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.

References

Wendt, A.S., Vidal, O. and Chadderton, L.T. (2002), Earth and Planetary Science Letters, 201, 593-607.

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