Petroleum Systems Analysis of the Gamtoos Basin, South Africa*

Anthea C. Davids[1], Chantell B. Van Bloemenstein[1], and Curnell J. Campher[1]

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[1]Petroleum Agency SA, Cape Town, South Africa (davidsa@petroleumagencysa.com)

Abstract

The Gamtoos Basin, off the southern coast of South Africa was formed as a consequence of the breakup of the African and South American plate during the Late Jurassic. (Broad et al., 2006). The oldest dated sediments encountered in the basin are of Kimmeridgian age and constitute a significant source rock. The basin is relatively under-explored with only 10 shallow wells drilled in an area of approximately 4000 square kilometers. These wells are focused around the main Gamtoos graben area. The current study aims to assess the maturity of three source rock units, namely, the Kimmeridgian, Tithonian and Valanginian/Hauterivian source rocks, intersected in a few wells in the Gamtoos Basin, on a regional scale. The study comprised the construction of 1-D models of 6 drilled wells and 29 pseudo wells spread over the area of the basin.

The maturity of all three source rock intervals in the 1-D models was integrated and assessed at various periods throughout geological time (Davids et al., 2018) to trace the evolution of source rock maturity up to the present-day. Results of the modelling show that the older Kimmeridgian source rocks are overmature in the basin depocentre but still hold potential for oil generation away from the depocentre, where they are less deeply buried. The Tithonian and Valanginian/Hauterivian source rocks show a similar trend with the more mature sections of the source rock in the main graben area, where there is a substantial sedimentary package. The study proved that the source rock is indeed more mature in the main Gamtoos graben and also highlights areas where the source rocks could be in the oil window.

Introduction

This study aims to assess the maturity of the Kimmeridgian, Tithonian and Valanginian/Hauterivian source rock intervals in the offshore Gamtoos Basin of South Africa, on a regional scale (Figure 1). The study comprises the construction of BasinMod 1-D models of 6 drilled wells, for calibration purposes, and 29 pseudo wells spread over the area of the basin. Regional grids of maturity in terms of vitrinite reflectance were then used to construct maturity maps through time.

Geological Background

The Late Mesozoic Gamtoos Basin comprises a half graben formed as a result of the strike slip movement along the Agulhas Falkland Fracture Zone (AFFZ) (Figure 2) during separation of the African and South American plate. The basin forms part of a series of half grabens that extend southwards into the greater Outeniqua Basin.

The Gamtoos Basin is controlled by one major basin-bounding normal fault (Figure 3a) to the east, namely, the Gamtoos Fault that extends onshore and finds its origin in the structural grain of the Permo-Triassic Cape Fold Belt (Roux, 1992). The oldest dated sediments encountered in the basin are of Kimmeridgian age and constitute a significant source rock interval (Figure 2). The basin is relatively under-explored with only 10 shallow wells drilled in an area of approximately 4000 square kilometers. These wells are focused around the main Gamtoos graben area.

Source Rocks in the Gamtoos Basin

Boreholes in the Gamtoos Basin intersected various source rock units which include the very good quality Kimmeridgian, the Tithonian and Valanginian / Hauterivian source rocks (Table 1), and five well had hydrocarbon shows (Figure 3b). The source rocks are classified as Type I, Type II and mixed Type II/III source rocks, respectively. Wet gas to oil-prone source rocks have been intersected by boreholes in the central and southern parts of the Gamtoos Basin (Roux, 1992). The Kimmeridgian source rock reaches thicknesses of over 100m in some boreholes with TOC values of more than 2%. The source rock has been regionally mapped on seismic and is postulated to reach a much greater thickness in the depocentre of the basin. The Tithonian and Valanginian / Hauterivian source rocks have only been intersected in a few wells concentrated along the main basin-bounding fault.

Gamtoos Basin 1D Calibration Modelling

The 6 real well models incorporate rifting heat flow with an initial spike during rifting and a gradual decay of the heat flow through time to present-day. Apart from localized deepening associated with early rifting, the paleo-water depth is modelled as a gradual increase to present-day values. Further analysis of this aspect would produce a more accurate geohistory.

Parameters

Important parameters include the following (Figure 4): well data, lithologies, gas logs, pyrolysis data, paleo-water depth (PWD) / sediment water interface temperature (SWIT) and crust type and thickness, stretching, and heat flow.

Calibrating Modelling Results – Example: The Ha-A1 Well

1D models of the actual wells are concentrated in and around the main Gamtoos graben, where results of the various source rocks indicate that they are at varying degrees of maturity at present. Well Ha-A1 is located about 50 km south of Port Elizabeth. The borehole reached a depth of

4391.9m and is modelled to approximately 4800m based on mapped basement. The borehole was abandoned and classified as a dry well. A thick sequence of mature shale was intersected between horizon P3 and U, yielding large amounts of light hydrocarbon gas from the cuttings. In Ha-A1 the Kimmeridgian and Tithonian source rocks reached early maturity during the Late Jurassic to Early Cretaceous. The modelled results (Figures 5 and 6) indicate that the Tithonian source rock is in the main gas generation phase at present. Modelled calibration of the Kimmeridgian source rock shows a reasonably good correlation with static borehole temperature measurements and vitrinite reflectance (Figure 5).

Pseudo 3D Modelling of Gamtoos Basin Source Rock

A total of 29 pseudo well locations (Figure 7) scattered over the Gamtoos Basin provide the framework used to assess the maturity of the basin and compare the evolution of the source rocks through time. Parameters determined through calibration of actual wells were applied to these models, with minor variations in keeping with their position within the basin. The maturity modelling of the Gamtoos Basin included some limitations in terms of timing, intensity and extent of erosional events, no hiatus in model, and no Horner correction.

The Kimmeridgian Source Interval

The Kimmeridgian source rock was assessed at three periods (viz., present-day, 120 Ma and 150 Ma) to generate three different maturity maps illustrating how the maturity of the Kimmeridgian source rock evolved through time (Figure 8). Modelled results at present-day of the Kimmeridgian source rock correspond very well with the prediction of overmature areas in the depocentre of the half grabens (Figure 9). During the Late Jurassic (about 150 Ma years ago) the Kimmeridgian source rock extended over vast areas in the Gamtoos Basin. An isopach of the Kimmeridgian source, rock based on seismic mapping, is illustrated and indicates the presence of thicker units along the-bounding fault. During this time the source rock is modelled as immature over vast areas of the western side of the basin with early to mid-mature areas in the half grabens along the major Gamtoos Fault. At 120 Ma during the Early Cretaceous the regional maturity map of the Kimmeridgian source interval shows that the source rock is in the gas window and is overmature in some places, especially in the depocentres of the half grabens.

The Tithonian Source Interval

The Tithonian sequence is seen as a continuation of the Kimmeridgian interval but with a moderate shallowing upwards and an increasingly oxygenated environment (McMillan et al., 1997). Four periods (viz., present-day, 62.5 Ma, 120 Ma and 145 Ma) were selected to generate four separate illustrations of how the maturity of the Tithonian source rock evolved through time. Three well locations have been selected in strategic positions within the Gamtoos Basin to examine the maturity of the Tithonian source rock. The Tithonian source rock farther south of the main Gamtoos depocentre was primarily immature during the Early Cretaceous and has gradually increased in maturity, entering the oil generation phase at 120Ma at well location Ha-B2 and entering the main gas phase at 62.5 Ma at well location Ha-A1. Farther east of the main depocentre on the flexural margins of the basin, the Tithonian source rock is modelled to be in the early mature phase at present-day (Figure 10).

The Valanginian/Hauterivian Source Interval

Three periods (viz., present-day, 120, Ma and 130 Ma) were selected to generate separate maps to illustrate how the maturity of the Valanginian/Hauterivian source rock advanced through time (Figure 11). At 130 Ma the source rock was immature as it had just been deposited; at 120 Ma the source rock was buried deeper and moved into the oil generation stage around the axis of the depocentre, and at present-day the source rock is in the gas-generation phase with some areas in the overmature stage, against the basin-bounding fault.

Conclusions

The source rocks in the Gamtoos Basin have been intersected by several wells, and the basin has been proven to be mature for oil and gas generation, evident in wet gas to oil-prone source rocks intersected in wells, such as Ha-A1 and Ha-B2. This rift basin has provided the ideal geological setting for the deposition of at least three source rocks identified in certain wells across the basin, the Kimmeridgian, Tithonian and Valanginian / Hauterivian intervals. The maturity of these source rocks varies across the basin.

- The older Kimmeridgian source rock, deposited more or less at the same time as the initial rifting phase and traceable through the basin is overmature in most modelled areas at present. The maturity level of this source rock is attributed to high heat fluxes during the rifting phase of basin formation.
- The Tithonian source rock is seen to follow a similar trend in maturity with the peak oil generation during the Early Cretaceous and is modelled to be in the main gas to overmature window at present.
- Modelled results of the younger Valanginian/Hauterivian source rock indicate that this unit could be at present in the oil window in some areas and could potentially charge some hydrocarbon traps.
- Petroleum systems modelling of the Gamtoos Basin source rocks has given insight into the regional maturity of the source units and highlighted areas that could be targeted for potential hydrocarbon exploration.

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Figure 1. The location of the Gamtoos Basin, off the south coast of South Africa.

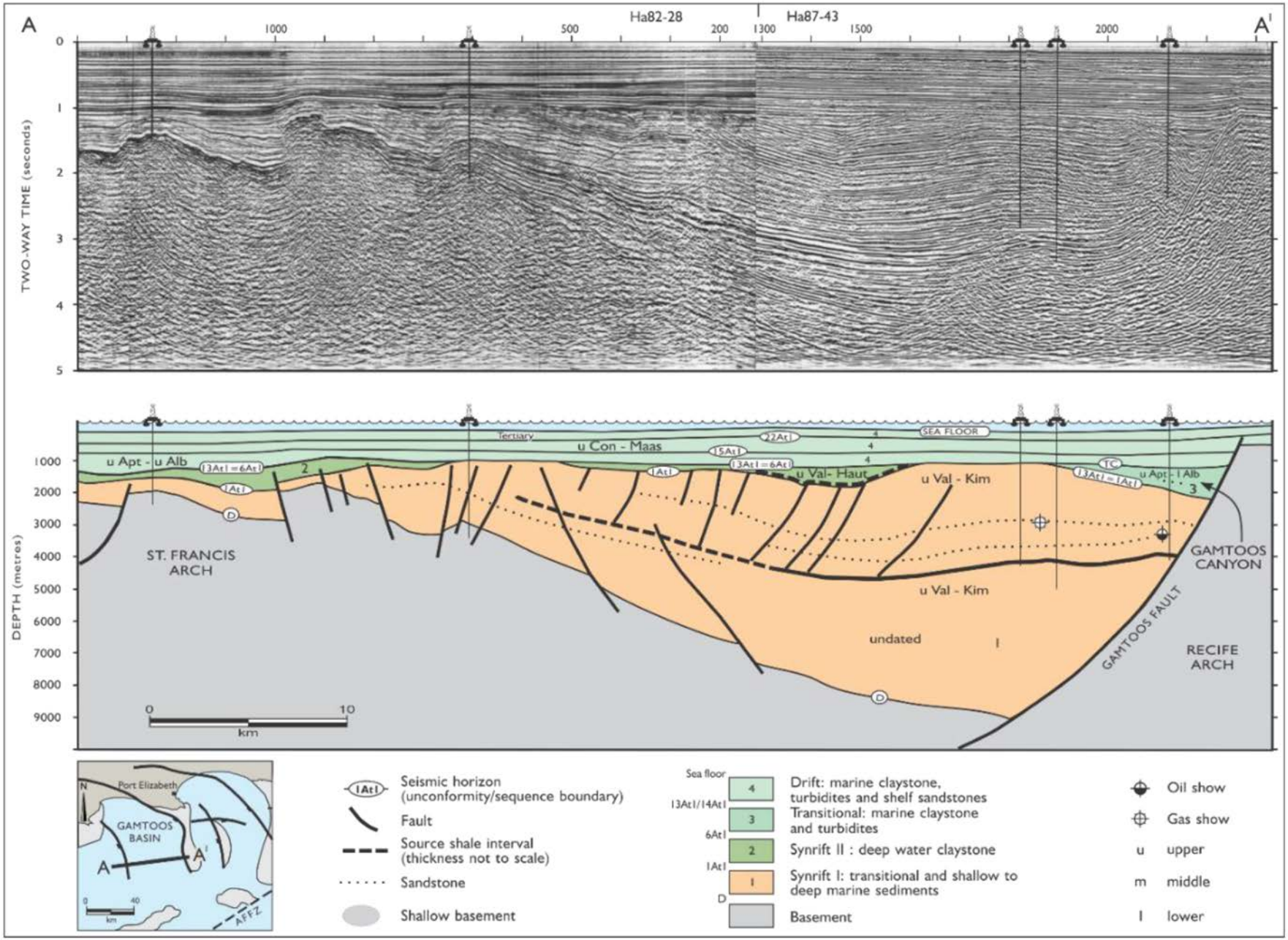

Figure 2. Stratigraphy of the Gamtoos Basin, demonstrating four phases of development (Broad et al., 2006).

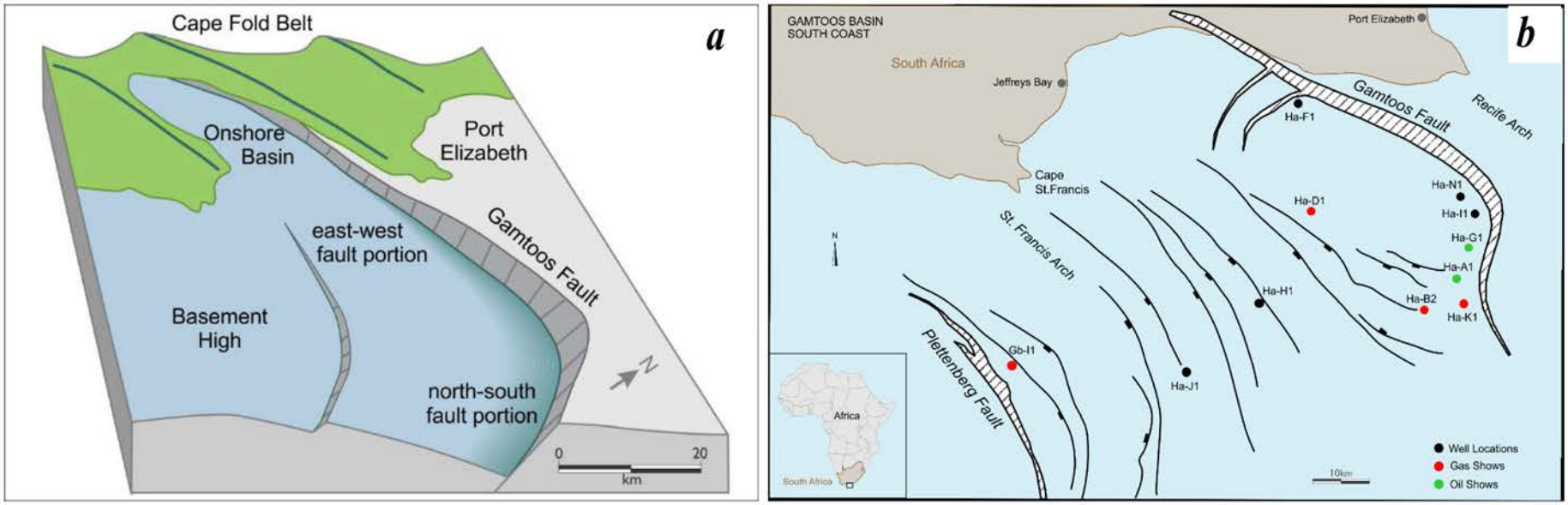

Figure 3. (a) The location of the Gamtoos Fault, a major basin bounding normal fault within the Gamtoos Basin. (b) The location of the Gamtoos Basin showing hydrocarbon shows at six wells, including the well in the Pletmos Basin (adapted from Broad et al., 2006).

Table 1: Source Rocks intersected in the Gamtoos Basin						
Well Name	**TD (Drillers)**	**Age**	**Depths/Thickness (m)**	**TOC %**	**HI**	**S2/S3**
Ha-A1	4392	Valanginian/ Hauterivian	1012-1026 (14m)	~1,3	21	0,13
		Tithonian	3627-3671 (44m)	~2	153	4,15
		Kimmeridgian	3805-4244 (105,35,33m)	~1,4	103	3,3
Ha-B2	3979	Tithonian	3582-3664 (81m)	~2	88	1
		Kimmeridgian	3938-3954 (16m)	~1,4	62	0,8
Ha-D1	3479	Valanginian/ Hauterivian	1088-1144 (56m)	~0.8	65	0,83
Ha-F1	2796	Valanginian/ Hauterivian	1944-2080 (136m)	~1,4	164	1,4
Ha-H1	2357	Tithonian	1712-1744 (32m)	~1,1	146	1
Ha-J1	1816	Tithonian	1163-1224 (61m)	~1,5	149	2,6
Ha-K1	4238	Kimmeridgian	3252-3287	~1,1	86	1,8
Ha-N1	3200	Valanginian/ Hauterivian	1960-1980 (20m)	~1,4	154	1,8

Table 1. Source rocks intersected in the Gamtoos Basin.

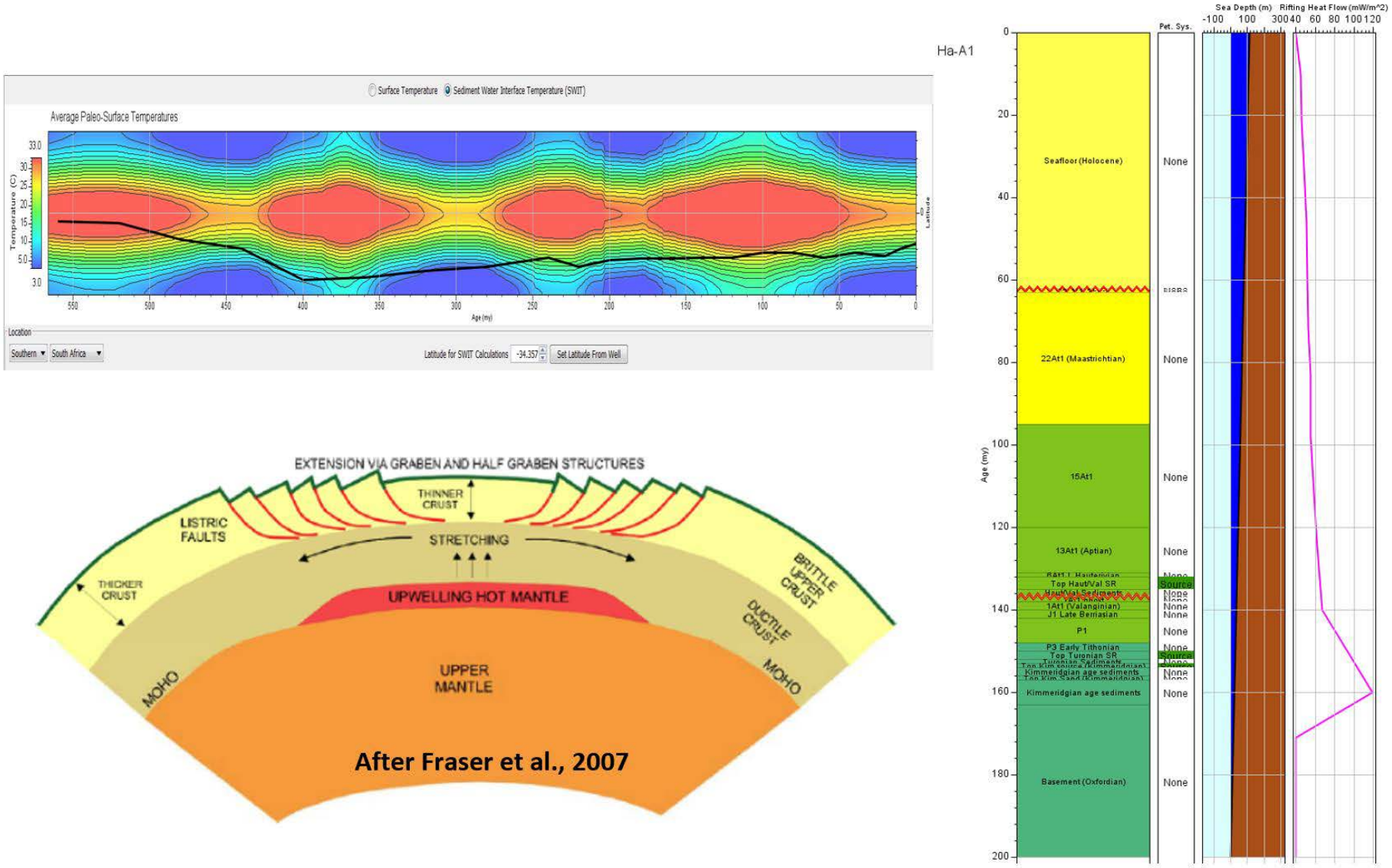

Figure 4. Parameters used include the global sediment-water interface temperature (SWIT), the McKenzie Model showing even crustal stretching within the lithosphere during rifting, and a Rifting Heat Flow Model at ~120 mW/m^2 at peak to ~40 mW/m^2 at present for well Ha-A1 in the Gamtoos Basin.

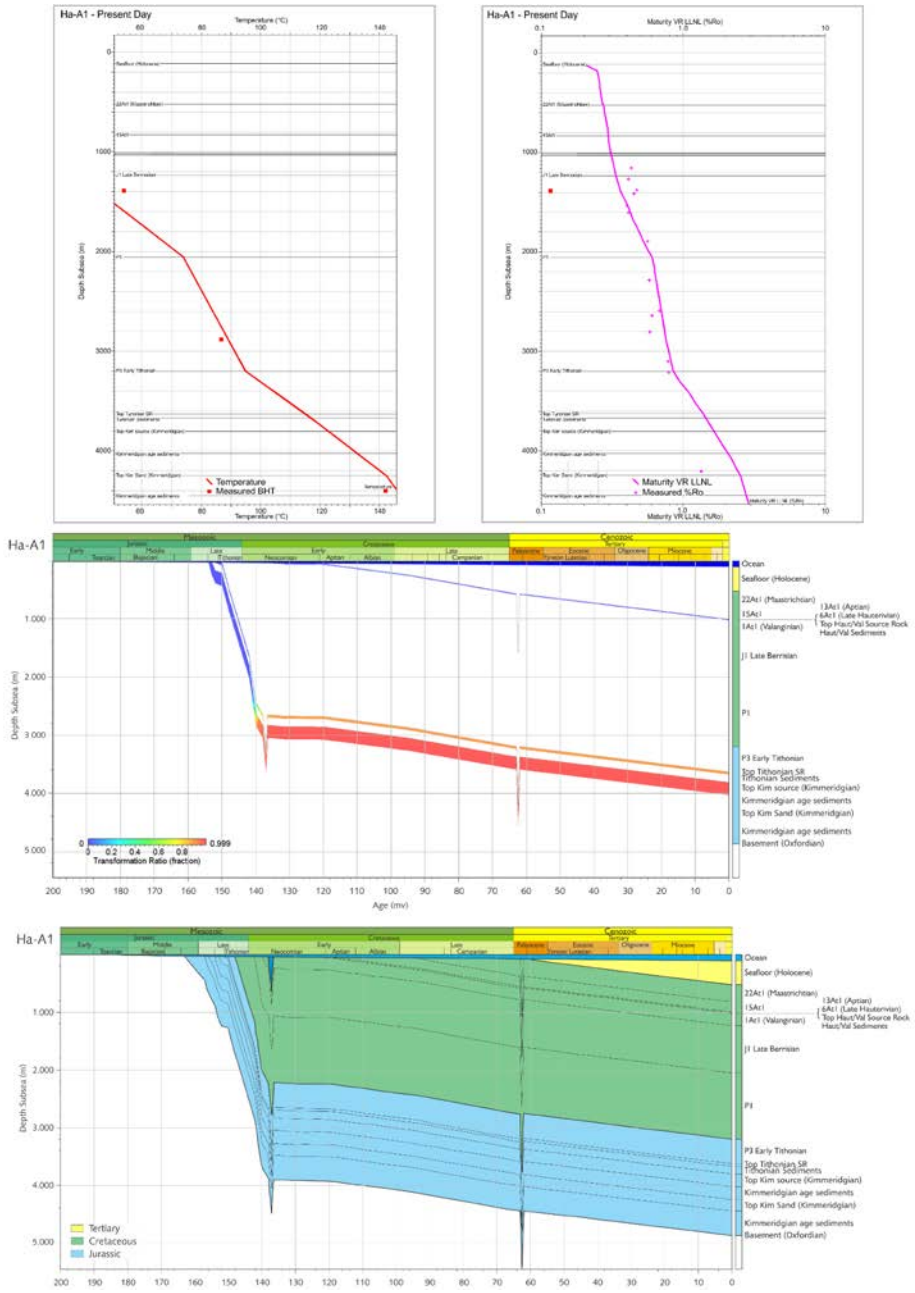

Figure 5. An example of Gamtoos Basin calibration modelling results for well Ha-A1.

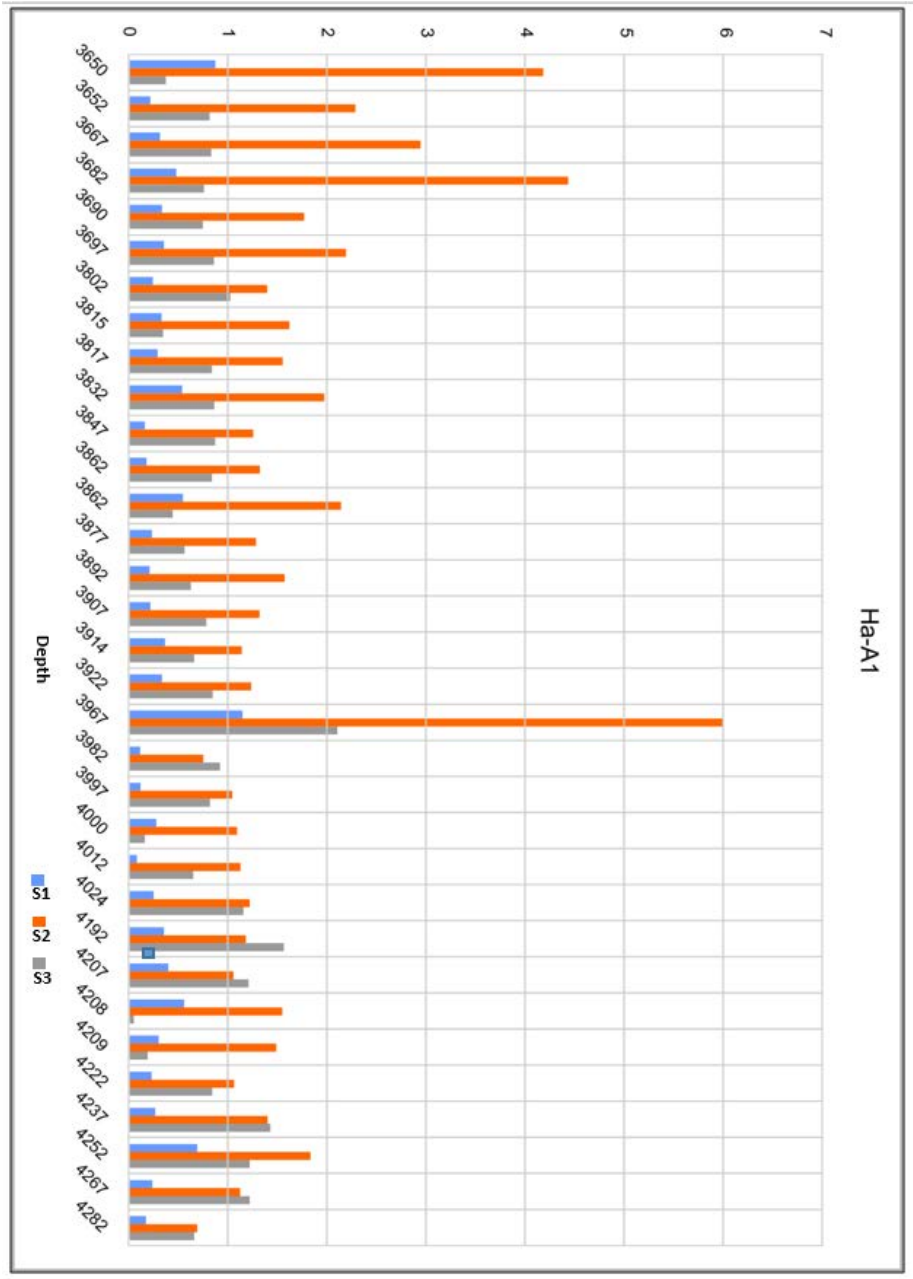

Figure 6. Geochemistry data for well Ha-A1.

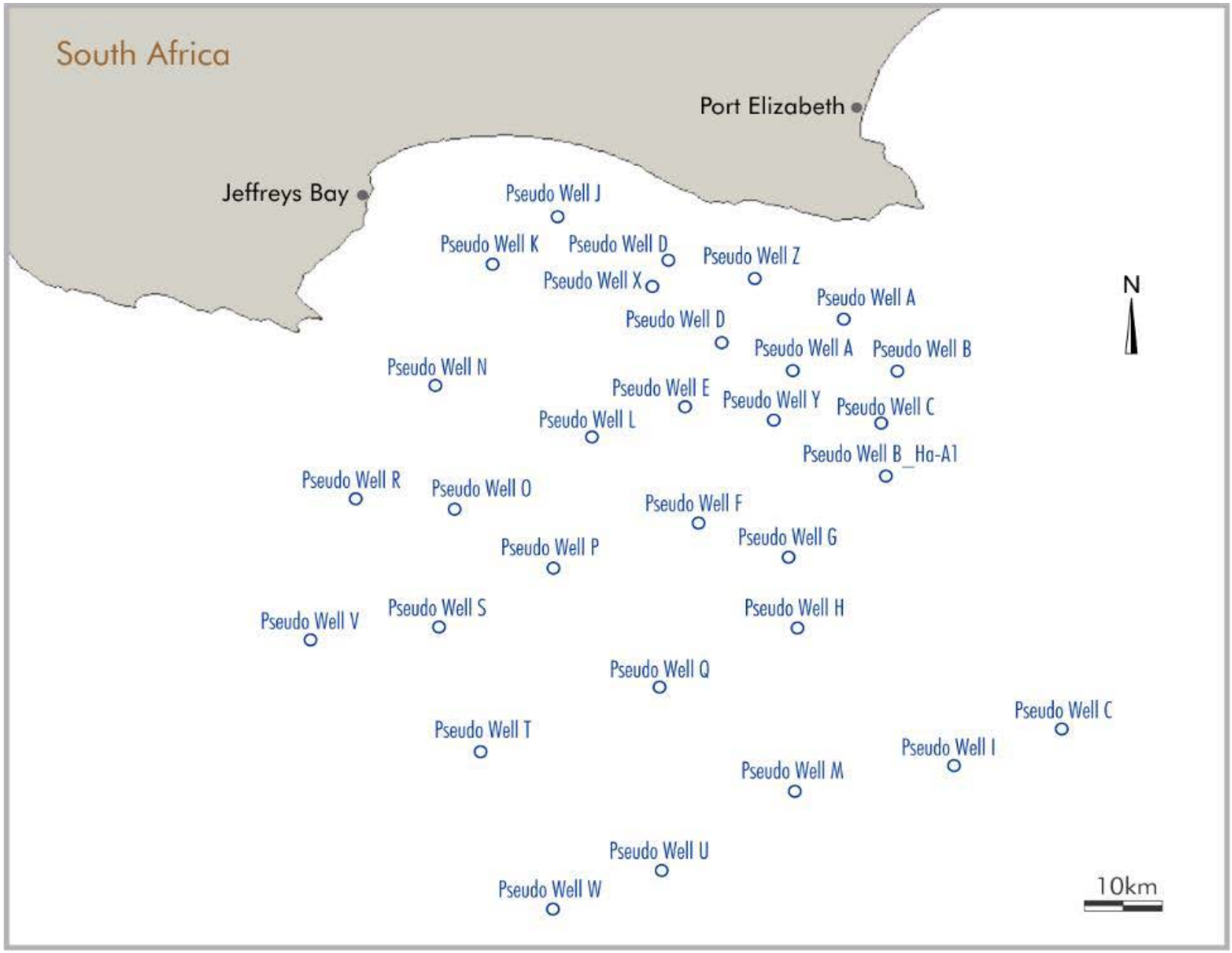

Figure 7. The location of the Gamtoos pseudo wells used for Basin Modelling.

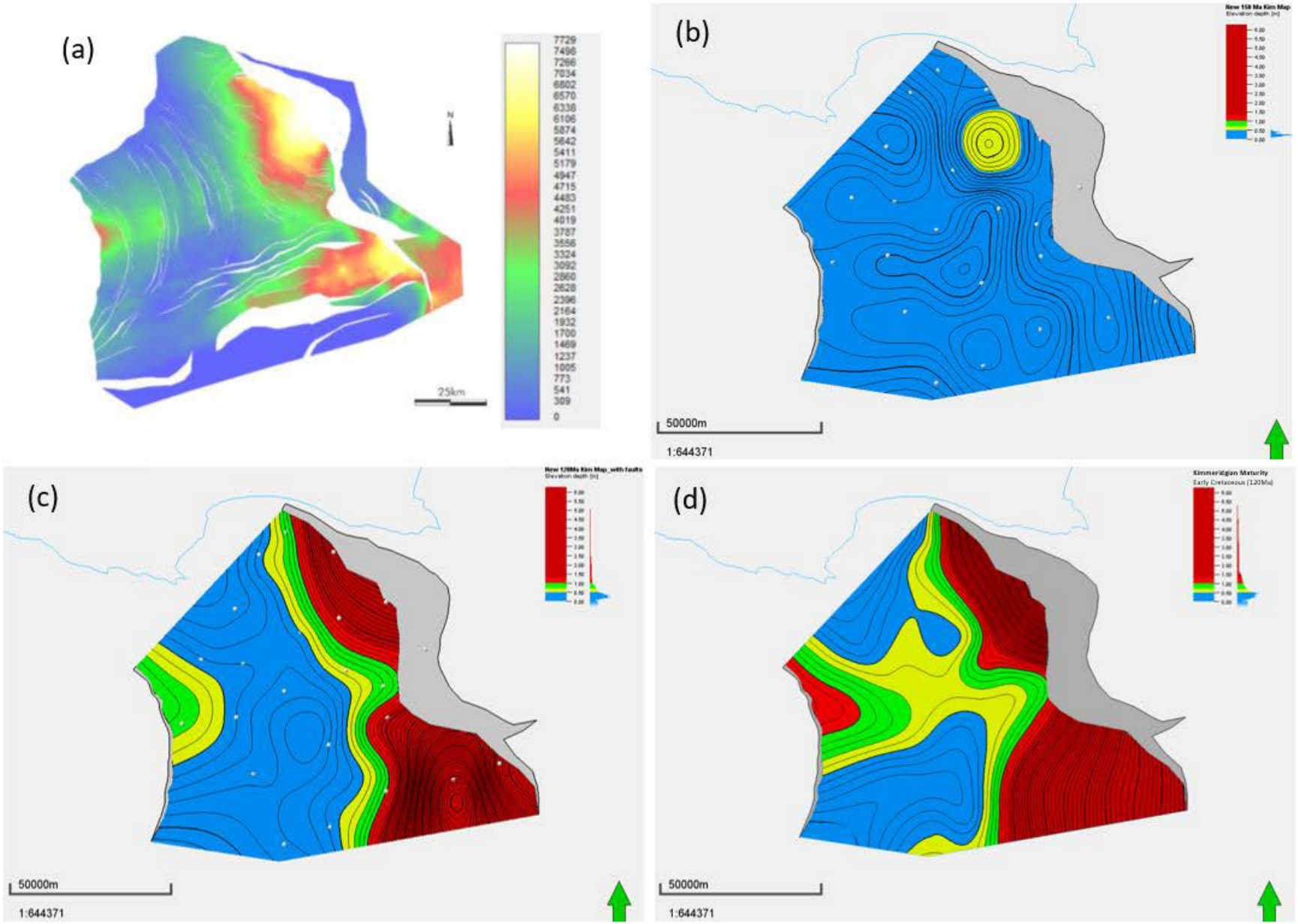

Figure 8. (a) The overburden which covers the Kimmeridgian Source Rock. The Kimmeridgian Source Rock interval at (b) 150 Ma ago, (c) 130 Ma ago, and (d) 120 Ma ago.

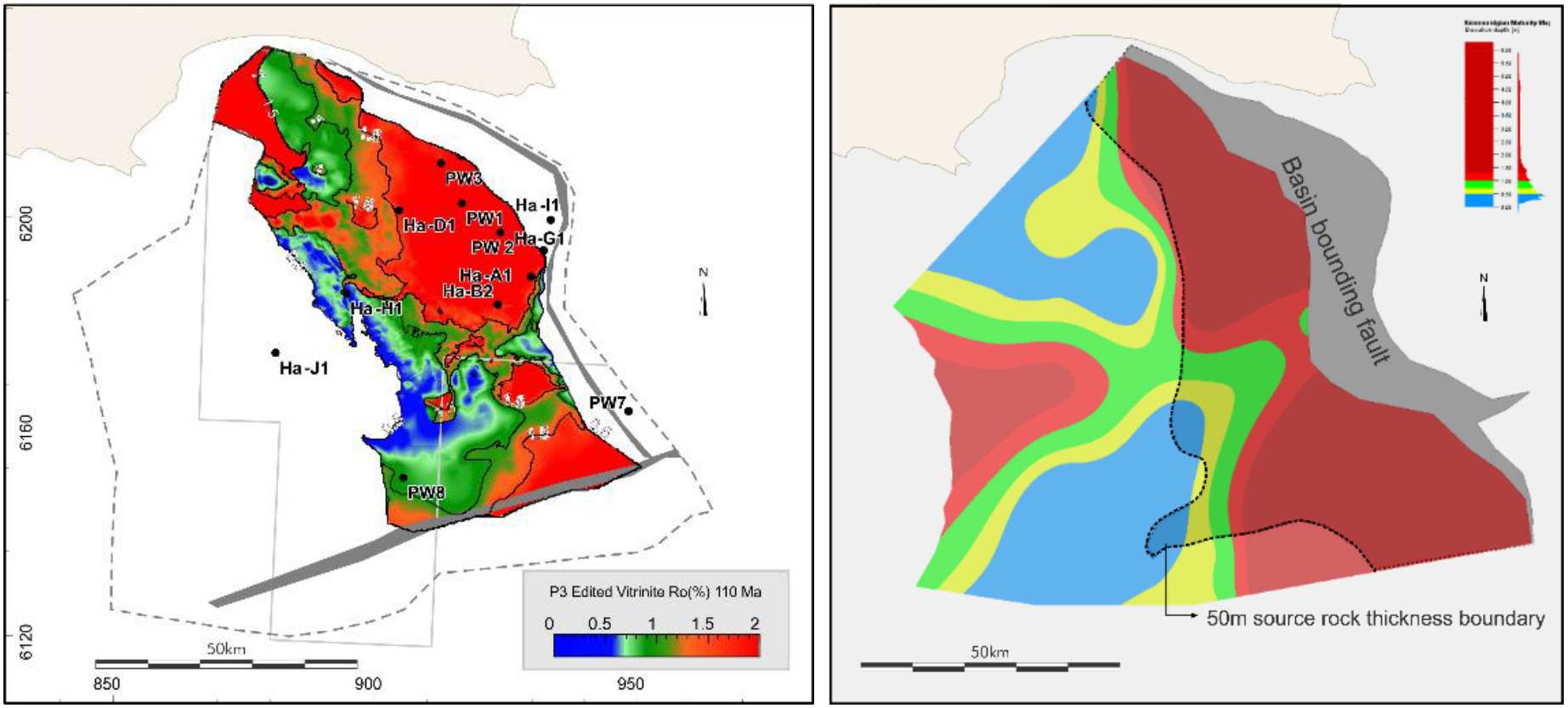

Figure 9. Regional modelling results in the Gamtoos Basin (Davids et al., 2018) can be compared with previous work by an operator (on the left) and is showing very similar results for the Kimmeridgian source rock (Integrated Geochemical Interpretation (2012). The diagram on the right illustrates the maturity of the Kimmeridgian source rock at present, with a 50 m source-rock-thickness boundary overlay.

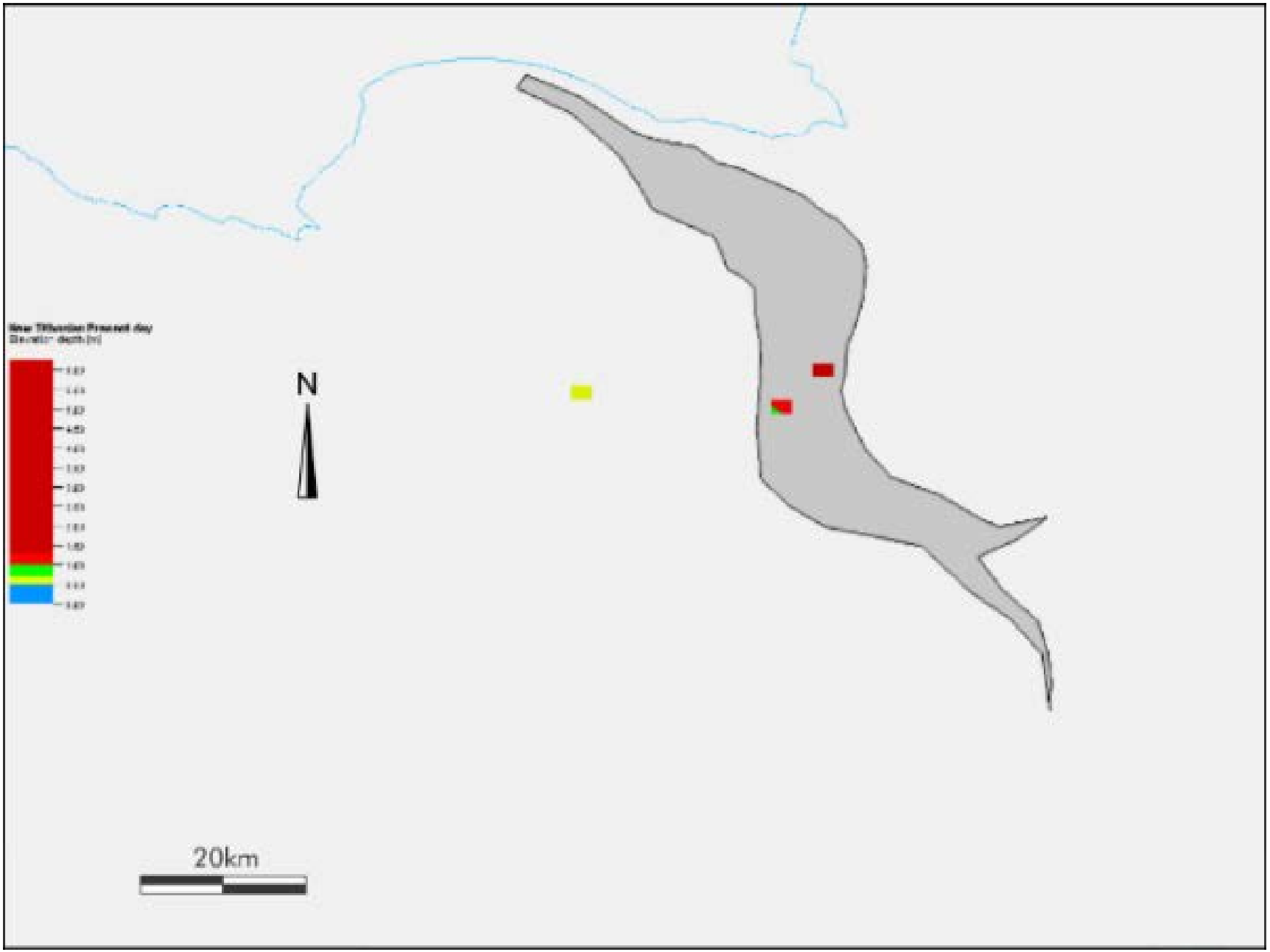

Figure 10. Maturity of the Tithonian source rock at the present.

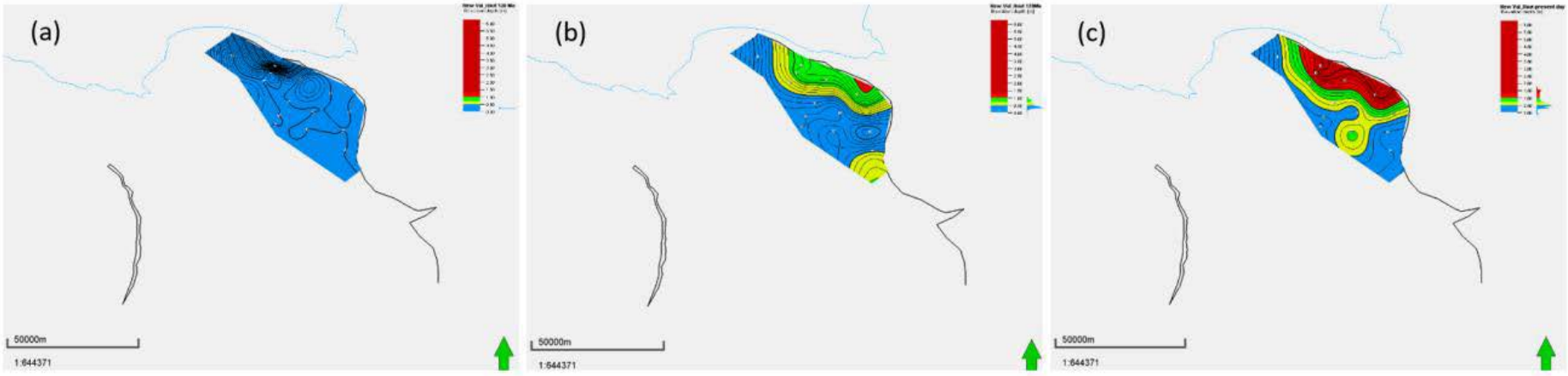

Figure 11. Maturity of the Hauterivian/Valanginian source rock at (a) 130 Ma ago, (b) 120 Ma ago, and (c) present.