4D Taranaki in New Zealand: Understanding a Petroleum System from Regional to Prospect Scale*

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Introduction

A working petroleum system and the entrapment of commercially significant amounts of oil and gas depend on a large number of factors. A complete assessment is often beyond the scope of many E&P workflows; however, and dependent on the geology of the prospect, some factors (for example, crustal composition and structural evolution, climatic and sea-level changes, fluid flow along faults) that could significantly impact prospectivity are commonly overlooked. We demonstrate a workflow ranging from regional basin screening and derivation of general properties of the petroleum basin to high-resolution facies analysis, structural analysis and migration modeling, using data from Taranaki Basin in western New Zealand. The 4D Taranaki project is a multi-year programme to map and model the large (330,000 km^2) and productive petroleum basin at high resolution (100x100 m cell size and 18 mapped horizons). This case study is used to identify basin-specific controls on petroleum systems and to illustrate how such controls might be included within exploration workflows.

Regional Screening: Structural and Stratigraphic Evolution and Thermal Properties

The temperature evolution of a sedimentary basin and the identification and mapping of petroleum source and overburden rocks are amongst the first steps in screening sedimentary basins for their hydrocarbon potential. Lithosphere stretching combined with the upward movement of crust and mantle beneath a sedimentary basin, and heat transfer related to tectonic subsidence or uplift of sedimentary rocks are widely recognised mechanisms that modify heat-flow patterns within sedimentary basins. The Taranaki Basin is an example where variability in thermal boundary conditions significantly affects the thermal regime and petroleum-generation potential. Importantly, we find that the composition (Figure 1A) and structural evolution of the crust (Figure 1B) exerts a strong control on basin heat flow. Surface heat flow in the basin varies between 48 and 85 mW/m^2, largely as a function of these two parameters. To predict change in heat flow through time, a crustal-scale 3D PetroMod™ model has been constructed that takes into account the structural change from rifting in the Cretaceous to subduction-related contraction from late Eocene time onwards. Related lithosphere thinning and thickening are variable throughout the basin and, in conjunction with late Miocene-Recent exhumation events, controls the variable pattern of generation and expulsion of petroleum.

An additional and often overlooked influence is climate change. It has recently been noted that climate warming has increased petroleum generation and expulsion in the early Eocene in several southwest Pacific basins by up to 50% (Kroeger and Funnell, 2012). With regard to the Taranaki Basin, we predict that the Eocene climate warming caused a significant volume of petroleum to be generated earlier compared to models using constant surface temperatures (Figure 1C). However, the preservation potential of oil generated and trapped before Oligocene-Miocene basin inversion is low. Therefore, combined with the dominance of terrigenous (coaly) organic material in the Cretaceous and Paleocene source rocks, this in part explains the predominance of gas in the Taranaki Basin.

High-Resolution Generation and Migration Model

For generation and migration modeling the basin has been subdivided into seven areas that are modeled separately. These areas were selected to investigate migration fairways related to individual and grouped kitchen areas across the basin. Modeled areas are further subdivided along major fault zones. We present examples from the Kupe region around the petroleum-producing Kupe gas and condensate field (Figure 2). The principal structures in the model are formed by the Manaia and Taranaki faults, which are inverted Cretaceous normal fault zones. Subdivision into hanging and footwall horizons and their connection along the intervening Manaia Fault allow for the geometrically correct inclusion of layers into the model, suitable for combined generation and migration modeling. Results of the basin-wide crustal scale model were integrated in the boundary conditions. For higher resolution charge modeling of the Kupe gas field and other prospective areas, the model was cut along the major faults.

The Kupe field lies within a complex structure related to Oligocene-Miocene basin inversion. Closure is related to a plunging anticline cut by a series of partially sealing faults. Although several large fault structures are present between the field and the kitchen to the northeast, charge of the structure is not difficult to reproduce. The main difficulty encountered during the charge modeling is the entrapment and preservation of gas within the structure. Gas venting at the sea floor and open faults in Plio-Pleistocene sediments indicate that fault leakage, possibly in combination with poor top seal, are the main risk in the Kupe Field and potentially for the successful drilling of similar prospects in the area. The modeling of compartmentalized reservoir leakage in a regional migration model is a significant challenge. We discuss associated problems and approaches to dealing with model leakage through time, as well as the spatial and temporal constraints to petroleum entrapment.

Summary

This regional to prospect-specific workflow presented here highlights a series of factors that significantly affect maturity of source rocks, expelled petroleum volumes, timing, and gas:oil ratio of charge and preservation of accumulations. Despite the fact that some of the data necessary to predict factors, such as composition of the crust, structural evolution, and climate, are not always available, we suggest they should be included as part of the required sensitivity analysis in early-stage basin screening and prospectivity assessment. These factors, or at least their impact on regional model results, should be included in the boundary conditions of high-resolution models used to investigate petroleum charge of individual prospects.

Reference Cited

Kroeger, K.F., and R.H. Funnell, 2012, Warm Eocene climate enhanced petroleum generation from Cretaceous source rocks: A potential climate feedback mechanism?: Geophysical Research Letters, v. 39/4, 6 p, doi:10.1029/2011GL050345.

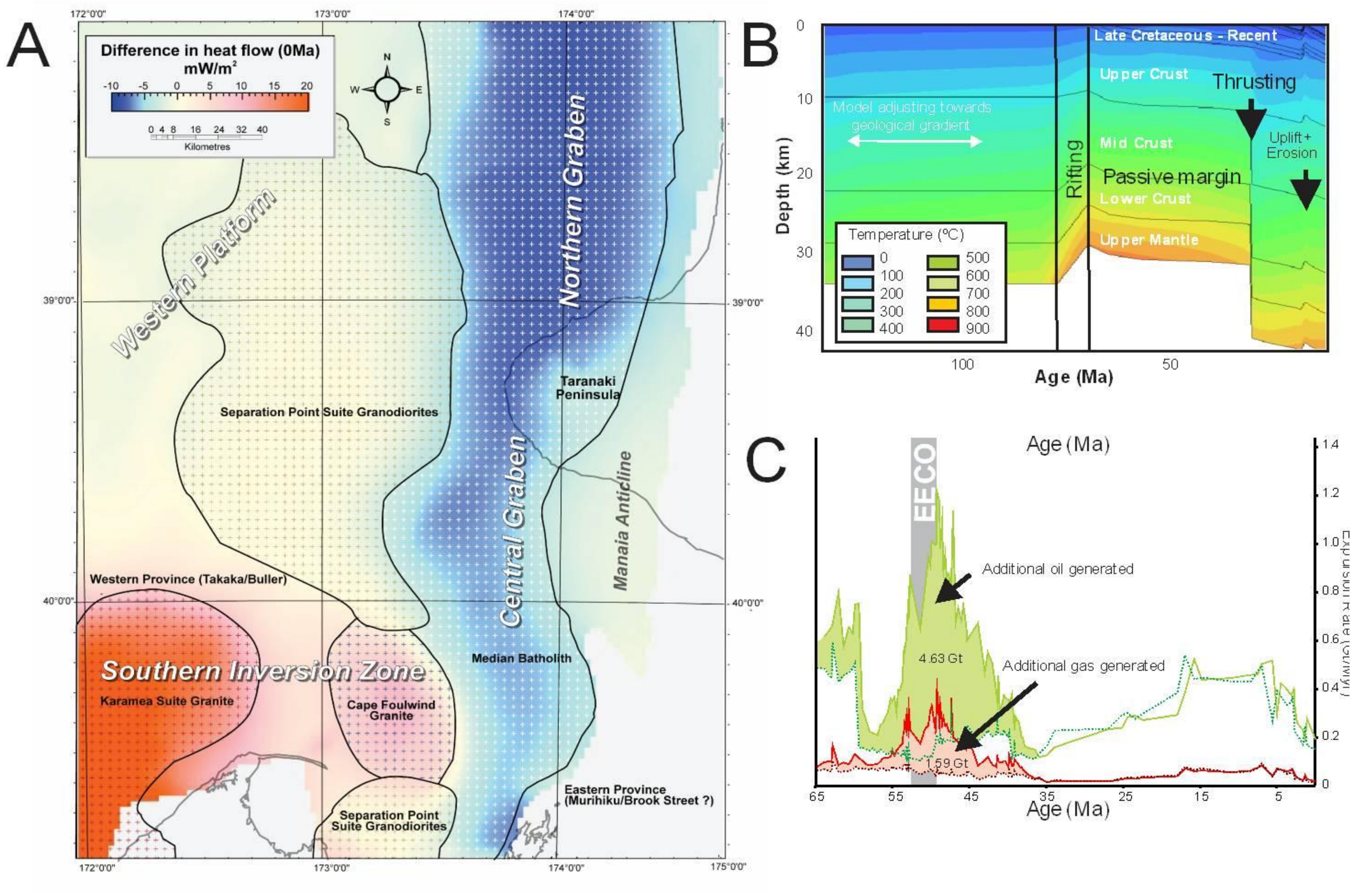

Figure 1. A. Map of basement terranes in the Taranaki Basin and the impact of their composition and radiogenic heat generation potential on surface heat flow. B. 1D time extraction from a PetroMod^{TM} 3D model showing the modeled influence of structural change. C. Impact of the increase in surface and deepwater temperatures by 10°C during the early Eocene climatic optimum (EECO) and impact on modeled basin-wide petroleum generation.

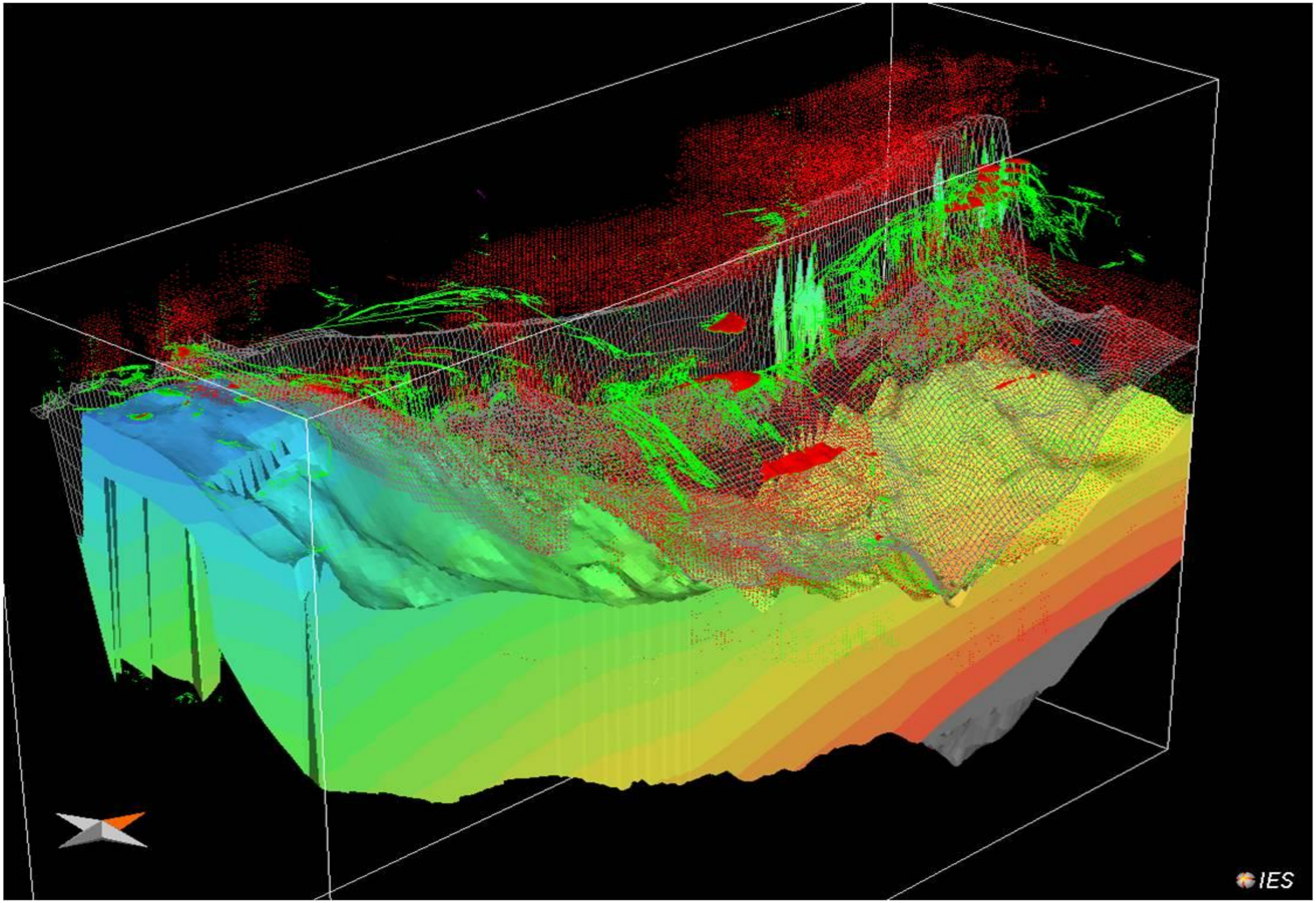

Figure 2. Migration model of the southeastern Taranaki Basin (Kupe field area) showing basin temperature and oil (green) and gas (red) flowpaths. Modeled area is 90 by 30km with vertical exaggeration of 2.5.