack International Pty. Ltd. to a former Mental Clinic - a report not to be missed!

This is my last issue as editor of On Track. It has been an all around pleasure serving the FT community. I am sure some people are probably tired of my twisting their arms to contribute. I have to say that editing OT in a world dominated by two incompatible computer worlds (and Mathematica!!!) was not always an easy task. But I hope everybody enjoyed it. So long!

Consequently I would like to introduce **Paul O'Sullivan** as the next editor. Paul received his B.S. and M.S. degrees in geology from the University of Alaska, and his Ph.D. in geology in 1993 from La Trobe University. He's currently employed as a Research Fellow by the Australian Geodynamics Cooperative Research Center, based at La Trobe University where he's part of a research team responsible for developing a fission track thermotectonic image of the Australian continent. He's also still extremely active in thermotectonic studies throughout Alaska (with John Murphy), western Canada (with Lisel Currie), western United States, Indonesia (with Kevin Hill, Dan Kendrick, Edy Sutrioyono), and western South America. He's also involved with dating artifact sites in Indonesia.

So please note the change in editorship and send all future contributions to Paul O'Sullivan. He also asked me to urge on his behalf for those folks who are sitting on interesting ideas/short papers/items of "Tracker" interest, to please contribute to OnTrack so that we can all keep this excellent newsletter continuing.

A Negative Association

by Tracker

(Your man at the microscope, with the uncertain age and the U concentration)

The following letter arrived recently by express post:

> Dave's Hat Shop,
> Grizzly Mountain, Alaska,
> June, 1993.
>
> Dear Mr. Tracker,
> I admit that I have never fought the giant panda, but I do know something about hats. Your recent article *Trials and Errors* (*OT*, May 1993) apparently contains more *Errors* than intended.
> Practically every rho has a missing hat. Not only is this extremely untidy, as Ophelia would often complain:
> "Lord Hamlet, with his doublet all unbraced;
> No hat upon his head; his stockings fouled,
> Ungart'red, and down-gyvéd to his ankle …"
> but also it makes a nonsense of the whole hat industry, with which many of us have been associated from an early age. Furthermore, some rho's have gone Latin and your square roots are ambiguously truncated to say the least.
> I remain, yours etc., D. Crockett.

A mad hatter it seems. But the honest fellow is perfectly correct. We use a Greek rho (ρ) to denote the real track density, and rho-hat (ρ with a ^ on top) to denote the measurement, or estimate, of ρ. The Greeks naturally use the opposite convention, which accounts for the rarity of Greek statisticians. In the aforementioned article, therefore, the *first* ρ in each equation (1) – (5), but not the others, should have a hat on. Also, a standard error refers to the estimate, not the true value, so when you see the expression se(ρ) or ρ ± 2se(ρ), the ρ should have a hat on. I leave you the exercise of retrieving your ancient issue of *On Track*, adding the appropriate hats, changing *r* to ρ in the first two of the three sentences before equation (4), and clarifying all square root signs. I regret the confusion and can only assume that our Editor has Greek relations (τηατ ωασ α πρεϖιουσ εδιτορ -- current editor).

But why are we so fussy with hats? Why do we distinguish between the "true" value of a quantity and the value observed when we measure it? Because not to do so can cause misunderstanding and mistakes, as I was unsuccessfully trying to explain. Plotting age against uranium is a good example.

Age and uranium

Ann Blythe, in the November issue of *On Track*, plotted fission track age against uranium concentration for three zircon samples, and found that older grains tended to have lower uranium concentration than younger grains. She conjectured a partial resetting of ages through metamictization of high-U zircons, but also noted a possible "counting bias" problem where old high-U grains (and young low-U grains) were more difficult to count. A similar negative association between age and U was noted by Andy Carter at Besançon, who also cited earlier references to it. He considered several possible causes, including variable annealing rates, poor thermalisation of the reactor, imperfect matching of detector, variable etching and counting bias.

Now, as AB and AC recognised, there will indeed tend to be a negative association between age and uranium within a sample due to selection of grains. Paul Green describes common practice for selecting zircons thus:

> "Start at one corner of the mount and traverse across looking at every grain and counting all (or enough) of those grains that fulfill the usual criteria (prismatic surface, well etched, etc.). The main criterion is that the track density should be countable — too high and you can't count it, too low and the tracks don't etch properly because the background alpha damage isn't sufficiently intense and the grain etches anisotropically. In practice, the band of acceptable track densities is probably around 5E5 to 5E6. I don't think anyone selects grains for uranium content, or takes account of grains with rho's that are too high to count. Chuck and Nancy published a paper some time ago (in *Nuclear Tracks* I think) suggesting different etch times to select grains of different track densities within one sample, but in practice I've never been convinced on this because when all is said and done the range of countable track densities is pretty narrow."

So a major limitation is that the spontaneous track density ρ_s should be in the acceptable range. Now ρ_s is roughly proportional to the *product* of age and U concentration, so if a grain is old, it stands to reason that it will need to have a lower U concentration in order to keep ρ_s to within the limits. And *vice versa*. Although I have expressed this in terms of the underlying *true* track density, in practice grains will be selected on the basis of the *observed* counts per unit area. Thus for example, if uranium concentrations are high enough, the observed numbers of spontaneous tracks may vary sufficiently that some will be uncountable, even if the true ages are the same for each grain. And if the true ages also varied, we would expect the selection effect to be stronger.

If you were trying to discover a real relationship between age and uranium, how could this bias be avoided? One way might be to select grains by looking at the *induced* tracks. Then you would sometimes select grains where spontaneous tracks are too dense to count (or inadequately etched). The spontaneous track counts for these grains would need to be treated as *censored* data — a statistical procedure much less exciting than it sounds. Nevertheless it could be done in principle.

Related measurements

But there is another, more subtle, statistical association that arises when you plot "age" against "uranium", even, indeed especially, when age and uranium are practically constant. What is really plotted is *measured* age against *measured* uranium (age-hat against U-hat). The former is roughly proportional to the ratio n_s/n_i while the latter is proportional to n_i/A, where A is the area of crystal surface in which tracks are counted. Even if the true ages and uranium contents were the same for each grain, the counts would differ because of their natural Poisson variation. Furthermore a larger than expected n_i would produce, other things being equal, a smaller than expected n_s/n_i and *vice versa*, resulting in a negative correlation. In other words, the measured ages and U-concs are not independent because they use the same n_i — and moreover n_i is imprecise.

Let us say this with numbers. Suppose the true $\rho_s = 50$, $\rho_i = 100$, so $\rho_s/\rho_i = 0.5$. And let us count tracks in equal areas, which we take to be unit area. Suppose we observe $n_s = 50$ (fortuitously equal to the true value of ρ_s) and $n_i = 108$, which is a random value from a Poisson distribution with mean 100. Then our estimate of uranium concentration (in suitable units) will be 108, which is a bit larger that the true value 100, while our estimate of ρ_s/ρ_i will be $50/108 = 0.46$, a bit lower than the true value of 0.5. If instead we had observed $n_i = 94$, which we might well have, we would estimate the uranium concentration to be 94 (an under-estimate) and simultaneously estimate ρ_s/ρ_i as $50/94 = 0.53$ (an over-estimate). For several grains with the same $\rho_s = 50$ and $\rho_i = 100$, induced track counts greater than 100 will tend to produce lower age estimates while induced track counts less than 100 will tend to produce higher age estimates. Thus when we plot the age estimates against the corresponding U estimates there will be a negative association. In practice, other things also vary — spontaneous track counts, areas, uranium concentrations and possibly true ages — which may partially hide this effect, but it will still exist. It is essentially a correlation between the estimation *errors* of age and uranium concentration. It exists precisely because n_i is imprecise.

Two associations

So there are *two* negative associations. When assessing any relation between age and uranium, we need to understand not only how grains are selected but also how the measurements are related.

Which effect is greater? As far as selection is concerned, the counter must get some feel about whether a high proportion of grains are rejected because ρ_s is outside the acceptable range. This effect seems likely to be relatively strong when both the true ages and uranium concentrations vary substantially. The correlation due to the related measurements, on the other hand, is easy to estimate and take account of if necessary. Its effect will be greatest when the true ages and Us are constant. And it will arise just as easily in apatite samples. For example, I happen to have results from Ian Duddy for the two apatite samples used for the Besançon interlaboratory trial. The sample correlations between age and uranium concentration (20 grains each) are −0.41 and −0.42.

In fact it is possible to measure age and uranium "independently" by the external detector method. After counting n_s, irradiating and counting n_i, send your grains back to the reactor to irradiate them *again* (using a new detector) and obtain a second induced track count n_{i2} for the same matched areas. Use n_s/n_i to measure age and n_{i2} to measure uranium, and you will not see the latter negative relation. Furthermore, any relation you do see will then have some other cause. Some years ago Chuck Naeser sent me some Fish Canyon Tuff zircon data where two irradiations were done to obtain duplicate induced track counts for 48 grains. The counts are beautiful, mostly between 200 and 400 for both spontaneous and induced tracks. The sample correlation between single grain age (Ma) and uranium (ppm), using results from the first irradiation only is −0.27. But the correlation between age from the first irradiation and uranium from the second irradiation is only −0.09, much nearer zero. I would expect the selection effect to be small here and the correlation of −0.27 to be essentially due to non-independence of the measurement errors.

Random numbers

You can demonstrate these correlations with random numbers. In Figure 1 there are 50 notional grains each with the same true $A\rho_s = 40$ and $A\rho_i = 80$. The counts have random Poisson values with these means. For simplicity let us suppose that the same area A is always used. The top left panel shows $A\rho_s$ plotted against $A\rho_i$ and the bottom left panel shows ρ_s/ρ_i

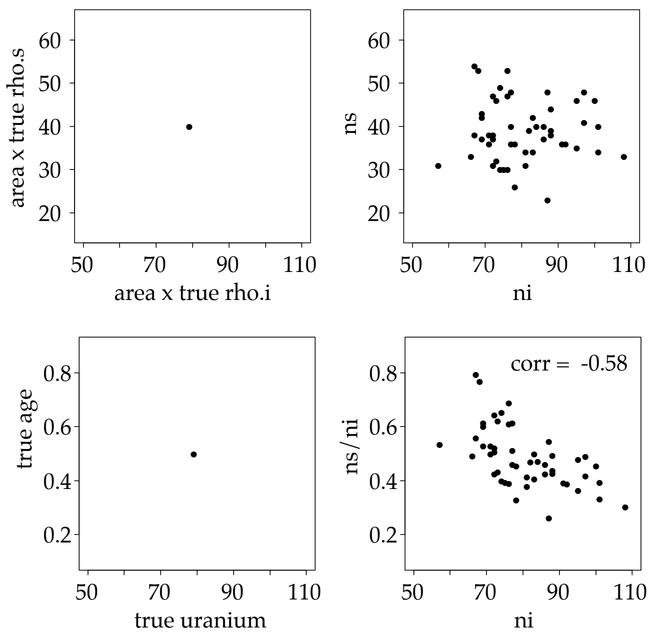

Figure 1: constant age and uranium

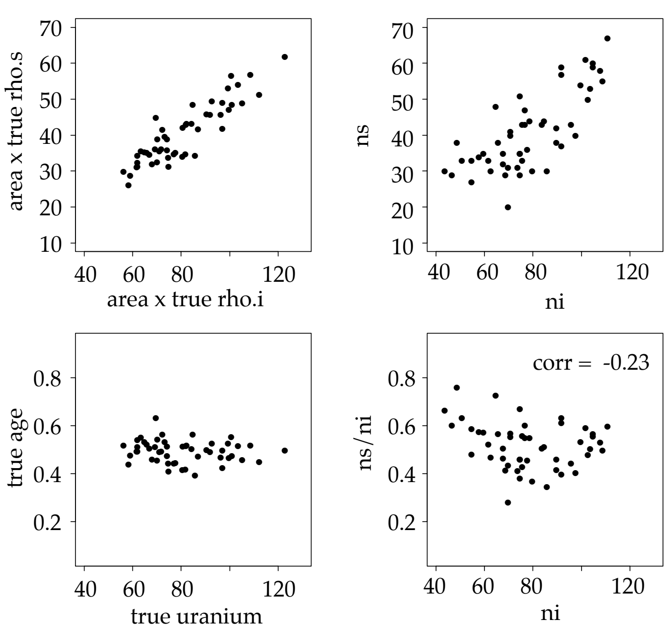

Figure 2: 10% age and 20% uranium variation

against $A\rho_i$, both of which are the same for each grain in this case. The right panels plot correspondingly n_s against n_i, and n_s/n_i against n_i, where the Poisson variation is added. The bottom left panel is effectively true age against true uranium while the bottom right panel is effectively measured age against measured uranium — and clearly shows the negative correlation we now expect. In Figure 2, I have generated random values of $A\rho_i$ with a 20% coefficient of variation and *independent* random values of ρ_s/ρ_i with a 10% c.v. The true ages and U-concentrations vary between grains, but are independent (bottom left), while the measured values are negatively correlated (bottom right). Now the association is not so strong. If the true ages and amounts of uranium vary enough, this variation will mask the Poisson variation and hide the correlation.

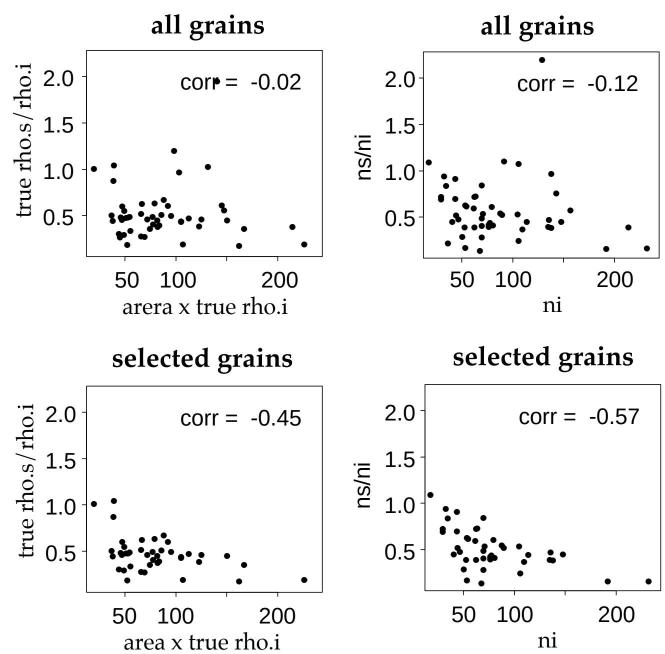

Figure 3: 50% age and 50% uranium variation

Figure 3 is different. This illustrates effects of both selection and related measurements when the true ages and uranium contents are independent and both have a 50% c.v. The top left panel plots independent random values of ρ_s/ρ_i against $A\rho_i$ for 50 grains, and shows a practically zero correlation. The top right panel plots the measured values n_s/n_i against n_i. The correlation is now slightly negative, but still quite near zero — the larger variation in true age and U has largely masked the Poisson variation. In the bottom panels I have selected only those grains whose spontaneous track count n_s is between 10 and 80. The real selection criterion is of course much more subtle than this. For these grains, there is a clear negative correlation between the *true* ages and U's due to selection (bottom left panel) and an even stronger one between the measured values, due to both selection and non-independence (bottom right panel). All panels use the same scales, so those with keen eyes can discern which points have been selected and which have been most affected by Poisson's law.

A formula

I have worked out an approximate formula for the correlation between n_s/n_i and n_i/A due to non-independence, based on the following assumptions. Areas A are randomly chosen with mean ν and coefficient of variation δ; values of ρ_i are randomly chosen with mean μ and coefficient of variation α; and values of ρ_s/ρ_i are randomly chosen with mean λ and coefficient of variation β. Then the correlation between n_s/n_i and n_i/A is approximately

$$-1 / \sqrt{\{ [1 + \nu\mu\alpha^2(1 + \delta^2)][1 + \lambda^{-1} + \nu\mu\beta^2(1 + \alpha^2 + \delta^2 + \alpha^2\delta^2)] \}} .$$

A few simulations suggest that this slightly under-estimates the strength of the correlation, but by substituting reasonable values for the various means and coefficients of variation it will probably give a rough idea of the size of this effect. If all areas are equal, put $\delta = 0$. Substituting $\delta = 0$, $\nu\mu = 80$, $\lambda = 0.5$, $\alpha = 0.2$ and $\beta = 0.1$, which are the parameters used for Figure 2, gives a correlation of –0.25, close to the empirical value of –0.23.

When all true ages, U's and areas are the same, $\alpha = \beta = \delta = 0$ and the above formula reduces to

$$-1 / \sqrt{(1 + \lambda^{-1})} = -\sqrt{\{ \rho_S/(\rho_S + \rho_i) \}}$$

which is the formula cited by Andy Carter. Substituting $\lambda = 0.5$ gives a theoretical value of –0.58, in miraculous agreement with the empirical value in Figure 1. Of course it is not possible to give a general formula for the correlation due to selection.

Change against initial value

Spurious negative associations have often arisen in the scientific literature, particularly in medical and social sciences, where measurements contain a substantial "random" component. Measurements on a number of individuals are taken before and after some treatment or intervention, and in order to see if the treatment effect might depend on the underlying level of the variable in question, the change (or treatment effect) is plotted against the initial measurement. A "significant" negative correlation is reported, often with much excitement, and it is concluded that the treatment reduces the response for those with an initial high value, but has an opposite effect for those with an initial low value. The fact is that there would be a negative correlation even if the treatment had no effect at all. What would be really interesting is if there were *no* correlation!

Actually, there is a clever trick for trying to see if any change depends on the size of the measurement. That is, plot the change (after minus before) against the *mean* of the before and after values. This seems intuitively wrong because the second measurement includes the treatment effect. But when the treatment effect is additive and the random component of variation is about the same for both the before and after measurements, this has the magical effect of eliminating the negative correlation. A trend on this plot might thus be of real interest — the average treatment effect might depend on the initial level, or the treatment might change the variance of the responses. I attribute this idea to the late Patrick Oldham, though our American friends might claim it to be one of John Tukey's many inventions.

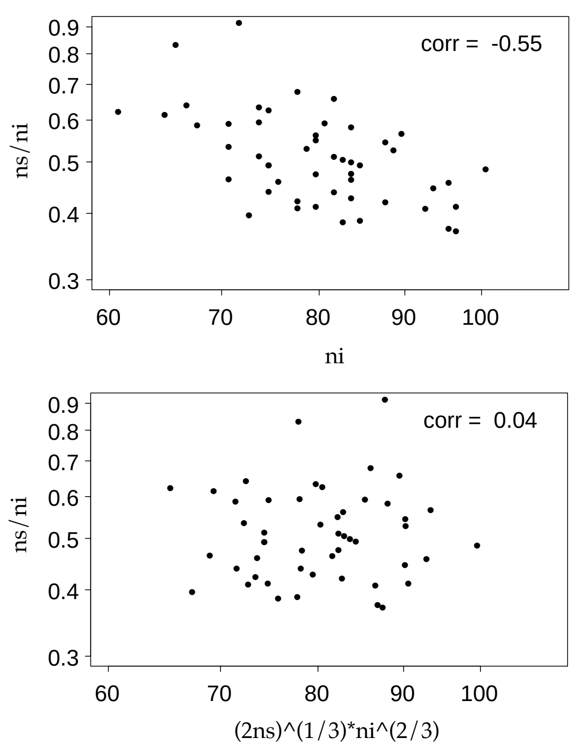

Figure 4

Now I can hear you thinking "If you plot the *logarithm* of n_s/n_i against the *logarithm* of n_i, is that not the same as plotting a difference against the initial value?" So it is — and therefore can we not "eliminate the negative" by plotting log n_s/n_i against the mean of log n_s and log n_i? Not quite, because n_s and n_i have different variances, but we can fix that up by using a weighted mean. For fun, I have worked out how to do it for the constant age and U case, as in Figure 1: any linear function of $\rho_s \log n_s + \rho_i \log n_i$ will do. The upper panel of Figure 4 shows n_s/n_i against n_i for 50 grains with the same parameters as for Figure 1, but now using log scales. The lower panel uses for the x-axis effectively $\log n_s + 2\log n_i$ instead of $\log n_i$, though I've first added log2 and then divided by 3 to get the same range of x as in the upper panel — thus on the x-axis we have the cube root of $2n_s$ times the square of the cube root of n_i, plotted on a log scale. Hey presto, no correlation! Fun lovers are invited to find the right transformation for Figure 2.

Good news from Ghent

The recent international workshop in Gent contained much good news. No more hydrothermal intrusion, crustal cooling, tectonic exhumation, extensional unroofing or (regrettably) uplift and erosion. Just denudation! But as every English schoolboy remembers, Ghent is the famous origin of some earlier good news, though what this news actually was, he has long forgotten, as have the inhabitants of Aix. I was reminded of this some years ago while visiting my wife's aunt. The first course of dinner was a rather thin consommé with croutons — or so I thought, until I noticed some paper floating in my bowl. To my astonishment it had writing on it:

I sprang to the stirrup, and Joris, and he;
I galloped, Dirck galloped, we galloped all three …

The text became somewhat faded, but I could just make out how it ended:

...no voice but was praising this Roland of mine,
As I poured down his throat our last measure of wine, Which
(the burgesses voted by common consent). Was no more than his
due who brought good news from Ghent.

An English aunt is by nature eccentric, but this needed more explanation. "A wonderful idea", I said, "to serve poetry with the soup, but isn't it rather difficult to read?" "Yes, I was curious too" she replied "but Mrs. Beeton clearly said If the Mixture fails to Thicken, put a little Browning in it."

Sources

Beeton, I.M. (1859-61) *Mrs. Beeton's English Cookery and Household Management.*

Blythe, Ann (1996) Preliminary note on Hf and U concentrations and fission-track annealing in zircon. *On Track, November, 1996.*

Browning, R. (1840–50) How they brought the Good News from Ghent to Aix. *The Poetical Works of Robert Browning.* Oxford University Press.

Carter, A. (1990) The thermal history and annealing effects in zircons from the Ordovician of North Wales. *Nucl. Tracks Radiat. Meas.* ***17,*** *309-313.*

Duddy, I.R. (1988) Fission track dating results for Besançon apatite age standards. *Personal communication.*

Green, P.F. (1997) E-mail message on selecting zircons. *Personal communication.*

Naeser, C.W. (1983) Fission track age determinations for Fish Canyon Tuff zircon. *Personal communication.*

Oldham, P.D. (1968) *Measurement in Medicine.* London, English Universities Press.

Shakespeare, W.S. (1605) Hamlet, II, i, 78. *The New Shakespeare.* Cambridge University Press.

Tracker (1993) Trials and Errors, *On Track,* May 1993.

U.S.A. (c1950) Eliminate the negative (accentuate the positive). *Popular song.*

Zircon PAZ and Very Low-Grade Metamorphism

by Meinert Rahn

Institut für Mineralogie, Petrologie und Geochemie, University of Freiburg
Albertstrasse 23b, 79104 Freiburg, Germany
(rahn@ruf.uni-freiburg.de)

In the beginning of the world, there was chaos. But then, there came light and order. In the beginning of our research, there was order. In the book of prophet Tony, it was said that zircons close at 240±50 °C (Hurford, 1986). But then, there came samples and data, and there came "chaos".

What are the criteria to determine the boundaries of the zircon partial annealing zone in sedimentary rocks? Criteria for the upper PAZ boundary are: (i) no single grain age older than depositional age, (ii) a unimodal single grain age distribution, that passes the χ^2 test (neglecting any compositional effects, see e.g. Blythe, 1996), and (iii) a lack of short tracks. For the lower temperature PAZ boundary, the following criteria are proposed: (iv) first single grain ages significantly younger than the depositional age of the sediment, (v) significant shift of geologically well defined grain age populations, (vi) appearance of short tracks.

Most of these criteria are not valid if observed separately. Short tracks in zircons could also be of detrital origin, e.g. from a slowly cooled hinterland. However, the combination of the different criteria is thought to be diagnostic, if no track length measurements are executed. The determination of the zircon PAZ boundaries in the field would represent an interesting parameter within very low-grade metamorphic areas.

In search of a mappable zircon closure boundary, we started with a profile of samples along a north-south gradient of metamorphic grade that was determined by fluid inclusion homogenization temperatures (T_{hom}), illite crystallinity (IC), and vitrinite reflectance (R_{max}). In particular, fluid inclusion homogenization temperatures play an important part in our interpretation of metamorphic grade. The measured fluid population has been taken from fiber quartzes that grew within syn-metamorphic opening joints in the flysch sandstones by a crack-seal mechanism. Within the range of 200 to 270 °C those inclusions contain a methane-bearing fluid. If the water-rich fluid was saturated with methane, the measured homogenization temperature represents the actual formation temperature (T_{form}, Mullis, 1987). Above 270 °C methane is cracked to water and CO_2. Within this water zone, T_{hom} cannot be linked to T_{form}, but in connection with neighboring fluid data, the lack of methane in the fluid inclusions can be interpreted as a formation temperature > 270 °C.

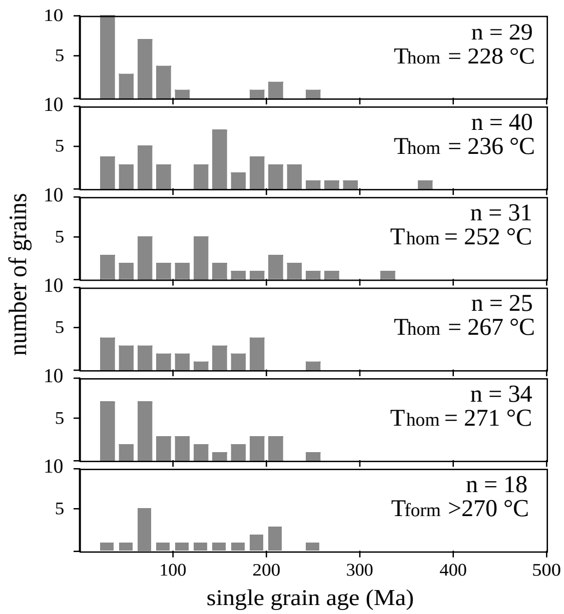

Figure 1: Single grain FT age distribution of flysch sandstone zircons along a horizontal fluid inclusion profile in the Glarus Alps, eastern Switzerland.

All samples of this first profile are Rupelian flysch sandstones, which are expected to initially show a large variety of zircon single grain age distributions. The profile starts at a metamorphic grade of uppermost diagenesis/beginning anchizone (T_{hom} = 228±5 °C, IC = 0.41±0.06 °Δ2q, R_{max} = 3.1%) and ends at the uppermost anchizone (T_{form} >270 °C, IC = 0.33±0.01, R_{max} = 5.1%). Within this temperature range, we expected to see the transition to Alpine reset zircon FT ages.

In **figure 1**, samples with increasing metamorphic grade are plotted with their single grain age distribution. From this figure, it is obvious that there is no single grain age shift toward younger ages with increasing grade. In contrary, the youngest central age is found for the sample of lowest metamorphic grade. This contradiction might be caused by the fact that this sample also has the youngest sedimentation age, and erosion of the hinterland moved down to "younger" levels. It is however, interesting to note that all samples show single grain ages of markedly less than 35 Ma. Applying criteria (iv) from above, we can assume that our samples in the range of 230 to 280 °C show partial resetting. Unfortunately, there is no well defined grain age population that would allow us to observe an age shift (criteria v).

With the upper end of the methane zone of the fluid inclusions, there comes a general lack of good temperature estimations. Although IC and R_{max} can be combined with chlorite geothermometry, which, despite of repeated criticism has often provided results consistent with other temperature estimations, and critical mineral parageneses, there is no good thermometer available between 270 and 350 °C, that would allow us to determine the temperature with a better accuracy than ± 50 °C. For zircons, this uncertainty might correspond to a third or even half of the PAZ. Data from our first study area (Fig. 1) indicate that the lower end of the zircon PAZ starts before 228 °C, but the upper end is distinctly higher than 270 °C.

A second, more extended and ongoing study tries to find the upper end of the partial annealing zone along 6 profiles perpendicular to the general strike in the external part of the Swiss Alps. Apart from the lack of precise thermometers, there comes an additional problem: Most of these profiles end within rocks of the central massifs (Variscan crystalline basement), where the methods of illite crystallinity and vitrinite reflectance cannot be applied, and critical minerals do not occur at this low metamorphic grade. If the profile ends within sedimentary rocks, and vitrinites can be measured, they often show strong graphitization, and the measured IC alone is a rather bad thermometer at this grade.

Along a vertical profile of 2000 meters of altitude difference in the western Swiss Alps, six samples were collected. Zircon fission track ages were determined together with IC and R_{max} data at the upper part of the profile. For the crystalline basement, K-Ar isotopic data on biotite reveal a late Variscan cooling age of 255 Ma (thus, no Alpine reset, Soom, 1990), whereas apatite ages vary from 4 Ma at the bottom to 8 Ma at the top. From the Variscan metamorphic overprint, an upper Permian cooling age could be expected for the zircon FT ages if unaffected by Alpine metamorphism.

Figure 2 reveals, that there is a nice linear trend to be seen for the zircon central ages getting younger from top to bottom. The only sample that drops out of the trend is a flysch sandstone from the paraautochthonous cover of the basement. The uppermost sample, taken from a large crystalline rock lens within the sedimentary cover plots on the same linear trend. With the exception of the flysch sandstone, all samples pass the χ^2 test. The age difference of more than 60 Ma from top to bottom can hardly be explained by a Variscan cooling pattern, but has to be an Alpine feature. The uppermost central age of 228 Ma is too young for a Variscan cooling age if compared with the K-Ar biotite age (closing temperature assumed at 300 °C!), the lowermost age of 148 Ma is too old for an Alpine cooling age. Therefore, all zircon FT ages must be mixed or partial reset ages.

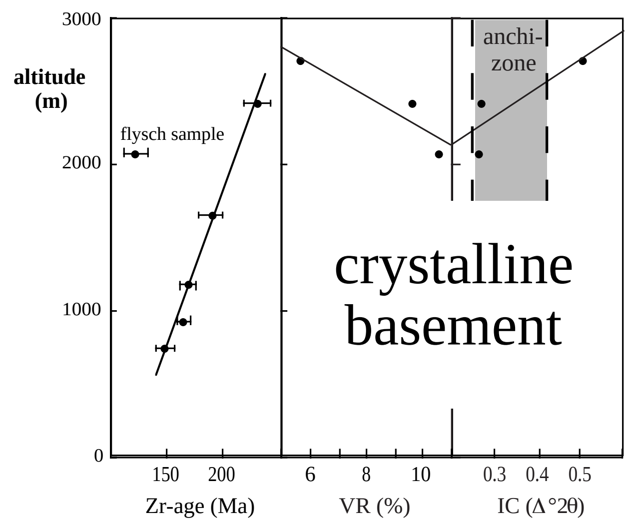

Figure 2: Zircon FT and metamorphic data along a vertical profile in the western Swiss Alps. Indicated age standard deviations are 1σ. For the zircon central ages number of counted grains vary from 26 to 40.

From the small data set of IC and R_{max} in the paraautochthonous cover, a maximum metamorphic temperature of around 300 °C can be assumed for the contact basement/cover. From the regional fluid inclusion data pattern (Mullis, 1987), we know that we are well within the water zone, i.e. well above a maximum temperature of 270 °C. Zircons are not reset 1.5 km further below. Even when assuming a conservative geothermal gradient of 20 °/km, the upper boundary of the zircon PAZ (and that for the K-Ar biotite system) has to be distinctly higher than 300 °C, which is in good agreement to predictions from the experiments in Yamada et al. (1995). In accordance with their data, we have to restrict the validity of our data to orogenic conditions and short-termed metamorphic events.

Conclusions

In accordance with experimental temperatures for the zircon PAZ, zircon FT age analyses from the external Swiss Alps reveal a lower temperature end of annealing below 230 °C, but an upper limit of the PAZ above 300 °C. It is worth noting that the failure of a χ^2 test is not a criteria for partial annealed data of zircons from crystalline rocks, but probably applicable for sediments that originally contained distinct grain age populations.

References Cited

Blythe, A., 1996, Preliminary note on Hf and U concentrations and fission track annealing in zircon, *On Track*, v. 6., p. 3-4.

Hurford, A.J., 1996, Cooling and uplift patterns in the Lepontine Alps South Central Switzerland and age of vertical movement on the Insubric fault Line, *Contributions to Mineralogy and Petrology*, v. 92, p. 413-427.

Mullis, J., 1987, Fluid inclusion studies during very low-grade metamorphism, in Frey, M. (ed.), Low-temperature metamorphism, Blackie & Son Ltd., Glasgow, p. 162-199.

Soom, M.A., 1990, Abkühlungs- und Hebungsgeschichte der Externmassive und der penninischen Decken beiderseits der Simplon-Rhone-Linie seit dem Oligozän: Spaltspurdatierungen an Apatit/Zirkon und K-Ar-Datierungen an Biotit/Muskovit (westliche Zentralalpen), unpubl. Ph. D. thesis, University of Berne, Switzerland.

Yamada, R., Tagami, T., and Nishimura, S., 1995, Confined fission-track length measurement of zircon: assessment of factors affecting the paleotemperature estimate, *Chemical Geology*, v. 119, p. 293-306.

International Workshop of Fission-Track Dating, August 26-30, 1997, University of Gent, Belgium - A Conference Review

by Ruth Siddall

Department of Geological Sciences, University College London,
Gower Street, London WC1E 6BT, UK
(r.siddall@ucl.ac.uk)

Due to an unfailing inability to say ‘no’ and an unfortunate and undeserved reputation as a reviewer of fission track conferences, I find myself feeling extremely guilt stricken that the event occurred some eight (!) months ago and I have done nothing despite the cajoling e-mails from our editor. As the event lies in the dim and distant past let this article suffice to remind you of those halcyon days of Summer (for us northern hemispherans, at least) when the rain fell in ‘stair rods’ and I spent thirty quid on an umbrella, which incidentally I have not lost yet. “Get on with it” I here you say. So, here goes.

The 8th International Workshop on Fission-Track Dating was held in August 1996 in the Aula of the University of Gent, Belgium. It was attended by 116 delegates and a total of 59 papers and 75 posters were presented. Oral technical sessions covered track formation and structure, methodology and case studies on the evolution of a variety of tectonic and geomorphological settings. Keynote addresses from **J. Vetter** (TEM investigation of latent tracks induced by high energy ions), **Tony Hurford** (Zeta: the ultimate solution or just an interim measure), **Andy Gleadow** (Geothermochronometry with the fission track age-length system) and **Gunther Wagner** (Fission-track analysis of continental basements: the central European basement) reviewed the current status of understanding and application of the technique. For the first time at these workshops, keynote speakers were also invited from outside the direct field of fission track analysis to discuss the influences of the technique on the Earth sciences in general. Interesting and enlightening talks were given by **Sierd Cloetingh** (Fission-track thermotectonics and basin modelling), **Melvin Giles** (Divining burial and thermal histories from indicator values: application and limitations) and **Mike Summerfield** (Geomorphology and the interpretation of fission tracks).

The conference opened with sessions concerned with the physical and chemical characteristics of fission-tracks and advances in methodology and technique. **Gyorgy Szenes** and **Hideki Iwano** presented work on track formation in insulators and detectors, **Giulio Bigazzi**, **Kiyoshi Wadatsumi**, **Frank Bellemans**, **Bart Kowallis** and **Y. Zhao** presented papers on new age standards and re-evaluation of existing age standards. **Richard Ketcham** looked at ways of counteracting the variation in track length with crystallographic orientation. Improvements in analysis and counting methodology, particularly image analysis, were presented by **Philip Schwarze** and **Peter Van den haute**. Technological advances were made by **Manfred Brix** and **Trevor Dumitru** who presented posters with demonstrations (!) of new 'inventions' for speeding etching and mineral separation processes.

The influence of chlorine on track retention and compositional variation within apatite populations was discussed by **Barry Kohn**, **Steve Bergman**, **Jocelyn Barbarand** and **Paul Green** (we're still waiting for that paper, Paul). And further resolution of this problem is apparently required before we fully understand the effects of variation in chemistry. Other studies on experimental and natural annealing of fission-tracks in apatite were presented by **Jan-Petter Stiberg**, **Michel Rebetez** and **Raymond Jonckheere**.

Although much of the work presented focused on the apatite fission-track system, annealing studies on zircon, sphene and glass were presented by **Dave Foster**, **Paul Green**, **Kit Johnson** and **Amanjit Sandhu**. Natural annealing of zircons was reported from the KTB deep borehole and the Vienna deep borehole by **Dave Coyle** and **Taka Tagami** respectively.

The 8th workshop will be perhaps remembered for the profusion of 'movies', heralding new refinements in modelling high density regional data and its interpretation in terms of landscape evolution. **Andy Gleadow** presented a synoptic evolution of SE Australia, **Wayne Noble** and **Rod Brown** presented a similar studies for regions of Africa (with music in the latter case!). **Paul Fitzgerald** presented an interesting talk on the use of apatite fission-track analysis to constrain rates of absolute uplift. Studies of apatite fission-track analysis as a tool for recording histories of fault movement were presented by **Peter Kamp**, **Meinert Rahn** and **Annia Fayon**. Regional studies of the evolution of segments of orogenic belts were presented by **Mary Roden-Tice**, **Di Seward**, **Shari Kelley**, **Anne Blythe**, **Paul O'Sullivan**, **Stuart Thomson**, **Ewald Hejl**, **Carlo Sanders**, **Ulrich Glasmacher** and **Dave Upton** revealing the unique capabilities of fission track analysis to record cooling histories in terms of denudation. Thermal histories of sedimentary basins, with important implications for hydrocarbon exploration were presented by **Max Rohrman**, **Paul Andriessen**, **Dave Issler**, **Nancy Naeser**, **Maurice Pagel**, **Shaohua Sun** and **Jos Terken. Andy Carter** and **Istvan Dunkl** used fission track analysis as a tool for sedimentary provenance studies.

The conference was rounded off in inimitable style with a **Rex Galbraith** double bill, inviting us all once more into the magical world that is statistics.

Posters were too many and too varied to discuss in detail. However, this of course does not detract from their importance. The majority of posters dealt with regional case studies, showing the technique spreading to almost world-wide coverage for data.

Social events were, of course, organised as part of the conference programme. Everything got off to a good start at the icebreaker on Sunday evening with a selection of the wonderful local beers. There was a move afterwards, I believe instigated by Kit "I've been here before" Johnson, to a riverside bar, "Het Waterhuis", where the opportunity arose to sample the rest of the local beers. This hostelry became something of a focal point for post-talks socialising. The route back from this establishment through the myriad streets of Gent to the Hotel Ibis is still engraved on my mind, though how I made it on some occasions I will never know.

We were invited to a very jolly reception by the Burgomaster of Gent at the Town Hall on Tuesday (more beer), and Wednesday afternoon was spent most enjoyably sampling the delights of the city of Bruges; canal trips, even more beer, and beautiful mediaeval buildings.

The conference dinner on the Thursday evening was held at the restaurant, "'t Molenhuis" in the village of Baarle-Drongen. Food was excellent ('a nice bit of rabbit') and the dinner was rounded off by delicious measures of 'fruity schnapps things' (FSTs, K. Gallagher, *pers. comm.*). On return to Gent, carousing continued at "Het Waterhuis" and I believe, more seedy locations were visited towards the end of the evening. At this point, I should mention that I have been asked to give a vote of thanks to **Mike de Wit** who unselfishly sponsored the all-night drinking session, although Kerry Gallagher did admit to getting the last round in at 8.00 am on Friday, before turning up to Mike Summerfield's keynote address at 8.30 am. Thanks should also be given to the Hotel Ibis at this point, for providing a free breakfast that morning, for all those who were accommodated elsewhere (you know who you are) and steadfastly stayed the pace with Drs de Wit, Gallagher, Brown *et al*.

The conference field trip on August 31st visited the classic Upper Devonian to Lower Carboniferous sections of SE Belgium; "a taste of Belgian chronostratotypes and associated reef deposits". The trip was organised and lead by **J. Verniers**, **F. Boulvain** and **B. Delcambre**. The weather was at last, relatively kind. In the morning we saw impressive quarry-face exposures of the famous reef knolls and their associated, enclosing sediments. The lunch stop, with a fine selection of sandwiches, was in a village on the Belgium/French border, which enabled the antipodean members of the party to flaunt their lack of visas and trespass on French soil illegally. The afternoon was spent examining the Lower Carboniferous type-sections near the town of Dinant. A final stop, once the rain had resumed, featured the bar in the locale of the Trappist Abbé de Maredsous to sample the cheese, and of course, the beer. In all, an excellent day and a great end to the workshop.

Once more, on behalf of the fission track community, I convey my thanks to the organising committee in Gent, the scientific committee and the sponsors, and particularly to **Peter Van den haute** and **Frans De Corte** who organised a splendid and thoroughly enjoyable conference and enabled the event to run like clockwork. I am sure we are all looking forward to the next workshop in 2000 (blimey, that sounds strange) in Apollo Bay, Victoria, Australia. This will give you the opportunity to write the next conference review, **Dr. Green**!

Short Tracks: News

Michael Hulver just completed his Ph.D. at the University of Chicago, entitled "Post-orogenic evolution of the Appalachian Mountain system and its foreland". His dissertation encompassed the entire Appalachian region, but the apatite fission-track work was mostly on sedimentary rocks from West Virginia and Virginia. His fission-track mentor as **Kevin Crowley** and the analytical work was carried out at Kevin Crowley's former laboratory at Miami University of Ohio. As part of his dissertation he modified and augmented Jeff Corrigan's inverse model, and directly compared the various annealing model given the same thermal histories and model parameters.

Thierry Calmus is starting up a new fission-track laboratory at the University of Sonora in Hermosillo, Mexico. He has been working with **Gerard Poupeau** on thermochronology of the southwestern margin of Mexico since 1995. Good luck with your new lab, Thierry!

Jon Linn is currently finishing up his Ph.D. at the University of Kansas, investigating the Mesozoic and Tertiary thermal evolution of the Canyon and Pavant Ranges in west-central Utah (also see OT, May 1995) under the supervision of **Doug Walker**. The fission-track analyses were conducted at the University of Texas-Austin with the help of **Rich Weiland**, **Rich Ketcham**, **Ray Donelick**, and **Mark Cloos**. Jon is now with the West Virginia Division of Environmental Protection as a GIS Technician/Geologist, using his more marketable skills working on GIS database development and managing one of WV's GPS base stations.

Kyoto Fission-Track Co., Ltd. announced that **Masao Kasuya** had left KFT lab and retired from fission-track dating. Currently working for KFT lab are **Tohru Danhara**, **Tohru Yamashita**, **Hideki Iwano** and **Tetsu Yoshioka**. Also note the new address of KFT in the directory update (this issue).

The **librarians of the CIC member universities** in concert with CICNet, have developed a web-accessible, fully managed collection of electronic journals -- the CIC Electronic Journals Collection (EJC). OnTrack has been selected for inclusion because of its quality (!?), and the importance of its content to the 500,000 faculty, staff, and students of the CIC universities (!?!?!?). The Committee on Institutional Cooperation (CIC, http://www.cic.net/cic/), with headquarters in Champaign, Illinois, is the academic consortium of the Big Ten universities and the University of Chicago.

As promised in OnTrack 13, **Dennis Trombatore** of UT-Austin has put On Track on the world wide web. The OnTrack back issues 9 through 13 are electronically available now at **http://www.lib.utexas.edu/Libs/GEO**.

This news section is once again far from complete. Any information is greatly appreciated. If you're moving, setting up a new lab, finishing your thesis or have info/gossip you want to share with the rest of us, please let **Paul O'Sullivan**, the new OnTrack editor know. It's your newsletter!

Jankov Moldavite: A Potential Glass Standard for Fission-Track Dating

by Maria Laura Balestrieri[1], Giulio Bigazzi[1] and Vladimír Bouska[2]

[1] Institute of Geochronology and Isotope Geochemistry, CNR, v. C. Maffi, 36, Pisa, Italy

[2] Institute of Geochemistry, Mineralogy and Mineral Resources, Charles University, Albertov, 6, Prague, Czech Republic

Introduction

The Fission Track Working Group of the I.U.G.S. Subcommission on Geochronology established that the unique reliable way for settlement of accuracy of all fission-track dating systems is the use of age standards, either the absolute approach or the ζ calibration are adopted (Hurford, 1990).

Experience has shown that different mineral species may yield different ζ factors (Wagner and Van den haute, 1992). Therefore, when a given phase is analysed, standards of the same phase should be used as reference material.

Whereas standards are currently available for apatite, zircon and sphene, only the glass Moldavite was included by the I.U.G.S. Subcommission on Geochronology in the list of the age standards, with the recommendation *only splits from a single Moldavite* (Hurford, 1990). However, a contact for distribution of this standard was lacking. This glass, studied by Wagner (1966) as soon as the fission-track dating method was developed, was later analysed by other fission-track groups. Its significance as a potential age standard had been confirmed by McCorkell and Naeser (1988), during the Besançon fission-track dating workshop. Several K-Ar and Ar-Ar data are available for this tektite. Wagner and Van den haute (1992) report two determinations of 15.21 ± 0.15 Ma (Ar-Ar, Staudacher *et al.*, 1982) and 15.1 ± 0.7 Ma (K-Ar, Gentner *et al*, 1967), respectively.

Other glasses had been proposed: the obsidian JAS-G1, Japan, (Wadatsumi et al., 1994; Kitada and Wadatsumi, 1995), the rhyolitic glass Roccastrada, Italy (Bigazzi *et al.*, 1993) and the obsidian Macusanite, Peru (McCorkell and Naeser, 1988). Among these four glasses, only Moldavite appears to have chance of fulfilling one of the basic requirements propounded by G. A. Wagner in 1980, during the fission-track dating workshop held in Pisa (Hurford and Green, 1981): *no corrections should be necessary in obtaining the fission-track age*. Published data have shown that only some Moldavites are unaffected by spontaneous track annealing. Therefore only splits from a single Moldavite containing undisturbed tracks should be distributed as standard: this requirement appears arduous to be respected, as Moldavites large enough are very rare. We analysed samples from various localities in southern Bohemia and Moravia in order to identify the Moldavite-bearing deposit(s) with negligible track annealing. Different Moldavites from such a deposit(s) might be a reasonable substitute of 'only one Moldavite'.

Fission-track analysis of Moldavites

Moldavite is a tektite found in sedimentary deposits covering a long time span, since Middle Miocene up to Holocene. These deposits, distributed in a wide area of central Europe, in southern Bohemia and Moravia (Czech Republic), yielded around 600,000 specimens. Few samples were collected also in Lusatia (Germany) and in Horn region (Austria). A detailed review on history, location and characteristics of this tektite is given by Bouska (1994).

The oldest Moldavite-bearing deposits (Domanín formation, lower Sarmatian) are only 1-2 Ma younger than the probable age of the impact which produced this tektite. Moldavites from these deposits are sharp-edged irregular fragments, with sharp, deep sculpture, as they were corroded over a long period of time.

Other Moldavite-bearing sediments formed after a long period of time, in Pliocene and Pleistocene times. Samples from these younger sediments have a shape characteristic of the peculiar deposit, indicating different reworking and transportation histories.

The different amount of annealing shown by different samples depends very likely on two factors: (1) the peculiar history experienced by the single Moldavite and (2) a differential track retentivity due to variable chemical-physical properties.

Several samples were selected from sediments with different characteristics, in order to identify the less affected by track annealing (Table 1). In principle, the most promising deposits should be the oldest ones (Vrábce - Nová Hospoda, Jankov and Slavice). Trebanice is also promising, as Moldavites do not appear to have experienced transportation. On the contrary, those from Chlum and Malsí and Radomilice are well rounded. The Kamenny Újezd deposit holds abundant fragments of fired wood: Moldavites may have experienced high temperatures during Pliocene times.

The results shown in Table 1 did not fully come up to our expectations. All Moldavites yielded spontaneous to induced track-size ratios (DS/DI) lower than 1. This indicates, following Storzer and Wagner (1969), that spontaneous tracks are partially annealed. The samples from Vráce-Nová Hospoda and Trebanice did not turn to be less disturbed than those from Radomilice, Chlum nad MalsÍ and, specially, Kamenny Újezd. The Slavice Moldavite, a *ca.* 12 g sample that could allow a significant number of multiple analyses, yielded a bimodal track-size distribution (Fig. 1)

Table 1. Moldavite-bearing deposits considered in this study

Deposit	**Notes**	ρ_s (cm^{-2})	**DS/DI**	**Apparent Age** (Ma)	ζ (A)	**Plateau Age** (Ma)	ζ (P)
SOUTHERN BOHEMIA							
RADOMILICE Plio-Pleistocene (3)	Long distance transportation	14,200	0.91	14.3 ± 0.3	338	15.1 ± 0.4	320
CHLUM NAD MALSÍ Pliocene (1)	Long distance transportation	13,400	0.90	13.3 ± 0.5	363	15.2 ± 0.7	315
TREBANICE Pliocene (1)	—	12,900	0.89	12.7 ± 0.5	380	15.0 ± 0.6	321
KAMENNY ÚJEZD Pliocene (1)	Fired wood	13,300	0.89	14.2 ± 0.6	340	14.7 ± 0.6	329
VRÁBCE - NOVÁ HOSPODA Miocene (4)	—	13,900	0.91	13.6 ± 0.3	356	15.2 ± 0.3	313
JANKOV Miocene (4)	—	14,200	0.96	14.8 ± 0.3	326	15.2 ± 0.3	313
MORAVIA							
SLAVICE Miocene (1)	Reworked in Quaternary	5,200	0.76	5.1 ± 0.3	—	—	—

ρ_S: spontaneous track density; DS/DI: spontaneous to induced track size ratio; ζ (A), ζ (P): zeta factor determined using the track densities corresponding to the apparent (A) and plateau (P) age determination; (3): number of analysed Moldavites (experimental data are mean values where more than one analysis was made). The following parameters were used for age calculation: $\lambda = 1.55125 \times 10^{-10}$ a^{-1}; $\lambda_F = 7.03 \times 10^{-17}$ a^{-1}; $\sigma = 5.802 \times 10^{-22}$ cm^2; $^{238}U/^{235}U = 137.88$. Samples were irradiated in the Lazy Susan (Cd ratio 6.5 for Au and 48 for Co) and Thermal Column (Cd ratio 85.3 for Au and 643 for Co) facilities of the Triga Mark II reactor of LENA, University of Pavia (Italy). Glass NIST SRM 962a was used for neutron fluence determination, using the mean of Cu and Au NIST calibrations as reference.

which indicates a peculiar thermal history. The Jankov Middle Miocene sediments yielded the glasses with the higher DS/DI ratio: a value of 0.98 was determined in one specimen (Fig. 1). All Moldavites from this deposit have fission-track ages computed using an absolute approach consistent with the quoted Ar-Ar and K-Ar ages. For the plateau technique for correction of thermally lowered fission-track ages (Storzer and Poupeau, 1973), thermal treatments of 4 hours at 220°C and 250°C were imposed. All plateau ages are consistent with the K-Ar ages (Fig. 2).

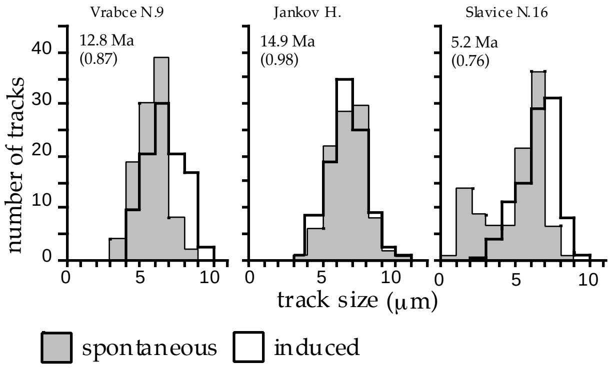

Fig. 1.: Track-size distributions normalised to 100 of three Moldavites. The determined apparent age as well as the spontaneous to induced track-size ratio, DS/DI (in brackets) are also shown. Whereas Vrabce N.9 experienced a moderate amount of annealing of spontaneous tracks, the Jankov sample appears to store almost undisturbed tracks. The bimodal distribution of Slavice N.16 indicates that this glass experienced a peculiar thermal history (see text).

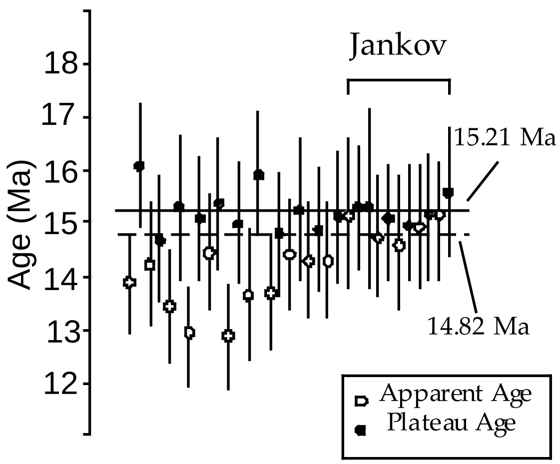

Fig. 2. Apparent and plateau fission-track ages determined on Moldavites from different sedimentary deposits located in southern Bohemia and Moravia (Czech Republic, see Table 1). Error bars are ± 2σ. The solid and dashed lines correspond to the Ar-Ar age measured by Staudacher *et al.* (1982) and to the mean value of 17 K-Ar and Ar-Ar determinations (Storzer *et al.*, 1995), respectively. The Jankov sediments yielded samples with older apparent ages.

Tracks resulted Poissonally distributed, except for one sample. Track densities are high enough to allow relatively precise determinations (around 1,000 tracks counted) in a short time. All samples did not show any etching pit due to microlites which might prevent a correct track identification.

The ζ factors shown in Table 1 are referred to the sandwich neutron fluence glass standard NIST SRM 612 - muscovite detector, using as reference Staudacher *et al.*'s age, preferred for its higher precision. The ζ factors computed using the track densities corresponding to the plateau age determinations, ζ (P), are well consistent each other, whereas those corresponding to the apparent age determinations, ζ (A), distribute over a relatively wide range. The ζ factor, mean of the ζ (P) values, is consistent with those determined at Pisa for apatites, using the population method (ζ = 328, Fish Canyon Tuff, ζ = 336, Durango).

A short comment on the Slavice Moldavite: this sample experienced during its history a thermal event which strongly reduced etching efficiency of pre-existing tracks. Fission-track data shown in Table 1 are mixed values, combination of those regarding two track populations. Considering the larger tracks, formed after that thermal event, we estimated that it occurred during Middle Pliocene. This is somewhat in contradiction with the note 'reworked in Quaternary.

Proposal for a potential standard: the Jankov Moldavite

All Moldavites studied here, excepted Slavice N.16, yielded plateau ages consistent with independent K-Ar or Ar-Ar ages. Therefore, they can be considered equivalent, provided that the plateau technique is applied. The ζ factors should be computed after an adequate thermal treatment imposed for re-establishing an identical etching efficiency for spontaneous and induced tracks (i.e., DS/DI = 1). However, the exact meaning of plateau ages is still somewhat controversial. So, we conclude that the most adequate glass for distribution to the fission-track community is the Jankov Moldavite.

Unfortunately, identification of a unique sample large enough to be distributed to all fission-track groups seems a utopia. Therefore, assuming that Moldavites from the Jankov deposit may have experienced the same thermal history, several specimens of various sizes have been selected (Table 2). They will be sent under request to the colleagues of the fission-track community. Contact:

Giulio Bigazzi - CNR. Istituto di Geocronologia e Geochimica Isotopica Via Cardinale Maffi, 36, 56127 Pisa, Italy
Ph: **39-(0)50-560110, Fax: **39-(0)50-900270, e-mail: iggi@iggi.pi.cnr.it

The total amount, around 200 grams, should be enough to meet the requirements of the fission-track community, specially considering that there are only few groups working with glass. We planned to supply around two grams for each request.

We can not certify that all these samples have the same characteristics as those we have analysed. However, as these glasses were collected from a not reworked Middle Miocene deposit, probability to have experienced some thermal disturbance appears negligible.

Conclusion

Several colleagues have already analysed Moldavite samples, but their provenance was often unknown. We considered some Moldavite-bearing sediments with different characteristics, and our results indicate that the Jankov sediments contain the less disturbed glasses. We selected for distribution only glasses from that formation.

Although fission-track ages are consistent with published K-Ar and Ar-Ar ages, a slight amount of annealing of spontaneous tracks can not definitely excluded. Therefore, application of the plateau technique is recommended. Track-size measurements are also important for checking (1) whether spontaneous tracks detect peculiar thermal histories and (2) whether spontaneous and induced tracks are revealed with an identical efficiency when the plateau age is determined.

By experience, a good control of the etching and heating conditions is recommended for obtaining reliable results.

Weight (grams)	**Number of specimens**
< 0.5	49
0.5 - 1	58
1 - 2	36
2 - 3	3
3 - 4	1
4 - 5	1
> 5	8

Table 2. Weight of the Moldavites (or splits of Moldavite) from the Jankov Middle Miocene deposit selected for distribution

Finally, we are somewhat in doubt what independent reference age to adopt. The age of 15.21 Ma of Staudacher *et al.* (1982) quoted by Wagner and Van den haute (1992) could slightly overestimate the age of the impact which generated the Moldavites. Storzer *et al.* (1995) report a mean of 14.82 Ma with a standard deviation of 0.32 Ma for 17 K-Ar and Ar-Ar determinations obtained by different authors. The independent reference age should be better constrained by further analyses. To have obtained plateau ages using an absolute approach well consistent with Staudacher *et al.*'s value does not imply neither that this age is definitely correct nor that our calibration system (checked against apatite age standards) does not contain a slight bias.

References

Bigazzi, G., Bonadonna, F.P., Laurenzi, M.A. and Tonarini, S. 1993. A test sample for FT dating of glass shards. *Nucl. Tracks Radiat. Meas.* **21**, 489-497.

Bouska, V. 1994. *Moldavites. The Czech tektites*. Stylizace, Prague.

Hurford, A.J. 1990. Standardization of fission track dating calibration: Recommendation by the Fission Track Working Group of the I.U.G.S. Subcommission on Geochronology. *Chem. Geol. (Isot. Geosci. Sec.)* **80**, 171-178.

Hurford, A.J. and Green, P.F. 1981. Standards dosimetry and the uranium-238 λ_f decay constant: a discussion. *Nucl. Tracks Radiat. Meas.* **5**, 73-75.

Kitada, N. and Wadatsumi, K. 1995. Proposal for a glass age standard "JAS-G1". *Bulletin of Liaison and Informations, IUGS Subcomission on Geochronology* **13**, 23-27.

Gentner, W., Kleinmann, B. and Wagner, G.A. 1967. New K-Ar and fission track ages of impact glasses and tektites. *Earth Planet. Sci. Lett.* **2**, 83-86.

McCorkell, R. and Naeser, C.W. 1988. Natural glass inter-laboratory reference materials for fission-track dating. 6th Int. Workshop on Fission-Track Dating, 5-9 Sept. 1988, Besançon, France. Abstract, 1p. Reproduced in *Nucl. Tracks Radiat. Meas.* **17**, 422.

Staudacher, Th., Jessberger, E.K., Dominik, B., Kirsten, T. and Schaeffer, O.A. 1982. ^{40}Ar-^{39}Ar ages of rocks and glasses from the Nördlinger Ries crater and the temperature history of impact breccias. *J. Geophys.* **51**, 1-11.

Storzer, D., Jessberger, E.K., Kunz, J. and Lange, J.-M. 1995. Synopsis von Spaltspuren- und Kalium-Argon-Datierungen an Ries-Impaktgläsern und Moldaviten. *Exkurs. f. u. Veröfftl. GGW* **195**, 79-80.

Storzer, D. and Poupeau, G. 1973. Géochronologie. -Ages plateaux de minéraux et verres par la méthode des traces de fission. *Compt. Rend. Acad. Sci., Paris* **D276**, 137-139.

Storzer, D. and Wagner, G.A. 1969. Correction of thermally lowered fission track ages of tektites. *Earth Planet. Sci. Lett.* **5**, 463-468.

Wadatsumi, K., Kitada, N., Bigazzi, G., Deino, A., Laurenzi, M., Kowallis, B., Nagao, K. and Masuda, H. 1994. Obsidian from Japan as a 'putative' glass age standard "JAS-G1". ICOG 8, Berkeley, California, USA, June 5-11 1994. *Abstracts*, 345.

Wagner, G.A. 1966. Altersbestimmungen an Tektiten und anderen natürlichen Gläsern mittels Spuren der spontanen Kernspaltung des Uran^{238} ("fission-track"-Methode). *Z. Naturforschung* **21a**, 733-745.

Wagner, G.A. and Van den haute, P. 1992. *Fission track dating*. Kluwer Academic Publishers, Dordrecht.

Fact and Fiction Regarding Apatite Fission-Track Annealing Kinetics

by Raymond A. Donelick

Donelick Analytical, Inc., 4819 Katy-Hockley Road,
Katy, Texas 77493-4826, U.S.A.
(72762.1465@compuserve.com)

Introduction

Much is currently being said about the usefulness of variations in fission track annealing kinetics between apatites of different etching characteristics and/or chemical compositions. As a whole, this discussion is to be applauded, regardless of the motivation behind various statements and the positions held. As the debate about this issue progresses, all apatite fission track workers and users will benefit from an increased understanding of the data being generated. If any caution should be issued, both to the debaters in and the observers of this process, it is that scientific objectivity should be kept in perspective.

Kinetic Parameters

The holy grail of grouping apatite grains according to their kinetic response is a single, easily and reliably measured parameter or combination of parameters by which fission track age and length data can be plotted, grouped, and modeled. Two parameters of this type are currently being used: *Dpar*, the arithmetic mean etch figure diameter parallel to the crystallographic c-axis (or, alternatively, the etch pit diameter parallel to the c-axis at the etched surface) and *[Cl]*, the concentration of chlorine. A good example of the application of these parameters to the interpretation of apatite fission track age *and* length data is detailed in Burtner et al. (1994). There is abundant fact and fiction surrounding both of these parameters.

Known Facts

Dpar

- Apatites with relatively small values of *Dpar* (say, less than about 1.75 mm for apatites etched for 20 seconds in 5.5M HNO_3 at 21°C) anneal rapidly and can generally be considered "typical" near-end-member fluorapatites, at least in terms of their fission track annealing kinetics. Apatites of this type are quite common.
- Apatites with relatively large values of *Dpar* (greater than about 1.75 mm for apatites etched for 20 seconds in 5.5M HNO_3 at 21°C) usually, but not always, anneal more slowly than their small *Dpar* counterparts. Apatites of this type are also quite common. Failure of the *Dpar* parameter is most pronounced for near-end-member hydroxyapatites which exhibit large *Dpar* values and anneal faster than fluorapatites.
- Use of *Dpar* for commercial purposes is restricted because it is patented (Donelick, 1993; Donelick, 1995). Academic, not-for-profit use of this parameter is encouraged, however.

[Cl]

- Apatites with relatively large values of *[Cl]* (say, greater than 1-2 weight percent) anneal slowly. However, there exists significant kinetic variability among apatites of this type.
- Apatites with relatively small values of *[Cl]* (less than 1-2 weight percent) usually, but not always, anneal rapidly relative to their large *[Cl]* counterparts. Failure of the *[Cl]* parameter occurs for apatites having unusually high concentrations of Mn, probably Fe (apparently, even in small amounts), possibly rare earth elements, and possibly some combination of OH and Cl.

Debunking Fiction

Dpar

- Measured values of *Dpar* need not be converted to some equivalent *[Cl]* value for interpretation purposes. Quite simply, the fission track age and length data are best related directly to *Dpar*, without reference to or need of *[Cl]*.
- Based on the experimental data set of W.D. Carlson, R.A. Donelick, and R.A. Ketcham (currently in various stages of publication), the use of *Dpar* is far from pseudo-science. When etching conditions are tightly controlled (and this, of course, is very important), reliable calibrations relating track length reduction to *Dpar* can be obtained.
- It is not known exactly what controls *Dpar* in apatite. Certainly, chemical composition plays a role, but other parameters related to the

concentration and type of crystallographic imperfections in apatite (e.g., accumulated alpha-decay damage, crystallization age, temperature of formation, deformation history) may also be very important.

[Cl]

- *[Cl]* alone does not completely account for the variation of fission track annealing kinetics in apatite. Other elements play a role and there is evidence that apatite solubility (related directly to *Dpar*) plays an important role as well.
- *[Cl]* is typically measured using an electron microprobe but this fact alone does not make it better science, especially considering the reality of limited funding for basic research and commercial studies. Rank ordering the parameters *[Cl]* and *Dpar* in terms of "first-order effect" and "second-, third-, or fourth-order effect" is baseless and misleading without a full disclosure of the methodology and resultant data leading to such conclusions.

Discussion

Both *Dpar* and *[Cl]* are very useful as indicators of fission track annealing kinetics in apatite and they appear to be approximately equal in their effectiveness. In a general sense, both are believed by the author to account for some 90 percent of the kinetic variation among apatites; for 90 percent of all apatite grains, these parameters appear to work as desired (although they work differently); for 10 percent of the grains, these parameters appear to fail (although they fail differently). Considering the interpretation risks when neither parameter is used (or a parameter as yet, undiscovered, untested, or not presented in the public domain), the 10 percent risk of failure when either is used is justified. Recognizing the existence and nature of the failures of *Dpar* and *[Cl]* is an essential step in the pursuit of knowledge concerning the understanding of fission tracks in apatite. If fact, apatites for which either *Dpar* or *[Cl]* fail may hold the key to a fuller understanding of the mechanism(s) by which fission tracks anneal in apatite. Any 100 percent successful model of fission track annealing in apatite must account for the failures as well as the successes of these parameters.

It is *essential* that a calibrated kinetic parameter be measured for each apatite age and length grain from which fission track data are obtained for purposes of detailed thermal history interpretation. Objectivity demands that this be accompanied by a presentation of the limitations, based on available information, of the kinetic parameter chosen. Whereas the least resistant to annealing apatites (say, *Dpar* = 1.50 mm; *[Cl]* = 0 weight percent) appear to experience total fission track annealing at around 110°C in the geological environment, the most resistant to annealing apatites (say, *Dpar* ≥ 3.00 mm; *[Cl]* > 3 weight percent) experience total fission track annealing at around 160°C (of course, these temperatures are subject to considerable debate and continuing study but the 50°C shift, or something close to it, is likely to survive intense scrutiny). When the least resistant apatites are entering the so-called "total annealing zone", the most resistant apatites are just entering the so-called "partial annealing zone." As an example of the importance of this effect, consider a hypothetical series of sedimentary samples analyzed over a range of temperatures in a drill hole (Table 1). Suppose all of the samples exhibit a typical distribution of apatite annealing resistivities, say 75 percent of the apatite grains of the least resistant to annealing kinetic type (*Dpar* = 1.50 mm in Table 1) and 25 percent of the grains of the most resistant type (*Dpar* = 3.00 mm in Table 1; actually, as a rule, a continuum of *Dpar* or *[Cl]* values is usually observed in clastic sedimentary rocks but the grouping assumed here helps to simplify the following argument). Suppose further that all apatite grains would give the same fission track age if the effects of heating could be removed and that all exhibit the same uranium concentration. In the relatively unannealed samples at low temperature, the least resistant to annealing apatite grains dominate both the fission track age and length data. However, with increasing temperature, the length data become increasingly dominated by the most resistant kinetic type because the probability of observing TINT fission tracks is proportional to the product of a) the square of the track density, b) the mean track length, and c) the width of the etched fission tracks (Donelick and Miller, 1991), whereas the age data maintain their initial 3:1 ratio of dominance by the least resistant kinetic type. Near the bottom of the drill hole, if temperatures are sufficient to totally anneal fission tracks in the least resistant apatites but not sufficient to totally anneal tracks in the most resistant apatites, the track length data become totally represented by the most resistant kinetic type while the grain age data maintain their initial 3:1 ratio. Throughout the drill hole, the combination of the fission track age and length data is a mixture of "apples and oranges" in terms of the annealing kinetics of their host apatite grains. Without a useful kinetic parameter by which to group both the age and length data, an interpretation that treats this "apples and oranges" mixture as a single kinetic system is, quite obviously, erroneous.

Importantly, this "apples and oranges" effect prevails at geological temperatures above approximately 90°C, even for apatite mixtures with a fractional component of the most resistant to annealing apatites significantly less than 25 percent. There is no doubt that a large quantity of data has been and continues to be generated that suffers from this problem, owing to the rather common occurrence of apatite grains that are resistant to annealing. This is especially true of drill hole studies. Simply assuming a particular kinetic system for a mixture of apatite grains under study (e.g., many workers assume Durango apatite is representative of their grain mixtures) does not overcome this problem.

Final Comments

Publications supporting the above assertions are forthcoming but were not finalized when this article was written. For this lack of supporting evidence, the author apologizes. Finally, for the record, this communication is not intended to serve as an advertisement. However, to satisfy those who would disagree, Donelick Analytical, Inc. has provided general funding to help offset the cost of publishing and distributing this issue of *On Track*.

References Cited

Burtner, R.L., Nigrini, A., and Donelick, R.A., 1994, Thermochronology of Lower Cretaceous source rocks in the Idaho-Wyoming thrust belt. American Association of Petroleum Geologists Bulletin, v. 78, no. 10, pp. 1613-1636.

Donelick, R.A., 1993, A method of fission track analysis utilizing bulk chemical etching of apatite. U.S. Patent Number 5,267,274.

Donelick, R.A., 1995, A method of fission track analysis utilizing bulk chemical etching of apatite. Australian Patent Number 658,800.

Donelick, R.A. and Miller, D.S., 1991, Enhanced TINT fission track densities in low spontaneous track density apatites using ^{252}Cf-derived fission fragment tracks: A model and experimental observations. Nuclear Tracks and Radiation Measurements, v. 18, pp. 301-307.

	Apatite with *Dpar* 1.50 µm			**Apatite with *Dpar* 3.00 µm**				
Sample Temp. (°C)	Grain Fission Track Age (Ma)	Grain Mean Fission Track Length (µm)	TINT Density Weighting Factor (per area)	Grain Fission Track Age (Ma)	Grain Mean Fission Track Length (µm)	TINT Density Weighting Factor (per area)	Age Data Contribution Ratio for 3 grains *Dpar*=1.50 per 1 grain *Dpar*=3.00 (1.50:3.00)	Length Data Contribution Ratio for 3 grains *Dpar*=1.50 per 1 grain *Dpar*=3.00 (1.50:3.00)
20	10.1	14.7	2250	10.3	15.3	4870	3:1	6750:4870
40	9.7	14.2	2004	10.0	14.9	4470	3:1	6012:4470
60	9.2	13.5	1714	9.7	14.5	4093	3:1	5142:4093
80	8.3	12.3	1271	9.3	13.9	3607	3:1	3813:3607
100	4.3	9.3	258	8.7	13.1	2975	3:1	774:2975
110	0.7	9.2	7	8.3	12.6	2604	3:1	7:2604
120	0.1	9.0	<1	7.8	11.9	2172	3:1	<1:2172
140	0	0	0	5.1	9.9	772	3:1	0:772
150	0	0	0	2.6	8.5	172	3:1	0:172
160	0	0	0	0.4	8.4	4	3:1	0:4

Table 1. Grain age and mean track length characteristics of apatite grains exhibiting different annealing kinetics and their relative contributions to whole sample age and length data in a hypothetical drill hole.

NOTES: TINT Density Weighting Factor = $(\text{Grain Fission Track Age})^2$ % Mean Track Length % *Dpar* (after Donelick and Miller, 1991; their Equation 1). Ages and mean lengths calculated using AFTSolve assuming isothermal temperature conditions for a period of 10 Ma.

More Short Tracks

Geotrack Moves to Mental Clinic

by Paul Green
Geotrack International Pty. Ltd.

When the last copy of "OnTrack" arrived, and I leafed though it with the usual eager anticipation, my eye quickly lit on something that made me realise we were guilty of gross negligence - yes, we had forgotten to inform the editor of our change of address!!!

The old "University of Melbourne" entry was still there for all of us in the 1996 Directory of the International Fission Track Community. For those of you who don't know (I think I told almost everyone at the Gent meeting!), we moved out of the University last year, into our own premises in Brunswick West, a suburb of Melbourne about ten minutes drive northwest from the University. If you know Melbourne, we are on the eastern flank of Moonee Ponds Creek (no Edna Everage jokes, thank you) overlooking the Tullamarine Freeway (the one that takes you from the airport into the city) opposite Moonee Valley Racecourse. The building itself used to be a Mental Clinic (no jokes there either, thank you!), but has now been extensively remodelled to suit our needs.

The move came about basically because the Department of Geology suddenly decided they needed the space we were occupying (strange that some of it still isn't being used then, eh?), and our existing lease was coming to an end. So we spent a considerable amount of time looking at buildings, a bit like something out of Goldilocks and the Three Bears - this one's too small, this one's too big, this one's got a wooden floor, this one's got an asbestos roof, this one's too far from a Pizza Restaurant. Finally, we found the Melville Clinic, which met our needs pretty much spot on. Several months later, after much discussion about who gets which room, what colour is the carpet to be, what colour do we paint the walls, we moved in during June last year. Various aspects of the fitting out were given particular attention - Paul, Ian and Kerry all have identically sized offices!

The move itself went almost without a hitch, which was pretty surprising considering that we were moving the probe, SEM, optical microscopes and multitudinous computers of various sizes, shapes and affiliations. We all remembered the stories of when the Geology Department moved from it's old site on campus to the new building in the mid-seventies, when the specialist firm brought in to move the SEM dropped it and it had to be replaced! (Incidentally, the replacement model was also broken when it arrived, and that had to be replaced too!!) So Pat insisted that we move everything ourselves, and in the end just about the only casualty of our move was a filing cabinet that got a bit bent. Even the probe, when it was all put back together and turned on, started to purr like a contented cat in front of a warm fire (or in our case, in front of a ducted heating outlet).

The final stage in the move came in late November, when the building was officially opened by John Lovering, who was presented with a magnificent memento consisting of a piece of Fish Canyon Tuff complete with a suitably inscribed plaque. We all owe John an enormous debt of gratitude, for it was his vision that led to the original creation of Geotrack as a business entity back in 1983, and it was particularly gratifying to have him open our new facility. It also gave us an opportunity to entertain old friends, including Andy, Barry and Paul from Latrobe, and to catch up with a number of ex-employees. We even managed to impress some local industry representatives!

So here we are in Brunswick West, having cut the link to our academic origins at last. I guess most of us were a little concerned that we were stepping into the unknown, but the main reaction so far is - why didn't we do it earlier? OK, Lygon Street is a bit further away than it used to be, but that's about our only serious problem. For those of you who want to contact us, the new details are as follows:

Geotrack International Pty Ltd.
37 Melville Road, Brunswick West,
Victoria 3055, Australia

Tel.: **+613 9380 1077**
Fax.: **+613 9380 1477**
e-mail **mail@geotrack.com.au**

Graduate Student Opportunities in Thermochronology and Tectonics

at La Trobe University, Australia

The School of Earth Sciences invites expressions of interest from science graduates interested in applying for Ph.D. scholarships which are available from La Trobe University and the Australian Geodynamics Cooperative Research Centre. Current fields of research and locations of potential projects include:

- Denudation history and evolution of continental landscapes (Africa, Australia, Canada, South America and Fennoscandia).
- Thermal evolution and structural setting of economically prospective terrains, in relation to their mineral and energy resources (Australia, SE Asia and South America).
- Thermochronology and morphotectonics of continental rifts and rifted margins (Australia, Africa and North America).
- Characterisation of ionising radiation damage in minerals and studies of fission track annealing kinetics in apatite, zircon and sphene.

The School has state-of-the art laboratories for fission track, and $^{40}Ar/^{39}Ar$ geochronology and thermochronology, workstation-based structural analysis, GIS and image analysis, thermal ionisation mass spectrometry and a broad range of computing and support equipment. In addition we also have advanced laboratories for analytical geochemistry (XRF and XRD), fluid inclusion studies, thermoluminescence dating and paleomagnetism. The School is part of the Victorian Institute of Earth and Planetary Sciences which includes access to facilities for stable isotope mass spectrometry, ICP-MS, and electron microprobe analysis.

The closing date for scholarship applications is 30 September, 1997. Enquiries may be sent to Professor **Andrew Gleadow** (a.gleadow@latrobe.edu.au) or Dr **Barry Kohn** (b.kohn@latrobe.edu.au), School of Earth Sciences, La Trobe University, Bundoora, Victoria 3083, AUSTRALIA. (Tel: 61-3-9479 2649, Fax: 61-3-9479 1272). Further information can be found at: http://www.latrobe.edu.au/www/geology/

Revamped "Basin Research"

by Kerry Gallagher
Imperial College, London

The journal Basin Research has been revamped recently and is actively looking for papers on geomorphology, surface processes and sediment transport. The journal is developing along the lines of publishing papers dealing with the evaluation and dynamics of macro-to meso scale topography on the Earth's surface and the creation and filling of sedimentary basins.

There is clearly wide scope for papers incorporating applications of fission track analysis in these contexts (save the annealing and etching ones for Nuclear Tracks, Chem. Geol., etc.). Of particular interest are studies of the total denudation-depositionsystem, basin inversion, long term denudation and sediment supply, quantitative basin modelling. There have been a couple of papers published recently by Peter Kamp et al. (vol. 8(4), 383-402) and Max Rohrman et al. (vol. 8(1), 45-64) which provide a good example of the kind of material that the editors are looking for. There should be more than just some fission track data from region X - demonstrating the utility of this data, integrated with other geological/geophysical information and modelling, is the way to present your work.

The all important impact factor, etc. has not been determined for Basin Research as the impact factor for 1997, for instance, is calculated on citations of papers published in the previous two years. This is will be the first year since appearing in Current Contents in 1995. However, it publishes a relatively small number of papers and these are of very complete studies. In calculating an impact factor the denominator is the number of papers published.

Call for Contributions to the November 1997 On Track issue 15

Dear Fellow Tracker:

The next issue of OnTrack is scheduled for release in late November, 1997 and we are already looking for contributions. OnTrack welcomes contributions of virtually any kind, including news and gossip, job openings, descriptions of new lab techniques, reviews of useful products, raving editorials about what all 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 us the final text no later than November 1, 1997 (DEADLINE). If you propose to submit a substantial article, please let the editor know ASAP. If possible, please send both a paper copy of your contribution and either a disk copy (3.5 inch, Macintosh), or as attachments via e-mail (please check with me prior to sending). All text should be saved in Microsoft word (Mac version). If you can't send a Macintosh disk, send an IBM disk (3.5 inch) with text in word or Word Perfect.

OnTrack includes a list of recent and forthcoming Fission Track papers. If you know of a paper that was published recently or that is in press and should appear in the near future, please let me know so that it can be added to the list. Of course the editor always welcomes full reprints if you have an extra copy. Also, if you happen to move locations (or know of someone who has moved) due to a change in jobs or finally finishing off the thesis and graduating, please inform us.

OnTrack is also happy to run Advertisements. There is no charge for line ads by non-commercial entities (e.g., universities). Please contact the editor for advertising rates for commercial ads (e.g., by equipment dealers). OnTrack has remained free of charge and will continue to do so (at least for the near future). However, to save costs we generally mail only one copy per lab so please be sure to photocopy the lab copy and pass copies around your lab. If possible, we will also send out OnTrack electronically, so please make sure the editor has an up-to-date e-mail address for each person/lab.

Send contributions to:

Paul O'Sullivan, Editor, OnTrack,
School of Earth Sciences, La Trobe University
Bundoora, Victoria 3083, Australia
Tel. (03) 9479-3517; International (61-3) 9479-3517
Fax. (03) 9479-1272; International (61-3) 9479-1272
e-mail: pos@mojave.geol.latrobe.edu.au

Recent Fission-Track Papers

Please send items for future listings in On Track to the NEW editor, Paul O'Sullivan. The reference or a photo copy of the first page will suffice but a copy of the entire paper is appreciated. We are also interested in non-fission-track papers that may be of special interest to the fission-track community. Papers in press are welcome, please include an estimate of the expected month of publication.

Aleinikoff, J. N., Muhs, D. R., Walter, M., Naeser, C. W., and Swinehart, J. B., 1995, Provenance of Holocene eolian sand, Central Great Plains; U-Pb and fission track ages of detrital zircons and Pb isotopic compositions of K-feldspar. Abstracts with Programs - Geological Society of America, Vol. 27, No. 3, p. 33-34

Andriessen, P. A. M. and Zeck, H. P., 1996, Fission-track constraints on timing of Alpine nappe emplacement and rates of cooling and exhumation, Torrox area, Betic Cordilleras, S. Spain. Chemical Geology, Vol. 131, No. 1-4, p. 199-206

Baker, J. and Seward, D., 1996, Timing of Cretaceous extension and Miocene compression in northeast South Island, New Zealand; constraints from Rb-Sr and fission-track dating of an igneous pluton. Tectonics ; Vol. 15, No. 5, p. 976-983

Barker, C. E., Lewan, M. D., Bone, Y., and Marshallsea, S. J., 1996, Thermochronological and petroleum generation studies next to dikes in the Upper Jurassic-Lower Cretaceous Strzelecki Group, onshore Gippsland Basin, Australia. Annual Meeting Abstracts - American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Vol. 5, p. 10.

Brandon, M.T., 1996, Probability density plot for fission-track grain-age samples: Radiation Measurements, v. 26, p. 663-676.

Clift, P. D., Carter, A., and Hurford, A. J., 1996, Constraints on the evolution of the East Greenland margin; evidence from detrital apatite in offshore sediments. Geology, Vol. 24, No. 11, p. 1013-1016

Collins, M., Arne, D., and Zentilli, M., 1996, Fission track, and compositional analysis of detrital apatite in terms of tectonic history and sedimentary provenance; Sawtooth Range, Sverdrup Basin, Canadian Arctic Islands. Atlantic Geology, Vol. 32, No. 1, p. 69

Danhara, T., 1995, Towards precise measurement of zircon and glass fission-track geochronology for Quaternary tephras. Quaternary Research, Vol. 34, No. 3, p. 221-237

Decker, J., Corrigan, J., and Bergman, S., 1996, Brookian maturation and erosion framework of North Alaska. Annual Meeting Abstracts - American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Vol. 5, p. 34

Dobretsov, N. L., Buslov, M. M.. Delvaux, D., Berzin, N. A., Ermikov, V. D., Yermikov, V. D., 1996, Meso- and Cenozoic tectonics of the Central Asian mountain belt; effects of lithospheric plate interaction and mantle plumes. International Geology Review, Vol. 38, No. 5, p. 430-466

Elliott, W. C, Roden-Tice, M., and Higley, D. K., 1996, Thermal history of the Denver Basin "hot spot". Annual Meeting Abstracts - American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Vol. 5, p. 41-42

Erikson, J. P., Kelley, S. A., Heizler, M., and Zeitler, P. K., 1996, Sedimentation in the Barinas Basin and uplift of Merida Andes, Venezuela, constrained by new temporal data. Annual Meeting Abstracts - American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Vol. 5, p. 43

Fukuoka, T., 1995, Recent progress in accuracy and precision of radiometric dating for Quaternary samples and understanding of their dates. Quaternary Research, Vol. 34, No. 3, p. 265-270

Green, P. F., Hegarty, K. A., and Duddy, I. R., 1996, Compositional influences on fission track annealing in apatite and improvements in routine application of AFTA. Annual Meeting Abstracts - American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Vol. 5, p. 56

Green, P. F., Hegarty, K. A., Duddy, I. R., Foland, S. A., 1996, Assessing zircon fission track analysis as a paleotemperature tool for sedimentary basins. Annual Meeting Abstracts - American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Vol. 5, p. 56

Hideki Iwano, Tohru Yamashita and Tohru Danhara, 1996, Three-dimensional analysis of fission track length in minerals: - A measuring system and its application - Fission Track News Letters No.9 13-22.

Ibetsberger, H. J., 1996, The Tsergo Ri Landslide; an uncommon area of high morphological activity in the Langthang Valley, Nepal. Tectonophysics, Vol. 260, No. 1-3, p. 85-93

Jacobs, J., Kaul, N., and Weber, K., 1996, The history of denudation and resedimentation at the continental margin of western Dronning Maud Land, Antarctica, during break-up of Gondwana. Geological Society Special Publications, Vol. 108, p. 191-199

Jacobs, J. and Thomas, R. J., 1996, Pan-African rejuvenation of the c. 1.1 Ga Natal metamorphic province (South Africa); K-Ar muscovite and titanite fission track evidence. Journal of the Geological Society of London, Vol. 153, Part 6, p. 971-978

Japsen, P., 1997, Regional Neogene exhumation of Britain and the western North Sea. Journal of the Geological Society of London ; Vol. 154, p. 239-247

Kaneoka, I., 1995, Fundamental problems in radio-metric dating; how we can define the meaning of a radiometric age? Quaternary Research, Vol. 34, No. 3, p. 261-264

Kitada, N. and Wadatsumi, K., 1995, Annealing properties of natural glass fission tracks at the controlled temperature and its implication on the isothermal plateau dating techniques. Journal of Geosciences, Osaka City University, Vol. 38, p. 1-12

Krol, M. A., 1996, Thermal and Tectonic Evolution of the Cenozoic Himalayan Orogen and a Mesozoic Newark Rift Basin; Evidence from 40Ar/39Ar Thermochronology. Ph.D. Thesis, Lehigh University, Bethlehem, PA, USA.

Laslett, G. M. and Galbraith, R. F., 1996, Statistical modelling of thermal annealing of fission tracks in apatite. Geochimica et Cosmochimica Acta, Vol. 60, No. 24, p. 5117-5131

Luczaj, J. A., 1996, Diagenesis of the Lower Permian Krider Dolomite, Southwest Kansas; fluid-inclusion, U-Pb, and fission-track evidence for reflux dolomitization during latest Permian time. Program and Abstracts; Biennial Pan-American Conference on Research on Fluid Inclusions, Vol. 6, p. 76-77

Mancktelow, N. S., and Grasemann, B., 1997, Time-dependent effects of heat advection and topography on cooling histories during erosion. Tectonophysics ; Vol. 270, No. 3-4, p. 167-195

McDonough, M. R., Stockmal, G. S., Issler, D. R., Grist, A. M.; Zentilli, M., Archibald, D. A., 1995, Apatite fission track and 40Ar-39Ar analysis of the external zone of the Canadian Rockies near Jasper, Alberta; implications for thermal maturity. Lithoprobe REPORT ; 47, p. 244-249

McDowell, Fred, W. and McIntosh, William, C., 1997, Laser-fusion 40Ar-39Ar dating of the Durango volcanic sequence, Sierra Madre Occidental volcanic field, Mexico. Abstracts with programs - Geological Society of America; South-Central and Rocky Mountain Sections, Joint Annual Meeting in El Passo, Texas, March 20-21, 1997.

Nakayama, K., 1996, The low vitrinite reflectance observed in the Miocene formations in S.E. Asia; suppressed or cooler thermal history?. Annual Meeting Abstracts - American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Vol. 5, p. 103

Olesch, M., 1995, The 100 Ma thermal event in Antarctica; relations between apparent apatite fission track ages and oceanic crust production. Terra Nostra, Vol. 1-95, p. 35

Omar, G.I., Lutz, T.M., Giegengack, R., 1994, Apatite fission-track evidence for Laramide and post-Laramide uplift and anomalous thermal regime at the Beartooth overthrust, Montana-Wyoming, Geological Society of America Bulletin, v. 106, p. 74-85.

Omar, G.I., and Steckler, M.S., 1995, Fission-track evidence on the initial opening of the Red Sea: two pulses, no propagation, Science, v. 270, p. 1341-1344.

O'Sullivan, P. B. and Currie, L. D., 1996, Thermotectonic history of Mt Logan, Yukon Territory, Canada; implications of multiple episodes of middle to late Cenozoic denudation. Earth and Planetary Science Letter, Vol. 144, No. 1-2, p. 251-261

Pagel, M., Braun, J. J., Disnar, J. R., Martinez, L., Renac, C., and Vasseur, G., 1997, Thermal history constraints from studies of organic matter, clay minerals, fluid inclusions, and apatite fission tracks at the Ardeche paleo-margin (BA1 drill hole, GPF Program), France. Journal of Sedimentary Research, Section A: Sedimentary Petrology and Processes, Vol. 67, No. 1, p. 235-245

Pevear, D. R. and Vrolijk, P. J., 1996, Using the illite/smectite paleo-thermo-chronometer. Annual Meeting Abstracts - American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Vol. 5, p. 112

Pemberton, G., 1996, Fluorescence of apatite; a fast method for discrimination of Cl/F compositional types. Atlantic Geology, Vol. 32, No. 1, p. 83

Pillans, B., Kohn, Barry P., Berger, G., Froggatt, P., Duller, G., Alloway, B., and Hesse, P., 1996, Multi-method dating comparison for mid-Pleistocene Rangitawa Tephra, New Zealand. Quaternary Science Reviews, Vol. 15, No. 7, p. 641-653

Rahn, M.K., Hurford, A.J., and Frey, M., 1997, Rotation and exhumation of a thrust plane: Apatite fission track data from the Glarus thrust, Switzerland, Geology, in press.

Raza, A., Hill, K. C., Gleadow, A. J. W., Brown, R. W., Korsch, R. J., and Kohn, B. P., 1996, Fission-track analysis of the central eastern margin of Australia; a record of the northward propagation of the Tasman rift system? Abstracts - Geological Society Of Australia, Vol. 41, p. 360

Riis, F., 1996, Quantification of Cenozoic vertical movements of Scandinavia by correlation of morphological surfaces with offshore data. Global and Planetary Change, Vol. 12, No. 1-4, p. 331-357

Ritter, U., Duddy, I., Mork, A., Johansen, H., and Arne, D., 1996, Temperature and uplift history of Bjornoya (Bear Island), Barents Sea. Petroleum Geoscience, Vol. 2, No. 2, p. 133-144

Rowe, J., Chadwick, R. A., Baily, H. E., and Kirby, G. A., 1996, The post-Triassic structural evolution of North-West England and adjacent part of the East Irish Sea [discussion and reply]. Proceedings of the Yorkshire Geological Society, Vol. 51, Part 2, p. 173-175

Sobel, E.R., and Dumitru, T.A., 1997, Thrusting and exhumation around the margins of the western Tarim basin during the India-Asia collision, Journal of Geophysical Research, v. 102, p. 5043-5064.

Spikings, R. A., Foster, D. A., Gleadow, A. J. W., and Kohn, B. P., 1996, Phanerozoic tectonic and denudational history of the Mt. Isa Inlier, Queensland. Abstracts - Geological Society Of Australia, Vol. 41, p. 414

Stockli, D.F. and Linn, J.K., 1996, Apatite Fission-Track Thermochronology of the Canyon Range, Utah: Denudation of the breakaway zone of the Sevier Desert detachment. Abstracts with programs - Geological Society of America; Vol. 28, no. 6, p.

Tingate, P. R., Lindsay, J. F., and Marshallsea, S. J., 1996, Impact structures as potential petroleum exploration targets; Gosses Bluff, a Late Jurassic example in central Australia. Journal of Australian Geology and Geophysics, Vol. 16, No. 4, p. 529-552

Tingate, P. R., Alexander, E. M., Michaelsen, B. H., Duddy, I. R., and Griffiths, C. M., 1996, Tectonic events affecting the thermal history of the western margin of the Eromanga Basin. Abstracts - Geological Society of Australia, Vol. 41, p. 442

Weiland, R. J. and Cloos, M., 1996, Pliocene-Pleistocene asymmetric unroofing of the Irian fold belt, Irian Jaya, Indonesia: Apatite fission-track thermochronology. Geological Society of America Bulletin, v. 108, n. 11, p. 1438-1149.

Wang Lu and Liu Shunsheng, 1996, Geothermal evolution of Dongpu Depression by fission track analysis. Journal of Central South University of Technology (English Edition), Vol. 3, No. 1, p. 88-91.

Winkler, J. E., 1996, Timing of exhumation of the Wichita Mountains, Oklahoma; a fission-track investigation. Master's thesis--University of Texas at Dallas, Richardson, TX, USA.

Wolf, R.A., Farley, K.A., and Silver, L.T., 1996, Helium diffusion and low-temperature thermochronometry of apatite: Geochimica et Cosmochimica Acta, v. 60, p. 4231-4240.

Wolf, R.A., Farley, K.A., and Silver, L.T., 1997, Assessment of (U-Th)/He thermochronometry: The low-temperature history of the San Jacinto Mountains, California: Geology, v. 25, p. 65-68.

Zentilli, M., Graves, M. C., and Grist, A.,1996, Fission track analysis applied to mineral deposits and exploration. Atlantic Geology, Vol. 32, No. 1, p. 92-93

1997 UPDATE: DIRECTORY OF THE INTERNATIONAL FISSION-TRACK COMMUNITY

This directory is published solely for the information of fission-track researchers. It is neither a comprehensive directory including all fission-track researchers nor an official document endorsing the scientific stand of individuals by the fission-track community. We provide here an update to the initial directory prepared by Rasoul Sorkhabi with the hope that we have accounted for the changes in addresses that have occurred since the last release of the directory. ***If you have changed your address, know someone else who has or think that someone should be on this list, please let the new Editor know (pos@mojave.geol.latrobe.edu.au)!***

Aizawa, Minoru
Dept. of Geology
Imperial College
Prince Consort Road
London SW7 2BP, *United Kingdom*
Tel.: +44 (0) 171-594-6468
Fax.: +44 (0) 171-594-6464
e-mail: m.aizawa@ic.ac.uk

Calmus, Thierry
Apartado Postal 908
Hermosillo, Sonora, 8300, *Mexico*
e-mail:
tcalmus@marina.geologia.uson.mx

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

Graefe, Kirsten
Institut fuer Geologie
Universitaet Tuebingen
Sigwartstrasse 10
D-72076 Tuebingen, Germany
e-mail: graefe@uni-tuebingen.de

Green, Paul F. /
Geotrack International pty Ltd
37 Melville Road
Brunswick West
Victoria 3055, *Australia*
Tel.: +61-3-9380-1477
mail@geotrack.com.au

Gunnell, Yanni
Laboratoire de Geographie
Physique
CNRS-UPRES-A 6042
Universite Paris 7, Case 7001
2 Place Jussieu,
75251 Paris cedex 05, *France*
Fax: +33 (0) 1 44 27 60 83
Tel.: +33 (0) 1 44 27 60 82
e-mail: gunnell@paris7.jussieu.fr

Hulver, Michael L.
Dept. of the Geophysical Sciences
The University of Chicago
5735 S. Ellis Avenue
Chicago, Illinois 60637,
United States of America

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

Laslett, Geoff
CSIRO Mathematical and
Information System
Private Bag 10, Clayton South
MDC, Clayton
Victoria 3169, *Australia*
Tel. : +61 3 9545 8018
Fax.: +61 3 9545 8080
e-mail: Geoff.Laslett@cmis.csiro.au

Jon Linn
WVDEP/TAGIS
10 McJunkin Rd, Nitro, WV 25143,
United States of America
Tel.: (304) 759-0519
Fax: (304) 759-0565
e-mail: jlinn@crimson.osmre.gov

Lutz, Timothy M.
West Chester University
Dept of Geology and Astronomy
West Chester, PA 19383,
United States of America

Miller, Donald S.
Dept. of Earth and Envir. Sciences
Rensselaer Polytechnic University
Troy, NY 12180-3590,
United States of America.
Tel.: 1-518-276-8523,
Fax: 1-518-276-8627
E-mail: milled2@rpi.edu

Rahn, Meinert
Institut fuer Mineralogie, Petrologie
und Geochemie
University of Freiburg
Albertstrasse 23b
79104 Freiburg, Germany
Tel: 49-761-2036416,
Fax: 49-761-2036407
Email:rahn@ruf.uni-freiburg.de

Ravenhurst, Casey E.
Dept. of Geology and Geography
University of Massachusetts
Amherst MA 01003,
United States of America
E-mail: cravenhu@geo.umass.edu

Perez De Armas, Jaime G.
Rice University
Dept. of Geology and Geophysics
MS-126
Houston, TX 77025,
United States of America
e-mail: jaime@rice.edu

Schaefer, Thorsten
Universitaet Bremen Fachbereich
Geowissenschaften PO Box 330
440 D-28334 Bremen, *Germany*
Tel.: 0049 421 218 3994
Fax: 0049 421 218 3993
postgrad@geopol.unibremen.de

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

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

FT STAge Systems

Automated microscope stage systems greatly increase operator productivity by automating tedious aspects of microscope work. Since their introduction, our systems have been adopted by more fission track laboratories than any other system.

Outstanding Hardware:

Our stage systems are based on a highly-reliable, high-precision Kinetek™ computer-automated microscope scanning stage. Several hundred Kinetek stages are currently in operation, mainly in the microelectronics industry. Compatible with almost any brand of microscope. Use of this popular, general purpose stage significantly reduces the system cost. System also includes a high-quality Calcomp™ 12x12" digitizing tablet. Assembly to full operational status generally requires only a few days.

Outstanding Software:

Software is a complete, highly sophisticated Apple Macintosh program developed with careful attention to all aspects of microscope work. Fully integrates track counting, track length measurement, slide scanning, and file management functions. Moves precisely from grain to mica print in 3 seconds. Very user friendly. Fully functional even with the lowest cost Macintosh models and with the MS-Windows compatible Macintoshes.

Innovative, Highly-Intuitive Stage Control System:

Stage is driven primarily with the digitizing tablet cursor rather than a joystick. For example, to center a grain or track, just superimpose the cursor on it, push a button, and the stage automatically centers it. This avoids tedious manual centering via the joystick. Most software commands are driven from the cursor buttons, which are easily distinguished by feel, so there is no need to look away from the eyepieces to the computer screen or keyboard.

Fission Track Laboratories Using the System:

•Stanford University, Stanford, California, installed in 1991
•University of California, Santa Barbara, California, installed in 1992
•ARCO Exploration and Production Technology, Plano, Texas, installed in 1992
•Universität Bremen, Bremen, Germany, installed in 1993
•E.T.H., Zürich, Switzerland, installed in 1993 using a preexisting stage
•Kent State University, Kent, Ohio, installed in 1993
•University of Wyoming, Laramie, Wyoming, installed in 1993
•University of Arizona, Tucson, Arizona, installed in 1993
•Max-Planck-Institut, Heidelberg, Germany, installed in 1993 using a preexisting stage
•Union College, Schenectady, New York, installed in 1994
•Monash University, Melbourne, Australia, installed in 1994 using a new Zeiss stage
•La Trobe University, Melbourne, Australia, installed in 1994 using two new Zeiss stages
•University of Pennsylvania, Philadelphia, Pennsylvania, installed in 1995
•Universität Tübingen, Tübingen, Germany, installed in 1995
•Universidad Central de Venezuela, Caracas, Venezuela, installed in 1995
•Brigham Young University, Provo, Utah, installed in 1995
•Central Research Institute of the Electric Power Industry, Chiba, Japan, installed in 1995
•Universität Salzburg, Salzburg, Austria, installed in 1996
•University of Southern California, Los Angeles, California, installed in 1996
•E.T.H., Zürich, Switzerland, second system installed in 1996 using a preexisting stage
•Geologisk Centralinstitut, Copenhagen, Denmark, installed in 1996 using a preexisting stage
•University of Waikato, Hamilton, New Zealand, installed in 1996 using a preexisting stage
•University of Bologna, Bologna, Italy, installed in 1997
•Centro di Studio di Geologia dell'Appenno e delle Catene Perimediterranee, Florence, Italy, to be installed in mid 1997
•University of Wyoming, Laramie, Wyoming, second system to be installed in mid 1997
•Universität Potsdam, Potsdam, Germany, to be installed in late 1997

Detailed Information:

The system is described in a paper in Nuclear Tracks and Radiation Measurements, vol. 21, p. 575-580, Oct. 1993 (proceedings issue for the 1992 Workshop on Fission Track Thermochronology held in Philadelphia).

For Further Information Contact: Dr. Trevor Dumitru, 4100 Campana Drive, Palo Alto, California 94306, U.S.A., telephone (auto-switching voice and fax line): 1-415-725-6155 (changes to 1-650-725-6155 on 5 August 1997)