Paleo-thermal Effects of Igneous Intrusions in Sedimentary Basins and Their Influence on Petroleum Systems*

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Abstract

The paleo-thermal effects of intrusions in sedimentary basins are normally thought of only in terms of the purely conductive contact heating typically affecting a thickness of surrounding rock similar to the width of the intrusion. However, our experience in a number of basins around the world applying thermal history reconstruction based on AFTA and VR has revealed a much more complex variety of different processes by which intrusions can influence the thermal history of sedimentary sequences, and thereby exert significant influence on petroleum systems. These events occur on all scales from local contact effects to basin-scale. This presentation illustrates this variety with a range of examples and we explain the principles involved in such studies.

References Cited


https://www.researchgate.net/publication/259501807_Impacts_of_Igneous_Intrusions_on_Source_and_Reservoir_Potential_in_Prospective_Sedimentary_Basins_Along_the_Western_Australian_Continental_Margin


Paleo-thermal effects of igneous intrusions in sedimentary basins and their influence on petroleum systems

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The paleo-thermal effects of intrusions in sedimentary basins come in all shapes and sizes, from local to basin-scale.
Thermal History Reconstruction in sedimentary basins requires reliable, accurate techniques (accuracy is more important than precision). Our principal tools are AFTA (Apatite Fission Track Analysis, above) and vitrinite reflectance (right).
What can we do with AFTA?

AFTA allows determination of maximum post-depositional paleotemperatures and when cooling began (up to three discrete episodes).
What can we do with VR?

VR values provide independent estimates of maximum paleotemperature (only).
Thermal history reconstruction - 1

THR relies on application of AFTA (Apatite Fission Track Analysis®) and Vitrinite reflectance (VR) to:

- **Identify** the timing of dominant episodes of heating and cooling that have affected a sedimentary section:

- **Quantify** the variation of paleotemperatures through the section:
Thermal history reconstruction - 2

And to *characterise* mechanisms of heating and cooling

The variation of paleotemperatures from AFTA and VR with depth provides direct insight into the processes responsible for heating and cooling.
Simple contact heating

Holford et al. WABS 2013
Simple contact heating: UK Rockall 164/25-1

Reality is often a little less tidy!

But heating in this well is clearly restricted to the immediate vicinity of intrusions.
Contact heating combined with deeper burial

The Sea of Hebrides-1 well (134/5-1) intersected a heavily intruded Jurassic sequence.
Contact heating combined with deeper burial

VR data from this well clearly show that the sampled sequence has been hotter but show wide scatter and in isolation the interpretation is not obvious.
Contact heating combined with deeper burial

AFTA data define two separate cooling episodes, one that began around 60 Ma and a later episode than began between 45 and 20 Ma.
Combining the two techniques results in definition of localised paleo-thermal effects related to intrusions and pervasive heating due to deeper burial prior to mid-Cenozoic exhumation.
AFTA and VR data in wells from the Canning Basin demonstrate widespread thermal effects due to intrusion of dolerite bodies into an aquifer sequence at shallow burial depths (Reeckmann & Mebberson, Canning Basin Symposium, 1984).

(Figures from Holford et al, WABS 2013)
The East Irish Sea Basin forms part of the Permo-Triassic rift network of western Europe and hosts major oil and gas fields, dominantly in Triassic sandstone reservoirs.

The Early Cenozoic (~60 Ma) Fleetwood dyke intrudes this sequence and has been encountered in boreholes.

The absence of organic matter in the Permo-Triassic section precludes direct detection of contact effects, but AFTA data across the basin reveal profound regional paleo-thermal effects related to the intrusion.
Sonic velocities show that in wells in the centre of the basin around 1500 metres of cover have been removed, while in the south of the basin up to 2500 metres or more has been removed.

AFTA shows that in the south of the basin Carboniferous and younger units began to cool from maximum paleotemperatures in the Early Cretaceous, representing the onset of exhumation.

In the centre and north of the basin, similar units cooled from maximum paleotemperatures in the Early Cenozoic (~60 Ma). In the North this was due to a decline in heat flow and the onset of exhumation. But in southern and central parts of the basin other processes were at work at his time.
Early Cenozoic paleotemperatures from AFTA and VR in samples from wells in the north of the basin show high thermal gradients and suggest amounts of removed section similar to sonic velocity studies. We will return to this later.
In contrast, Early Cenozoic paleotemperatures from AFTA and VR data in samples from wells in the south of the basin show low thermal gradients. These cannot be explained in terms of deeper burial or elevated basal heat flow, and suggest transport of heat by fluids.
Despite multiple episodes of deeper burial and subsequent exhumation, over much of the basin maturation was achieved through heating due to hot fluids produced by the Fleetwood dyke.

Minor intrusions in sedimentary basins 1

The Jurassic cliffs of Traill Island, East Greenland, contain solid bitumen residues interpreted as the remnants of exhumed oil fields. (Price & Whitham 1997 AAPG Bulletin)
AFTA data from Mesozoic sandstones of Traill Island define three Cenozoic phases of cooling from elevated paleotemperatures.
Paleotemperatures at 35 Ma define a paleogeothermal gradient of >~45°C/km in samples close to the intrusions (Zone 3, below), ~40°C/km further away in Zone 2 and ~30°C/km in Zone 1. But data in all three zones are consistent with similar amounts of missing section.
Paleotemperatures at 10 Ma define a paleogeothermal gradient of ~34°C/km in samples close to the intrusions (Zone 3, below), ~32°C/km further away in Zone 2 and ~28°C/km in Zone 1. Again data in all three zones are consistent with similar amounts of missing section.
Paleotemperatures at 5 Ma define a paleogeothermal gradient of ~25°C/km in Zones 3, 2 and 1, again with similar amounts of missing section in each zone.
Implications for hydrocarbon prospectivity:

Emplacement of these intrusive bodies was accompanied by increased heat flow at distances far greater than the size of the intrusions.

Generation of the hydrocarbons once present in the exhumed Jurassic reservoirs in the cliffs of Traill Island is likely to have been enhanced by this increased heat flow combined with relatively modest burial depths.

Similar “haloes” of enhanced maturation may be present around similar intrusive bodies in other basins (e.g. Faroe-Shetland Basin).
In Northern England, AFTA and VR data define a period of regional cooling associated with a reduction in basal heat flow combined with exhumation.
The Paleocene event in Northern England is broadly synchronous with igneous activity in the Hebridean igneous province, to the north.

This could be coincidence. But …
The Paleocene event in Northern England is broadly synchronous with igneous activity in the Hebridean igneous province, to the north.

This could be coincidence. But …

we see the same thing in North Africa at ~200 Ma (CAMP) where we see evidence of elevated gradients at the same time as the CAMP igneous activity but in areas where igneous activity is absent.

Logan and Duddy 1998

An investigation of the thermal history of the Ahnet and Reggane Basins, Central Algeria, and the consequences for hydrocarbon generation and accumulation

Summary

The paleo-thermal effects of igneous intrusions in sedimentary basins may show a range of different styles, varying from local to basin scale.

In many basins, igneous activity has had a profound effect on hydrocarbon prospectivity.

Ultimately, these effects are difficult to predict and application of paleo-thermal indicators such as AFTA and VR is the only reliable way to define their true extent (and to resolve them from the effects of deeper burial and/or elevated heat flow).