On Track

The Newsletter of the International Fission-Track Community
September 2003, Volume 13, Number 2, Issue 26

Contents

RECENT PHD THESES:

On Track is a newsletter of the international fission-track community published electronically in the months of July and February. The views expressed in On Track articles are those of the authors and do not reflect those of the fission-track community or the editor of On Track. The copyright of articles belongs to the authors. Articles may not be reproduced without written permission. Trademarks and patents are the property of the corporations and/or individuals indicated in the article.

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Editor's Notes

Next August will bring two important meetings for thermochronology. The 10th International Conference on Fission Track Dating and Thermochronology will be held in Amsterdam from August 8-13th. This meeting is held every 4 years and is THE meeting where the entire International FT community comes together. The meeting will also include other low temperature thermochronologic methods. Shortly afterwards, the 32nd International Geological Congress will be held in Florence, from August 20-28. This meeting includes several sessions of direct interest to trackers. Details about both of the meetings are presented later in this issue. Please try to attend!

Continuing the trend from the last issue, this issue highlights a suite of recent PhD theses. These give an idea of the current work in several FT labs, as well as letting you know about potential new co-workers. Naturally, submission of such abstracts for upcoming issues of OnTrack are strongly encouraged!

Three longer articles focus on a range of topics. The question of whether the external detector method is appropriate for FT-dating of glasses is discussed by Giulio Bigazzi. Michael Krochmal presents an update of technological advances in FT analysis for software as well as hardware. The important issue of whether pressure affects He diffusion and track annealing in apatite is discussed by Ray Donelick et al., based on a suite of new experimental data.

Many of the back issues of OnTrack have been placed on the Universitaet Potsdam web site in pdf format. These can be found at www.geo.uni-potsdam.de/Labore/Spaltspurlabor/ontrack.html. The remaining issues are slowly being scanned and will be added when they are ready.

In the last year, I have been asked to post advertisements for several post-doc positions as well as meeting announcements. These have been sent to the entire OnTrack mailing list. Hopefully these emails have not bothered you, the reader. I hope that the next editor will continue this practice, as it brings useful information to the track community.

The next editor will be Roderick Brown. He has courageously volunteered to take on the job without any arm-twisting. Many of you know him through his program MacTrack and his FT-modeling and landscape development papers. Rod will be quite busy next year. He has accepted the position as Professor of Earth Sciences at the Division of Earth Sciences, University of Glasgow and will start there in April 2004. Please make his job easier by sending him contributions for the next issue of OnTrack! For at least the next few months, Rod can be contacted at rwbrown@unimelb.edu.au.

[Ed Sobel]

Short Tracks

Inter-laboratory Track Length Comparison

Prior to the Amsterdam FT Workshop, I (Tony Hurford) plan to circulate several samples of Durango apatite containing specific track length distributions. This will be the first attempt at a global comparison of anything other than the very basic induced and volcanic-type track length patterns. The plan is to circulate between 30 and 40 sets each containing three Durango aliquots. In each aliquot the spontaneous tracks will have been totally annealed prior to irradiation, the resulting induced tracks then being further annealed. One aliquot will be circulated as "known" i.e. it will have a note of what we measure and can thus serve as an open comparative baseline.

The other two aliquots will be supplied as unknowns. In each case the recipient should process the sample in their usual way, polishing, etching, measuring. Results (anonymous) will be presented at the Amsterdam FT Workshop in August 2004.

The mass of material to be irradiated will restrict the number of sets and so, of necessity, there will be some sharing. I will consult the holders of the FT lab database to ensure an equitable distribution as possible, but you may make representations directly to me, if possible nominating other workers or laboratories who share your etching approaches and with whom you might be able to share a sample set.

The timetable is:
* from now until February 2004: prepare samples, anneal, irradiate, cool, re-anneal, check lengths
* from February 2004 circulate samples
* data to be supplied to me by 1st June 2004 if possible; analysis should not take more than a few hours per person
* analysis of reported data and presentation of results in August 2004. Only I will know the identity of analysts / labs.

If you have comments ideas or suggestions please contact me. Three aliquots represents a specific and realistic assessment of the time involved in preparation - so please don't ask for more unless you want to do the whole experiment!

Many thanks,
Tony

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Bart Hendriks has finished his PhD at the Isotope Geochemistry department of the Vrije Universiteit in Amsterdam. His PhD thesis, titled 'Cooling and Denudation of the Norwegian and Barents Sea Margins, Northern Scandinavia - Constrained by apatite fission track and (U-Th)/He thermochronology', can be downloaded from http://www.geo.vu.nl/news/thesis_barthendriks.pdf

The pattern of AFT ages in transects perpendicular to the northern Norwegian Atlantic margin is strongly asymmetric. It is demonstrated that the observed pattern is very similar to that of models of passive margin evolution that represent a retreating scarp. On the margin itself the AFT ages are as young as 90 - 100 Ma and further inland, right across the Northern Scandes mountain range ('the Caledonides'), the ages increase to more than 300 Ma on the gentle eastern flank of the range. Late Cretaceous - Paleogene (U-Th)/He ages in a vertical profile on Kebnekaise, the highest peak in the range, together with the observed age pattern suggest a rift shoulder origin for the range. Nevertheless, additional uplift mechanisms must have played an important role in the later development of the range. On the margin, the youngest AFT ages coincide spatially with a strong, negative gravity anomaly. Overall, the pattern of AFT ages in northern Scandinavia is very different from that observed in previous studies in southern Scandinavia (Max Rohrman - Southern Norway, Charlotte Cederbom - South/Central Sweden).

Since the 1st of April, Bart is working as a post-doc at the Geological Survey of Norway. He will continue to be working with AFT and (U-Th)/He data from northern Norway, and also use the Survey's Ar/Ar lab. The focus will be on the link between the very strong positive and negative gravity anomalies in the Lofoten and Nordland areas respectively and the late Mesozoic - Cenozoic denudation in these areas.

In January, 2003, Jeremy Hourigan finished his Ph.D. at Stanford University, and moved to Yale University to start a post doctoral position at Yale University. His research with Peter Reiners and Mark Brandon includes isotopic dating of exhumed metamorphic rocks in the Sredinniy Range of Kamchatka (Russia) and Alpi Apuane in the northern Apennines (Italy). He is also working on combined Pb and He dating of detrital zircons.

In May, 2003, Stuart Thomson moved from University of Bochum to start a post doctoral position at Yale University. His research with Peter Reiners and Mark Brandon will focus on He thermochronometry in the northern Apennines to study syn-convergent extension there, as part of the RETREAT project, funded by the NSF Continental Dynamics program.

His main research theme will involve applying (U-Th)/He and fission track thermochronology to help better understand the evolution (in particular the denudational history) of the northern Apennines, Italy. He also intends to continue ongoing research in the southern Andean and Mediterranean regions.

Phil Armstrong was awarded a Petroleum Research Fund grant entitled "Low-temperature thermochronology of the eastern Los Angeles Basin".

Rasoul Sorkhabi has moved to Salt Lake City to become a Research Professor at the Energy & Geoscience Institute of the University of Utah.

The Thermochronology Laboratory of the Universidad Central de Venezuela has been very active. Last year, the Ministry of Science and Technology of Venezuela funded a project on “Terrestrial sources for the Neogene Maracaibo and Barinas Oil basins” The thermochronology group includes Professor Jorge Mora (coordinator; email: jlmoram@hotmail.com), Professor Pedro Alson (investigator; email: palson@euler.ciens.ucv.ve), and Mauricio Bermudez (investigator: email: mbermude@euler.ciens.ucv.ve). Three papers are in press (see Bermúdez-Cella and Alson-Haran in the Fission Track papers section). They have had the support of the following investigators: John Garver of Union College, who participates in their project, Mathias Bernett and Mark Brandon of Yale University, Charles Naeser of USGS, Miguel Balcázar of the ININ, Mexico and Jorge Nieto of the UNAM, Mexico.

In July 2003, Matthias Bernet started a new postdoc position at the Laboratoire de Géodynamique des Chaînes Alpines, Université Joseph Fourier, in Grenoble, France. This position is funded by a Marie Curie Fellowship from the European Union. Matthias is working there with Peter van der Beek on detrital FT analysis of Himalayan sediments, age-elevation profiles in the Western Alps, and trying to advance single zircon FT and U-Pb dating.

Johan De Grave has started a Postdoctoral project supported by the Fund for Scientific Research – Flanders (Belgium). It is entitled “Far field effects of the India-Eurasia collision in Central Asia as revealed by low-temperature thermochronology.” It has been shown that ongoing convergence of the Indian and Eurasian plates and resulting strain-partitioning is responsible for active deformation occurring far in the interior of the Eurasian continent. The goal of this project is to investigate if the timing and intensity of the active intracontinental tectonics affecting the various tectonic and geodynamic units composing Central Asia can be constrained by using low-T thermochronological techniques. The areas the research will focus on are mainly the Altai and Sayan Mountains in South Siberia and Kazakhstan (of particular interest: Irtysh shear zone) and the Tien Shan Mountains in Kyrgyzstan, Uzbekistan and Tadjikistan (of particular interest: Talas-Fergana fault zone). Low-T techniques will include AFT (incorporating existing data from the researcher’s PhD) and apatite U-Th/He. If possible also ZFT and ^{40}Ar/^{39}Ar will be used. AFT analyses will be conducted at the Geological Institute of the University of Gent (Belgium) in co-operation with Peter Van den haute, while the He-analyses will be take place at Stanford (CA, USA) in co-operation with Michael McWilliams. Therefore Johan will work at the Noble Gas Lab of Stanford during one year (starting beginning of 2004).

CSIRO Australia and Patterson Instruments have entered into a collaborative research agreement to develop prototype instrument packages for (U-Th)/He thermochronology to be commercialized under the trade name “AlphachronTM”. The collaboration integrates the Patterson Instrument's gas handling system with CSIRO's diode-laser extraction module to produce an automated, turn-key instrument for the thermochronology research community. CSIRO Australia manages R&D projects for the global minerals and petroleum industry and undertakes R&D to advance the technology required to perform thermal history analysis. Patterson Instrument's has built helium extraction and gas handling systems in Australia, USA and Europe. For further information contact Brent McInnes (brent.mcinnes@csiro.au).

Meetings

10th INTERNATIONAL CONFERENCE ON FISSION TRACK DATING AND THERMOCHRONOLOGY

In 2004 the 10th International Conference on Fission Track Dating and Thermochronology will take place at Amsterdam, the Netherlands (http://www.Amsterdam.nl). The meeting begins on Sunday afternoon August 8 and lasts till Friday afternoon August 13. The conference meeting is hosted in the building of the Royal Netherlands Academy of Arts and Sciences (KNAW), in the center of Amsterdam city (http://www.knaw.nl).

Registration for conference participants and their partners is open on Sunday afternoon at the KNAW building , where a party will be organized to welcome the delegates.

The scientific program is planned as a single session and includes oral presentation and posters on all aspects of fission track analyses and methodology and its applications. Within the program for each day time slots of at least 2 hours are reserved for posters sessions. Special attention will be given to recent developments in methodology, integration with other relevant low-temperature geochronometers, annealing kinetics and modeling.

Contributions can be submitted either as oral or poster presentations, including software presentation. Oral and poster contributions will be selected for presentation by the Organizing committee on the criteria of originality and relevance of an submitted abstract to the matter of a particular theme.

English will be the official language of the Conference, both for oral and poster presentation. The organization committee will provide support for accommodation. However Amsterdam is a popular place in the summer and hotels are booking up fast. Many budget and low cost hotels can be booked directly. Please consult the Amsterdam Tourist Bureau website for a comprehensive listing of hotels in the city, including contact information for each (http://www.hotels.nl).

A comprehensive web site will be established this autumn with further details. The site will be updated regularly and will allow for on-line registration and abstract submission. We are planning to publish a special volume with contributions of the meeting.

A post-conference Field Trip may be offered depending on the initial response received. The Field Trip will be organized by Dr U. Glasmacher, Prof. G. Wagner of Heidelberg, Germany and Dr E. Hejl of Salzburg, Austria. The excursion will cover the Mesozoic and Cenozoic thermotectonic history of central Europe and starts Saturday August 14. During the excursion stops will be made in Germany and in the Austrian Alps. The participants of the Field Trip will arrive in time at Florence, Italy to participate the 32nd Internal Geological Congress (Florence, Italy August 20-28, 2004 (http://www.32igc.org).

More details about the 10th International Conference on Fission Track Dating and Thermochronology and the Excursion will be given on the web-site.

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TOPICAL SYMPOSIUM ON EXHUMATION OF OROGENIC BELTS, organized as part of the **32ND INTERNATIONAL GEOLOGICAL CONGRESS** (IGC). The IGC will be held in Florence, August 20-28, 2004, at the Congress Center, Fortezza da Basso, Viale Strozzi 1 - Firenze. General information about the congress is available at http://wwww.32igc.org. The deadline for abstracts is January 10, 2004.

This symposium will have four sessions, focusing on different aspects of exhumation of orogenic belts, as described below. The organizers welcome submission of contributions, either as oral or poster presentations.

Below the description of this symposium, there is also a summary that highlights other activities at the IGC related to exhumation research.

IGC TOPICAL SYMPOSIUM T07: "EXHUMATION OF OROGENIC BELTS"

SESSION 1: "CLIMATE AND SURFACE PROCESS AS THEY RELATE TO EROSIONAL EXHUMATION": Sean Willett (U Washington) and Mark Brandon (Yale U). Email: Sean Willett <swillett@u.washington.edu>, Mark Brandon <mark.brandon@yale.edu>

Erosion is know to be an important exhumational process, capable of rates of more than 10 km/m.y. This session will focus on our current understanding of surface processes important in orogenic regions, such as fluvial incision, mass failure, and glacial erosion. Also of interest is changes in climate occurring at the global scale or induced by the growth of orogenic topography, influence erosional surface processes.

SESSION 2: "DETRITAL THERMOCHRONOLOGY: THE SEDIMENTARY RECORD OF OROGENESIS": John Garver (Union College) and Massimilliano Zattin (U Bologna). Email: John I Garver <garverj@idol.union.edu>, Massimiliano Zattin <zattin@geomin.unibo.it>

There has been increasing work on using detrital cooling ages from synorogenic sediments to study the long-term evolution of exhumational processes in convergent orogens. This session will focus on new developments in detrital thermochronology, including new analytical methods, interesting applications, and new approaches for analysis and interpretation of detrital grain-age distributions.

SESSION 3: "STRUCTURAL AND THERMOCHRONOLOGIC OBSERVATIONS FOR DEEP EXHUMATION": Uwe Ring (U Mainz) and John Wheeler (Liverpool University). Email: Uwe Ring <ring@mail.uni-mainz.de>, John Wheeler <johnwh@liv.ac.uk>

There have been a number of exciting field studies that have documented in detail specific normal faults where 10's of km of metamorphic section have been cut out. In some cases, these structures remain intact (e.g. South Tibetan detachment of the Himalaya), and others they appear to have been strongly modified by later deformation (e.g., Gressoney Shear Zone in the Western Alps). We encourage contributions that help to detail such structures, and also provide information about their context relative to the whole orogen.

SESSION 4: "GEODYNAMIC MODELS FOR TECTONIC EXHUMATION": Russell Pysklywec (U Toronto) and Mark Brandon (Yale U). Email: Russ Pysklywec <russ@geology.utoronto.ca>, Mark Brandon <mark.brandon@yale.edu>

A challenging problem has been to come up with a geodynamic model capable of explaining the time-temperature history of deeply exhumed rocks including ultra-pressure crustal rocks and high-pressure garnet peridotites. This problem has become more acute as the geodynamic modeling begins to include a more complete representation of heat transport and thermally-activated rheologies. We encourage contributions that help illustrate this problem or make new contributions towards resolving this challenge.

IGC DEADLINES
JANUARY 10, 2004: Abstract submission deadline

FEBRUARY 20, 2004: Abstract acceptance

MARCH 31, 2004: Return of Congress registration form

EXHUMATION-RELATED ACTIVITIES AT IGC

IGC TOPICAL SYMPOSIUM T-36: ULTRA-HIGH PRESSURE METAMORPHISM (UHPM): FROM THE NANO SCALE TO THE PLATE TECTONICS SCALE (with 6 sessions).

IGC WORKSHOP DWO-17 (during congress): TERTIARY TECTONICS OF SE EUROPE: EXTENSIONAL COLLAPSE AND RIFTING OR DETACHMENT TECTONICS
Date: to be defined, 8 hours - Place: Florence
Convener: I. Zagorchev (Bulgary)

IGC WORKSHOP PWO-01 (before congress): LOW-ANGLE NORMAL FAULTING - TWENTY YEARS AFTER
Date: August 29 - September 3, 2004 - Place: Elba and Corsica islands and Perugia
Conveners: G. Lavecchia (Italy), G.S. Lister (Australia), L. Jolivet (France)

IGC FIELD TRIP B-21 (before congress): ULTRA-HIGH AND HIGH-PRESSURE ROCKS OF SAXONY (GERMANY)
Leader: H. J. Massonne (University of Stuttgart - Germany)
Associate Leader: H. J. Bautsch (Humboldt University, Berlin - Germany)

IGC FIELD TRIP B-32 (before congress): THE EXHUMATION OF HIGH-PRESSURE METAMORPHIC ROCKS WITHIN AN ACTIVE CONVERGENT MARGIN, CRETE, GREECE
Leader: J. Rahl (Yale University, USA)
Associate Leaders: C. Fassoulas (University of Crete), M. Brandon (Yale University, USA)

IGC FIELD TRIP P-01 (after congress): TECTONICS AND HIGH-PRESSURE METAMORPHISM IN NORTHWEST TURKEY
Leader: A. I. Okay (Istanbul Technical University - Turkey)
Associate Leader: B. Yikilmaz (Istanbul Technical University - Turkey)

IGC FIELD TRIP P-38 (after congress): GEOLOGY OF THE ALPI APUANE METAMORPHIC COMPLEX (NORTHERN APENNINES, CENTRAL ITALY)
Leader: L. Carmignani (Università di Siena)
Associate Leaders: P. Conti and M. Meccheri (Università di Siena)

IGC FIELD TRIP P-61 (after congress): MONTE ARGENTARIO AND ISOLA DEL GIGLIO (SOUTHERN TUSCANY, ITALY): A RECORD FROM CONTINENTAL BREAK-UP TO SUBDUCTION, NAPPE THRUSTING AND POST-OROGENIC EXTENSION
Leaders: J. Reinhardt (University of Natal - South Africa), C. Faccenna (Università di Roma Tre), F. Rossetti
(Università di Roma Tre), F. Storti (Università di Roma Tre), H Stuenitz (University of Basel - Switzerland)

IGC FIELD TRIP P-65 (after congress): BASIN AND RANGE IN THE CENTRAL AND SOUTHERN APENNINES
Leaders: A.M. Blumetti (Servizio Sismico Nazionale, Roma)
Associate Leaders: A.M. Michetti (Università dell, Insubria, Como), F. Dramis (Università di Roma Tre, Roma),
L. Guerrieri (APAT, Roma), B. Gentili and E. Tondi (Università di Camerino)

APATITE FISSION-TRACK THERMOCHRONOLOGY OF THE ALTAI MOUNTAINS (SOUTH SIBERIA, RUSSIA) AND THE TIEN SHAN MOUNTAINS (KYRGYZSTAN): RELEVANCE TO MESOZOIC TECTONICS AND DENUDATION IN CENTRAL ASIA

JOHAN DE GRAVE

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The Central Asian mountain belt forms the world's largest intracontinental mountain chain, stretching over a distance of over 5000 km north of the Himalayan-Tibetan deformation zone. The entire area, known as the Central Asian Deformation Zone (CADZ), is subjected to widespread active deformation, resulting in processes of intracontinental mountain building and basin formation. This active deformation is a distant result of the ongoing convergence between the Indian and Eurasian plates. Both the Altai (South Siberia) and Kyrgyz Tien Shan mountains are situated within the CADZ. The main goal of our work was to constrain the thermotectonic evolution of both these areas using apatite fission-track (AFT) analysis. It was also the aim to investigate whether the AFT thermochronometer was able to constrain the onset of the recent tectonic reactivation of both regions.

The Altai mountains at the border zone between Russia, Kazakhstan, China and Mongolia occupy the NW sector of the CADZ. The Russian Altai mountains are composed of several tectonic units, all reflecting the Paleozoic evolution of the Paleo-Asian Ocean and Paleozoic accretion of the Siberian continent. As a result of Cenozoic reactivation, the Paleozoic basement rocks are locally overlain by Cenozoic (mainly Neogene and Pleistocene) sediments. A total of 50 bedrock apatite samples from 5 distinct zones in the Russian Altai Mountains (RAM) were analyzed. The majority (29) of the samples originate from the Lake Teletskoye basement. The lake is situated in a Quaternary graben in the NW part of the RAM. A second set of samples (9) comes from the Chulyshman Plateau, south of Lake Teletskoye, a third set (4) from the Dzhulukul Basin area near the Mongolian border to the east, while a fourth set (3) from the Chuya-Kurai Basin margins delineates the southernmost sample area. A fifth set (5) groups samples from various localities along a western transect through the RAM.

Generally, the AFT results from all RAM samples are very similar. Only minor differences between the various sample areas are noticeable. Apparent AFT ages are Cretaceous and all length distributions exhibit clear effects of track shortening. Modeling of the data (AFTSolve) revealed a consistent three-stage cooling history throughout the RAM. A first stage is a Mesozoic cooling event that brought the rocks below the 120°C isotherm in Late Jurassic – Early Cretaceous times. The event halted in the Late Cretaceous, between ~80 and 90 Ma ago. This cooling is followed by a period of stability during which no or moderate cooling of the RAM rocks occurred. Finally, a rapid Late Neogene-Quaternary cooling event is observed for all samples. We attribute the Mesozoic cooling to an important phase of denudation of the Altai orogen. This denudation is thought to be a far-field effect of the Mongol-Okhotsk orogeny that affected Siberia, Mongolia and North China in the Jurassic and Early Cretaceous. West to east scissors-like closure of the Mongol-Okhotsk Ocean resulted in the collision of the North China craton with the amalgamized orogenic rim of Siberia and reflects further accretion of the Eurasian continent. The second stage of the reconstructed cooling history, the period of stability and slow cooling is interpreted to reflect peneplanation of the Mesozoic Altai in a regime of tectonic stability. Remnants of a widespread regional Late Cretaceous – Paleogene peneplanation surface are locally preserved throughout the region. Late Neogene – Quaternary cooling is linked to the recent reactivation and active tectonics associated with continuing convergence of the Indian and Eurasian plates, and is corroborated by various tectonic markers in the study area.

The Kyrgyz Tien Shan Mountains (KTSM) are situated to the N of the Pamir Mountains and the NW of the Tarim Basin. The ancestral KTSM were shaped in the Late Paleozoic between the rigid Tarim microplate and the stable Kazakhstan-Junggar platform. Currently the KTSM are also reactivated due to the India/Eurasia convergence and form one of the most active intracontinental mountain chains in the world. Their present morphology is dominated by E-W trending ranges and intermittent intramontane basins. A total of 22 apatite samples from granitoid intrusives from the area around the intramontane Issyk-Kul Basin (IKB) (northern KTSM) were analyzed. The main sample localities are the Kungei Range, bordering the IKB to the north and the Terzkey Range in the south. Additional samples from the western part of the IKB basement were also collected. Similar AFT data for most KTSM samples were obtained. Compared to the RAM, apparent AFT ages were found to be older, with most samples yielding Late Jurassic – Early Cretaceous ages. Length data also show a distinct thermal influence. Modeling of the data reconstructs a uniform three- to four-stage thermal history for the KTSM. Although different in timing, the overall KTSM thermal history exhibits some similarities with the RAM history. The first stage is a Jurassic – Early Cretaceous cooling (older than for the RAM) lasting until ~115 Ma when a period of stability is initiated. This second phase persists until the Early Neogene, although locally, some samples exhibit a stage of reheating between ~40 – 20 Ma. This reheating event is only observed for samples from the W and NW parts of the IKB basement. From about 10 to 15 Ma onwards a second, rapid cooling is seen for all KTSM samples. Analogous to the RAM, the Mesozoic cooling is attributed to denudation due to tectonic reactivation of the area in Jurassic times. Again, this reactivation might be a distant result, in this case of the Cimmerian orogeny that affected the S Eurasian margin when closure of the Tethyan Ocean culminated in the accretion of the Tibetan tectonic units to Eurasia. This again is followed by a stage of peneplanation, while the last rapid cooling can also be assigned to the onset of reactivation of the modern KTSM as the result of the propagation of deformation away from the India/Eurasia collision zone proper. The local Oligocene reheating event is only shown by samples taken in the direct vicinity of basaltic and diabasic rocks with $^{40}Ar/^{39}Ar$ ages of ~50 to 20 Ma. Therefore it is logical to interpret this stage of reheating in terms of a local increase in geothermal gradient accompanying the emplacement of these igneous rocks.

NEOGENE TO QUATERNARY THERMO-TECTONIC EVOLUTION OF NORTH-EASTERN CORSICA

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This work is focused on the brittle tectonics and the low thermal exhumation of north-eastern Corsica. The brittle tectonic evolution has been studied through field mapping of mesostructures and through paleostress calculations. Results indicate that north-eastern Corsica during Neogene to Quaternary was affected by a complex tectonic evolution characterized by an alternating sequence of extensional and compressional deformations. The first brittle deformations are related to a NE/E-trending extension and to the formation of the Early to Middle Miocene basins at the top of the Alpine metamorphic units. During the Tortonian, these basins were affected by an inversion tectonics involving also the Alpine units, and showing a NNE-trending compression. During the Messinian, extensional deformations reactivated again the brittle structures of north-eastern Corsica which deformed under low stress ratio conditions resulting in a multidirectional extension. During Quaternary, compressional deformations are recorded by the Pliocene and Pleistocene sediments of the eastern plains of Corsica and in the St. Florent basin, and are related to a NW-trending compression. The structural analysis is integrated and supported with apatite and zircon fission-track data. The fission-track analysis on metamorphic units enables to quantify fault offsets through the identification of different exhumation times at the hanging wall and at the foot wall of the structures. The determination of the vertical throws is based on the assumptions of a geothermal gradient of 35°C/km. Results indicate that vertical throws along major faults range between 4 and 1 km and therefore brittle faults played a significant role in the exhumation process of Corsica.

The fission-track analysis on detrital apatites yield a high exhumation rate of ca. 1 km/my during Early to Middle Miocene. These results are concordant with thermal modeling data and with the exhumation rate established on the basis of zircon and apatite-fission track analysis performed on crystals from the same sample. The fission-track analysis allow to determine the thermal evolution of the metamorphic units beneath the Miocene basins of north-eastern Corsica given that, during the basin formation, these units are affected by a temperatures range overlapping the apatite Partial Annealing Zone (70-120°C). The thermal evolution is assessed on the basis of thermal modeling, and temperature data are converted into depth assuming a geothermal gradient of 35°C/km. The basement of the Miocene basins, after being exhumed, was buried to a depth of more than 1 km and likely up to 2 km in the St. Florent basin, and of ca. 900 m in the Francardo basin. A post-exhumation thermal event affects also the western Balagne region where sedimentation could have occurred although at present there are no remnants of Miocene successions. Thus, apatite fission-track data indicate that the thickness and the extent of Miocene sediments in the study area might have been greater than predicted on the basis of stratigraphic data.

Provenance of siliciclastic sediments and river longitudinal profiles provide constraints on the uplift related to the exhumation of north-eastern Corsica. Provenance data indicate that the HP Alpine units exposed at present in Corsica were locally being eroded during Early Miocene, and the present relief of Alpine Corsica was uplifted above sea level during the Tortonian. The shape of river longitudinal profiles indicate that uplift likely continued from Neogene to present as suggested also by stratigraphic and leveling data.

THE LONG-TERM THERMAL EVOLUTION OF CENTRAL FENNOSCANDIA, REVEALED BY LOW-TEMPERATURE THERMOCHRONOMETRY

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While widely accepted, the nature and origin of craton stability remains unclear. Their physical stability is clearly evident, though low-temperature thermochronometry studies tend to show that the thermal state of cratonic crust can be, and often is, disturbed by the thermal processes associated with various thermotectonic episodes that they are subjected to during their post-formative evolution. Central Fennoscandia is an example of a craton that has exhibited long-term physical stability and, in contrast to other cratonic settings, extreme long-term, low-temperature, thermal stability also. Establishing whether the thermal history of central Fennoscandia has been disturbed by the various significant thermotectonic events that have occurred in the later post-formative evolution of the craton will elucidate the nature of its thermal stability. Apatite fission-track thermochronometry has been applied to determine the low-temperature thermal history of central Fennoscandia and the expected old ages necessitate that the analysis and interpretation be made with an unusual degree of care and detail.

Twenty-nine samples from Finland have been prepared for apatite fission-track thermochronometry with the established annealing model of Laslett, *et al.* (1987). Thermal histories are presented and the influence on the model of several assumptions is assessed. The presence of the sub-Cambrian peneplain plays a large role in the nature of the modeled thermal histories. In general the derived thermal models are consistent and produce several recurring phases of cooling and re-heating. These include a phase of cooling in the Neoproterozoic and a re-heating phase in the Paleozoic. The processes responsible for each observed heating/cooling phase are examined.

Multi-kinetic apatite fission-track thermochronology, an advance in the technique, is introduced. The laboratory and analytical procedure at the Vrije Universiteit required modification and calibration and the details of this are stated. A multi-layered comparison between the established method and the new multi-kinetic approach has been made in order to fully understand the implications of applying one model over the other.

Refinement of the AFTT thermal history is made by the production of an independent AFTT data set produced with a new multi-kinetic annealing model. In this 22 surface samples, along with 9 core samples and Paleozoic intrusive samples have been analyzed. Multi-Kinetic Apatite Fission-track Thermochronology re-produces the thermal histories presented earlier but also provides additional information regarding the thermal evolution of the samples by incorporating a kinetic parameter in the analysis. The thermal models reproduce all the phases of heating and cooling discussed in chapter 4 though with subtly different thermal constraints.

The AFTT thermal histories have been validated and extended by the application of K-Fsp $^{40}Ar/^{39}Ar$ and (U-Th)/He thermochronometry. Step heating $^{40}Ar/^{39}Ar$ analysis of 10 samples scattered throughout Finland produce an age signal corresponding in time with the emplacement of the anorogenic association of diabase dykes and Rapakivi granites and a younger signal corresponding with a period just preceding emplacement of Postjotnian diabases. Multi-diffusion domain modeling of 4 samples, 2 from either side of Mesoproterozoic structure in the south of Finland and 2 from central Finland, produce the same signals. The data suggests that the thermal effect of the emplacement of the Rapakivi association and the Svecofennian domain was widespread. The (U-Th)/He method is introduced and the results of a 'reconnaissance' study are presented. While the results are promising and generally in support of the AFTT derived thermal models, no robust conclusions are made.

The overall thermal history of the area (especially the Proterozoic domain) is characterized by a series of thermal pulses reflecting a particular characteristic of an alternative model for the development of the Svecofennian domain and implications arising from this observation for the thermal evolution of the craton are raised

The spatial distribution of fission-track ages is characterized by areas of 'young' and 'old' ages. The latter is interpreted to be due to the existence of a crustal 'cold spot' and implications arising from this for the physical and thermal evolution of the craton are raised.

LATE-STAGE TECTONIC PROCESSES IN OROGENS: CONSTRAINTS FROM AR-AR, FISSION TRACK DATING AND STRUCTURAL STUDIES

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The Alpine-Balkan-Carpathian-Dinarides (ABCD) orogen is characterized over large sectors by the superposition of Tertiary collisional structures on Early to Late Cretaceous ones. The Cretaceous orogen formed during an independent orogenic cycle due to consumption of oceanic tracts and subsequent early Late Cretaceous collision of continental blocks. The assembled Cretaceous terrane collage was heavily modified by Tertiary collisional, extrusional and oroclinal processes during invasion of these units into the Carpathian arc and the indentation of the Moesian block as the present-day arcuate mountain belt formed. The Cretaceous orogenic belt displays significant variations along strike, namely strong subduction-collision metamorphism and missing Cretaceous magmatism in western sectors of the belt, and apparent weak metamorphism/ deformation in southeastern sectors (Apuseni Mts. And Southern Carpathians). There, the belt is superposed by extensive Late Cretaceous plutonism/volcanism ("banatites") associated with widespread mineralizations. Magmatism is contemporaneous with the formation of collisional-type successor sedimentary basins.

The reconstruction of Cretaceous collisional structures, magmatic features, and mineralizations reveals significant variations along strike, which are not well understood at present and which are the focus of current investigations as part of the GEODE ABCD project of the European Science Foundation. The proposed research (FWF) includes:

(1) $^{40}Ar/^{39}Ar$ dating of minerals including biotite, amphibole and muscovite from magmatic rocks to reveal the timing and duration of magmatism, specifically of volcanism and plutonism, of ca. 5 - 6 selected sites distributed along the northern sectors (ca. 400 km) of the ca. 1,500 km long banatite belt.

(2) $^{40}Ar/^{39}Ar$ dating of alteration minerals like adularia and sericite to reveal the timing of mineralization of these sites.

(3) Fission track dating (zircon, apatite) of banatites to reveal the cooling and exhumation history.

(4) Structural investigations on ore deposits to reveal kinematic and dynamic conditions of the emplacement of plutons and the mineralizations.

Together, the new data should allow to distinguish between different geodynamic models which were proposed for that region: post-collisional slab break-off vs. subduction related origin.

FISSION TRACK THERMOCHRONOLOGY OF THE CRETACEOUS SINDONG GROUP AND THE PALGONGSAN GRANITE, GYEONGSANG BASIN, KOREA

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Based on the apatite and zircon fission track analyses, thermal history of the Cretaceous Sindong Group and cooling history of the Palgongsan Granite were investigated. For the fission track analysis, the fission track age calibration constants were determined. Both apatite and zircon age standard samples were analyzed using an external detector method, and zeta -values are firstly calculated using the NAA-1 facility in HANARO reactor. The overall weighted mean zeta values (±2σ) determined against a dosimeter glass NIST SRM612 are 337.6 ± 25.4 for apatite, and 344.5 ± 10.0 for zircon, showing no significant difference between the two minerals. The high Cd ratio of the NAA-1 facility in the HANARO reactor indicates that the facility tested in this study, NAA-1 is well-thermalized, and therefore suitable for fission track dating.

Sixteen sandstone samples from the Sindong Group were analyzed to reconstruct the thermal history using apatite and zircon fission track analyses. All apatite samples have consistent FT ages of ca. 60 Ma with unimodal and narrow age population, whereas the zircon FT ages show a wide range with various single-grain ages and the youngest peak ages are ca. 85 Ma. These results suggest that the Sindong Group was heated into the ZPAZ and cooled below the APAZ at ca. 60 Ma. Based on the zircon FT and previous VR data, the maximum paleotemperatures to which the Sindong Group has been subjected can be considered to be about 260°C. The time of maximum paleotemperature is thought to be around 80 Ma. To assess the thermal influence caused by the Upper Cretaceous intrusive rocks, eight zircon fission track ages were also obtained from the Palgongsan Granite and adjacent Jinju sandstone samples. Although the paleogeothermal gradient of the Gyeongsang Basin might have been increased due to the emplacement of plutonic rocks, thermal alteration of the Sindong Group was mainly controlled by burial.

The cooling and uplift history of the Upper Cretaceous Palgongsan Granite within the Gyeongsang Basin has been derived from the apatite and zircon fission track data combined with other thermochronometric data. The Palgongsan Granite shows a simple concave cooling curve pattern, which suggests that it has not affected by any thermal event after emplacement. The Palgongsan Granite experienced rapid cooling (33.3 °C/Ma) from the moment of intrusion to ca. 72 Ma with a subsequent deceleration of the cooling rate. The rapid initial cooling rate during the Late Cretaceous has been caused by the large thermal contrast (~500-600°C) between the pluton and the country rocks. Direct conversion of the early rapid cooling rate into the uplift rate is not possible in the Palgongsan Granite because this is a high-level pluton emplaced at shallow depth less than ~3 km. The decelerated cooling rates of the late stages are, however, interpreted to have been controlled by uplift. Although restricted to low temperature range, the uplift rate of the Palgongsan Granite can be calculated from the corresponding cooling rates. The average uplift rate of the Palgongsan Granite is calculated to be ca. 0.043 mm/yr over the temperature range from 100°C to the surface temperature. The cooling history of the Palgongsan Granite is in good agreement with other Cretaceous Bulguksa granites distributed in the eastern and southern parts of the Gyeongsang Basin. No significant difference in cooling pattern exists between the Palgongsan Granite and other Bulguksa granites.

POST LATE PALEOZOIC TECTONOTHERMAL EVOLUTION OF THE NORTHEASTERN MARGIN OF IBERIA, ASSESSED BY FISSION-TRACK AND (U-TH)/HE ANALYSIS: A CASE HISTORY FROM THE CATALAN COASTAL RANGES

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The Catalan Coastal Ranges (CCR) belong to the northern sector of the margin that separates the extremely thinned continental crust of the Valencia Trough (~8km) from the thickened crust of the Iberian microplate (22-40 km). In this research the CCR have been chosen as a natural laboratory for the study of the tectonic and thermal evolution of this margin using thermochronological analysis. The structural and magmatic complexity of this area is the result of the relative movements that have been taking place between the African, Iberian and Eurasian plates since the Mesozoic. Hence, the region of the CCR have been submitted to various periods of extensional and shortening tectonics which reflect the different evolutionary phases of the Atlantic and western Mediterranean: **a)** a phase prior to the opening of the Atlantic, which includes the Hercynian Orogeny followed by a period of Late Hercynian magmatism and Permian erosion; **b)** a Mesozoic phase, in which the Central Atlantic opened originating several periods of intraplate extensional tectonics; **c)** a phase related to the opening of the North Atlantic and Bay of Biscay, which caused the anti-clockwise rotation of Iberia and its subsequent collision with Eurasia during the Late Cretaceous-Early Oligocene; **d)** finally, as a result of this collision, the build up of intraplate stresses in Iberia led to the shift of the zone of convergence from the Iberian-Eurasian plate boundary to the Iberian-African plate boundary. This marked the onset of the Betic Orogeny, during the Early-Middle Miocene, while a phase of continental rifting opened the Valencia Trough and the Liguro-Provençal Basin in western Mediterranean.

The aim of this study is to better understand the tectonic and surface processes that generate vertical movements of basement rocks in the CCR. Despite intensive geological research in recent decades the issue of the thermal history has hardly been addressed. Therefore, this study seeks to provide new insights into the mass and heat flux in the upper crust synchronous to each of the tectonic phases occurred. Zircons and apatites were extracted from Hercynian basement rocks and Triassic and Cenozoic sediments along the CCR, and dated using fission-track analysis (ZFT and AFT, respectively), with apatite further dated using (U-Th)/He thermochronometry. Each of these thermochronometers has a characteristic temperature sensitivity of between 175-300°C, 60-110°C, and 40-85°C respectively. Changes in temperatures of rock masses in the upper crust are generally caused by the deposition or removal of excess material, driven by sedimentary, erosive and tectonic processes, but also by the intrusion of magma and groundwater flow. Hence, thermochronological data is crucial in order to measure the exhumation, erosion and uplift of rift margins and orogens, deposition and burial of sediments in peripheral basins, and also for studying the thermal state of the Earth's upper crust and the processes associated with the generation, transport and storage of heat within it. In this study the interpretation of the thermochronological data was based on the modeling of the thermal histories derived from AFT data, comparison of these results with the data extract from the ZFT and (U-Th)/He thermochronometers, geological data and numerical modeling of geodynamic processes at crustal scale.

ZFT and AFT analysis of the Hercynian basement yield ages between 250±40 Ma-104±16 Ma and 223±27 Ma-16±2 Ma respectively. (U-Th)/He ages range between 146±10 Ma and 3.0±0.2 Ma. These results allow the tectonothermal evolution of the CCR to be divided in different phases: **a)** a late Carboniferous-Permian phase in which the intrusion of the Late Hercynian magmatic plutons resulted in the total resetting of all FT thermochronometers of apatite and zircon in the basement, followed by a cooling and exhumation phase which brought these lithologies to the surface; **b)** a Mesozoic phase, where basement rocks experienced periods of increased in temperature between ~110ºC and 175ºC, mainly during the Triassic-Early Jurassic synrift stage, but also during the Late Jurassic-Early Cretaceous. Sedimentary burial under Triassic sequences, made up of siliciclastic and carbonates (600-800 meters in thickness) and evaporates (hundreds to thousands of meters (?) in thickness), and the fluctuation of the geotherm, as a result of magmatic and hydrothermal activity are the most likely factors to explain the elevated temperatures detected; **c)** a Paleogene phase characterized by thermal quiescence. Paleogene build-up of intraplate compressional stresses induced the inversion and erosion of the Mesozoic basins, forming the Catalan Intraplate Chain (CIC) during the Alpine Orogeny. The insignificant changes of temperature detected in the basement relate to minor exhumation due to the accommodation of 8 km of lateral shortening at the front section of the CIC only. This resulted in the passive uplifting of various tectonic blocks, minor deformation and erosion which dismantled part of the Mesozoic sequences of up to 800 meters in thickness; **d)** finally, a late Oligocene-Neogene phase where periods of moderate and substantial cooling are detected for basement samples within short lateral distances of a few kilometers. During this phase, the CIC was dissected into several horsts and grabens by the tectonic inversion of older Paleogene basements thrusts, forming the Catalan Coastal Ranges (CCR) as they are today. At that time the Valencia Trough also opened to the SE. Based on fission-track and (U-Th)/He analysis, erosion along the horst areas (Litoral and Prelitoral Ranges) is estimated to be less than ~2km from the Late Oligocene to present. The presence of synchronous hydrothermal activity has caused some AFT to be totally reset, which indicate elevated temperatures ~110ºC at shallow depth <2 km. These results point out the significant influence that groundwater flow might have on the geotherm in the upper crust. In the CCR, hydrothermal activity is interpreted as the result of topographical driven flow originating during the late Oligocene-Miocene extensional phase.

The results of this research contribute to the continued development of FT and (U-Th)/He thermochronology, especially with regard to their interpretation and applicability in areas with complex tectonic histories. Moreover, the combination of the different thermochronometers, geological data and numerical modeling has proved to be useful in this study to better estimate the range of temperatures of rocks in the upper crust, and to better interpret and quantify the factors which influence their thermal history.

EDM FOR GLASSES?

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Most colleagues dealing with fission-track (FT) method apply this technique to crystal phases such as apatite, zircon and sphene. EDM is the dating method commonly used for these minerals, because it offers some advantages in comparison with the traditional population method (Gleadow, 1981). Only in a restricted number of FT groups natural glasses are also studied. Probably for this reason peculiar characteristics of glasses with respect to FT dating are less known also inside the FT community. This does not imply disappointing consequences, provided that one has the opportunity to reply to extravagant questions, comments or criticisms he may receive.

Recently I and a colleague had submitted to an international journal a manuscript where also a FT age determined on a sample of glass shards had been reported. One of the criticisms made by one referee that contributed to lead the editor to decide rejection was that we had used the population method, instead of EDM. As the manuscript was rejected, we had no opportunity of explaining why commonly the population method is used for glasses. Moreover, this referee did not quote any article where application of EDM to glasses had been discussed. Considering that I do not know such an article, I do not know how I could use this method for glasses.

The most important points that convinced me to persist in using the population method for these materials are essentially two: (1) peculiar characteristics of track etching in glasses and (2) presence of partial annealing of spontaneous tracks in most glasses.

With respect to track etching, glasses behave very differently from crystals (see Wagner and Van den haute, 1992, and references therein). Whereas in crystals the track etching rate (V_t) is much higher than the bulk etching rate (V_g), in natural glasses V_t/V_g is typically between 1.5 and 3. Consequently, during etching a layer of not negligible thickness will be removed from the glass. Fleischer and Price (1964) showed that only a part of the latent tracks that crossed the glass surface – those which have an incidence angle θ > a critical angle $\theta_c = \arcsin V_g/V_t$ – are developed by etching. At the same time, internal tracks which reached prior etching this layer can be etched, provided that their incidence angle

θ is > θ_c. The track density one can determine under a microscope after an etching time t is a complex function of V_g, t and V_t. The relationship track density – etching time does not attain a plateau, and its trend is characteristic of each glass, due to its peculiar V_g and V_t. For these reasons it appears somewhat difficult to know the value of the geometric factor G to be used if the induced tracks are counted in an external detector, because G depends on the sample and on the etching time.

In minerals the problem of the value of G is overcome by the use of the ζ calibration. For glasses the use of the ζ calibration is not obvious: it may work well only when the standard for the determination of the ζ factor has the same characteristics of the glass to be dated in relationship to track revelation. In addition, spontaneous tracks have to be etched in the same way in both glasses. Actually, sensitivity to etching is variable also for glasses of the same type, such as obsidians. Therefore, it is not very easy to attain an identical level of spontaneous track development on glasses used for ζ factor determinations and on glasses to be dated. Moreover, only one glass was included in the list of the age standard for FT dating by the Subcommission on Geochronology of I.U.G.S., that is Moldavite, the central European tektite (Hurford, 1990). If EDM is used, Moldavite can not be considered a reliable standard for the determination of the ζ factor for other types of glass, such as, for example, obsidians or basaltic glasses.

The second point mentioned above – partial annealing of spontaneous tracks – is also an obstacle which prevents the application of EDM. Stability over geological times of fission tracks in natural glasses is rather poor. Most glasses show a certain amount of track annealing. Partially annealed spontaneous tracks are etched with reduced efficiency compared to the 'fresh' induced tracks, assumed as reference undisturbed tracks. Therefore, a FT age in glass is a rejuvenated age, referred to as 'apparent' age. Two correction techniques of thermally lowered FT ages can be applied, the size-correction method (Storzer and Wagner, 1969) and the plateau method (Storzer and Poupeau, 1973). In the first technique the apparent age is corrected through an experimental curve which relates reduction of track density with track-size decreasing. In the plateau method an identical etching efficiency of spontaneous and induced tracks is re-established through thermal treatments imposed to spontaneous and induced tracks. The plateau condition is attained when the spontaneous to induced track-size ratio is = 1. Both these techniques require that spontaneous and induced track densities and track sizes are determined in two fraction of the glass itself, etched in the same conditions. In other words, the population method has to be applied.

In principle, both the absolute approach as well as the ζ calibration could be used for the population method. As the ζ factor is determined through a ratio of two track densities measured in the glass itself, track density ratios corresponding to the plateau condition or corrected with the size-correction method could be used. On the contrary, the application of EDM - ζ calibration would require a further requisite, that the age standards to be used for determination of ζ should be unaffected by track annealing, Note that identification of a set of glass age standards of various types unaffected by track annealing is an arduous task, if not impossible.

It has to be pointed out that one of the reasons for which EDM was preferred for crystals is its performance also in case of large inter-grains U-fluctuations. Commonly track counts of glasses follow Poisson distributions. Only in few cases the U-content shows some minor inhomogeneities.

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- Universität Bremen, Bremen, Germany (1993)
- E.T.H., Zürich, Switzerland (1993*)
- Kent State University, Kent, Ohio (1993)
- University of Wyoming, Laramie, Wyoming (1993)
- University of Arizona, Tucson, Arizona (1993). Moved to Syracuse University, Syracuse, New York, in 2000.
- Max-Planck-Institut, Heidelberg, Germany (1993*)
- Union College, Schenectady, New York (1994)
- Monash University, Melbourne, Australia (1994*). Moved to University of Melbourne in 1999.
- La Trobe University, Melbourne, Australia (two systems, 1994*). Moved to University of Melbourne in 1999.
- University of Pennsylvania, Philadelphia, Pennsylvania (1995)
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Further Information:

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

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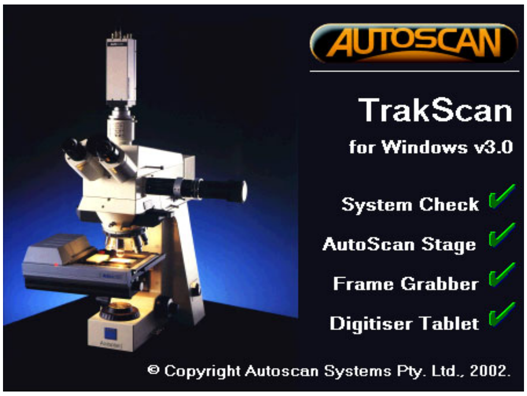

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Technology

The first system operated with the aid of an 8-bit North Star^{TM} Horizon computer, and made use of a modified Zeiss^{TM} microscope stage. Later systems used custom-built stages. These systems were subject to all the usual inaccuracies inherent in mechanical assemblies: backlash, dead-band, etc. More importantly, the stepper motors used in the focus mechanism of the early stages limited the utility of these units because of inherent noise, speed limitations, and other disadvantages. (For a more detailed discussion of these issues, please refer to the Autoscan website: http://www.autoscan.com.au/onestep.html).

The later Autoscan stage systems made use of dc motors with shaft encoders. These motors are operated as servo motors in a closed-loop configuration with PID control. In plain English, this means that our electronic controllers know at all times exactly where the motors are, even when the operator "twiddles" the mechanical stage movement knobs. Further, the movement of the stage motors is optimized through the PID control loop, so that the motor always chooses the most direct and fastest path between any two points. This configuration enabled us to achieve a repositioning accuracy of +/- 2 microns in the X and Y (horizontal) axes, and +/- 0.2 microns in the Z axis (focus). In contrast, the stepper motor stages available on the market do not contain motor positioning encoders. What this means, in brief, is that if the electronic controller issues a movement command, it must assume that the motor has moved to the intended target position. If the motor does NOT move to this target position for any reason (e.g. motor stall or slip), the controller will never know about this, and the stage will be "lost in space" forever, until the system is re-zeroed in some fashion.

One fundamental problem, even with the Autoscan stages which have been representing state-of-the-art in FTD for the last twenty years or so, is that the movement measured is that of the driving motor, not the actual stage plates. The specimen being examined is, for all intents and purposes, fixed to the top plate of the Autoscan stage. If there is any difference in position between the motor and this top plate, this will directly translate into a positioning error for the specimen. In reality, there are several such errors which affect positioning accuracy: backlash in the mechanism which connects the motor to the plates and minute inaccuracies in the manufacture of the leadscrew are just two of these. For this reason, the recent availability of extremely accurate "external sensors" has allowed an entire new generation of stages to be created. Generally, these external sensors are strips of magnetic or optical material which can be directly attached to the moving plates and which can sense the actual movement of the plate, rather than the movement of the motor. This translates into vastly increased positioning accuracies for the stages.

Advances

i) Microscope stage system hardware

Autoscan Systems is proud to announce a world first: in August 2003, we installed the first-ever Sony^{TM} holographic linear external positioning sensors on two stages at the Max Planck Institute in Heidelberg, Germany. One of these stages will be used in advanced FTD research. These sensors were the very first to roll off the Sony assembly line in Japan, and are capable of reproducibly achieving an incredible positioning accuracy of 50 manometers! This dimension, for the non-physicists among you, is much less than the wavelength of visible light. The mid-spectrum wavelength of visible light is of the order of 650 manometers. Because of a fundamental physical limitation called the Raleigh limit, this means that the smallest consistently resolvable object in such light would be of the order of half of this value, or about 300 manometers.

ii) Sample processing software

As regards Software, the FTD community is well known for contributing to our software development. For example, during the next few months we will be releasing three new Trakscan software modules which are based largely on the contributions of the Heidelberg and Freiberg FTD groups in Germany. We are very grateful for these contributions, and I am sure that such activities will continue to arise from the FTD community.

iii) Data presentation software

A number of geologists have contributed significantly to the quality and volume of data presentation software available. For fear of leaving someone out and thus mortally offending them, I will not list them here, but I believe that the FTD community is well aware of their existence. The fact that most of this software is available to geological laboratories free of charge is a very big bonus.

iv) Cameras

There have been some very exciting developments in CCD cameras. Some of these developments have been apparent in the availability of digital cameras on the consumer products market. The original cameras used in conjunction with the Autoscan software were CCD cameras with analog output. In order to convert the camera output into the digital form required by the computer to process and display images, a frame grabber card was required to be installed in the computer. Nowadays, much better cameras are available at an ever-decreasing price. These cameras directly output a digital signal at incredibly high resolution, and operate via a Firewire^{TM} interface. The installation of such devices is much simpler and less frequently fraught with incompatibilities than the frame grabber/analog camera combination. Image resolutions of 1.5 Megapixel are typical, and resolutions of 5 Megapixel and more are easily achievable.

v) Microscopes

The new generation of microscopes is featuring ever more automated and motorized features. These include motorized turret rotation (objective selection), motorized focus, motorized filter selection, and electronic control of light levels. Current negotiations between Autoscan and a major microscope company will result in the incorporation of microscope control in our future software. Thus the operator will be able to select the objective to be used, and the relevant objective calibration parameters will be changed automatically.

vi) Sample processing hardware

Much of the equipment used in the sample processing laboratory has been around since “The Times of Noah’s Ark”: the Frantz magnetic separator, for instance, is a piece of machinery which time seems to have left behind. Many of the more poisonous/carcinogenic heavy liquids are, thankfully, a thing of the past, but much of the rock crushing equipment is still comparatively crude by the standards of current technology. Having said that, of course, I should be quick to add that “if it works, why not?”. But I believe that there is a lot of scope for improved efficiency and effectiveness in this area.

vii) The science of FTD

In tandem with the ongoing march of technology, rapid developments are taking place in many countries around the world. For instance, FTD is a burgeoning technique in countries such as China and Brazil, where many new laboratories have been set up in the last couple of years. The training of FTD personnel is proceeding apace. Through the confirmation of the accuracy of FTD dating (based on comparative confirmation with other dating techniques), the assumptions underlying FTD have been largely confirmed, and the technique has become an established and accepted method of dating materials in the range of 500,000 to 1 billion years. It is to be expected that the wider acceptance of this technique will provide a wider base of laboratories which can carry out such work, and free up the more advanced groups to contribute to the cutting edge of the technique.

viii) New techniques in FTD

In recent times, a number of divergent techniques have emerged. It would not be constructive for me to be drawn here into the old discussion of the relative merits of the population method versus the external detector method. However, there are new and different techniques for mounting the samples and for (hopefully) avoiding the use of expensive ion probes, which are currently being developed by various groups around the world.

ix) Irradiation

One of the issues which is of great concern to FTDers is the shrinking availability of suitable atomic reactors which can carry out the irradiation of samples for the external detector method. Whilst the trend for closing down reactors may continue, it is not inconceivable that other techniques will emerge which may bypass the need for such irradiation. Two side benefits of such a development would be the avoidance of a need for FTD laboratories to handle radioactive materials (with all the attendant safety and certification concerns), and a vast increase in the speed of obtaining results.

Conclusion

Some of you may might remember that in the past, there were numerous attempts to fully automate the process of track characterization and counting. I have no doubt that this endeavor will resurface, stimulated by the advances in technology and techniques briefly addressed above. In particular, this task will be made easier by the use of linear sensors (as in the new Autoscan stages), increased camera resolution, continually improving computing capability, and advances in microscopy. In addition, new approaches will result from advances in the geological techniques and the ever more frequent and unique contributions from the physicists, who are now becoming an influential factor in the development of FTD.

My guess is that the most significant contribution to FTD in the next 10 years will come from cross-disciplinary contributions, whether these be physicists, chemists, electron microscopists or workers in other, yet to be identified, disciplines.

This article has been written, to a certain extent, from the point of view of an “outsider”: my discipline is biomedical engineering, and the very poor and rudimentary insights I have into geology are the result of many years of mixing with friendly FTDers (Geology was never my strong suit at school!). Despite this, I hope that this article will be of interest to OnTrack readers – any factual errors are all mine. We look forward to meeting you at the next FTD conference in Amsterdam in August 2004.

EXPERIMENTAL EVIDENCE CONCERNING THE PRESSURE DEPENDENCE OF HE DIFFUSION AND FISSION-TRACK ANNEALING KINETICS IN APATITE

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General

We offer this short note to document data we have collected regarding the pressure dependence of He diffusion and fission-track annealing kinetics in apatite. This work is a direct result of the provocative EPSL paper by Wendt et al. (2002). Should their data stand, so should many of their conclusions. For the record, we have communicated constructively with Anke Wendt and through her, her co-authors, and we have the singular goal of better understanding their data and the issues raised in their paper.

Methods

A description of our experiments follows. Shards of Durango apatite (160-180 μm; powder) containing natural He and natural fission tracks were wrapped in copper foil and then attached to a thermocouple using a layer of aluminum foil and platinum wire. The copper pouch is ~15 mm long and the thermocouple tip is centered along its length; the along-axis temperature gradient over this distance is less than 2°C in the cold-seal pressure vessel we used. The thermocouple/sample assembly was inserted into a pressure vessel that was already stabilized at the run temperature to avoid heating transients and then pressurized using Ar gas as a pressure medium. The Ar gas permeated the copper foil resulting in hydrostatic pressure conditions around the apatite shards. Within 15 minutes, the P-T conditions had stabilized to within 2°C and a few bars of the ultimate run conditions. After the duration of each run, each charge was quenched by releasing the pressure and removing the device from the furnace. The apatite was removed from the foil and divided into fractions for He and fission-track analysis. All experiments were done in the same apparatus using the same thermocouple and same pressure medium (Ar gas); the thermocouple was calibrated against the freezing and boiling points of distilled H2O.

He concentrations were determined on the treated aliquots as well as an untreated reference aliquot of Durango apatite. Diffusion coefficients were computed from the amount of He lost during P-T treatment using standard calculation procedures.

Relative degrees of fission-track annealing for the treated aliquots and several reference aliquots of Durango apatite (natural and unannealed induced tracks) were determined from the mean lengths of horizontal, confined fission tracks. Fission tracks were revealed for measurement by chemical etching in 5.5M HNO_3 at 21°C for 20 seconds. Prior to etching, all polished apatite grain surfaces were irradiated with ^{252}Cf-derived fission fragments in a nominal vacuum. All length measurements were performed blindly by two analysts (Donelick, RAD, and O'Sullivan, POS) without prior knowledge of the P-T run conditions or the results of the other worker.

He diffusion results

We observed no pressure dependency of He diffusion coefficient outside of analytical error at the two temperatures studied (Table 1). For example, at 302°C we obtained $\ln(D/a^2)$ values of -16.24, -16.05, and -16.27 (0.25) at 1000, 500, and 20 bars, respectively. From these data, we conclude that He diffusion in Durango apatite is not pressure sensitive over the pressure range relevant for thermochronometry. By extension, it seems likely that the apatite (U-Th)/He closure temperature determined from vacuum diffusion measurements can be applied to the natural setting.

Fission-track annealing results

In comparison to the experiments of Wendt et al. (2002), our P-T conditions are rather limited (Table 1). However, we observed no significant pressure effect at the three temperature-time conditions studied. For example, at 302°C we obtained mean track length values of 9.94±0.12 μm, 10.20±0.10 μm, and 9.79±0.12 μm (1σ) at 1000, 500, and 20 bars, respectively (Donelick data; O'Sullivan data very similar). Most importantly, we were unable to reproduce the Durango data of Wendt et al. (2002) for 168 hours at 250°C between 1 bar and 1 kbar. We attempted to seek variation in the fission track results (again, blindly) by studying powdered grains versus single slabs of a larger crystal, induced tracks, tracks that were etched under very different conditions, and tracks that were effectively randomly oriented. Additionally, unpublished experimental data of Naeser and Hawkins concerning the pressure dependence of fission-track annealing in apatite, conducted using either water or air as the pressure medium, indicate that the pressure medium has little effect on fission-track annealing kinetics. We found absolutely no basis to call upon these variables as an explanation for the data presented by Wendt et al. (2002).

Conclusions

Our experiments differed from those of Wendt et al. (2002) in the pressure range of 1 bar to 1 kbar. Unlike Wendt et al. (2002), we used the same apparatus with the same thermocouple and pressure medium. We conclude, therefore, that the significant pressure dependence of fission-track annealing observed by Wendt et al. between 1 bar and 1 kbar is likely due to incompatible calibrations between thermocouples used in the different apparatus.

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Table 1. Summary of the Durango apatite fission track length data in this study.

Sample Name	Time (h)	Temp. (°C)	Pressure (bar)	He Diffusion $\ln(D/a^2)$	Track Type	Track Lengths (tracks)	Mean ± Standard Error (μm)	Standard Deviation (μm)
RAD Measurements								
DR1A slab (A2Z control aliquot)	>10 years	room	1		unannealed induced	153	16.46±0.07	0.86
DR-D (A2Z control aliquot)	natural	natural	natural		unannealed natural	100	14.56± 0.09	0.92
DURP1E (Caltech control aliquot)	natural	natural	natural		unannealed natural	129	14.41±0.09	1.02
P powder split 1 (Caltech control aliquot	natural	natural	natural		unannealed natural	147	14.49±0.09	1.04
P powder split 2 (Caltech control aliquot	natural	natural	natural		unannealed natural	142	14.38±0.08	0.99
DURP1B	24	250±3	1	18.8±0.7 18.9±0.7	natural	144	12.98±0.09	1.06
DURP1C	24	250±3	500	19.3±0.7 18.9±0.7	natural	140	13.26±0.09	1.08
DURP1D	24	250±3	500	18.5±0.7 18.2±0.7	natural	143	13.38±0.08	0.98
DURP1A	24	250±3	985	18.8±0.7 18.4±0.7	natural	141	13.06±0.09	1.03

DURP1G	24	302±3	20	16.3±0.7	natural	140	9.79±0.12	1.41
DURP1F	24	302±3	500	16.0±0.7	natural	141	10.20±0.10	1.21
DURP1H	24	302±3	1000	16.2±0.7	natural	140	9.94±0.12	1.42
Q slab (20 second etch)	168	250±3	1	19.3±0.7	induced	157	12.94±0.07	0.81
Q slab (40 second etch)	168	250±3	1	19.3±0.7	induced	156	13.17±0.09	1.16
R slab (20 second etch)	168	250±3	1000	18.8±0.7	induced	153	12.73±0.07	0.81
R slab (60 second etch)	168	250±3	1000	18.8±0.7	induced	159	13.05±0.08	1.06
Q powder (prismatic sections)	168	250±3	1	19.3±0.7	natural	142	12.32±0.09	1.04
Q powder (random orientations)	168	250±3	1	19.3±0.7	natural	144	12.11±0.08	1.01
R powder (prismatic sections)	168	250±3	1000	18.8±0.7	natural	143	12.26±0.08	1.00
R powder (random orientations)	168	250±3	1000	18.8±0.7	natural	143	12.13±0.08	0.93
POS Measurements								
DR1A slab (A2Z control aliquot)	>10 years	room	1		unannealed induced	170	16.14±0.06	0.78
DR-D (A2Z control aliquot)	natural	natural	natural		unannealed natural	138	14.59±0.08	0.98
DURP1E (Caltech control aliquot)	natural	natural	natural		unannealed natural	128	14.46±0.08	0.96
P powder split 1 (Caltech control aliquot	natural	natural	natural		unannealed natural	150	14.37±0.09	1.11
P powder split 2 (Caltech control aliquot	natural	natural	natural		unannealed natural	126	14.13±0.09	0.98
DURP1B	24	250±3	1	18.8±0.7 18.9±0.7	natural	104	13.33±0.10	0.97
DURP1C	24	250±3	500	19.3±0.7 18.9±0.7	natural	71	13.97±0.12	0.98
DURP1D	24	250±3	500	18.5±0.7 18.2±0.7	natural	126	13.92±0.09	0.96
DURP1A	24	250±3	985	18.8±0.7 18.4±0.7	natural	101	13.74±0.09	0.92
DURP1G	24	302±3	20	16.3±0.7	natural	115	10.13±0.12	1.30
DURP1F	24	302±3	500	16.0±0.7	natural	125	10.40±0.11	1.22
DURP1H	24	302±3	1000	16.2±0.7	natural	110	10.03±0.13	1.34
Q slab (20 second etch)	168	250±3	1	19.3±0.7	induced	214	12.64±0.06	0.91
Q slab (40 second etch)	168	250±3	1	19.3±0.7	induced	200	12.83±0.06	0.87
R slab (20 second etch)	168	250±3	1000	18.8±0.7	induced	150	12.60±0.07	0.89
R slab (60 second etch)	168	250±3	1000	18.8±0.7	induced	200	12.81±0.07	0.95
Q powder (prismatic sections)	168	250±3	1	19.3±0.7	natural	125	12.26±0.09	1.01
Q powder (random orientations)	168	250±3	1	19.3±0.7	natural	130	12.31±0.09	1.05
R powder (prismatic sections)	168	250±3	1000	18.8±0.7	natural	125	12.24±0.09	1.05
R powder (random orientations)	168	250±3	1000	18.8±0.7	natural	135	12.12±0.08	0.89

Fission-Track Papers

The following is a list of recent and soon-to-be published fission track papers. I have tried to avoid duplications from the list in OnTrack25; therefore, only a few 2002 papers are listed herein. While a few were submitted by the authors for inclusion in this issue of On Track, the majority were found using a database and the keywords “fission track”. The list is extensive but far from complete. It may however serve as a starting point for compiling a 'complete' list of fission-track papers. We would all agree that such a list has practical use as a reference to what is happening in fission-tracks or in your study area. This cannot be achieved without everyone's active co-operation. So, if you have or know of a paper that you would like to see listed in this section, please email the citation to the editor. We are also interested in non-fission-track papers that may be of interest to the fission-track community.

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Call for Contributions

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On Track includes a list of recent and forthcoming fission-track papers. If you know of a paper that was published recently or is in press and should appear in the list, please let the editor know so that it can be added to the list. Also, if you happen to change location due to a change in jobs or finishing off the thesis and graduating, please inform the editor. Thesis abstracts are particularly encouraged! On Track is also happy to print advertisements. Please contact the editor for advertising rates.

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