Thermal History Data and Missing Section - The Great Uplift Debate gets into Deep Water

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'The Great Uplift Controversy'

'Among the subjects which have for some years past engaged the thoughts of geologists, none perhaps has excited so general and intense an interest as the Theory of Elevation' - George Bellas Greenough, Geological Society Meeting 1834.

In the early to mid-1800's a great debate raged over the true meaning of unconformities as recognised by Hutton, Smith and others. This was a key time in the history of geology with the realisation that not all geological time is represented in the preserved stratigraphic record.

In the late 1980/90's another debate followed the publication of thermal history data around Britain interpreted in terms of km-scale uplift and erosion during the Late Cretaceous and Tertiary. Since then the body of evidence is become overwhelming that Britain and other continental margins have been uplifted during the 'passive' post-rift stage of basin development.

The 'Science' of Thermal History Reconstruction (THR)

THR is a scientific technique based on data measured directly from rock samples giving information on the temperature-time history. THR goes back to the 1970's, where vitrinite reflectance (VR) profiles were used to estimate the amount of uplift at unconformities. It received a significant boost with advent of kerogen kinetics, enabling VR to be converted to temperature and plotted on a linear scale against depth allowing paleo-temperature profiles and paleo-geothermal gradients to be defined. A new dimension was introduced in the 1980's with the advent of apatite fission track analysis (AFTA) providing the crucial timing element for THR.

THR revolves around the recognition of thermal episodes which represent times of cooling in the thermal history. If a rock was once at a high temperature and is now at a lower temperature then clearly it has cooled. If there has been no cooling, the rock is at 'maximum temperature now' (or MTN). In this case thermal history data will only indicate the present-day temperature. If the rock was once hot and has cooled, then it was 'hotter in the past' (or HIP) and THR can provide information on how hot it got and when it began to cool.

Cooling, Missing Section, Uplift & Erosion

Thermal history data collected in a vertical profile from a well provide a paleo-temperature profile from which paleo-geothermal gradient can be measured. This allows valuable insight to the mechanism of heating and cooling recognised by the thermal history data. Uplift is indicated where a linear paleo-gradient is offset to higher temperatures than the present-day gradient, and extrapolation of a linear gradient to an assumed paleo-surface temperature intercept forms the basis of estimating the thickness of the 'missing section', and therefore the amount of erosion, from thermal history data.

When rocks are cooled and missing section is indicated, it is erosion that causes the cooling by moving the rock section nearer to the surface. A stratigraphic hiatus or period of non-deposition, or up/down movements of the earth's surface with no erosion, would not leave a thermal signature and would not be recognised by thermal history data. We acknowledge that erosion does not always mean uplift.

Uplift & Erosion along the Atlantic Passive Margin

In theory the post break-up phase of passive margin development should be undergoing uninterrupted McKenzie-style thermal decay subsidence. However thermal history data along the West African and other passive margins show that this is not the case. Data from Equatorial Guinea and Cameroon show an initial high heat flow in the mid-Cretaceous then the expected trend of overall cooling to the present-day but interrupted by several extreme cooling events in the Late Cretaceous, Early Tertiary and Neogene. This is interpreted as sub-aerial erosion which requires km-scale uplift and this is supported by time gaps in wells and truncational unconformities on seismic data.

Received wisdom is that this scale of uplift and erosion only affected basin margins and that the distal domain will only have undergone simple and continuous subsidence where sediments would be at MTN. However recent work and data have thrown doubt on this view by showing that recognised episodes of uplift and erosion may extend basin-wards over transitional or even oceanic crust.

In the Gulf of Guinea, well L-2 is situated in ~ 2000m of water in the distal Rio Muni basin on proto-oceanic or transitional crust. A recent revision of the stratigraphy in L-2 has shown a significant stratigraphic break with Miocene lying on Mid-Eocene. VR data from the Paleogene section in L-2 broadly lie on a linear trend but are significantly offset towards higher values indicating HIP. The data require 1200 to 1600 m of missing section removed by pre-Miocene erosion and seismic data support this interpretation with truncation below the unconformity extending out over oceanic crust. This erosional episode correlates well with the 45-35 Ma event recognised in wells and outcrop along the basin margin.

On new regional seismic data along offshore Atlantic Morocco of the NW African margin a 'basinward-truncating unconformity' can be seen extending from stretched continental crust out over oceanic crust cutting deeply into the Cretaceous stratigraphy. In DSDP core-holes drilled on oceanic crust the oldest sediments above the unconformity are Paleocene giving a Base Tertiary age. In the distal basin DSDP 397 where the time-gap at the unconformity is Miocene to Hauterivian, VR values of 0.50-0.55% in the Hauterivian indicate removal of a significant amount of missing section.

We plan to further investigate the evidence for distal basin erosion by sampling offshore Morocco DSDP cores for new thermal history data (AFTA/VR).

Modern Petroleum Systems Analysis

Thermal history data are too frequently overlooked in petroleum systems analysis. There appears to be a general reluctance to accept large-scale uplift and erosion during post-rift passive margin development. Objections raised concern the mechanism for such large-scale vertical movements, the whereabouts of the erosional products and the mechanisms required for renewed subsidence/sedimentation. To be scientific, these objections should not invalidate the observations but rather accelerate the search for explanations.

Ignoring thermal history data and the evidence for 'missing section' can lead to spurious heat flow models, under-estimation of subsidence and misinterpretation of source rock maturity and hydrocarbon generation.

This becomes ever more pertinent as petroleum systems analysis moves into deeper water situations overlying oceanic crust, where there is a tendency to assume a McKenzie style cooling history and continuous burial and rely on theoretical modelling.