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The Promises and Pitfalls of Integrating Geodynamic with Petroleum System Modeling

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ABSTRACT

Petroleum system modeling is a key component of the exploration workflow. A wide range of plausible maturation histories, migration scenarios, and structural evolutions are routinely investigated before exploration decisions are made. Petroleum system models (PSM) are designed to simulate multi-phase porous flow as well as the details of petroleum generation and expulsion. They are, however, not well suited for investigating the structural and thermal evolution of rift systems. In fact, PSM usually only resolve the sedimentary basin itself – all larger scale geodynamic processes need to be parameterized in terms of a basement heat flow boundary condition.

Recent advances in 2-D and 3-D lithospheric rift modeling have significantly increased our understanding of how strain is partitioned and temperature evolves during rift formation [*Brune et al.*, 2014; *Huismans and Beaumont*, 2011; *Ranero and Perez-Gussinye*, 2010]. It seems a natural way forward to integrate these new insights into the petroleum system analysis workflow by instructing PSM with information on basement heat flow extracted from lithosphere-scale models. For such a multi-model approach to work, progress has to be made in the understanding of feedbacks between shallow sedimentary and deep lithospheric processes. The reason for this is that sediment deposition has strong effects on the lithospheric temperature field and thereby on basement heat flow. Sediments usually have a lower thermal conductivity than crustal rocks, which changes the steady-state geotherm thereby causing a reduction in basement heat flow and a slow down of postrift cooling [*Theissen and Rüpke*, 2010; *Zhang*, 1993]. Furthermore, the deposition of cold sediments depresses the geothermal gradient, which results in a sedimentation rate dependent reduction of both the surface and the basement heat flow [*De Bremaecker*, 1983; *Rüpke et al.*, 2013; *Ter Voorde and Bertotti*, 1994; *Wangen*, 1995]. Finally, radiogenic heating within the sediments changes the lithospheric geotherm and depresses the basement heat flow. These processes are often collectively referred to as sediment blanketing effects. Their cumulative effect is quite difficult to assess, which hints at complex interactions between shallow sedimentary and deep lithospheric processes. Here we present results of a Norwegian margin case study that illustrates how strongly the time-varying rate of sedimentation deposition affects strain partitioning, temperature, and mantle serpentinization during margin formation.

We then take these ideas further and investigate how predictions of geodynamic models can be integrated into petroleum system models. For this purpose, we have performed case studies for the Norwegian and North Sea. We find significant differences in the timing of hydrocarbon maturation and in the GORs of hydrocarbon accumulations predicted by models that do and do not resolve the interrelations between sedimentation, crustal thinning, and basement heat flow. To investigate the underlying mechanisms, we have analyzed the predictions of thermotectonostratigraphic forward models [*Rüpke et al.*, 2008; *Rüpke et al.*, 2013] on the evolution of basement heat flow in terms of the relative contributions from tectonic and sedimentary processes. We find that sediment blanketing effects and the diminishing importance of crustal radiogenic heating during extension often dominate over the tectonic heat flow component. This implies that in terms of basement heat flow, resolving a basin's sedimentation history is at least as important as the details of the employed rifting model. A consequence is that predictions from geodynamic models that do not resolve the sedimentation history cannot be easily transferred into basin-scale petroleum

system models. We here show how such integration can be successful, which benefits are to be expected, and what kind of pitfalls should be avoided.

In conclusion, we find that strong feedbacks exist between shallow sedimentary and deep lithosphere processes. These should be considered in geodynamic and in petroleum system models. Multi-model approaches that combine both types of models are promising and have the potential for significant improvements in the quality of the thermal and structural solutions used in PSM but care must be taken that model consistency is ensured and sediment blanketing effects are accounted for.