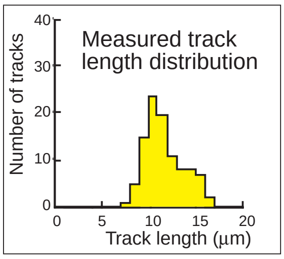
Thermal history interpretation of AFTA data

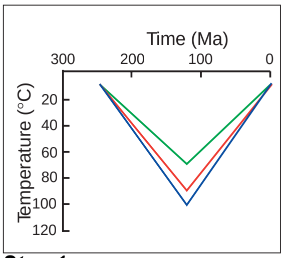
AFTA is based on the progressive reduction in track length as a function of temperature and time ("fission track annealing"). This reduction in track length is also manifested as a reduction in fission track age. New tracks are produced throughout geological time, as a result of spontaneous fission of uranium impurity atoms within the apatite crystal lattice. In a sample which is heated and then cooled, tracks produced up to the time at which cooling begins will be shortened to a length determined by the maximum paleotemperature, while tracks produced after the onset of cooling will be longer. The proportion of shorter to longer tracks is determined by the time at which cooling began, in relation to the overall duration of the history.

The basic process of extracting thermal history solutions from AFTA data involves modelling AFTA parameters through various thermal history solutions, so as to define the range of maximum paleotemperatures and timing of cooling for which predictions are consistent with the measured data. This process requires a detailed knowledge of the kinetics of the annealing process, and the way this depends on apatite composition.

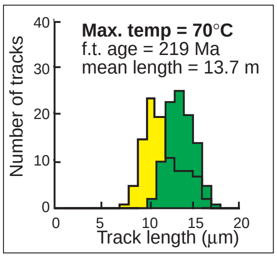
The following example, based on a simple mono-compositional example, illustrates the basic principles involved.

Triassic sandstone:
Depositional age = 240 Ma
Fission track age = 183 ± 12 Ma
Mean track length = 11.7 ± 0.2 Ma

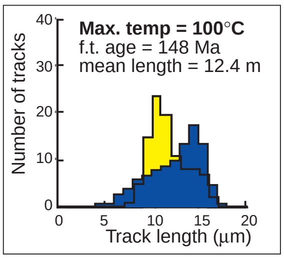




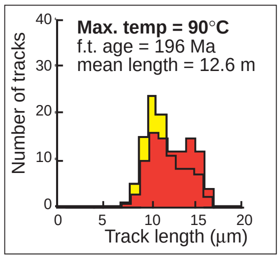
Step 1:
Vary maximum paleo-temperature while holding the timing of cooling fixed. at 120 Ma (the mid-point of the history). Compare predictions with measured parameters.



Main mode in the length distribution is not short enough. Insufficient age reduction.

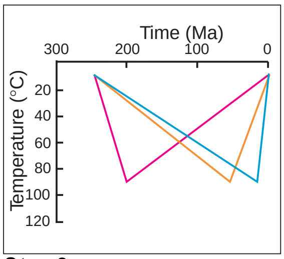


Too many short tracks. Too much age reduction.

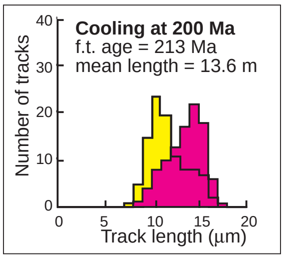


Shorter mode in the predicted length distribution matches the measured lengths, but too many short tracks.
Predicted f.t. age is close to measured value.

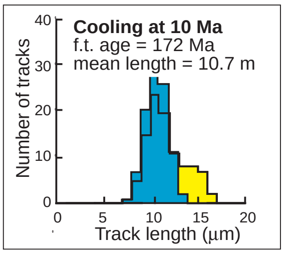
A maximum paleotemperature around 90°C is appropriate for this sample, but the timing is still uncertain.



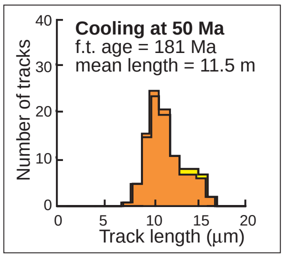
Step 2:
Fix maximum paleotemp-erature and vary the timing of cooling. Compare predictions with measured parameters.



Too many long tracks. Insufficient age reduction.



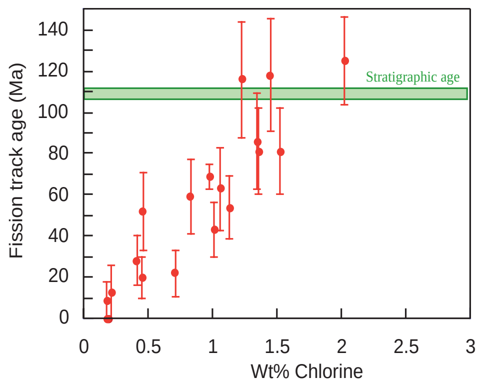
Too many short tracks. Predicted f.t. age is within error of measured value.



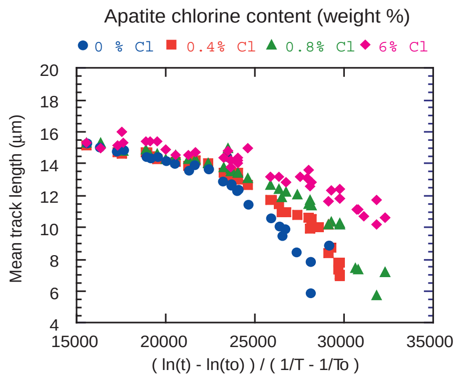
Predicted length distribution shows a good match to the measured track lengths. Predicted age is close to the measured value.

Of the options illustrated, cooling from a maximum paleotemperature of 90°C beginning at 50 Ma gives the best match between measured data and predicted values. Further optimisation would allow formal definition of best fit values of maximum paleotemperature and time of cooling, each with 95% confidence limits.

In practice, annealing kinetics depend on Cl content.

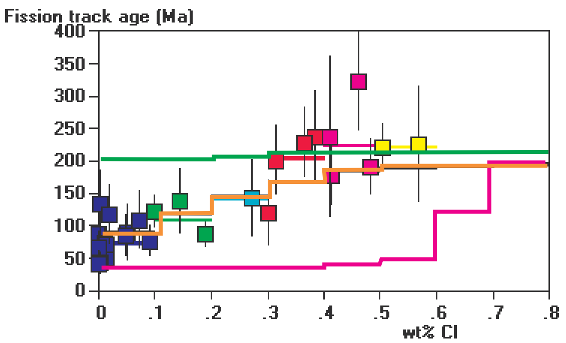


Fission track age against Cl content for individual apatite grains from a single sample of volcanogenic sandstone from a present-day temperature of ~95°C in the Flaxmans-1 well, Otway Basin. Fission tracks in fluorine-rich (Cl poor) grains are more easily annealed than grains with higher Cl contents. As a result, zero fission track ages (totally reset) are measured in Cl-poor grains while Cl-rich grains in the same sample have undergone little or no age reduction.

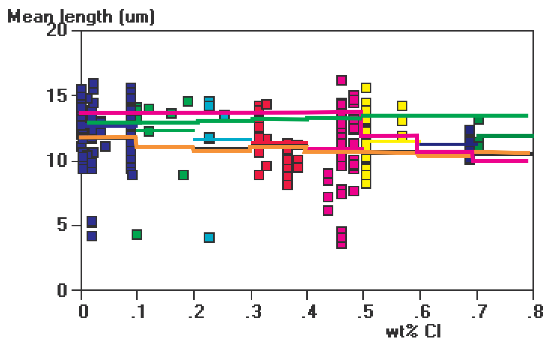


Laboratory annealing studies also reveal the systematic influence of chlorine content on annealing kinetics. In this plot, measured mean lengths are plotted against a function of annealing temperature and time, designed to bring all data onto a common scale. At any given temperature-time combination, low Cl apatites show a greater degree of annealing than Cl-rich apatites.

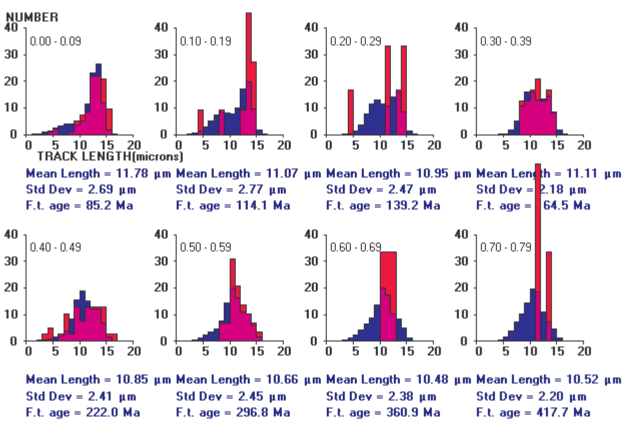
Thermal history solutions are extracted from data broken down into discrete compositional groups, using separate kinetics for each group. The final thermal history solution should not only match the pooled data but the variation of fission track age and length with wt% Cl.



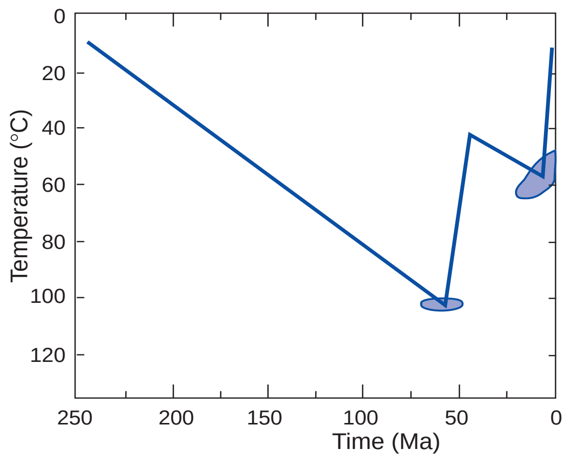
This plot shows real data from a Triassic sandstone, with predicted patterns of f.t. age vs wt% Cl for three different thermal histories:
1: 80°C at 100 Ma   2: 100°C at 60 Ma   3: 120°C at 40 Ma
A maximum paleotemperature of 100°C at 60 Ma gives the best fit.



Track length data, pooled into compositional groups, are also used in defining the preferred values of maximum paleotemperature and time at which cooling began.



The match between predicted and measured track length data is easier to display visually in terms of track length distributions for each wt% Cl group. In the above example, data from eight discrete compositional groups within the same sample are used to define the final thermal history solution.



Rigorous statistical procedures allow definition of best-fit values of maximum paleotemperature and the timing of cooling, with associated ±95% confidence limits. A later event can often be similarly constrained, as illustrated above.

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