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Research paper

Basin modelling of the SW Barents Sea

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ABSTRACT

The SW Barents Sea is an epicontinental platform consisting of N- to NNE-oriented basins separated by basement highs. The basins were formed during four distinct rift-phases in the Carboniferous, Late Permian, Late Jurassic-Early Cretaceous, and Paleocene-Eocene. Progressive rifting culminated in continental breakup and seafloor spreading along the North Atlantic axis approximately at 55 Ma. We present tectonic and thermal models of basin evolution along two seismic profiles crossing the SW Barents Sea. The thermal and isostatic history of basins is constrained through time-forward basin modelling based on an automated inverse basin reconstruction approach. We estimate the effects of continental breakup and near-margin processes (magmatic underplating and sill intrusions) on the thermal history and kerogen maturity below the Vestbakken Volcanic Province. Basin models are calibrated against well data. The results imply that both breakup and underplating alter the thermal and isostatic history of sediments along the margin. The hydrocarbon potential of source rocks modelled along the margin suggests breakup has a permanent thermal effect on the present-day sediments promoted by lateral heat flow, while heat conduction by underplating is more diffuse, inhibited to some degree by deeply-buried, low-conductivity shales and limestones.

1. Introduction

The Barents Sea is a shallow sedimentary platform on the northwestern part of the Eurasian continental shelf (Fig. 1). It is bounded to the south by the Norwegian and Russian landmasses, to the north by the Arctic Ocean, to the east by Novaya Zemlya, and to the west by the North Atlantic Ocean. The SW Barents Sea is characterized by a series of NNE-SSW oriented rift basins filled with clastic/carbonate sediments separated by basement highs, formed by multiple rifting events since the collapse of the Caledonian Orogeny in Devonian time. Rifting culminated into seafloor spreading and continental breakup along a sheared margin in Eocene time (Rønnevik, 1981; Faleide et al., 1984, 1993; 1996, 2008; 2015; Dengo and Røssland, 1992; Gudlaugsson et al., 1998). Breakup was followed by passive margin development which continues to present day.

It is well known that the occurrence of oil and gas in a sedimentary basin depends on the maturation of source rocks which is in turn controlled by the thermal history of the sediments. The latter therefore needs to be constrained in order to reduce uncertainty. The thermal history of sediments depends on burial, sedimentation rate, and the thermal properties of the sediments, crust and mantle lithosphere (Theissen and Rüpke, 2009; Marcussen et al., 2010). It also depends on the amount of heat provided by the sub-lithospheric mantle during the basin formation. Basin formation is usually explained by lithosphere extension (McKenzie, 1978). During the rifting phase, extension of the lithosphere causes local thinning of the crust and mantle lithosphere providing large heat supply to sediments deposited in a fault controlled subsiding basin. The magnitude of extension is characterized by stretching factors (β factors) for the crust and mantle lithosphere. The rifting phase is followed by a tectonic quiescent post-rift phase characterized by thermal cooling of the entire lithosphere and sag subsidence.

The thermal history of sediments in a specific basin can be inferred from modelling the thermal and tectonic evolution of the basin. The thermal and mechanical properties of sediments are usually known data. However, the extension parameters (stretching factors) have to be constrained. There exist two different approaches for constraining the stretching factors. Backstripping determines the basin evolution in a time-reversed manner, progressively removing each stratigraphic sequence, decompacting sediments, removing slip along faults, and restoring horizons to their interpreted water depths. The stretching factors are then calculated through analysis of the subsidence history (Fjeldskaar et al., 2004). However this method has disadvantages, notably the thinning of sediment layers during rift phases is neglected leading to biased stretching factors for older rift episodes (Wangen and Faleide, 2008). In contrast, time-forward modelling uses coupled

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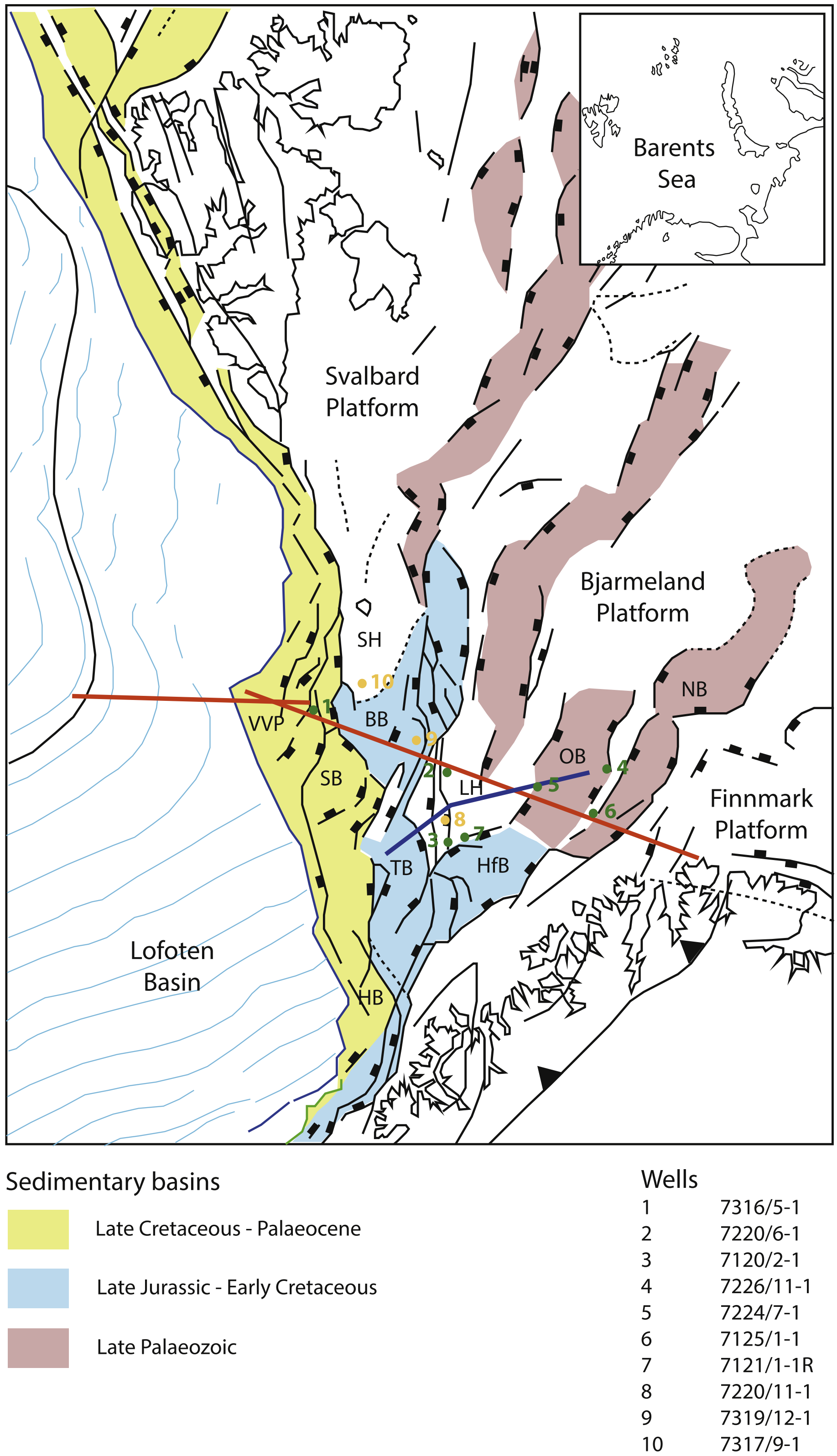

Fig. 1. Tectonic map of the south-western Barents Sea. The PETROBAR-07 profile (red line; Clark et al., 2014) ties-in with the HB-3-96A seismic reflection line near the COB, extending the profile westward to the Knipovich Ridge. The regional seismic line of Glørstad-Clark (2011) is shown as a blue line. Major faults are shown as black lines (Faleide et al., 2008). Calibration well locations are labelled in green and other wells in orange. BB: Bjørnøya Basin, HB: Harstad Basin, HfB: Hammerfest Basin, LH: Loppa High, NB: Nordkapp Basin, OB: Ottar Basin, SB: Sørvestnaget Basin, SH: Stappen High, TB: Tromsø Basin, VVP: Vestbakken Volcanic Province. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

thermal, kinematic, and isostatic calculations of lithospheric deformation to produce sedimentary basins progressively through time. β factors and water depths are then tuned to fit the predicted stratigraphy to the observed basin (Rüpke et al., 2008).

Basin modelling is “rare” in the SW Barents Sea publication record. Glørstad-Clark (2011) performed basin modelling along an E-W seismic transect crossing the Loppa High using a backstripping approach. However, their work was not published in the peer-reviewed literature. Clark et al. (2014) performed basin modelling along a regional NW-SE seismic transect crossing sedimentary basin structures and platforms in the SW Barents Sea using the two different approaches, backstripping and inverse. Their models satisfactorily reproduced the present-day geometry of the basins along the profile assuming 4 rifting episodes. However, near-margin processes were not taken into account (breakup,