CONSTRAINED BASIN MODELLING: DIRECT CALIBRATION OF THERMAL AND BURIAL HISTORIES USING AFTA® APATITE FISSION TRACK ANALYSIS AND VITRINITE REFLECTANCE DATA.

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Calibration of thermal and burial histories as currently practiced for basin modelling is an inexact science at best, with many aspects of these histories unconstrained, leading to large errors in the predictions of hydrocarbon generation and migration.

Geotrack has developed a data-based approach to calibration called thermal history reconstruction (THR) based on integration of AFTA® Apatite Fission Track Analysis and vitrinite reflectance (VR) data (Laslett et al., 1987; Green et al., 1989, 2004; Bray et al., 1992; Duddy et al., 1998). Based on analysis of samples from an existing exploration well or appropriate outcrop section, THR provides direct measurement of the time and magnitude of maximum paleotemperature and the paleogeothermal gradient at this time, together with similar measurements on at least one other subsequent heating episode, each constrained with formal estimates of uncertainty (±95% confidence limits). These measurements allow accurate calculation of paleo-heat flow at key points in a sedimentary basin’s evolution and when combined with explicit assumptions, the burial history can also be accurately determined within the constrained thermal history framework: all of these factors being essential elements to a rigorous basin modelling strategy (e.g. Duddy and Erout, 2001).

Because the thermal response of both the AFTA and VR data are dominated by the maximum temperature that a sample has reached, interpretation begins by investigating whether the measured data could have been produced if present-day sample temperatures are the maximum values at any time since deposition. If this is the case, the data preserves no information on the paloethermal history. As a starting point, we construct a "Default Thermal History" for each sample, which forms the basis for commencing the interpretation. Default Thermal Histories for samples throughout a well section are derived from the stratigraphy of the preserved sedimentary section, combined with constant values for paleogeothermal gradient and surface temperature equal to present-day values.

Using this Default Thermal History, AFTA parameters are predicted for each sample using a multicompositional kinetic description developed by Geotrack (Green et al., 1996). If the measured data show a greater degree of fission track annealing (in terms of either fission track age reduction or track length reduction) than expected on the basis of this history, the sample must have been hotter at some time in the past. In this case, the AFTA data are analysed using the kinetic model to provide estimates of the magnitude of the maximum paleotemperature in that sample and the timing of cooling from the thermal maximum. In many cases, similar constraints can be obtained on a subsequent heating event of lower magnitude. An example of an AFTA thermal history solution from a single well sample is shown in Figure 1.

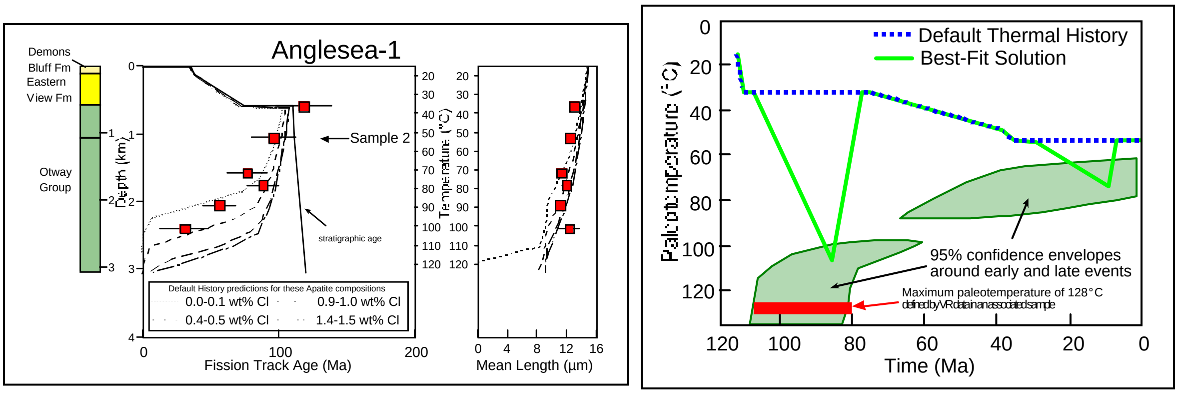
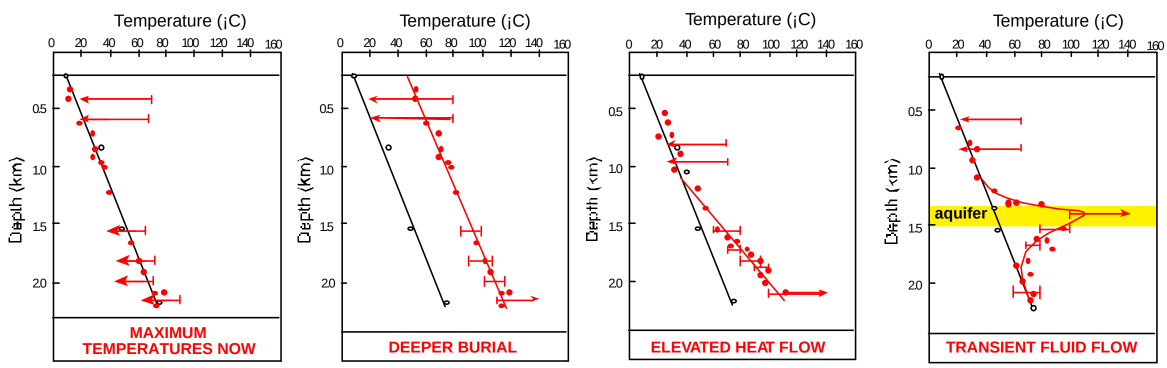


Figure 1: Left: Plot of AFTA measured and predicted AFTA parametres versus depth and present temperature in the Anglesea-1 well, Otway Basin (Green et al., 2004). Right: AFTA thermal history solution for a single sample (2) from the AFTA reveals two heating events while the VR results from an associated sample constraints the maximum paleotemperature to 128°C, which AFTA only allows between 110 and 80 Ma. Similar constraints from all AFTA samples allows the thermal history of the whole well sequence to be reconstructed.

A similar approach is used for the interpretation of VR data. If a measured VR value is higher than the value predicted from the Default Thermal History (making due allowance for analytical uncertainty), the sample must have been hotter at some time in the past. In this case, an estimate of maximum paleotemperature can be calculated from each VR value using an appropriate heating rate and timing information provided by AFTA data from the well. VR (specifically $R_o$max values) is predicted using the distributed activation energy model describing the evolution of VR, with temperature and time developed by Burnham and Sweeney (1989). The VR measurement methodology is a critical factor in obtaining accurate calibration data. The most robust technique is that recommended by the ICCP (International Committee for Coal and Organic Petrology) and adapted to DOM (Dispersed Organic Matter) in Australian Standard (AS) 2486. This method uses primary in-situ vitrinite identified on petrographic grounds within polished sections of whole rock, with measurement of the maximum reflectance on each VR particle. While this method may result in fewer measurements than random reflectance determined on dispersed organic particles from demineralised samples (the mostly commonly used VR methodology), the resulting $R_o$max data are inherently more accurate than data obtained from other methods, as correct identification of vitrinite is more easily achieved and problems with surface relief and surface quality are controlled. Vitrinite identification is made primarily on textural grounds, and this allows an independent assessment to be made of cavings and re-worked vitrinite populations. Histograms are only used for population definition when a cavings population significantly overlaps the range of the indigenous population. If a measured VR value is lower than expected on the basis of the Default Thermal History, either present temperatures have been overestimated or temperatures have increased very recently. In such cases, the measured VR value or AFTA on an associated sample may allow an estimate of the true present-day temperature. Alternatively the measured VR value may underestimate the true maturity for some other reason, e.g., anomalously low vitrinite reflectance values in association with some defined maceral assemblages, especially telalginite and lamalginite (e.g Hutton and Cook, 1980), an effect commonly oversimplified by the use of the term suppression of vitrinite reflectance. Other reasons may be misidentification of true "in-situ" vitrinite or the presence of caved material etc. Comparison of AFTA and VR data and recourse to the detailed description of the organic matter assemblages within a sample usually allows such factors to be identified.

Combining paleotemperature estimates from a suite of down hole AFTA and VR sample allows definition of the paleotemperature profile and this in turn allows the mechanisms of heating and cooling to be assessed as illustrated in Figure 2.



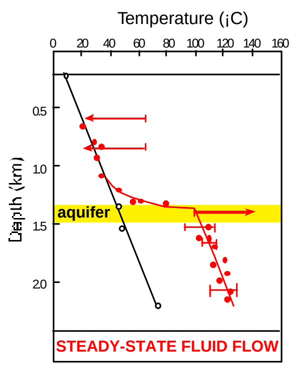


Figure 2:
Characteristic paleotemperature depth profiles derived from AFTA (bar constraints) and VR (solid circles) data. The way in which paleotemperatures characterising a particular paleo-thermal episode vary with depth (i.e. the Òpaleotemperature profileÓ) provides ke information on the mechanisms of heating and cooling as illustrated .

If the paleotemperature profile is linear then a quantitative estimate of the paleogeothermal gradient (±95% confidence) can be determined in each of the paleo-thermal events revealed by AFTA (Bray et al., 1992). Extrapolation of the paleogeothermal gradients to an appropriate paleo-surface temperature then allows quantitative attribution of heating to the correct combination of additional burial and paleogeothermal gradient (i.e. paleo-heat flow). These paired estimates provide rigorous constraints at each well location and removes the uncertainty that often surrounds the mechanism of paleo-heating when VR data alone is used for calibration of thermal history in basin modelling. By restricting the range of allowed values of paleo-heat flow and additional burial (and denudation), THR thus provides a more accurate basin modelling framework for the prediction of patterns of hydrocarbon generation and migration.

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