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# Analysis of Large Thermal Maturity Datasets from the Canadian Arctic Islands

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## Summary

An approach for verifying thermal maturity data is illustrated using a large historical dataset from the Canadian Arctic Islands. A compilation of more than 6,000 maturity measurements (vitrinite reflectance and Rock-Eval Tmax) collected over the span of three decades involved a rigorous assessment of data quality. Some common anomalies in interpreting thermal maturity dataset include: (i) elevated thermal maturity due to Cretaceous igneous intrusion in the region, (ii) reworking of refractory material from older rocks into younger strata, (iii) suppression of vitrinite reflectance and Tmax in hydrogen-rich samples, (iv) low maturity values due to cross-contamination by younger sediments during the drilling process (caving), and (v) offset maturity values obtained from different maturity measurements.

A strategy of using complimentary evidence from diverse, independent maturity parameters was used to assess data quality. These parameters include vitrinite reflectance, gas wetness, Rock-Eval Tmax and Hydrogen Index, and sonic interval transit time. The comparison between thermal maturity as derived from vitrinite reflectance and/or Tmax with the sonic velocity of shale was extremely useful in discriminating between contradictory data. While such a correlation may vary in different sedimentary basins, it produces a useful independent assessment of thermal maturity in the Sverdrup and Franklinian basins. The results indicate that increased heat flow during the Jurassic-Early Cretaceous rifting of the Canada Basin may have elevated the maturity beyond that expected from the burial depth. Given the fact that vitrinite reflectance records only the maximum temperature to which the enclosing rocks were exposed, deviation of the collected reflectance values from the current depth of burial serves as an indicator for the amount of geological uplift.

## Introduction

Thermal maturity data are a key component of basin analysis and hydrocarbon assessment. These data provide constraints on the maximum depth of burial and paleogeothermal gradient in an exploration borehole. In a frontier area, like the Canadian Arctic Islands where drilling is very widely spaced and petroleum systems poorly known, generating new exploration plays requires the best possible thermal maturity data to estimate the areas in which source rocks are likely to produce hydrocarbons, and whether oil or gas is expected.

Compiling these disparate data into a single, reliable dataset posed a significant challenge. This paper describes an approach to verifying the dataset using independent parameters such as the sonic velocity from well logs. Lastly we try to use the datasets to resolve the heating caused by burial from elevated heat flow, and calculate uplift.

## Correlation of maturity parameters

Quick checks of the data can be made by comparing the depth—maturity curve from a well to those from nearby wells. The thermal maturity derived from vitrinite and Rock-Eval can also be compared to fossil colour alteration parameters such as the conodont colour alteration index (CAI) or pollen-spore thermal alteration index (TAI; e.g., Utting et al. 1989). While these checks may help point to problems with the data from a particular well, they seldom are sufficient to decide which data are suspect and which are reliable.

A second check on the thermal maturity is given by the gas wetness (Snowdon and McCrossan, 1973; Monnier et al., 1981; data in Dewing et al., 2007). Gas wetness is defined as the proportion of methane (C1) to methane, ethane, propane, and butane (C1 to C4). These data were collected from canned cutting samples shortly after drilling. In the lab the cuttings were homogenized with water in a gas-tight blender. The headspace gas was then analyzed for methane, ethane, propane, and butane. Comparison of the change from dry to wet gas (95% methane) and the best-fit curve derived from vitrinite and Rock-Eval data shows that the dry-to-wet transition occurs at 0.5±0.13% Ro Vi eq. Gas wetness data from drill holes in the lower Paleozoic succession documents the change from wet gas in shallower rocks to dry gas in deeper rocks as the butane, propane and ethane are cracked to methane. Data from five wells in the lower Paleozoic succession for which there is good reflectance or Rock-Eval data show the gas wetness decreases dramatically between 1.78 Ro % and 2.44 Ro% with the gas wetness dropping below 50% at about 2.0 Ro%.

A third check of the best-fit depth-maturity curve was obtained by comparing the Rock-Eval hydrogen index (HI=100*S2/TOC) with the expected reflectance derived from the depth—maturity curve. There is a well-known decrease of HI with increasing thermal maturity in the range of 0.8 Ro% to 1.4 Ro% (Peters, 1986; Cornford et al., 1998). The data for wells that are not consistent with expected decrease in HI were removed from the dataset for the purposes of mapping.

The best independent check of thermal maturity comes from comparison with the sonic velocity of shale. As the organic matter in a shale is buried, its temperature and vitrinite reflectance increase. Burial also compacts shale, so that the velocity of sound through the rock will increase, implying that there should be a correlation between sonic velocity and thermal maturity. Mallick and Raju (1995) documented a positive correlation between increasing sonic velocity and increasing vitrinite reflectance for Tertiary strata in India. Figure 1 shows the correlation of reflectance and sonic interval transit time (SITT) for several shale units in the Arctic Islands. The SITT measures the time for sound to travel a set distance and hence is the inverse of the sonic velocity.

The SITT was determined at the base of three widespread shale units in the Arctic: the Jurassic Jameson Bay Formation, the Triassic Murray Harbour Formation, and Devonian shales from the clastic wedge (Cape de Bray, Weatherall, Beverley Inlet formations). In each case, sandstone intervals were excluded using the gamma log response, and a best-fit curve established for the sonic log. The value of the SITT at the base of the formation was determined from the best-fit curve. Changing the sandstone—shale cutoff on the gamma log within a reasonable range has very little effect on the SITT curve. The correlation between vitrinite equivalent reflectance and SITT (Fig. 1) is reasonably good between vitrinite equivalent reflectance of 0.4% to about 1.0%, with the data scattered by about 0.1% on either side of the best fit curve. Once the shale is fully compacted the sonic velocity no longer increases with depth; the sonic velocity in this dataset is insensitive to burial beyond a vitrinite equivalent reflectance of about 1.0% Ro. Correlation between vitrinite equivalent reflectance and SITT will be different between sedimentary basins since the heat flow, rate of burial, and chemistry of the shales will differ.

## Geological interpretation

Comparison of thermal maturity to SITT may aid in separating the effects of heating due to deeper burial from heating due to increased heat flow. Figure 1 shows that the SITT (a proxy for compaction) and vitrinite reflectance (a proxy for thermal stress) correlate well for most boreholes in the Canadian Arctic Islands. This would imply that the thermal response relative to the depth of burial is consistent over most of the islands, and that there were no great variations in geothermal gradient. These lower Paleozoic samples in the western Arctic (squares on Figure 1), consistently plot below the curve at lower depth of burial as inferred from the sonic interval transit time. This suggests that the lower Paleozoic samples are thermally matured at a higher temperature than would be expected from their burial compaction. Given the location of these wells in the western Arctic, in the area of Jurassic-Early Cretaceous rifting of the Canada Basin (Harrison and Brent, 2005), it seems likely that the elevated vitrinite reflectance was due to an increased thermal gradient during rifting rather than deep burial during the Ellesmerian Orogeny.

Given that vitrinite reflectance is not reversible from its maximum level and cannot decrease after is it set, it should be possible to determine the amount of uplift a sample has undergone by comparing the depth inferred by the vitrinite reflectance to the current depth of burial. The thermal maturity at the level of the Upper Triassic Gore Point Member of the Roche Point Formation was established for each well using the best fit line through the vitrinite equivalent reflectance points. The Gore Point Member is a useful marker because it is the only widespread limestone in the Sverdrup Basin so it is consistently chosen in wells, it is a good seismic reflector, and it is close to the two main oil-prone source rocks in the Sverdrup Basin. Figure 2 shows the depth of the base of the Gore Point Member below sea level plotted against the vitrinite equivalent reflectance.

A normal burial curve is established using boreholes drilled in areas with no structural complexity. This curve, shown by the shading between the two black lines on Figure 2, indicates the path that the Gore Point Member in the Sverdrup Basin took during burial. Most exploration for oil and gas took place on large, salt-cored anticlines, so most samples of the Gore Point Member come from uplifted areas. The salt-cored structures formed late in the basin history in the Eocene, during the Eurekan Orogeny, and hence post-date maximum burial (Fig. 2). This means that they once sat within the shaded area and have been uplifted, so that the reflectance is much greater than the current depth of burial would indicate.

A minimum estimate of uplift can be derived from the vertical distance between the normal burial curve and the current position. For instance, samples of the Gore Point Member from large, salt-cored anticlines at Cape Allison C-47 and Skate C-59 shown on Fig. 2 have uplifts of about 400 and 800 m, respectively. On-going stratigraphic and seismic studies seek to confirm or refute these estimates.

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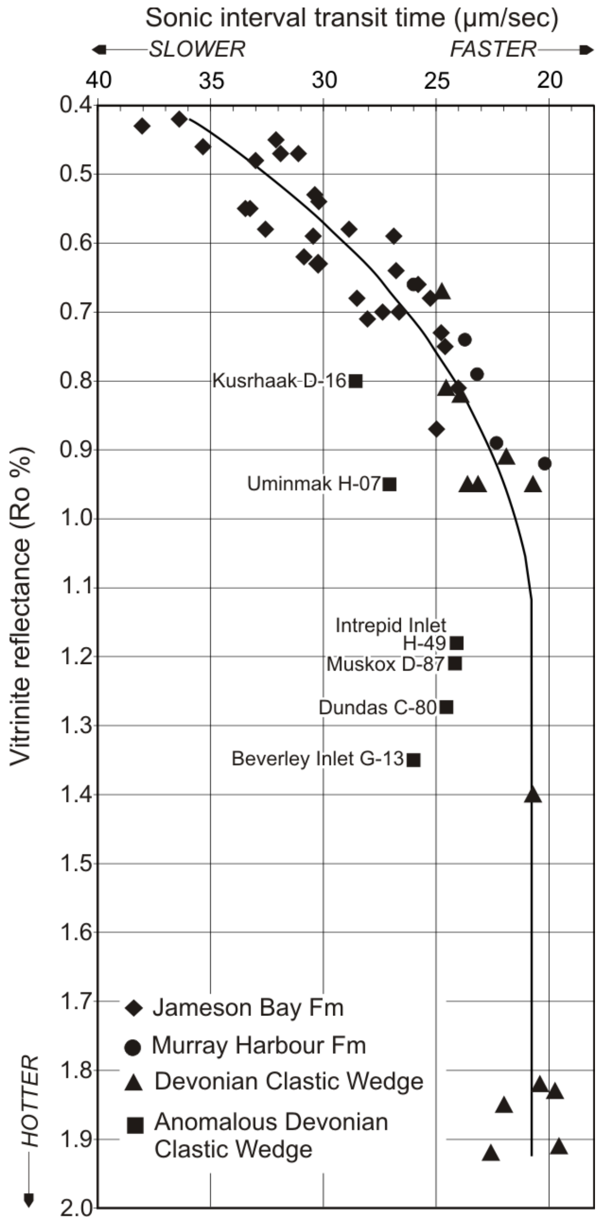

Figure 1. Comparison of vitrinite reflectance (Ro%) and the sonic interval transit time (SITT; μm/sec) for three shale units in the Canadian Arctic Islands. There is good correlation between SITT and reflectance for most samples up to a reflectance of about 1.0%. At this point the shale is fully compacted and its velocity does not increase with deeper levels of burial. Samples from the western Arctic (squares) consistantly plot below the curve, indicating an anomalous heating event.

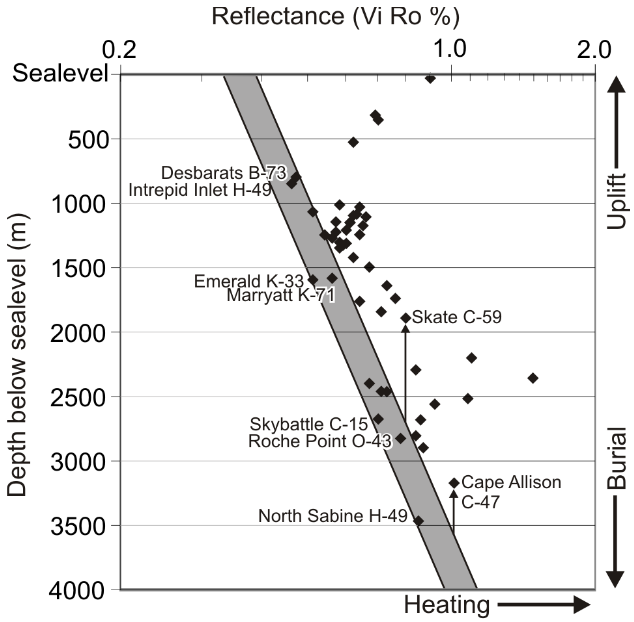

Figure 2. Depth vs. reflectance for the Gore Point Member of the Roche Point Formation (Triassic). The shaded area is the normal burial curve for the Gore Point Member in the Sverdrup Basin as defined by wells from structurally undisturbed areas. Samples of the Gore Point Member from large, salt-cored anticlines at Skate C-59 and Cape Allison C-47 have reflectances much greater than their current depth of burial indicates. The difference between the normal burial curve and the current position gives an estimate of the uplift amount.