Thermal regime of the Irish Atlantic basins

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Introduction

The basins of the Atlantic Margin in Northern Europe extend from Norway to southern Ireland. The inner basins of the Irish Atlantic Margin have complex histories with phases of inversion. The timing of these basin inversions has controlled to some extent the accumulation of gas resources. There are similarities in this respect to the Norwegian Vøring basin, where a large underplating body has been identified (Fjeldskaar et al, 2003) as having a great influence on the source rock maturation. In the Irish Atlantic Margin, there is ample evidence of magmatic activity on a number of scales.

The GAMIO project aims to understand the impact of geodynamic variations and large scale magmatism on maturation by assessing the geodynamic evolution of the inner basins on the Irish Atlantic Margin (Porcupine, Erris and Slyne) at the lithospheric scale by means of tectonic heat flow modelling.

Geodynamic evolution of the inner basins of the Irish Atlantic Margin

The model generally accepted for the opening of the North Atlantic involves multiphase rifting culminating in Early Eocene crustal separation of Greenland and Europe. The result of this opening is a North West European continental shelf 300-500 km wide with a complex structure composed of several basins developed from the late Paleozoic to the Cenozoic. The basins can be divided into two major groups (see Figure 1). The inner basins of Jurassic age include the Erris and Slyne Troughs and the Porcupine Basin in the Irish Margin and the Halten Terrace and Viking Graben in the Norwegian Margin. The Cretaceous to Tertiary outer basins include the Rockall and Hatton Troughs to the south and the Møre, Vøring and Lofoten Margins to the North.

The Porcupine Basin is the largest of the three inner basins of the Irish Atlantic Margin, with a length of c. 250 km and a width of up to 65 km. Its crustal thickness varies, and is thinnest in the south, reaching a value as low as c.6-8 km (Readman et al, 2005). There are up to 10 km of preserved sediments in other areas (Shannon & Naylor 1998). The Erris and Slyne Troughs are 'perched' basins with an average crustal thickness for their inner position of c. 20-25 km. The sedimentation in both has a thickness of c. 3-4 km.

Figure 1: Tectonic elements map of the northwest European Atlantic margin (Dore et al., 1999). B: Brønnøysund Basin, BJ: Bjørnøya Basin, ET: Erris Trough, F: Frøan Basin, FS: Faeroe-Shetland Basin, G: Gjallar Ridge, H: Halten Terrace, HB: Hammerfest Basin, HG: Hel Graben, HT: Hatton Trough, JM: Jan Mayen, MB: Møre Basin, N: Nordkapp Basin, NOR: Nordland Ridge, P: Porcupine Basin, R: Rockall Trough, RB: Røst Basin, SB: Sørvestnaget Basin, ST: Slyne Trough, T: Tromsø Basin, UB: Unst Basin, VB: Vøring Basin, VG: Viking Graben, VV: Vestbakken Volcanic Province.

Modelling methodology

The modelling relies on two essential factors:
- the description of the sedimentary layers (present and eroded)
- the definition of the major geological events during the lifetime of the basin

For each 1D location the following information is required and has been collected in the wells considered in this work:
- the sedimentary layers still in place and the eroded layers
- timing of deposition and erosion described in the well reports
- lithological description of the remaining or eroded layers.
- description of the major layers in the lithosphere (Upper Crust, Lower Crust, Lithospheric Mantle)
- description of the major geodynamic phases that have impacted the basin

Using these parameters, a heat model is generated that allows the maturation modelling to be undertaken

Figure 2: General workflow adopted in the modelling approach (modified after van Wees et al., 2009). VR values: Vitrinite Reflectance values

To assess the correctness of our modelling assumptions, Vitrinite Reflectance (VR) data are required for calibration. A gathering of VR data has therefore been performed from the wells in the Irish offshore. In total, 18 wells (15 in the Porcupine Basin) from the 36 wells that have VR data have been modelled based on the quality and number of VR data and available sedimentary information.

Results of the modelling

Geodynamic steps of the inner basins of the Atlantic margin

Five main geodynamic steps have been identified from the tectonic subsidence curve and the literature (e.g., Naeth, 2004):
- An initial rifting phase with fast sedimentation at the early stage of the basin's development accompanied with a magmatic intrusion in the crust during the late Carboniferous (Late Wesphalian/Stephanian)
- Uplift phase with intense erosion during Permian
- 1st extension phase at Middle/Late Jurassic
- 2nd extension phase at Early Cretaceous
- Uplift due at the Paleocene due to the Iceland Plume (?)

These steps have been used as inputs for the modelling. Figure 3 show the resulting tectonic subsidence (modelled Tect. Sub. in grey) compared with the described tectonic subsidence (Modelled Tect. Sub. in Black) to assess the accuracy of the modelling.

Figure 3: Modelled and observed tectonic subsidence, and main geodynaimical stages considered

Thermal results

The thermal results from the modelling is a basement heat flow curve through time and the thermal calibration is made by comparing the modelled Vitrinite Reflectance (VR) with measurements. Figure 4 shows a selection of five representative wells with a typical Permian intrusion in the crust (26/28-1), no intrusion (26/29-1), a wide range of possibilities with the intrusion (35/6-1), the local impact on the maturation of dykes or sills (35/8-1), and a only shallow VR information (43/13-1). The overall results obtained from the modelling show a heat flow of around 70 mW.m-2 at the early stage of development of the basin with this progressively decreasing to reach a value of around 60 mW.m-2 for the present days. In addition, an intense thermal activity occurs at the end of the Carboniferous and generates, when it happens, a heat flow around 110 mW.m-2.
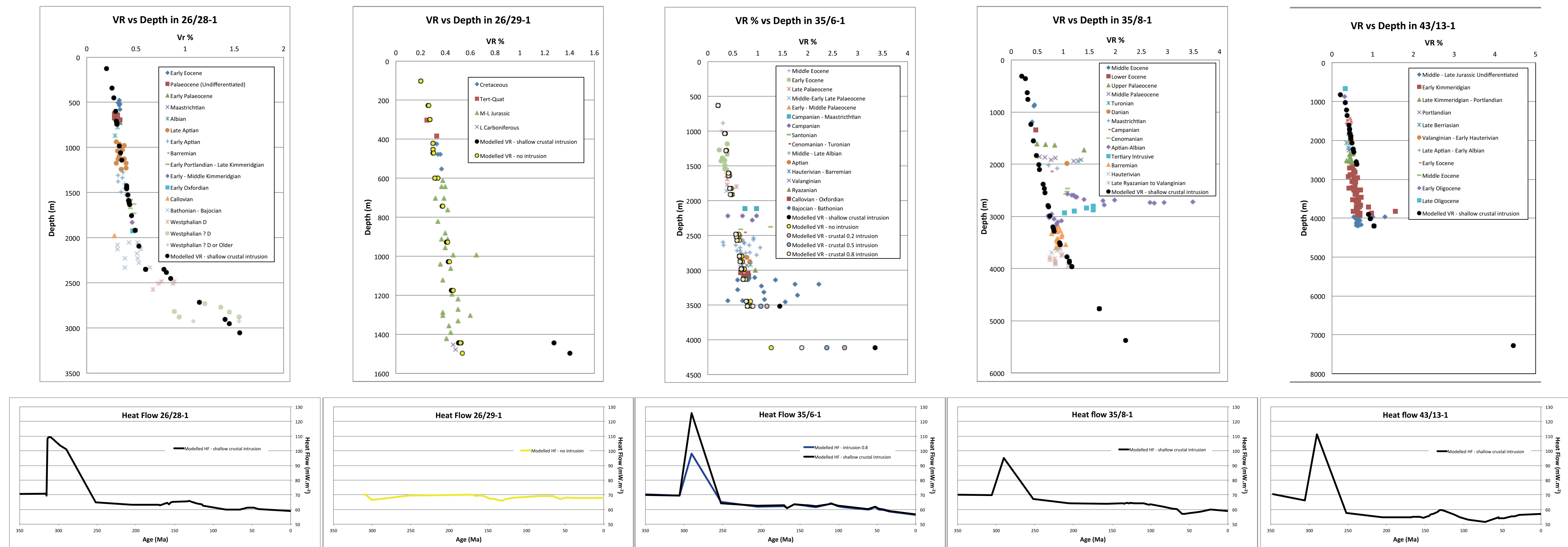

Figure 4: Modelled basement heat flow (bottom) and comparison between modelled and measured VR for five wells:from left to right 26/28-1, 26/29-1, 35/6-1, 35/8-1, and 43/13-1

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