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Basin Modeling in Marginal Basins of the Norwegian Southern North Sea: Post-Mortem Studies of Selected Wells and Areas*

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Abstract

The Danish-Norwegian Basin, Egersund Basin, Ling Graben, and Sele High is one of the oldest exploration provinces of the Norwegian Continental Shelf with wells drilled as early as 1966. It is an area with many dry wells where a good understanding of source rock facies, maturity, and migration is critical for exploration success. The Norwegian Southern North Sea has two prolific petroleum systems: in the South-West (the Central Graben) and the North-West (the South Viking Graben), with fields like Ekofisk and Sleipner, respectively. The latest significant discovery is on the Southern Utsira High, where the Johan Sverdrup Field is part of the South Viking Graben petroleum system. Outside these two graben systems, in the Danish-Norwegian Basin, Egersund Basin, Ling Graben, and Sele High, the Upper Jurassic source rocks are marginally mature to immature. There are, however, still some potential for discoveries here, but the success rate in exploration drilling is low. Over the last ten years, approximately fifteen exploration wells have been drilled in the areas with marginally mature Upper Jurassic source rocks. Ten of these wells were selected for a “post mortem” examination: 8/5-1 (dry), 8/10-3 (dry), 8/10-4 S (oil), 9/1-1 S (dry), 10/4-1 (dry), 11/5-1 (dry), 16/8-3 S (dry), 16/10-5 (dry), 17/6-1 (oil shows), 26/10-1 (gas). Only one well (8/10-4 S) made a commercial discovery, the Oda Field. The post mortem evaluations use a regional basin modelling study from 2007 to make charge and accumulation history predictions for the wells. The study is based on a regional stratigraphic framework from seismic interpretation and sequence stratigraphy and includes geochemical source rock facies mapping and pseudo-3D basin modelling. Expelled volumes of four components of hydrocarbon are calculated at time steps from the source rocks. Charge predictions are made by integration of these volumes through time within drainage areas and geohistories. The results of the post mortem evaluation show a good match between predictions that could have been carried out prior to drilling and the actual results. It seems that a higher success rate in exploration drilling could have been achieved with more emphasis on basin modelling results. This study demonstrates the value of high quality basin modelling work in marginal areas such as parts of the Norwegian Southern North Sea.

Introduction

This study investigates how predictive a basin modelling study of good quality can be in an area with marginally mature source rocks. The Danish-Norwegian Basin, Egersund Basin, Ling Graben, and Sele High was selected as study area (Figure 1). This is one of the oldest exploration provinces of the Norwegian Continental Shelf, where exploration is still active. The province, which is bordered by two prolific petroleum systems in the South-West (the Central Graben) and the North-West (the South Viking Graben), has many dry wells, often due to lack of effective source.

The investigation was done by comparing predictions made from a basin modelling study carried out in 2007 with subsequent well results. In the 10-year period between 2007 and 2017 approximately fifteen exploration wells were drilled in the area. Ten of these wells were selected for post mortem examination: 8/5-1 (dry), 8/10-3 (dry), 8/10-4 S (oil), 9/1-1 S (dry), 10/4-1 (dry), 11/5-1 (dry), 16/8-3 S (dry), 16/10-5 (dry), 17/6-1 (oil shows), 26/10-1 (gas). One well (8/10-4 S) made a commercial discovery, the Oda field.

The 2007 study used a map-based pseudo 3D basin modelling system, integrating 1D basin modelling results and geochemistry data with sequence stratigraphy well tops and seismic horizons. The software and methods were similar to those used by Dahl and Meisingset 1996 and Justwan et al. 2006.

Technical Summary:

- Temperature and maturation histories were modelled by 1D basin simulation, with optimisation against vitrinite reflectance, sterane and hopane isomerization plus temperature.
- The 3D model consisted of 25 horizons from Seafloor to Basement, of which 11 were interpreted from seismic and 14 constructed from isochores. Structural reconstruction versus geological time was made for all the layers.
- Depth conversion was done with a high quality regional velocity model.
- The proven Upper Jurassic source rock (Mandal, Farsund, Haugesund, and time equivalents) were subdivided into 4 isochronous events. For each event the organic matter, after reconstruction to its original potential, was mapped and further subdivided into type II, type III, and IV (dead organic matter).
- Four component kinetic models were assigned to each organofacies type, modified from Burnham and Dahl, 1993 and Justwan et al. 2006.
- Erosions, magnitude, and timing, were assessed using shale compaction, assisted by the velocity model outside of wells and tested with 1D basin modelling in appropriate wells.
- Generation and expulsion was calculated at a set of time steps, resulting in grids of expelled (primary migrated) amounts of oil and gas components.

Discussion

Post mortem evaluations of the ten wells drilled after the study were done in a standard prospect evaluation workflow, using public domain information from the NPD and structure maps from the 2007 study. These structure maps were based on a regional 2D seismic interpretation and lack some details with respect to the desired detailed topography of the fields and prospects. However, the larger structural forms are correct.

The post mortem evaluation of well 8/10-4 S in the Oda field is shown in Figure 2 with a depth structure map and oil migration flowlines. The colour scale for the flowlines has a unit of kg/m^2. Secondary migration loss has been assumed but does not affect the result. The generated volume in Oda's catchment area is excessive and the flow lines focusing oil from the southern part of the drainage area straddles the Oda discovery polygon and suggest an oil accumulation. Well 8/10-4 S targeted Upper Jurassic sands of the Ula Formation and found oil. This outcome is predicted by the 2007 study.

A similar plot from the area of well 9/1-1 S is shown in Figure 3. This well was drilled on the Gardorfa prospect on the Northern edge of the Egersund Basin, testing Middle Jurassic Bryne sandstones, and was a dry. The migration direction and its intensity shows that is not reaching the prospect. However, a focusing element to the east is dircting oil into a small 4-way closure in whitch a minor accumultion or shows could be expected. The post mortem evaluation predicts a dry well when a moderate secondary migration loss is taken into consideration. Without migration loss the prediction would have been a (small) oil discovery.

The 2007 basin modelling study also evaluated two hypothetical source rocks. The Permian Kupfersciefer is present in many wells in the study area, but it is very thin (2 m in average) and is not known to be an effective source. In the Farsund Subbasin a hypothetical Toarcian source was modelled. This is a strike-slip basin along the northern tip of the Fjerritslev fault, with an unknown basin fill. Toarcian rocks with source potential have been encountered in the region (e.g. in Well 9/2-1, Egersund Basin), and the study considered that a more substantial Toarcian source might be present in the area.

Two of the ten wells, 8-10/3 and 16/8-3 S, tested hypothetical Permian or Carboniferous source rocks, and both were dry. These were predicted dry by the 2007 study, based on two observations. 1) Many wells have been drilled targeting the Permian in this area since the 1960's, and all have been dry. There is no evidence of an effective source rock at that level. 2) Also, the modelling of the hypothetical Kupferschiefer shows that it is too thin to expel enough oil and gas to support significant secondary migration.

One well, 11/5-1, tested the Farsund Subbasin and was dry. This basin is close to the Norwegian mainland and might have been subjected to uplift and erosion. With sufficiently large Neogene erosion the source rocks might have been mature at maximum depth of burial such that oil and gas have been generated. If not by the Upper Jurassic source system, then hopefully by the deeper Toarcian potential source rock. The 2007 study considered this, using shale compaction, and found that there were no data to support such an erosion hypothesis. The basin was predicted to be immature at both levels, and the well was predicted to be dry.

Well 26/10-1 tested a Miocene sand in a location where the study suggested a "migration shadow" from mature source rocks. This shadow occurs when both lateral and vertical migration is considered. The well discovered biogenic gas, something the 2007 study did not consider and could not predict.

The remaining wells were conventional Jurassic sand / Upper Jurassic source tests. Dry well 8/5-1 tested a local source kitchen which appeared to be deep enough to generate oil. The 2007 study predicted no expulsion in this basin, as a result of insufficient source rock quality. The expulsion threshold was not overcome in the model. Well 10/4-1, drilled on the Southern edge of the Egersund Subbasin, was similar to well 9/1-1 S. Not enough oil expelled within the drainage area to overcome a moderate secondary migration loss, and the model successfully predicted it as dry. Well 17/6-1 in the Åsta Graben drains from a local basin with marginally mature source and had oil shows. The model predicts a dry well, for the same reason as in wells 9/1-1 S and 10/4-1, lack of generated petroleum and secondary migration loss.

Conclusions

The post mortem evaluation shows a very good match between predictions from the 2007 basin modelling study and well results. If the study had been applied as-is with no questions asked only the Oda Field discovery well 8/10-4 S would have been drilled, and there would have been no dry wells. The Miocene biogenic gas discovery would, however, have been missed.

Several of the dry wells show some expulsion of oil within their drainage areas, and only a small change in the basin model could have led to an oil discovery prediction. An important observation with regards to this is the importance of secondary migration loss modelling. This appears to be necessary in a marginally mature basin.

The conclusion from this study is that a basin modelling study of good quality can be predictive in an area with marginally mature source rocks. Carefully executed basin modelling is obviously a tool which can lead to fewer dry wells and improve exploration success rate.

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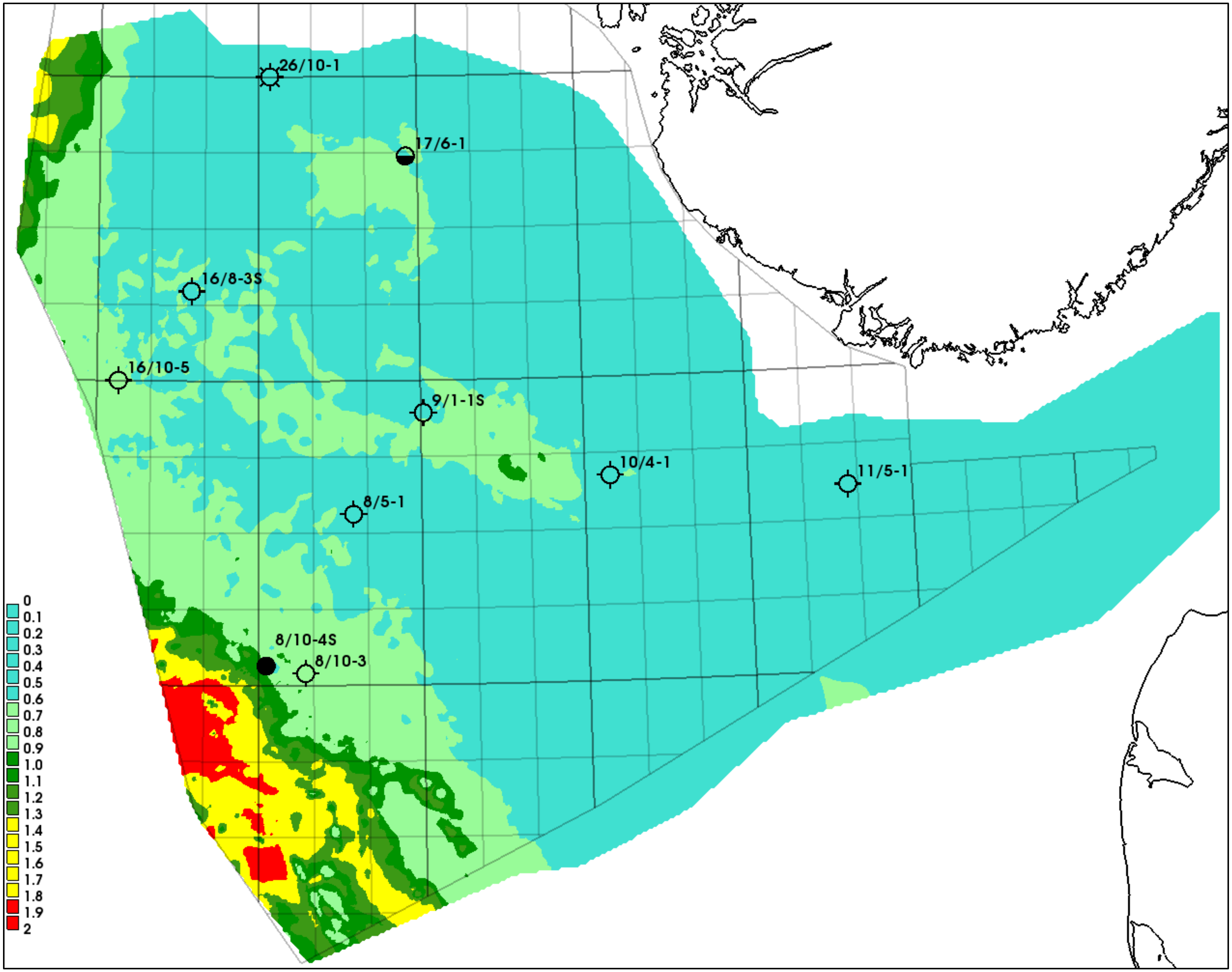

Figure 1. Vitrinite reflectance maturity on Top Mandal and study well locations.

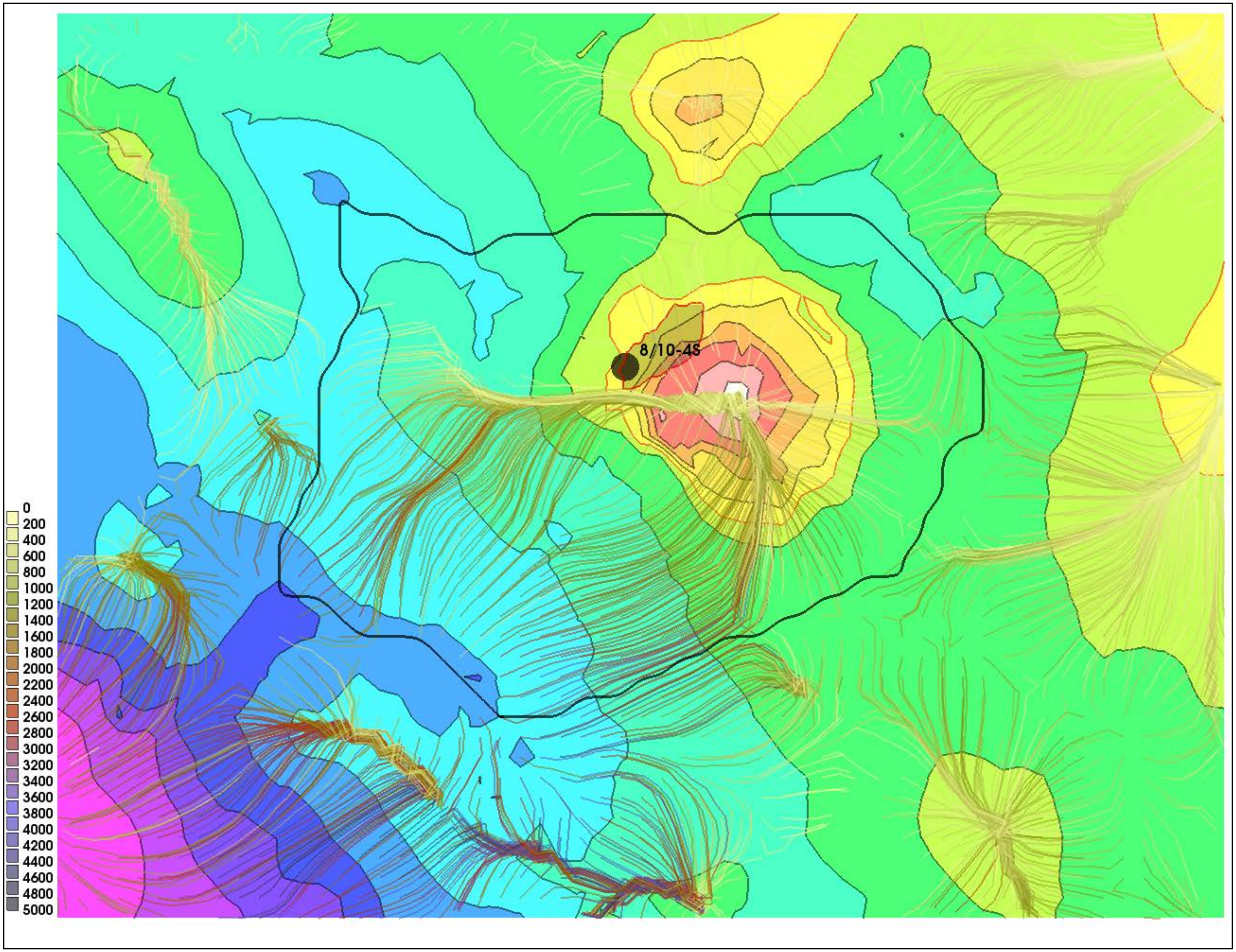

Figure 2. Well 8/10-4 S with the Oda discovery and its drainage area and migration flow lines.

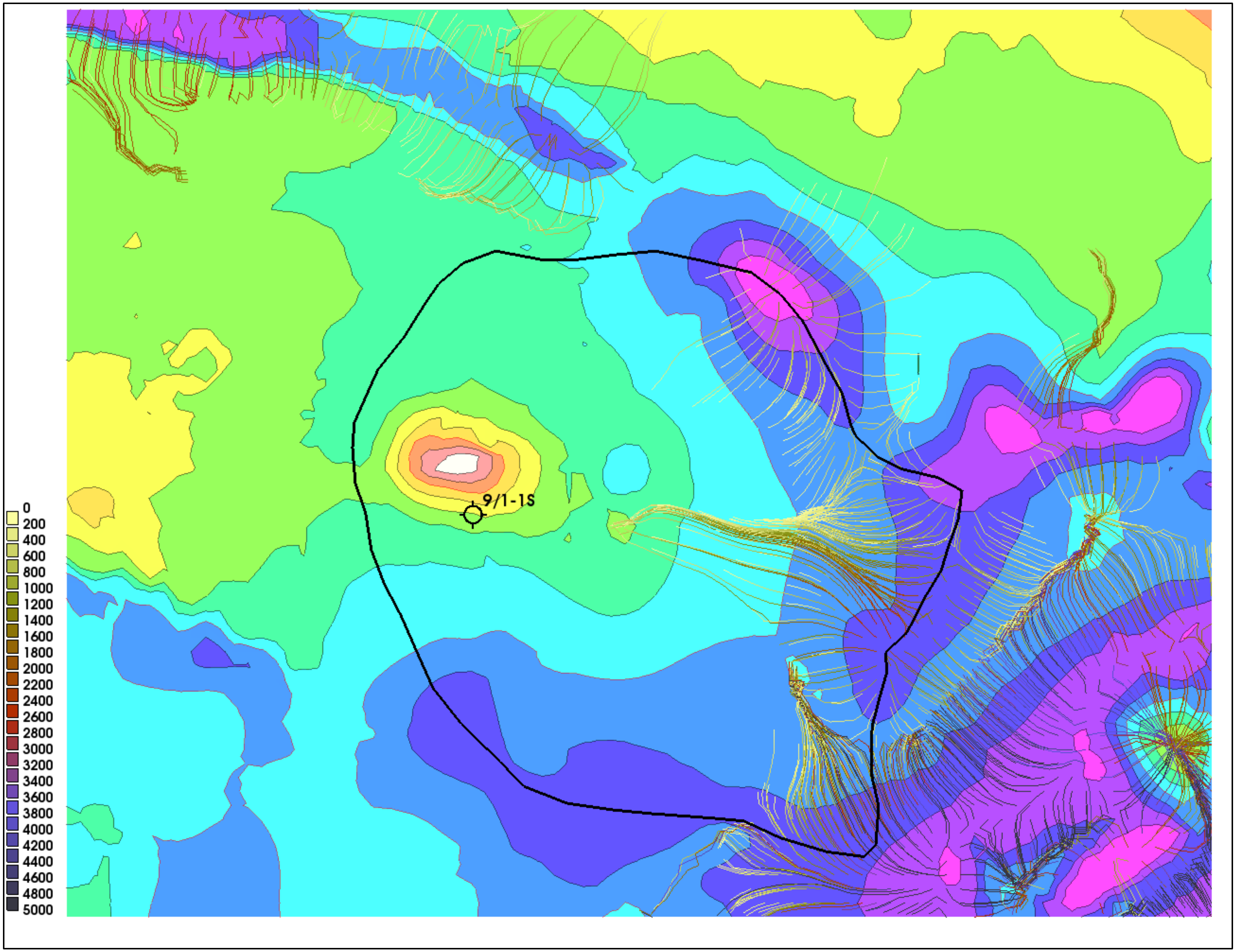

Figure 3. Well 9/1-1 S on the Gardrofa prospect with migration flow lines and catchment area.