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Quartz cement abundance as a thermal history indicator: – A case study from the Gjallar Ridge, Vøring Basin.

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The temperature history of Cretaceous and Tertiary sediments in the Vøring Basin is poorly known. The further outboard one looks in the Mid-Norway region, the more complex the basin history with several tectonic events including rapid burial, uplift and erosion. In addition, igneous sills and underplating bodies occur in some areas but not others (Brekke et al., 1999; Swiecicki et al. 1999). There are few exploration wells in the deeper water area of the Vøring Basin and most of those that do exist lack published data from paleotemperature indicators (e.g. vitrinite reflectance, fission tracks, fluid inclusions etc.). This excludes the use of more traditional methods to constrain thermal history modeling in the region.

Quartz cement abundance is a useful constraint on basin thermal history (Awwiller and Summa, 1997; Lander, Walderhaug and Bonnell, 1997). This is due to the observation that temperature history and the surface area available for quartz precipitation control the volumes of quartz cement in most sandstones from hydrocarbon bearing basins (Walderhaug, 1994; Walderhaug, 1996). Quartz cement volumes cannot, however, differentiate between thermal effects due to igneous activity and those due to deeper burial. We use compaction state of the cleaner Cretaceous sands in addition to regional trends in sediment thicknesses to help constrain the burial history of the Gjallar Ridge, western Vøring Basin. In the 16th and 17th Norwegian licensing rounds, reservoir quality was considered a key element in determining the prospectivity of available acreage (i.e. the Vøring Basin and Margin and the neighboring Halten Terrace margin). We initially collected the petrographic database for reservoir quality prediction studies in various targets in the Mid-Norway region. During those studies, we have gained an understanding of sandstone compaction and quartz cementation trends over large areas of the Vøring basin. The database contains numerous Halten Terrace exploration wells as well as most of the released deeper water wells from the area. We now apply that understanding to constrain the thermal and burial history of the Gjallar Ridge well (6704/12-1).

Methods

We constrain the uncertainties in the basin margin thermal history using careful petrographic description of Cretaceous sandstones from five key wells on the Vøring Margin (quads 6704, 6706, 6707 and 6607). We compare models of compaction and quartz cementation for sandstones from similar depositional environments in reference wells from Halten and Donna Terraces to a model from Well 6704/12-1 on the Gjallar Ridge in the western Vøring Basin. Calibrated model parameters determined from wells on the Halten and Donna Terraces are applied to a well that may have experienced significant erosion and various types of thermal effects. Compaction and quartz cement abundance is simulated in a forward model called Exemplar®, Geologica's proprietary tool for reservoir property prediction. Using 1D basin models (Fobos®) calibrated on wells from the terraces, we calculated a thermal history model for Well 6704/12-1. However, using this thermal history we would predict much lower quartz cement volumes than we observe in 6704/12-1. This indicates that a significant thermal effect must have occurred in addition to those related to the traditional rifting and underplating basin-modeling approach. In all cases, the basin modeling results for present-day temperatures are compared to measured temperature data in the well. Sensitivity analysis of the models were made to constrain possible burial and erosion scenarios and possible scenarios for thermal events in an iterative fashion to find a likely thermal history for the Gjallar Ridge well. All indicate that a major thermal event lasting several million years must have occurred in the mid Miocene or later.

Results

Figure 1 presents the calculated heat-flow and temperature history from four different models for the Gjallar Ridge Well 6704/12-1. In all models we have included the heat effect of a 5 km thick igneous underplating body located at 15 km depth. We assume that accretion occurred from 56-54 Ma in conjunction with the break-up of the Northeast Atlantic and the initiation of the Icelandic plume (Roberts et al., 1999). In addition, we investigated the thermal effect of a Mid Miocene erosion event by assuming 1 km or 2 km of erosion. If either of these suggested erosion events occurred, the now-eroded sediments would have increased the state of compaction and resulted in an increased thermal conductivity structure of the underlying rocks. This needs to be compensated for by an increase in the basal heat flow in order to match the measured present day temperatures within the well. The heat flow compensation is achieved in the modeling by either an Early Oligocene or Mid Miocene heat pulse, either of which could have occurred in conjunction with the recorded tectonic activity (H. Brekke, NPD, personal communication, 2002). Extensive deposition and later erosion in a deep marine setting dominated by carbonate oozes may seem unlikely (Eidvin et al, 2000). However, the compaction state of samples from the Springar Formation (measured IGV values from 15 to 25 volume %) suggest that these sandstones have been buried approximately 600 meters deeper than they occur today. Measured quartz cement abundances in the Springar Formation sandstones range from 3 to 7% (Figure 2). Yet, the thermal effects of the underplating body and 1 km of erosion in the Mid Miocene cannot explain the observed quartz cement abundance. Therefore an additional thermal event is required. We model a major Late Oligocene heat flow event, which contributes a maximum temperature difference of 40°C lasting over several million years (Figure 1b). The basement heat flow is in this case equal for both the cases of 1000 and 2000 m erosion, however, not the effective temperature at Top Nise (Figure 1b).

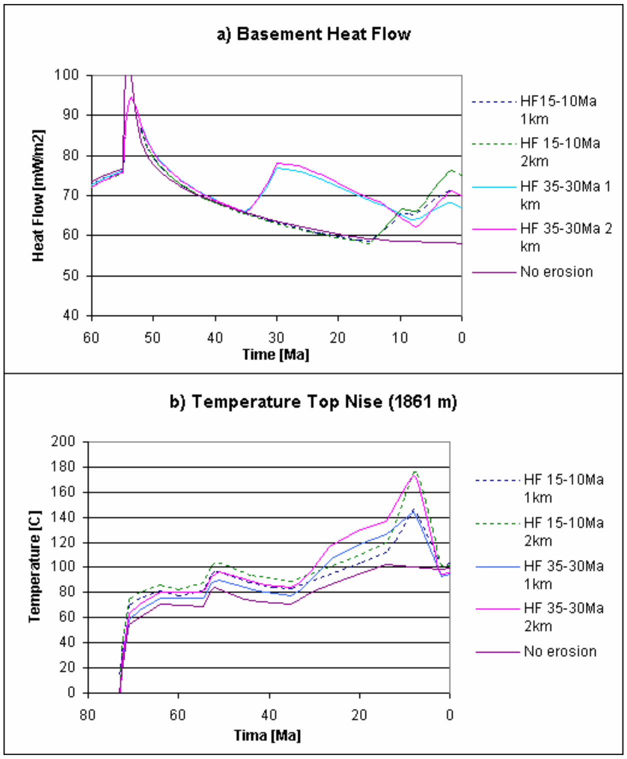

Figure 1. Modeled heat flow and temperature in Well 6704/12-1. Plot a) shows the modeled heat flow history with an Early Oligocene and a Mid-Late Miocene heating episode for the top basement for different magnitudes of erosion for the Mid Miocene-Pleistocene unconformity. Plot b) shows the calculated temperature histories for the heat flow scenarios above.

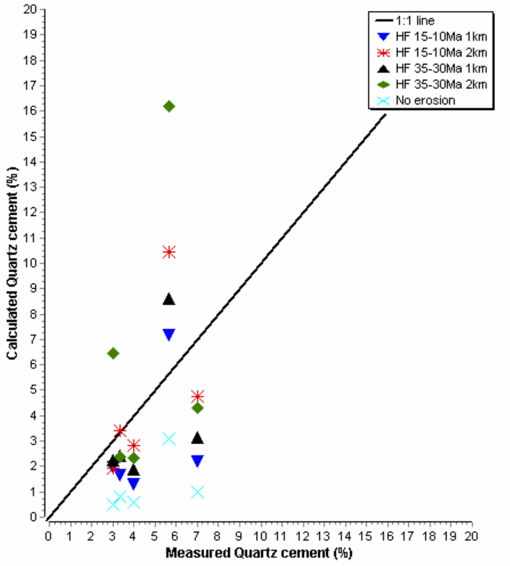

Figure 2. Predicted vs. measured quartz cement volumes for the Springar Formation in the 6704/12-1 well. The cross symbols are quartz calculated by a thermal model excluding both extensive Mid Miocene erosion and heating event. The down triangle, star, triangle and diamond symbols were calculating quartz cement assuming 1 km and 2 km of erosion in the mid Miocene, and an Early Oligocene and a Mid-Late Miocene heating episode respectively. All models include the heating of an underplating from 56 to 54 Ma

Conclusions

Well 6704/12-1 (Gjallar Ridge) probably experienced significant erosion in the mid Miocene based on the compaction state of the cleanest Springar Formation sandstones and arguments from chrono- and lithostratigraphy preserved in the well. Modeling quartz cement in the Gjallar ridge sandstones indicates that a temperature increase related to both deeper burial and magmatic underplating in conjunction with the opening of the Atlantic is not sufficient to explain the observed quartz cement abundances. The Upper Cretaceous and Tertiary sandstones were buried at a depth of a thousand meters at the proposed time of underplating. Thus, the temperature increase due a deep magmatic body did not significantly impact predicted quartz cement volumes. Two kilometers of deposition and later erosion in the Miocene can explain the observed quartz cement abundances, however, this magnitude of erosion seems too large. Alternatively, increased Miocene heat flow and only 1 km of Miocene deposition and erosion can explain the observed quartz cement abundances. The anomalously high quartz cement content is most likely related to a temperature increase caused by a combination of deeper burial and late Tertiary thermal effects.

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