by A. D. Carr
Global Exploration Services Ltd.
West Sussex, UK

Thermal Modeling – Oil or Gas?
Examples from the Faroes-Shetland (NW Europe) and Casamance (NW Africa) Basins

From the South China Sea to the deepwater of West Africa, basin modelers frequently predict gas, yet oil is found. This presentation reviews where the modeling was in error and how the science can be put right. Examples will be shown of how the oil window may be deeper than traditionally modeled in some basins (e.g., Faroes-Shetland Basin), and how it can be shallower in other basins (e.g., Casamance Basin). In the latter case, the origin of the 2BBO plus oil charge to the Dome Flore discovery is now readily apparent whereas in the past it was necessary to draw on unproven source horizons. The message is that charge risks cannot be properly assessed, in either frontier basins or established plays, until the correct thermal model is applied.

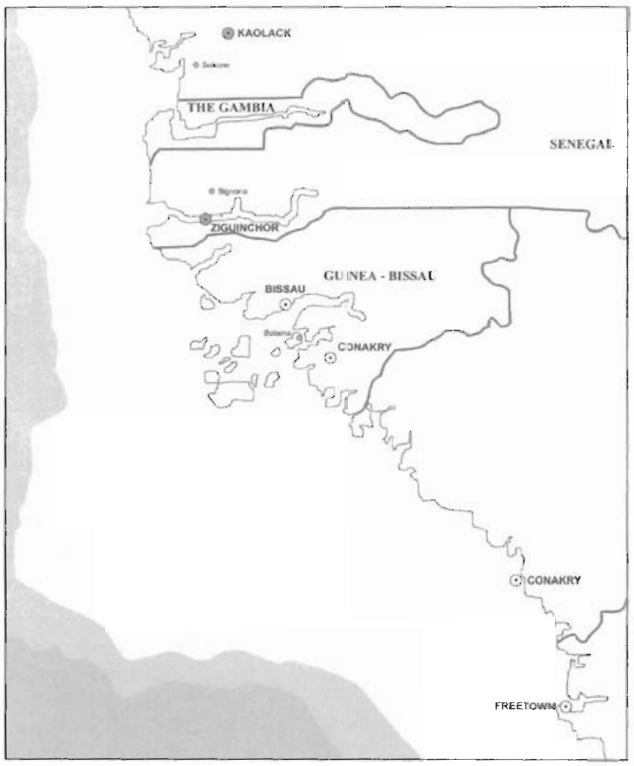

Figure 1. *Location map.*

Probably the most difficult task facing the basin modeler is the prediction of an accurate heat flow history. The most widely used method for thermal history prediction involves the use of maturation parameters, e.g., vitrinite reflectance in a kinetic model. With time provided by the stratigraphy, the thermal history is obtained by comparing the predicted and observed vitrinite reflectance data and adjusting the thermal history so that the predicted and observed values are the same. This can rarely be achieved without violating the thermal predictions of the established basin subsidence models (McKenzie, 1978), or without incorporating anomalies such as a heat flow pulse (Jensen and Doré, 1993). In some cases the basin subsidence thermal history models are ignored and a constant heat flow is applied. Geologists then have to devise other features to account for the hydrocarbon occurrences; for example, 'holding tank' (Doré et al., 1997) or 'whoopee cushion' models (Iliffe et al., 1999) in the Faroes-Shetland Basin.

As there is much more mass in the rocks than the vitrinite, the subsidence and exhumation histories of the rocks in a basin must provide the primary source of information from which the heat flow history can be determined. However, the vitrinite reflectance values predicted by heat flow histories obtained from tectonic models are much higher than the observed values. This has led geochemists and basin modelers to question the accuracy of tectonically derived heat flows (Yalçin et al., 1997; Waples, 1998).

continued on next page

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As there cannot be two different heat flow histories for any one point in a basin, discrepancies will occur between the heat flows obtained by the tectonic and the maturation calibration methods, mainly as a result of a flaw in the kinetic models used for heat flow modeling. Removing this flaw allows the use of a single heat flow history to predict both the tectonic development and the maturation and hydrocarbon generation histories.

The kinetic models used for maturation assessment assume that time and temperature control the reactions. However, these models fail to recognise the importance of pressure in a gas phase reaction. Vitrinite generates gas during maturation and while an increase in temperature increases the rate at which the reaction proceeds, increasing pressure reduces the rate at which the reaction occurs (Carr, 1999). This relationship between the influences that temperature and pressure have on a chemical reaction is known as Le Chatelier's principle. As high pressures retard maturation, the incorporation of pressure into a kinetic model (PresRo®) enables the vitrinite reflectance data to be modeled in high-pressure areas such as the Faroes-Shetland Basin. The thermal model developed for this basin contains elevated heat flows during the three periods of Cretaceous rifting, a further period of heat flow associated with the end of Paleocene volcanism, and a smaller event associated with the Oligocene-Miocene compression that exists along much of the NW European Atlantic margin. The use of the PresRo model overcomes the problem observed by modelers using a non-pressure dependent kinetic system, namely, that while their models indicate the source rocks should have generated significant quantities of gas, the hydrocarbon discoveries contain very little gas (GOR ~ 0.1). The PresRo model indicates that the maturation and hydrocarbon generation of the source rocks is being retarded by the high pressures in the basin, and that oil as opposed to gas, will be the main product generated.

In the case of shelf margin basins in northwest Africa, e.g., the Casamance Basin of southern Senegal and northern Guinea-Bissau (Figure 1), the sedimentary succession is rarely overpressured although, as in overpressured basins, the vitrinite reflectance values of the main source rock (Cenomanian to Turonian) are generally low (< 0.6% *Ro*). The source rock therefore, appears to be relatively immature in the region of the Dome Flore oil discoveries, which contain approximately 1×10^9 BBLS of 12-13° API (biodegraded) oil. It is also impossible to model the maturation of the wells in this area with a heat flow history based on the tectonic development of the basin. However, the reflectance values obtained from these organically rich (Type II kerogens) source rocks are suppressed and removing the effects of this suppression enables a heat flow history based on the McKenzie (1978) rift model to be used. The Cenomanian-Turonian source rocks are actually mature for oil generation over a significant proportion of the shelf. Given the quality and extent of these mature source rocks and the emplacement of at least 2×10^9 BBLS of 35° API oil prior to biodegradation, there is no need to invoke the presence of an alternative source rock. Figure 2 illustrates, for the Dome Flore region, the previously applied top peak oil window and the shallower corrected oil window. The difference is 900 meters.

In the Faroes-Shetland and Casamance Basins the maturation modeling forms part of a single consistent model that accounts for both tectonic development and hydrocarbon generation. The ability to model independent parameters, e.g., tectonics and maturation within a single heat flow history, is an indication of the accuracy of the thermal model. Finally, the use of an accurate thermal model reduces the risk associated with hydrocarbon generation and produces an overall improvement in the understanding of the petroleum systems operating in a basin.

Biographical Sketch

DR. ANDREW D. CARR obtained a BSc in Geology from Swansea University and a PhD in organic geochemistry from Newcastle University in 1978. He worked for 16 years with BG, leaving in 1996 to form his own consultancy (Advanced Geochemical Systems). Recently, in conjunction with colleagues, he set up an integrated service company (Global Exploration Services).

Andy works mainly as a petroleum geochemical and basin modeling specialist in teams involved in prospect and basin evaluation. More recently he has specialized in predicting heat flow histories for other basin modelers to model hydrocarbon generation.

You can contact Andy at Global Exploration Services Ltd., Little Lower Ease, Cuckfield Road, Ansty, West Sussex, RH17 5AL, UK (telephone: 011-44-1509-881284, e-mail: andy@globalexplor.com).

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Figure 2. An illustration showing correct placement for the oil window, when overpressure retardation and vitrinate suppression are accounted for, using the PresRo® program. It is now evident that Dome Flore and Dome Gea were charged from the known source section and there is no longer any need to rely on an unproven Albian source. This display was re-drawn, re-interpreted, and is presented by FIRST EXCHANGE Corp. as exclusive agent for the AGC (the Agency for JointCooperation between Guinea Bissau & Senegal) using materials available to that controlling government agency (AGC) in reports relinquished to the AGC and originally provided by Atlantic Resources, Beicip and Petroconsultants.