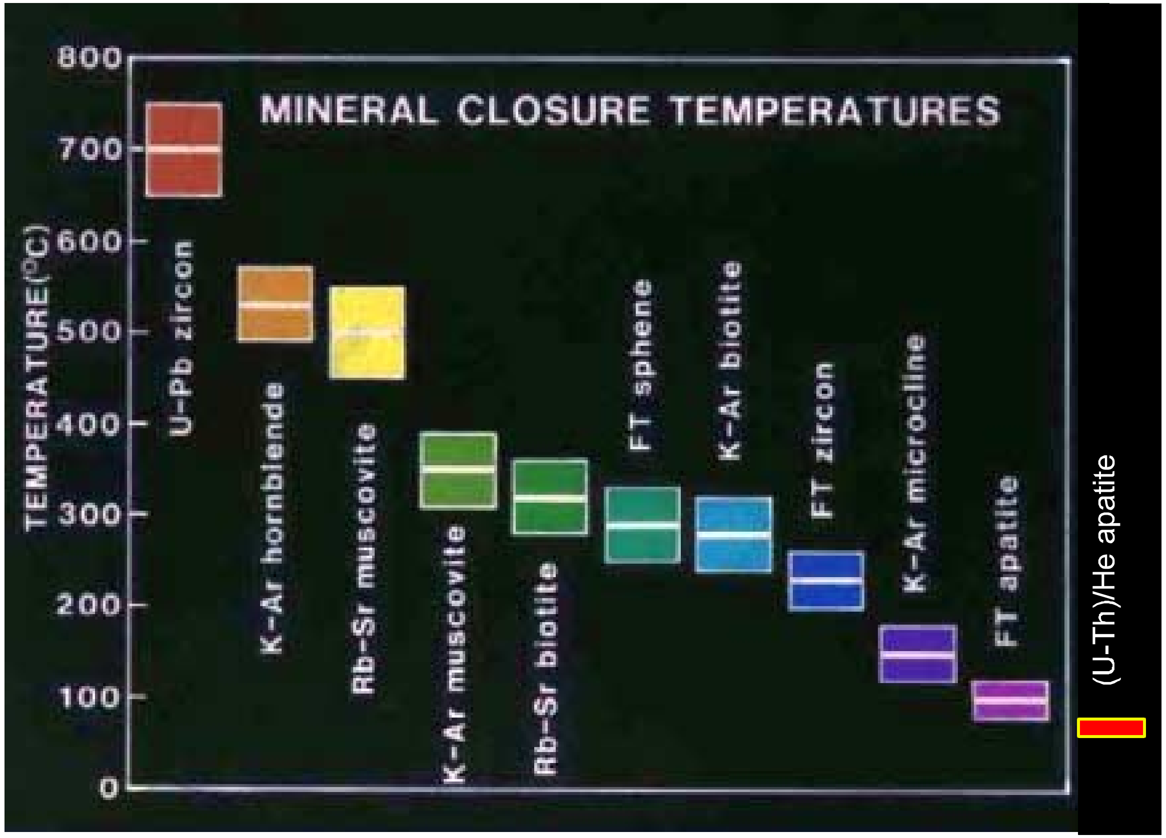
(U-Th)/He dating of apatite -1



A new method of low-temperature thermochronology, based on the balance between production of radiogenic Helium by alpha decay of Uranium and thorum isotopes, and the diffusive loss of Helium. The technique has an effective closure temperature of ~70¡C .

Rate of diffusive loss is controlled essentially by temperature and grain size. Laboratory diffusion studies provide the basis of quantitative modelling of the (U-Th)/He system.

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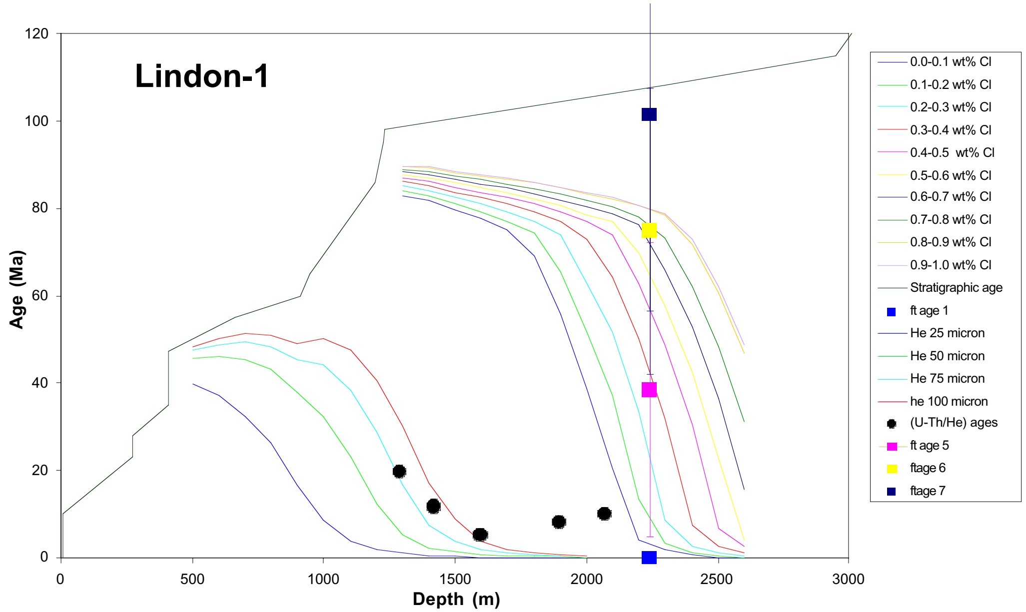
(U-Th)/He dating of apatite -2

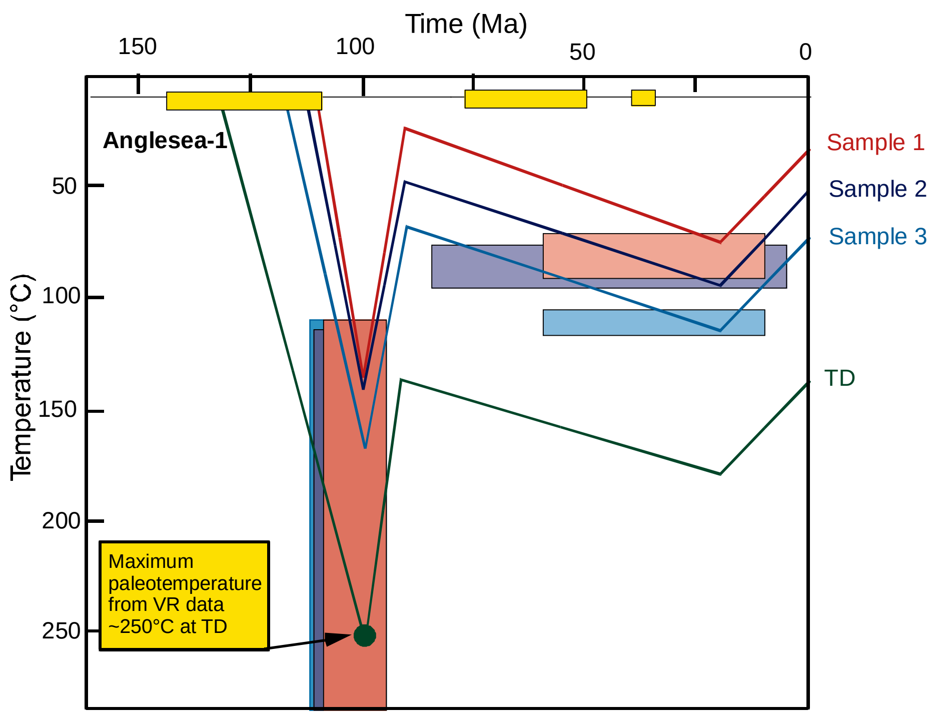
The method depends on the accumulation of He within the apatite lattice due to alpha-decay of Uranium and Thorium isotopes. In similar fashion to fission track dating, measurement of the amount of He, U and Th allows an age to be determined.



These results from the Lindon-1 well, located in the Otway Basin, SE Australia, are part of an ongoing study to assess the thermal stability of the He system in apatite.

Also similar to fission track dating, the daughter-product , in this case radiogenic He gas, is very easily lost from the apatite, at a rate which depends on temperature. He is lost at lower temperatures than those at which fission tracks are annealed. Diffusion rates depend on grain size, so that larger grains give older ages than smaller grains for the same thermal history.

ANGLESEA-1 AFTA & (U-Th)/He dating



AFTA and VR data in the Anglesea-1 well define two paleo-thermal episodes: cooling from maximum paleotemperatures began in the Early Cretaceous (between 110 and 95 Ma), with subsequent cooling from a lower paleo-thermal peak in the Tertiary (beginning between 60 and 10 Ma, from AFTA). The Tertiary stratigraphy further constrains the most recent cooling episode to post-35 Ma (assuming that heating was due to deeper burial), but this still represents a considerable range of possible timings.

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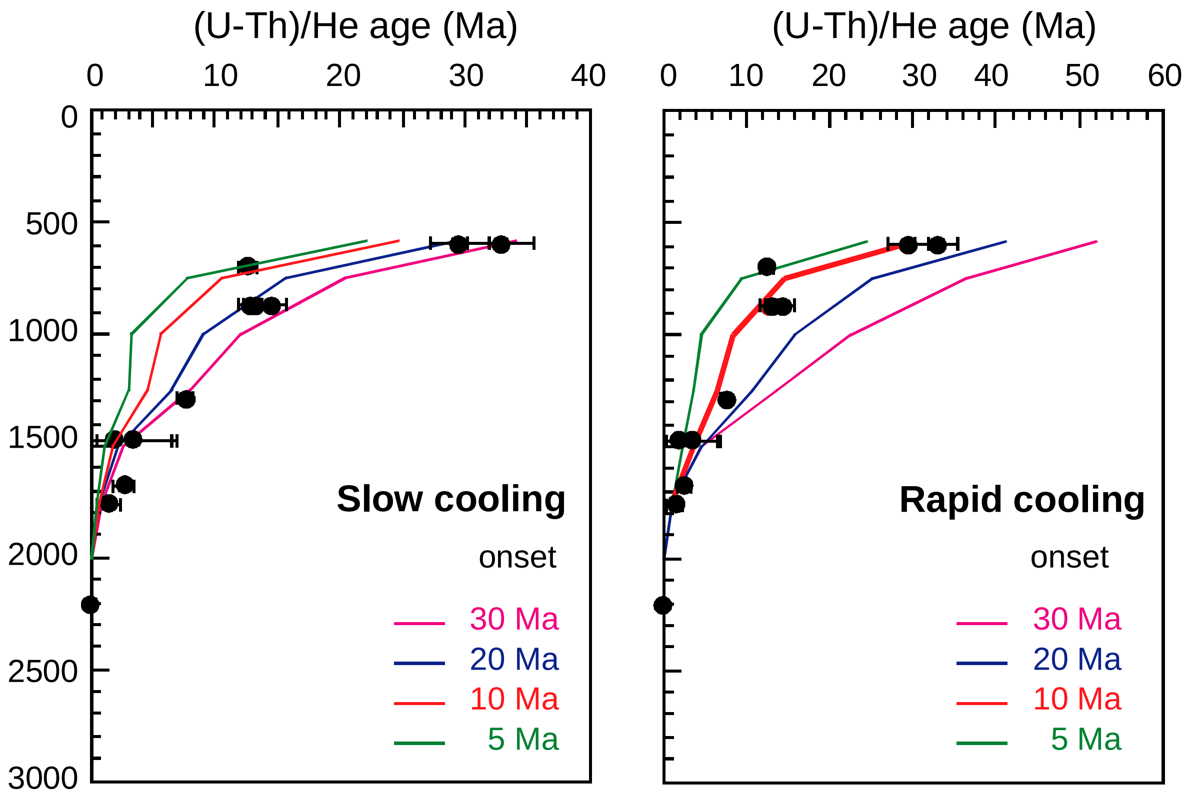
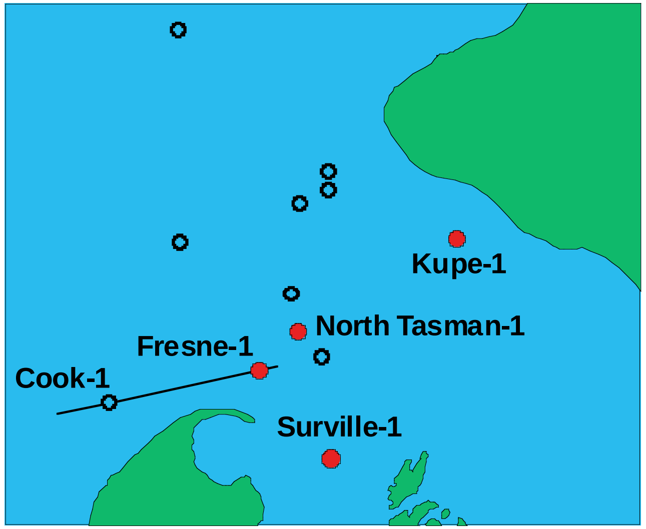
ANGLESEA-1 apatite (U-Th)/He ages

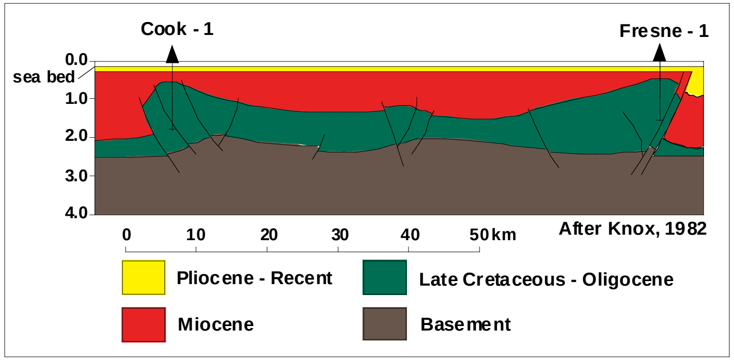


Data from House et al., Earth and Planetary Science Letters, v170, 1999, pp463-474

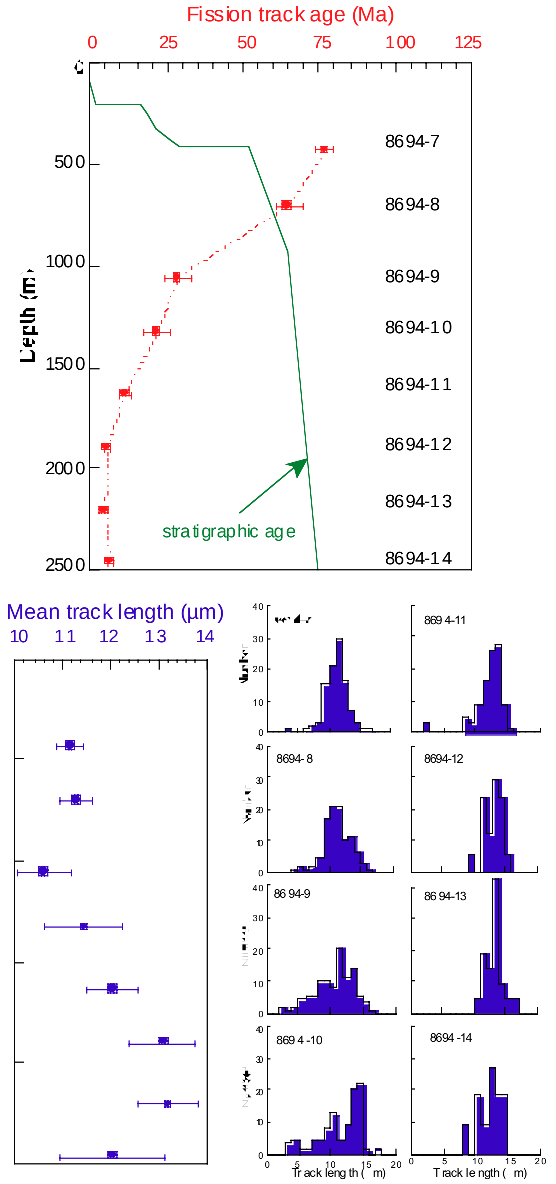
(U-Th)/He ages in apatites from the Anglesea-1 well (House et al., 1999) show a close fit to modelled ages for a scenario involving rapid cooling beginning at around 10 Ma (red line, right panel). This timing is consistent with the regional geology, characterised by a widely recognised Late Miocene unconformity.

FRESNE-1, Taranaki Basin, NZ





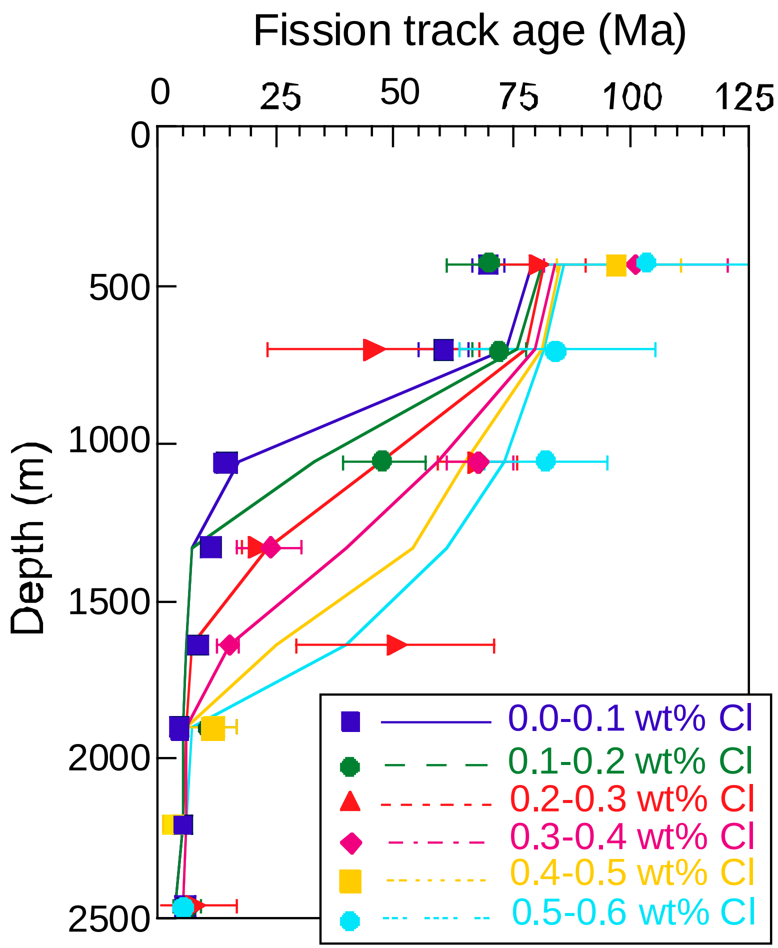
The Fresne-1 well, located in the Southern Taranaki Graben, between the North and South Islands of New Zealand, was drilled on one of several prominent Late Miocene inversion structures in the region. The stratigraphy of the section intersected in the well establishes tight constraints on the timing of inversion to between 15.5 and 2 Ma. The seismic section through the structure (after Knox, 1982) suggests between 2 and 3.5 km of section have been eroded from the structure during inversion. This well therefore provides an excellent test-bed for use of paleo-thermal techniques in determining the timing of cooling and amount of section eroded from the structure.



FRESNE-1 AFTA DATA

Apatite fission track ages show a progressive reduction with depth , showing a pattern characteristic of sections that have been hotter in the past, with the point marking the transition from rapidly decreasing ages to consistent values corresponding to the paleotemperature at which all samples are totally annealed prior to the onset of cooling. Mean track length and track length distributions show complementary behaviour. Shallow samples are dominated by shorter tracks, representing partially annealed tracks formed prior to the onset of cooling, with only a small proportion of longer tracks formed after cooling. With increasing depth, as fission track ages are progressively reduced, due to increasing maximum paleotemperatures, so is the mean length of the shorter component in each sample, representing an increasing degree of partial annealing of tracks formed prior to the onset of cooling. In the three deepest samples, all tracks were totally annealed prior to cooling, and only longer tracks, formed after cooling, are present.

FRESNE-1 Apatite chlorine distributions



To highlight the importance of compositional effects in these data, this Figure shows the fission track age of individual Cl content groups within each sample, plotted against depth. While the behaviour of the data in this plot are more erratic than those in the previous Figure, due mainly to the small numbers of grains involved, the trend is clear with apatites with higher Cl contents achieving a particular degree of age reduction at progressively deeper levels, corresponding to higher maximum paleotemperatures. As a guide to visualising these effects, also shown are the trends of fission track age with depth for separate compositional groups corresponding to the best-fit thermal history solution. Similar trends are also evident within the track length data in these samples, but these are not illustrated here.

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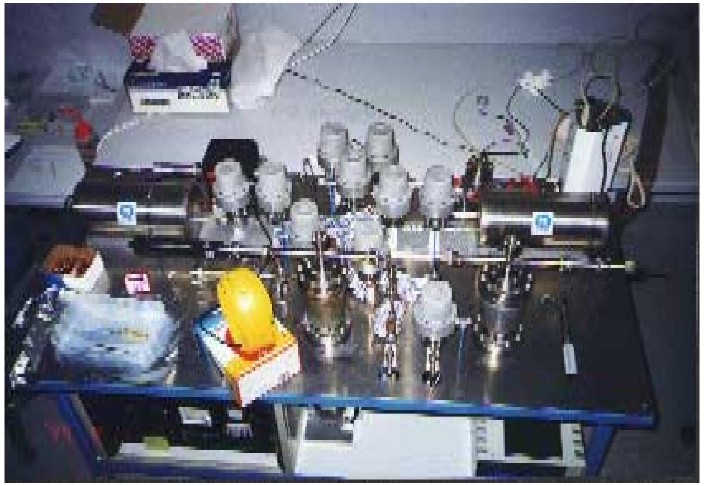
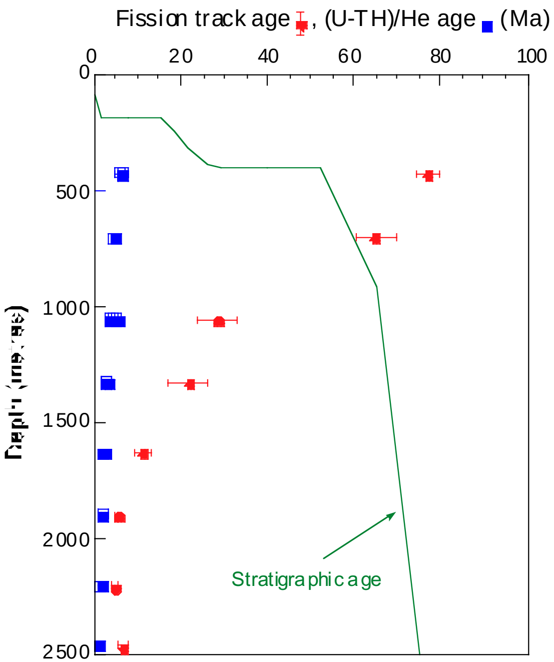
FRESNE-1
(U-Th)/He ages





The upper panel shows the equipment used to measure (U-Th)/He ages (courtesy of CSIRO Division of Petroleum Resources, Sydney). The lower Figure shows (U-Th)/He ages in the eight samples from Fresne-1, plotted against depth. Fission track ages, and the variation of stratigraphic age with depth, are also shown, for comparison. In the shallower samples, the He ages are much younger than fission track ages in the same sample, while the difference is much less pronounced in the deeper samples. Helium ages in the shallower samples are similar to the fission track ages in the deeper samples. These He ages are clearly responding to cooling at around the same time as recorded in the fission track ages. But because of the effects of He loss at present-day temperatures, these (U-Th)/He ages cannot be interpreted directly as dating specific cooling events. Instead, the cumulative effects of the thermal histories of the samples within the sedimentary basin context must be taken into account.

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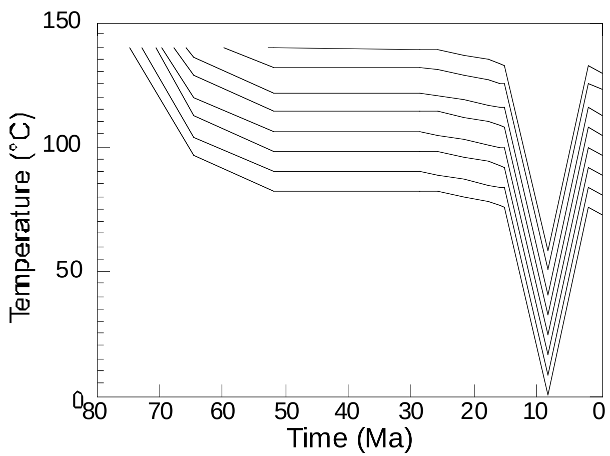
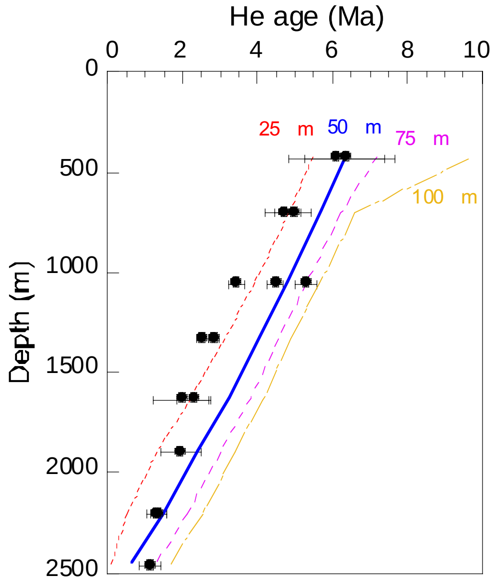
FRESNE-1 (U-Th)/He modelling

a) Thermal histories from AFTA



b) U-Th/He ages with predicted trends

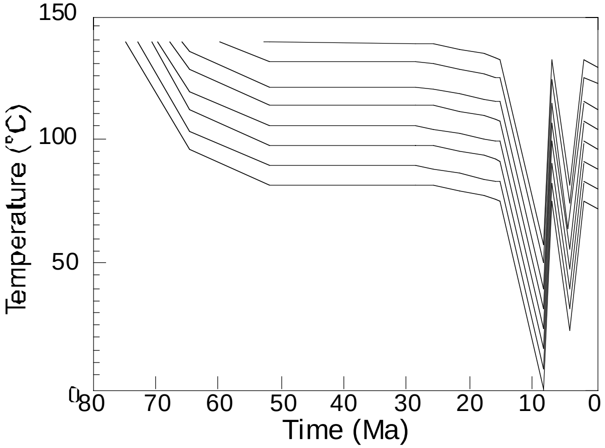


The upper Figure shows the first pass thermal history solutions derived from the AFTA and VR data in the Fresne-1 well. The AFTA and VR data suggest around 2.6 km of section has been removed during inversion, which is highly consistent with reconstructions based on seismic sections. AFTA shows that cooling began between 9 and 8 ma, also highly consistent with the geological evidence, which brackets inversion to between 15 and 2 Ma.

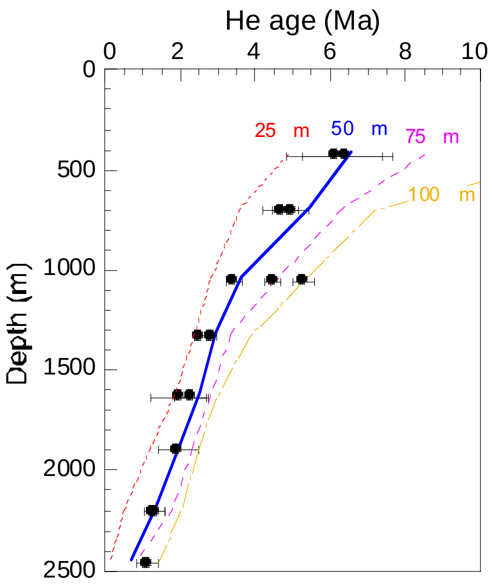
The lower Figure shows the (U-Th)/He ages measured in apatites from the eight AFTA samples in the Fresne-1 well, together with modelled values expected in each sample on the basis of the thermal history framework obtained from the AFTA and VR data (upper). Predicted ages are shown for four grain radii (since grain size affects diffusion rates, larger grains retain more He than smaller grains, for a given thermal history). The mean radii in the samples analysed from Fresne-1 are generally around 50 µm, and this trend is the most appropriate for direct comparison with the measured ages. In general, the predicted and measured ages show a fair degree of agreement, particularly at the shallowest and deepest extremes of the depth range, while predicted values from the middle of the sampled interval are higher than measured values.

FRESNE-1 (U-Th)/He final model

a) two separate cooling events



b) U-Th/He ages with predicted trends



The upper Figure illustrates an alternative thermal history scenario which is based on the previous Figure, but now involves two discrete cooling episodes, with an initial phase at 8.5 Ma and a later cooling phase beginning at 4 Ma (with 50¡C of cooling since 4 Ma). The lower Figure shows the age trends predicted from this scenario, and in this case the agreement between measured and predicted ages is extremely good across the whole depth range.

While it remains, to some extent, uncertain whether this treatment represents over-reliance on the extrapolation of laboratory diffusion systematics, and more tests are required in controlled geological conditions, this procedure certainly illustrates the potential of the (U-Th)/He technique to complement AFTA and VR data in sedimentary basins to provide further definition of thermal history styles, particularly in terms of refining the most recent, low temperature, phase of the history.

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