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Maturity trends from vitrinite data on the northern Grand Banks

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Abstract

Vitrinite reflectance data are presented from drill cuttings of 15 offshore exploration wells on the northern Grand Banks of Newfoundland, Canada. The wells are in the Flemish Pass, Flemish Cap, northern Jeanne d' Arc and East Newfoundland basins. They show an inhomogeneous maturation system and there is no obvious geospatial correlation. The geothermal gradients expressed as LogRo vary by a factor of two. The maturity at 3 km below sea floor varies from 0.47 to 0.91% Ro. The maturity at the base of the Tertiary Banquereau Formation ranges from 0.28 to 0.70% Ro. Although there are significant unconformities within the sedimentary section, only two wells show a clear break in the maturity profile across the Avalon unconformity. Generally, the Ro profiles show a gradual increase with depth, in a stepping pattern that is more pronounced in some wells than others.

This inhomogeneity is not surprising: data from the better understood Jeanne d' Arc Basin show a similar trait. One possible cause is local movement of hydrothermal fluids through the section. Bonanza M-71 appears to show this effect. A second possibility is retardation in vitrinite maturity from overpressure. Other wells appear to show opposite trends, but not all wells do have overpressure. A final unlikely cause may be reworking of vitrinite eroded from other sources. The variation in geothermal gradient makes thermal modelling and prediction of maturity levels at undrilled locations very difficult.

Well Locations

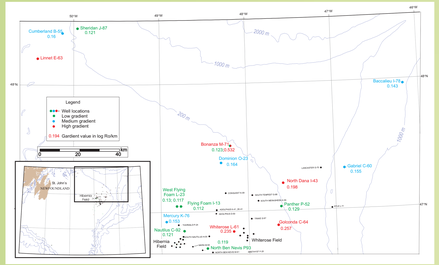


Figure 1: Location map

The northern Grand Banks well locations are shown in relation to Newfoundland, the oil fields at Hibernia and Whiterose. Green wells have a low, blue wells an intermediate, and red wells a high maturity gradient; that number is indicated. The wells are also on Figure 2.
Gradients of red wells are at least twice that of the green wells. The maturity groups show no geographic pattern.

Geology of study area

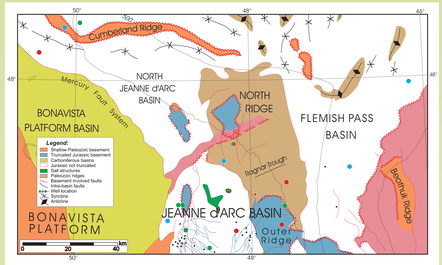


Figure 2: Tectonic Elements map

This is an excerpt from the Tectonic Elements map (Edwards et al., in press) showing basins, major tectonic and geologic features. The Tertiary is underlain by an erosional surface that may have eroded as deeply as the Carboniferous rocks shown. Salt diapirs are shown in dark-green. The studied wells have the same colours as on Figure 1. There appears to be no relationship between geologic location and the LogRo gradient, age of the underlying basin, or to known heat conductors such as salt diapirs.

Time - distance stratigraphic diagram

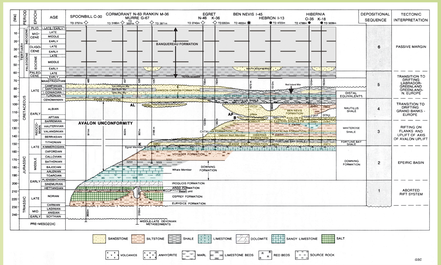


Figure 3: Time-distance diagram

The diagram shows time, not depth, versus distance and was modified from McAlpine (1990) by adding detail in the Tertiary as outlined by Deptuck et al. (2003). The Tertiary Banquereau and Late Cretaceous Dawson Canyon and Eider Formations are underlain by the Avalon unconformity that removed rocks from Late Cretaceous to Carboniferous age. Note also the pervasive base Tertiary unconformity.

Unconformity offsets

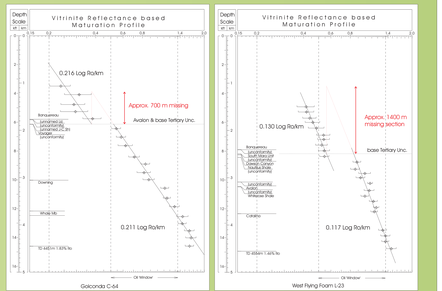


Figure 4: Avalon and base Tertiary Break

Only a few wells show a distinct break in the Ro gradient at the Avalon and base Tertiary unconformity. The underlying section reached a higher maturity gradient prior to erosion than the overlying sediments do now. This may have been caused locally by active paleo-hydrothermal systems in some wells. Bulges in the profile of wells like Bonanza M-71 can be so explained, or by vitrinite reflectance retardation.

Maturity profiles

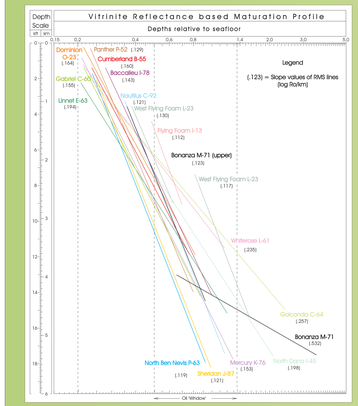


Figure 5: LogRo gradients

The LogRo gradients of the investigated wells show three groups. Low values are around 1.2, medium around 1.5, and high values are 1.9 and above. The well locations are on Figures 1 and 2. Bonanza M-71 has two gradients with significantly different slopes: 0.123 and a very high 0.532.

Retardation of maturity due to overpressure

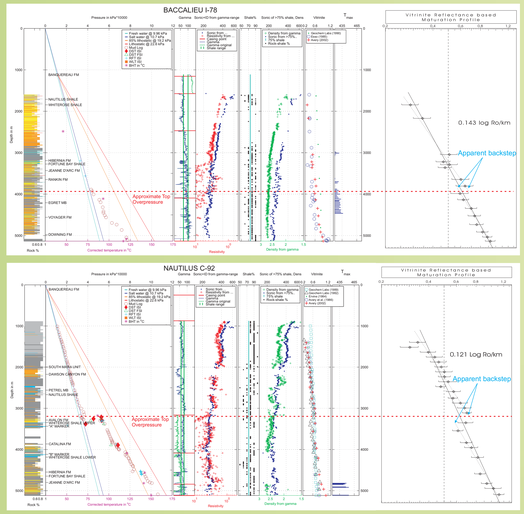
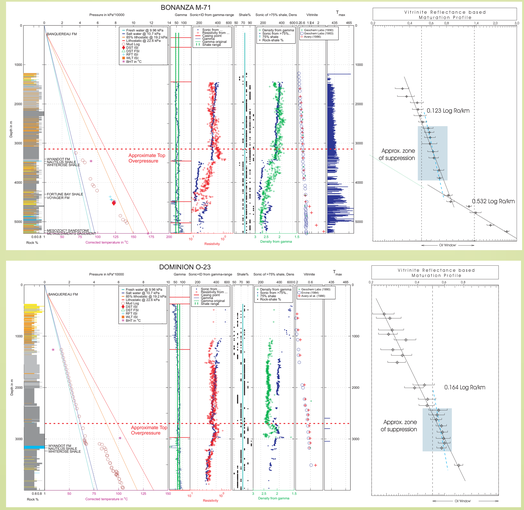
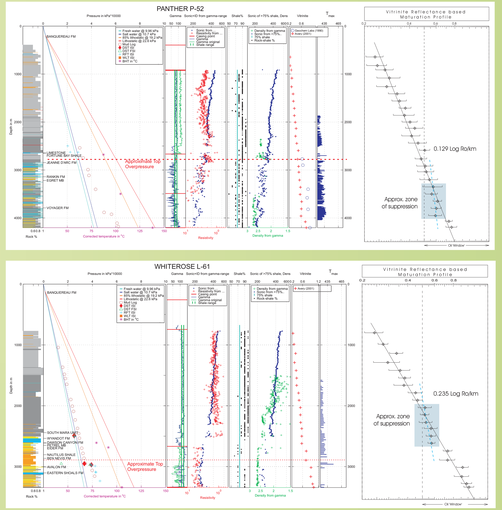


Figure 6: Pressure-Ro plots

Diagram explanation:
The pressure plots were made to show overpressuring and its relation to wireline logs, borehole temperature, lithology, stratigraphy, vitrinite reflectance retardation and Tmax retardation. All data are from the BASIN database. The plots for each well show five panels. The first panel shows the lithology in commonly used colours, as well as formation tops. The hydrostatic pressures of fresh and salt water are shown in light and dark blue, the lithostatic pressure in red and 85% of lithostatic pressure in orange. Red stars are for corrected borehole temperatures. Pressures are from tests (shut-in pressure) and drilling mud weights. **Overpressure** is defined as pressure points that are significantly above the hydrostatic gradient; it is called 'hard' when near the lithostatic gradient. The pressure profile generally increases in steps.

Retardation of vitrinite reflectance at onset of oil generation





Fertl (1976) showed that wireline logs from wells in the Gulf of Mexico, especially the sonic, density and to some extent resistivity, indicate overpressures, in the form of a 'dogleg' in the logarithmic slope. This works only in shales and is shown in panels two and three. Sonic (blue dots) and resistivity (red crosses) were plotted only if the gamma ray shale range (first part of second panel) confirmed shale. A shift has been applied to the gamma ray log where obvious digitising errors were made at casing points. This is not strictly correct, a scale factor should have been applied but was not available. Another technique is to use the lithological data. On the third panel, sonic (blue dots) and density (green crosses) were plotted where rocks were more than 75% (blue vertical line) shale. The next two panels show vitrinite data from several authors, and Tmax data. Both may show retardation. The last panel shows our Ro data with gradients and observations.

What does it all mean?

Maturity retardation due to overpressure and vitrinite reflectance retardation due to hydrocarbon generation.

Only Baccalieu I-78 and Nautilus C-92 show a distinct expression of retardation of vitrinite reflectance (Carr, 2000), although indications appear in several wells. The Ro data appear to show retardation between Ro=0.55 to 0.6, the onset of the oil window, such as in Bonanza M-71, Dominion O-23, Panther P-52 and Whiterose L-61. In many wells the Tmax also shows retardation (Bonanza M-71). Near that same depth the overpressure starts. On Grand Banks and the Scotian Shelf the overpressure does not start at a specific sediment depth or rock formation. It appears that the overpressure is not caused by undercompaction such as in the Gulf of Mexico, but by the generation and migration of hydrocarbons into traps with impermeable seals, as seen in the North Sea. An explanation of the retardation is the retention of generated volatiles within the macerals due to the overpressures (Carr, 2000; Wielens & Jauer, 2001).

The borehole temperatures from one well to another at the same depth or in the same formation are significantly different. Extrapolated to surface, many do not even intersect near 0° C, e.g. Dominion O-23. Combined with the large variation in, and erratic relation between LogRo slopes and location in Figures 1, 2 & 5, it suggests to us that local, fairly recent hydrothermal systems affected the maturity in the medium and high LogRo gradient wells. Overprinted on this is vitrinite reflectance retardation by hydrocarbon generation. Hydrothermal effects late during deposition of the Whiterose Shale Formation would explain the kinked LogRo trend in Bonanza M-71. In wells farther south on Grand Banks (e.g. St George J-55) a pronounced bulge is present on the LogRo profile. The only explanation appears horizontal hydrothermal flow confined to a carrier horizon.

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