[PS]Heat-Flow and Source Rock Maturity Modelling in the Distal Domain of the West African Margin*

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Abstract

Organic-rich intervals (ORIs) are extensively documented in the distal domain of passive continental margins, often associated with oceanic anoxic events. However, it is the general perception of the industry that potential source rocks overlying old oceanic crust, or ocean-continent transitional basement, lack the necessary thermal stress and/or sediment burial to mature and generate hydrocarbons. For this study, we selected eight DSDP/ODP sites at key locations along the West African Margin, between NW Morocco and South Africa, to model the maturity of the regionally relevant ORIs. The models test a variety of plausible tectonic/thermal model scenarios, based on the available constraints on the structure of the underlying lithosphere, kinematic models and heat flow data. The work presented here is part of the "Eastern Atlantic (West African Margin) Oceanic Crust Project", where we are also reviewing the evidence for the occurrence of ORIs on African plate oceanic/transitional crust based on a re-evaluation of biostratigraphic and geochemistry data. The 1-D modelling experiments predict that the majority of the DSDP/ODP drilled ORIs along the distal West Africa Margin are immature. The exceptions are arguably the Aptian, oil- and gas-prone source rock horizons (likely also Barremian) offshore Namibia and South Africa where, in agreement with the available maturity data, early- to mid-oil maturity may occur in less than 1500 m sediment burial, as a result of pre- and syn-break up voluminous magmatism and/or sub-lithosphere mantle dynamics. To the north of the Walvis Ridge the modelling results show that for a normal oceanic lithosphere setup, i.e. cooling towards steady-state following break-up, the maturity of the Jurassic-Cretaceous ORIs takes place for burial depths greater than 3000 m. Alternative thermal model scenarios, which include variations in the nature/thickness of the crust and lithosphere, magmatism and hot-spot activity, basin exhumation and by-pass of mid-ocean ridge segments across transform faults, suggest, however, that in many areas a sediment burial of approximately 2000 m may suffice for the maturation of regionally important ORIs to occur. The models also highlight the potential risk of early source rock maturity and hydrocarbon generation, possibly before trapping/sealing conditions have developed. Global sediment thickness compilations (e.g. CRUST-1; Laske et al., 2013) show vast areas with > 2000 m sediment cover in oceanic and ocean-continent transition domains off West Africa, which may thus encompass active petroleum systems. In the follow-up to the work discussed here we will focus in areas where we have better constraints on the sediment coverage, from new seismic and potential field data, and use 2-D and 3-D modelling techniques to help de-risk these large-scale petroleum systems.

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Artemieva, I.M., 2006, Global 1°×1° thermal model TC1 for the continental lithosphere: Implications for lithosphere secular evolution: Tectonophysics, v. 416, p. 245-277.

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Heat-flow and Source Rock Maturity Modelling in the Distal Domain of the West African Margin

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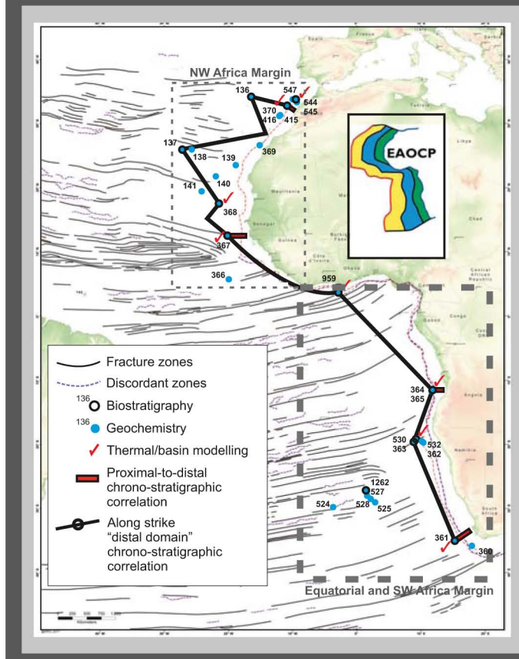
Introduction: Organic-rich intervals (ORIs) are extensively documented in the distal domain of passive continental margins, often associated with oceanic anoxic events. However, it is the general perception of the industry that potential source rocks overlying old oceanic crust, or ocean-continent transitional basement, lack the necessary thermal stress and/or sediment burial to mature and generate hydrocarbons.

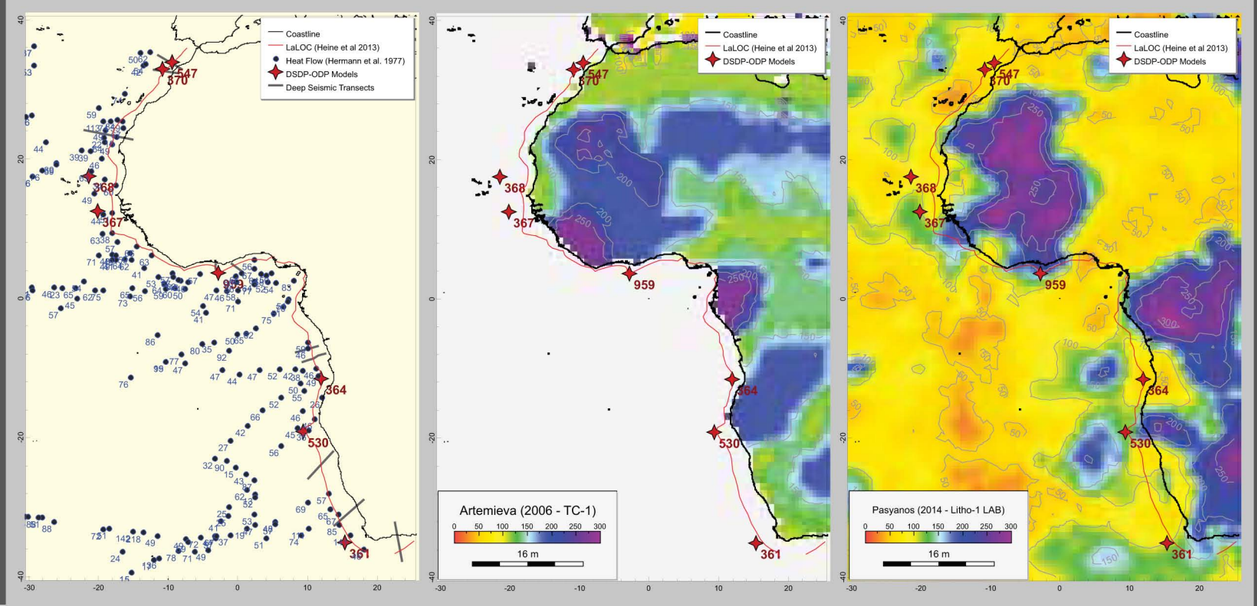
For this study we selected eight DSDP/ODP sites at key locations along the West African Margin, between NW Morocco and South Africa, to model the maturity of the regionally relevant ORIs. The models test a variety of plausible tectonic/thermal model scenarios, based on the available constraints on the structure of the underlying lithosphere, kinematic models and heat flow data.



The Eastern Atlantic Oceanic Crust Project (EAOCP) is a research project being carried out by IGI Ltd. and SRC Ltd. The project is based on public domain DSDP/ODP data (from 30 'key' sites along the Eastern Atlantic between 1970 and 1995 in DSDP Legs 14, 40, 41, 50, 73, 74, 75 & 79 and ODP Legs 159 & 208), and studies on the oceanic/volcanic islands of Fuerteventura (Canary Islands) and Maio (Cape Verde Islands). IGI Ltd.'s proprietary software p:IGI is used for geochemistry databasing and interpretation.

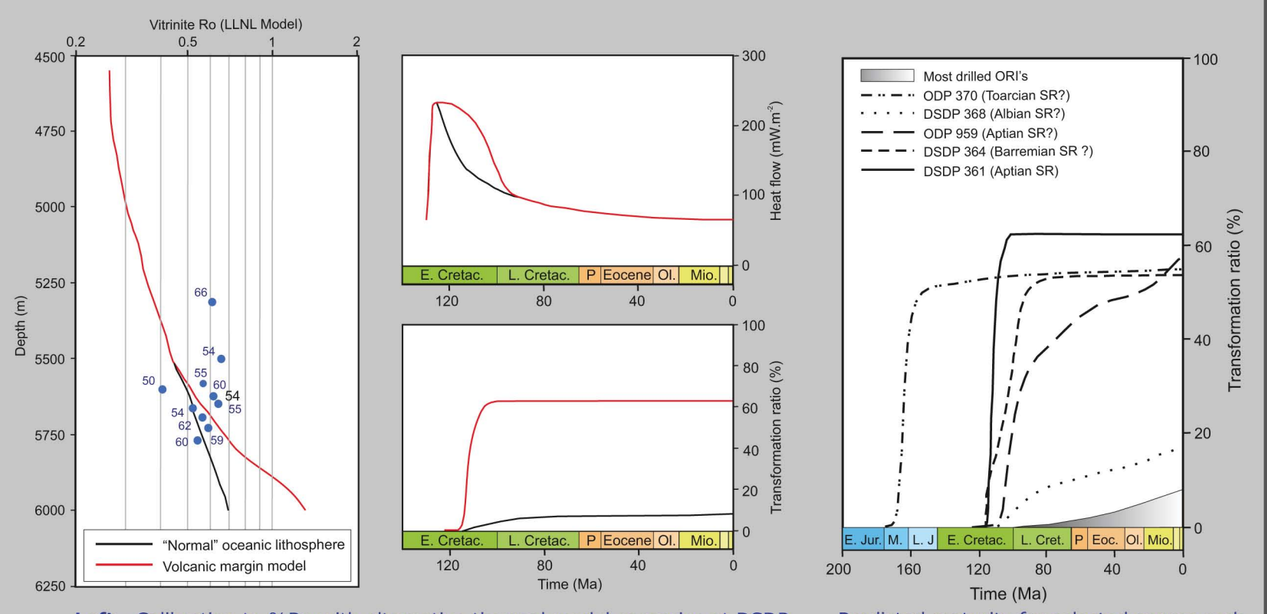
The specific aims of the project are to advance the understanding of **organic-rich intervals** (ORIs) development in the distal domain and the maturity/hydrocarbon expulsion history of souce rocks on oceanic crust. The overall objective is to define areas where exploration could be successfully extended onto oceanic and/or transitional crust along the West African margin.

HEAT-FLOW AND SOURCE ROCK MATURITY MODELLING



Heat flow compilation by Hermann et al. (1977; blue circles), and selected deep seismic profiles (grey lines). Red stars show the location of the modelled DSDP/ODP sites.

Global models for the thickness of the lithosphere, or the lithosphere-asthenosphere boundary (LAB). **Left** - Artemieva (2006) TC-1 thermal model for the lithosphere. **Right** - Pasyanos et al. (2014) LITHO-1 surface wave dispersion model. Red dashed line is the landward limit of oceanic crust (Heine et al. 2013).

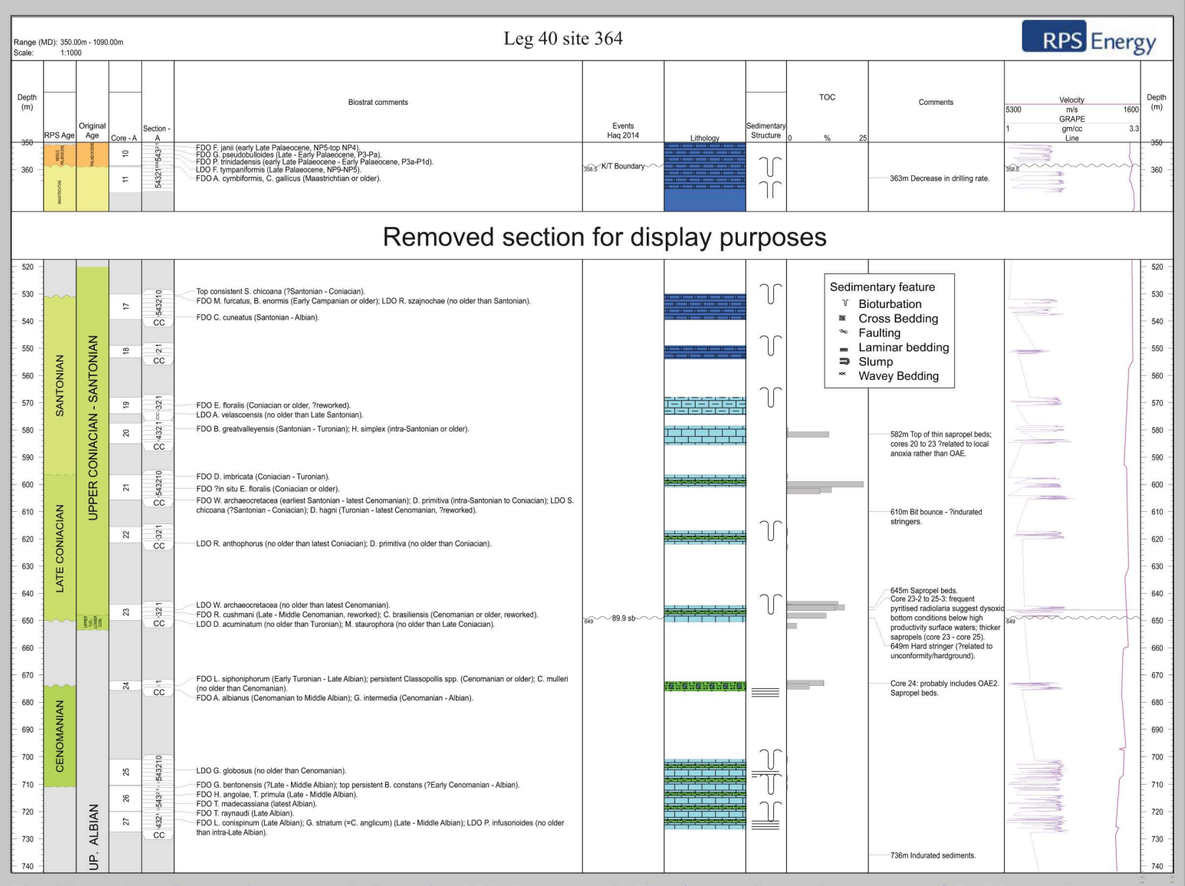


Left - Calibration to %Ro with alternative thermal model scenarios at DSDP 361 (deep Orange Basin, South Africa). **Top right** - Predicted heat flow at base sediments. **Bottom right** - Predicted kerogen transformation ratio. The volcanic margin model accounts for prolonged high heat flow associated with voluminous magmatism along the SW Africa margin.

Predicted maturity for selected source rock horizons along the West Africa Margin. Dashed and dotted lines are horizons below TD of recognised regional quality, and defined based on seismic data.

REVISED DSDP/ODP SITES STRATIGRAPHY

Stratigraphic ages were revised and a sequence stratigraphic breakdown applied to 15 DSDP/ODP sites (with recognition of sequence boundaries and condensed sequences where possible). These results were used to construct a series of 'proximal-to-distal' stratigraphic correlations along the margin to provide a framework for the analysis of ORI occurrence/distribution in the distal domain.



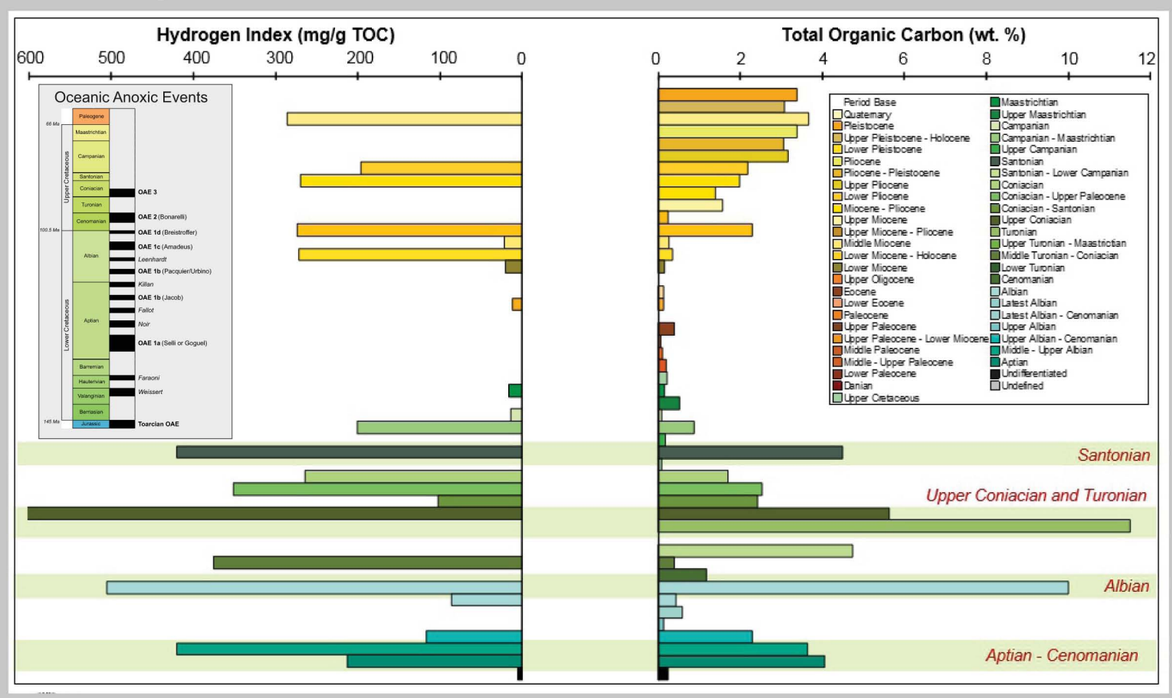
The biostratigraphic work was carried out by RPS Energy, Ltd. The figure above shows part of DSDP site 364 revised stratigraphy, where the section between the Maastrichtian and the Santonian was removed for display purposes.

SOURCE ROCK GEOCHEMISTRY

The geochemistry database comprises data from 30 DSDP/ODP sites (51 boreholes).

The nature of the ORIs, their internal character, and their potential as petroleum source rocks was evaluated through the compilation and interpretation of the publicly available geochemistry data in the DSDP/ODP sites.

In places, the identified ORIs correlate with the globally recognised and/or regional mapped **Oceanic Anoxic Events** (OAEs; see inset). However, some ORIs also extend outside the designated age and/or thickness range of the OAEs.



Tornado plot showing summarized source rock screening data from the geochemical database for the Southern Sector.

Preliminary Modelling Results:

1 - Most DSDP/ODP drilled ORIs along the margin are thermally immature. It should be noticed, however, that site selection often avoids thick sediment sections.

2 - The exceptions are arguably the Aptian-Barremian source rocks offshore Namibia and South Africa.

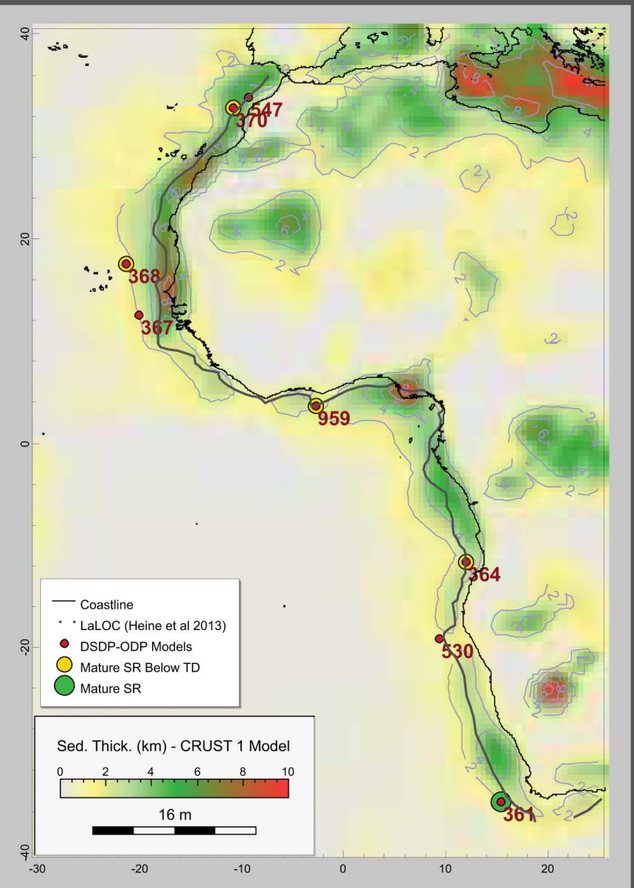
3 - In cooled oceanic basement, maturity of the Jurassic - Cretaceous ORIs takes place at burial depths > 3 km.

4 - Alternative thermal model scenarios constrained by heat flow data and lithosphere models suggest, however, that in extensive areas maturity may occur at lesser burial depths.

5 - The models also highlight the potential risk of early maturity and hydrocarbon expulsion.

Future Modelling Work:

- Use seismic and gravity constrained sediment thicknesses to delineate potential kitchen areas in selected, deep-offshore regions.
- Model along selected 2-D seismic transects, with a better constrained stratigraphy and crustal structure.
- Build charge risk maps for basins in transitional-oceanic domains along the West Africa Margin.



Sediment thicknesses (CRUST-1 Model; Laske et al. 2013) highlighting areas where syn/post-rift source rocks might reach maturity (i.e. oil window maturity colour scheme).

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