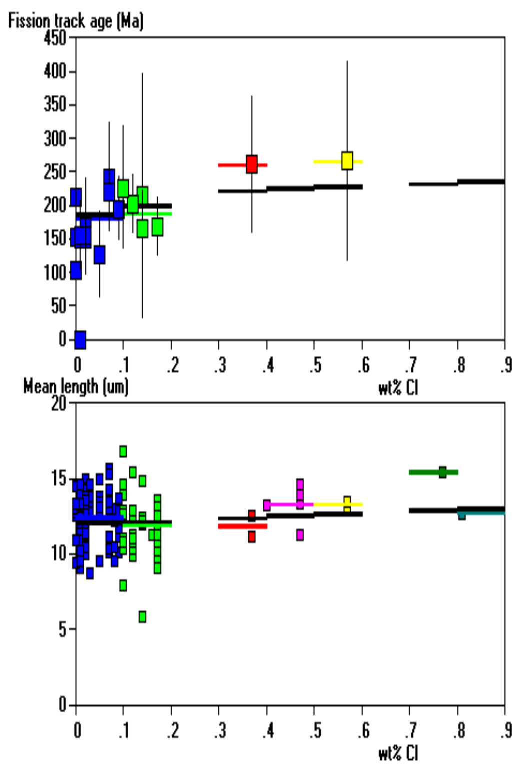
NEW DEVELOPMENTS IN AFTA®:
Routine determination of chlorine content in all apatite grains analysed

In Apatite Fission Track Analysis (AFTA), the chlorine content of apatite grains exerts a significant control on fission track annealing rates. Previously this was allowed for by assuming a particular spread of Cl contents in each sample.

Geotrack now routinely measure the chlorine content of every apatite grain analysed in each sample. AFTA data are grouped into 0.1 wt% Cl intervals and interpreted using a multi-compositional kinetic model which makes full quantitative allowance for the influence of Cl content.

This improved treatment provides both improved precision and accuracy in the magnitude and timing of paleotemperatures determined from AFTA.



Measured data are pooled into 0.1 wt% Cl intervals for interpretation, allowing direct comparison of predicted and measured parameters as a function of Cl content.

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Background

The ability of Apatite Fission Track Analysis (AFTA) to provide independent determination of the timing of heating episodes, as well as the magnitude of peak or maximum paleotemperatures, allows unique insight into the thermal history of sedimentary basins, and of hydrocarbon generation histories. A key factor in application of this technique is knowledge of the kinetics of fission track annealing (Green et al., 1986; Laslett et al., 1987).

Naturally occurring apatites generally have the composition $Ca_5(PO_4)_3(F,OH,Cl)$. Most common detrital and accessory apatites are predominantly fluor-apatites, but may contain appreciable amounts of chlorine. Studies of fission track annealing in laboratory and geological conditions (Figure2) have shown that chlorine content exerts a subtle but important control on annealing kinetics (Green et al., 1986).

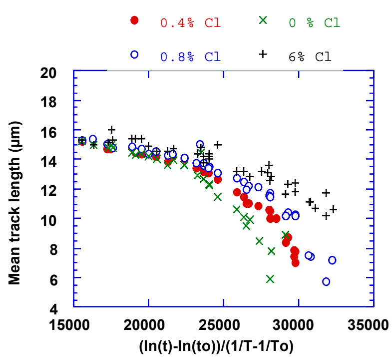

Figure 1: Laboratory annealing data showing mean track length in apatites with four different chlorine contents, against a combined function of temperature and time to reduce the data to a single scale. Fluorapatites are more easily annealed than chlorapatites, and the annealing kinetics show a progressive change with increasing Cl content.

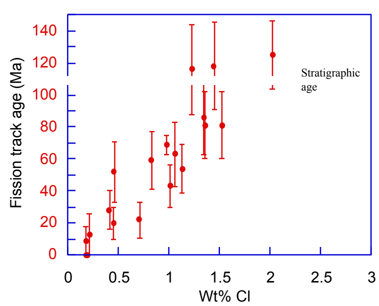

Figure 2: Geological annealing data, in the form of fission track age plotted against chlorine content in a sample from a present day temperature of ~95°C, show the influence of Cl content on annealing kinetics.

Multi-compositional annealing kinetics

Our original understanding of the annealing kinetics of fission tracks in apatite (Green et al., 1986; Laslett et al., 1987) was based on a series of laboratory experiments in a single crystal of apatite with a uniform composition (Durango apatite, ~0.45 wt% Cl). In 1990 we extended this quantitative understanding to apatites with Cl contents up to ~3 wt%. This multi-compositional kinetic model is based both on new laboratory annealing studies on a range of apatites with different F-Cl compositions (Figure 1), and on observations of geological annealing in apatites from a series of samples from exploration wells in which the section is currently at maximum temperature since deposition. A composite model for Durango apatite composition was first created by fitting a common model to the old laboratory data (from Green et al., 1986) and the new geological data for a similar composition. This was then extended to other compositions on the basis of the multi-compositional laboratory and geological data sets.

Predictions of this multi-compositional model are in good agreement with the geological constraints on annealing rates (Figures 3, 4). Since the AFTA data from these Otway Basin reference wells were among those used in construction of the new model, this should not be viewed as independent verification, but rather as a demonstration of the overall consistency of the model.

AFTA data can be interpreted using this multi-compositional model using an assumed or measured distribution of Cl contents within a sample.

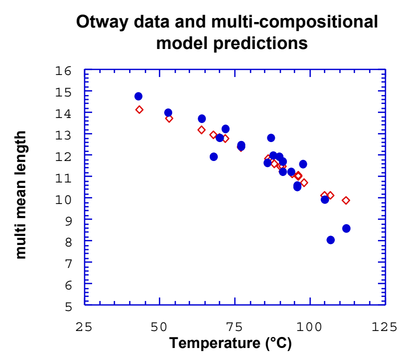

Figure 3: Comparison of measured mean track length (solid circles) in samples from four Otway Basin reference wells (from Green et al, 1989a) and predicted mean track lengths (open diamonds) from the multi-compositional kinetic model of fission track annealing. The agreement is very good over the range of the data.

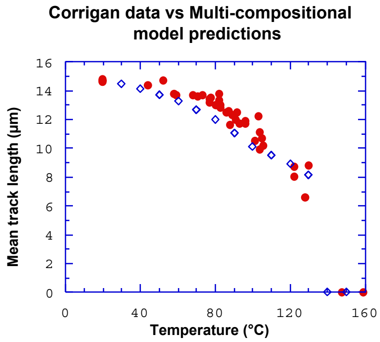

Figure 4: Comparison of measured mean track length (solid circles) in samples from a number of South Texas wells (Corrigan, 1993) and predicted mean track lengths (open diamonds) from the multi-compositional kinetic model of fission track annealing. The agreement is very good over most of the temperature range, providing independent confirmation of the validity of the model.

New developments

It became clear to us that in order to obtain the best possible interpretations of AFTA data it is essential to have better control on Cl contents of individual grains. Therefore in 1994 we implemented a system in which Cl contents are measured in every apatite grain analysed (i.e. those in which fission track ages and/or track lengths are measured).

Chlorine contents are measured using a JEOL JXA5A electron microprobe equipped with three wavelength dispersive spectrometers using an accelerating voltage of 15KV and a beam current of 29 nA. The electron beam is defocussed to 20µm to avoid problems associated with apatite decomposition which occur with a more tightly focussed beam. Apatite grain locations are read from disk files created by our AUTOSCAN™ computerised microscope stages, so all grains can be located automatically for probing. Pure rock salt (NaCl) is used as a standard for chlorine, which is the only element determined in each apatite grain. Count rates are converted to wt% Cl using an empirically determined correction factor. This allows for atomic number, absorption and fluorescence matrix effects which are normally calculated explicitly when analysing for all elements. Durango apatite (Melbourne University Standard APT151) is used to monitor probe performance during analytical runs.

Data analysis and interpretation

Measured AFTA data are pooled into compositional groups in intervals of 0.1 wt% Cl, and AFTA parameters are evaluated for each group. Predicted AFTA parameters can also be calculated for each group using the multi-compositional kinetic model.

Interpretation proceeds by seeking conditions of maximum paleotemperature, timing of cooling and style of cooling history which best explain the observed pattern of AFTA parameters within each group (Figure 5).

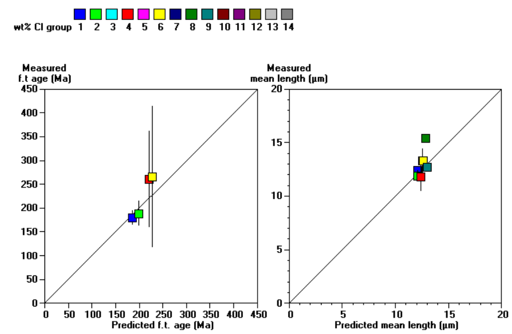

Figure 5: Comparison of predicted and measured fission track age and mean track length in 0.1 wt% Cl intervals allows verification of a thermal history solution.

We have recently developed new methods to automate this interpretive process. These provide not only wholly objective estimates of the maximum paleotemperature and timing of cooling, but also ±95% confidence intervals on those estimates. In addition, peak paleotemperatures during a subsequent heating episode can also be evaluated in similar fashion, if appropriate.

References

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Laslett, G.M., Green, P.F., Duddy, I.R. and Gleadow, A.J.W. 1987, Thermal annealing of fission tracks in apatite 2. A quantitative analysis. *Chem. Geol. (Isot. Geosci. Sect.)*, 65, 1-13.