# A Standardized Approach to Optical Thermal Maturity Assessment with Application to the Beaufort-Mackenzie Basin, Arctic Canada*

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## Abstract

New and legacy percent vitrinite reflectance (%Ro) data were compiled by the Geological Survey of Canada (GSC) for approximately 80 wells in the Beaufort-Mackenzie Basin. We have attempted to standardize the data obtained from different sources based on what we have learned about organic recycling and other factors that affect the quality of the measurements. The data were quality-checked by comparison with complementary thermal maturity indicators such as Rock-Eval Tmax, liptinite reflectance, and the degree of apatite fission track annealing, and were quality-ranked on a scale of “A” to “C”, depending on the amount of information available for each set of analyses (e.g. petrographic descriptions, raw measurements, etc.). Where possible, raw legacy measurements were reinterpreted based on the analysis or reanalysis of samples in the same wells or in the same stratigraphic successions of nearby wells. The “cleaned-up” %Ro data have been used to map regional maturity trends across the basin. Preliminary analysis shows that thermal maturity for a given depth decreases northward from onshore exhumed areas along the southern basin margin to offshore, rapidly-deposited Cenozoic successions beneath the Beaufort Sea. These data are valuable for ongoing petroleum assessment studies and for constraining basin thermal modeling.

## Introduction

From 2001 to 2010, the GSC was involved in a multi-disciplinary, government-industry funded study of petroleum systems of the Beaufort-Mackenzie Basin. The purpose of the study was to acquire a broad range of geological, geochemical, geophysical, and multi-parameter well data to characterize petroleum source rocks, and to constrain conceptual and quantitative models of thermal history, and petroleum generation, migration and accumulation. The analysis and publication of this large set of data is continuing under the Natural Resources Canada Earth Sciences Sector Geo-Mapping for Energy and Minerals (GEM) Program. As part of this work, new and legacy %Ro data for approximately 80 wells have been compiled, quality-assessed, and used to map thermal maturity trends across the basin. These data are important constraints for basin thermal models because they provide information on maximum paleotemperatures, paleogeothermal gradients, and erosion magnitudes. The %Ro data will be used in the future to constrain forward burial/thermal and inverse apatite fission track thermal history models that incorporate the most up-to-date geological data that were generated over the course of this comprehensive project.

## Method

Vitrinite reflectance is a well-established, commonly used thermal maturity parameter for constraining thermal history and petroleum potential of sedimentary basins. Temperature-dependent, kinetic models for vitrinite reflectance (e.g. Sweeney and Burnham, 1990) are typically included in basin thermal models, allowing model predictions to be tested and calibrated using measured %Ro values. However, sample contamination and alteration can complicate %Ro measurement and interpretation, and therefore will have impact on the quality of %Ro data. Sources of geological contamination/alteration include: (1) recycling and mixing of older, higher reflecting populations of vitrinite with indigenous organic matter at the time of deposition, (2) petroleum migration and impregnation (oil staining) that can suppress vitrinite reflectance values, and (3) organic oxidation that can increase %Ro values. Drilling-related contamination/alteration can include: (1) caving and mixing of drill cuttings samples from different depths, (2) use of organic additives (e.g. lignite) in the drilling mud, and (3) excess heating of sample material during drying. In addition, variation in %Ro values may arise from changes in lithology and organic facies, the analysis of coal versus dispersed organic matter, and the choice of analytical method (e.g. whole rock versus concentrated kerogen). For all these reasons, it is essential that %Ro measurements and interpretations are done by experienced analysts who are familiar with the regional geology.

Legacy %Ro data were obtained from GSC publications, internal databases, contracted consultants' reports and well history files of the National Energy Board. Where possible, %Ro data quality was assessed using complementary paleotemperature-sensitive indicators such as Rock-Eval Tmax, liptinite fluorescence, and degree of apatite fission track annealing (see Stasiuk et al.,2009; and Issler et al., 2012 for a discussion of methods and examples). Wells with problem data were selected for reanalysis and reinterpretation (e.g. Stasiuk et al., 2005), and new %Ro data were generated for additional wells by the organic petrology laboratory at GSC Calgary to improve regional coverage. In general, extensive organic matter recycling is the major factor affecting data quality whereas sample caving, oxidation and oil staining, although important, are less significant factors.

Data quality was assessed on a scale of "A" to "C" where "A" ranked data are the best-documented data and "C" ranked data are the least-documented and therefore associated with the greatest uncertainty. "A" quality %Ro data were generated by the GSC organic petrology lab and are based on detailed petrologic descriptions, abundant raw %Ro measurements, and associated complementary data sets such as Rock-Eval. "B" quality data are from external consultants and lack detailed petrologic descriptions but have raw %Ro measurements that are available for reinterpretation. These data can approach "A" quality data when the raw measurements are reinterpreted based on %Ro populations observed by the GSC laboratory for the same well samples or for the same stratigraphic successions in nearby wells. "C" quality data are from publications and well history reports and typically lack raw data and petrologic descriptions. Usually only mean %Ro values are recorded along with the number of measurements and %Ro ranges or standard deviations.

## Results

Recycled organic matter is particularly abundant in the Upper Cretaceous-Cenozoic, post-rift successions of the Beaufort-Mackenzie Basin and it can be dominant in the Neogene Iperk, Akpak and Mackenzie Bay sequences. Depending on the relative abundance of recycled vitrinite and the number and distribution of raw measurements, it can be difficult to reinterpret some of the "B" quality data without reanalyzing samples. Figure 1 shows how recycled vitrinite can distort %Ro trends. Figure 1a shows a reinterpretation of the original data of Pearson & Associates that was provided under contract to GSC Calgary in 1989. The measurements at depths of 3200 m or less are interpreted to represent recycled vitrinite. At greater depths, the measurements are interpreted to represent the true low thermal maturity of this rapidly-deposited (> 700 m/m.y. Iperk deposition rate) succession. Figure 1b shows the revised thermal maturity trend based on the reanalysis of samples by the GSC organic petrology laboratory. The extent of organic recycling is further shown by the anomalously high Tmax values (converted to %Ro equivalent values) in the Iperk Sequence (Figure 2).

"C" quality data are more difficult to assess due to the lack of raw measurements and must be judged in terms of regional structural/stratigraphic trends and maturity patterns in nearby wells. Eighteen (22%) of the study wells have "C" quality data but five of these wells also contain "A" and/or "B" quality samples that show good agreement with the "C" quality data. In other cases, there are nearby wells with "A" or "B" quality data that exhibit similar %Ro-depth trends to the "C" quality wells.

The standardized %Ro data were used to create contour maps and cross sections showing maturity trends across the basin. Figure 3 shows a preliminary north-south cross section that illustrates how %Ro values are highest along the exhumed southern basin margin and lowest in the rapidly-deposited Cenozoic strata of the outer shelf region beneath the Beaufort Sea. In general, the data conform to structural/stratigraphic trends.

## Conclusions

A careful examination of new and legacy %Ro data has shown that organic matter recycling is the dominant factor affecting the quality of vitrinite reflectance measurements for the Beaufort-Mackenzie region. Legacy %Ro data from different sources have been reinterpreted and integrated with new measurements to provide a standardized set of quality-assessed %Ro data. Complementary paleotemperature-sensitive indicators (e.g. Rock-Eval Tmax, liptinite reflectance, degree of apatite fission track annealing) aided in the quality assessment of the %Ro data. These %Ro data are consistent with regional structural, depositional, and erosion trends and they provide a useful paleotemperature framework for petroleum systems studies and basin thermal modeling. The maturity evaluation method presented here could prove useful in the study of other sedimentary basins with diverse data sources.

## Acknowledgements

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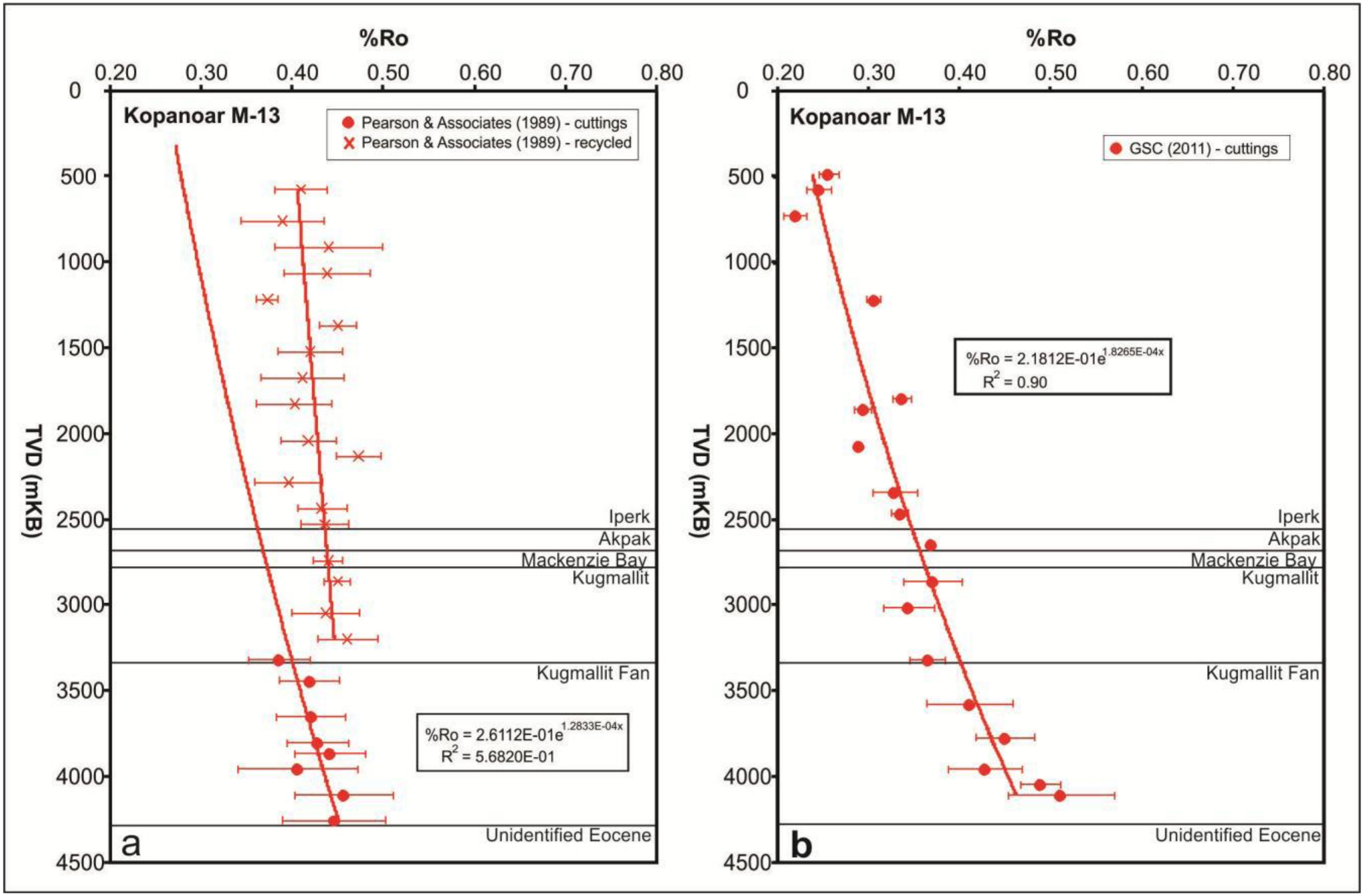


Figure 1. %Ro versus depth for the Kopanoar M-13 well, Beaufort Sea. (a) Reinterpreted data of Pearson & Associates (1989), and (b) reanalysis by GSC Calgary.

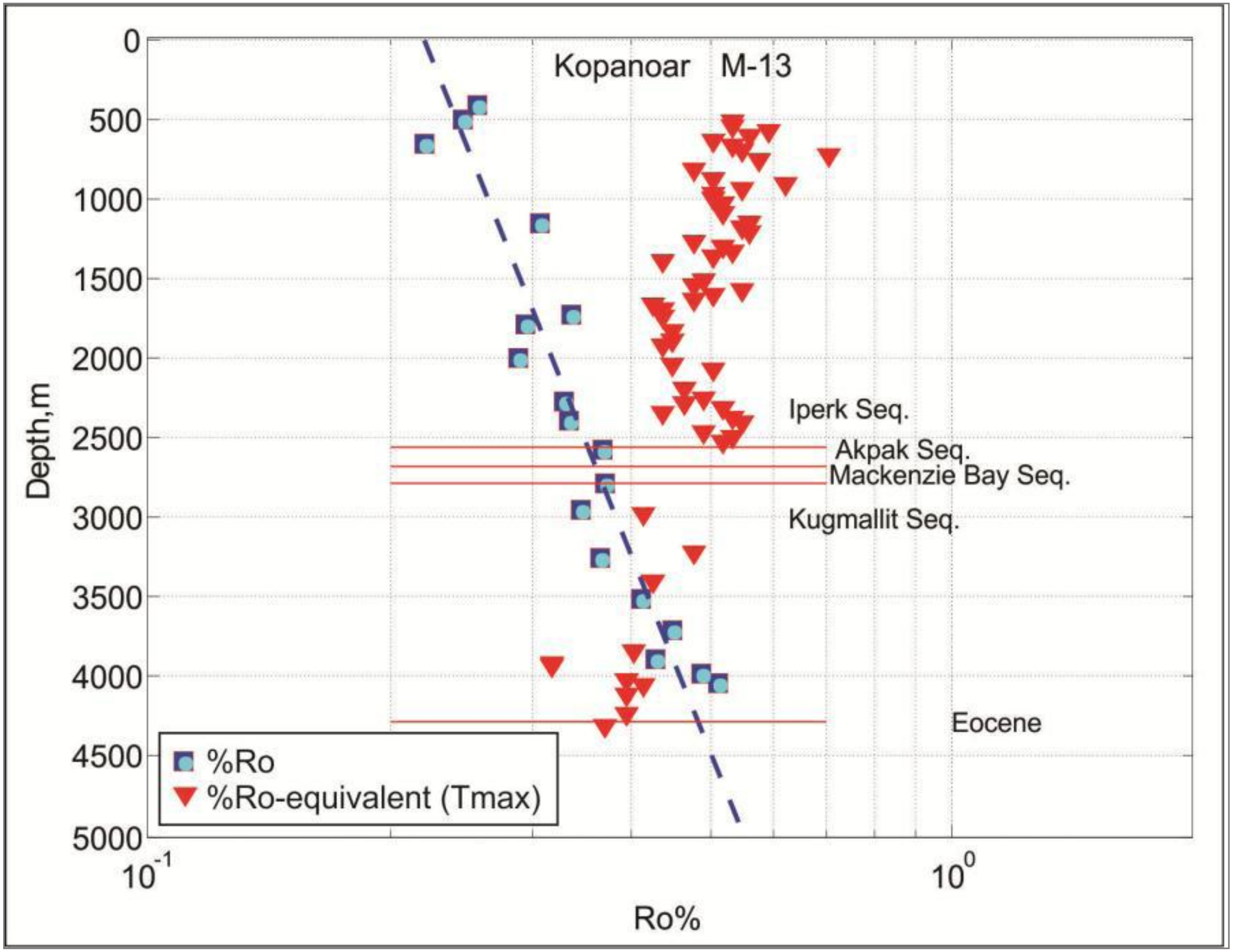


Figure 2. Comparison of %Ro and Rock-Eval Tmax versus depth for the Kopanoar M-13 well, Beaufort Sea. %Ro data were measured by GSC Calgary.

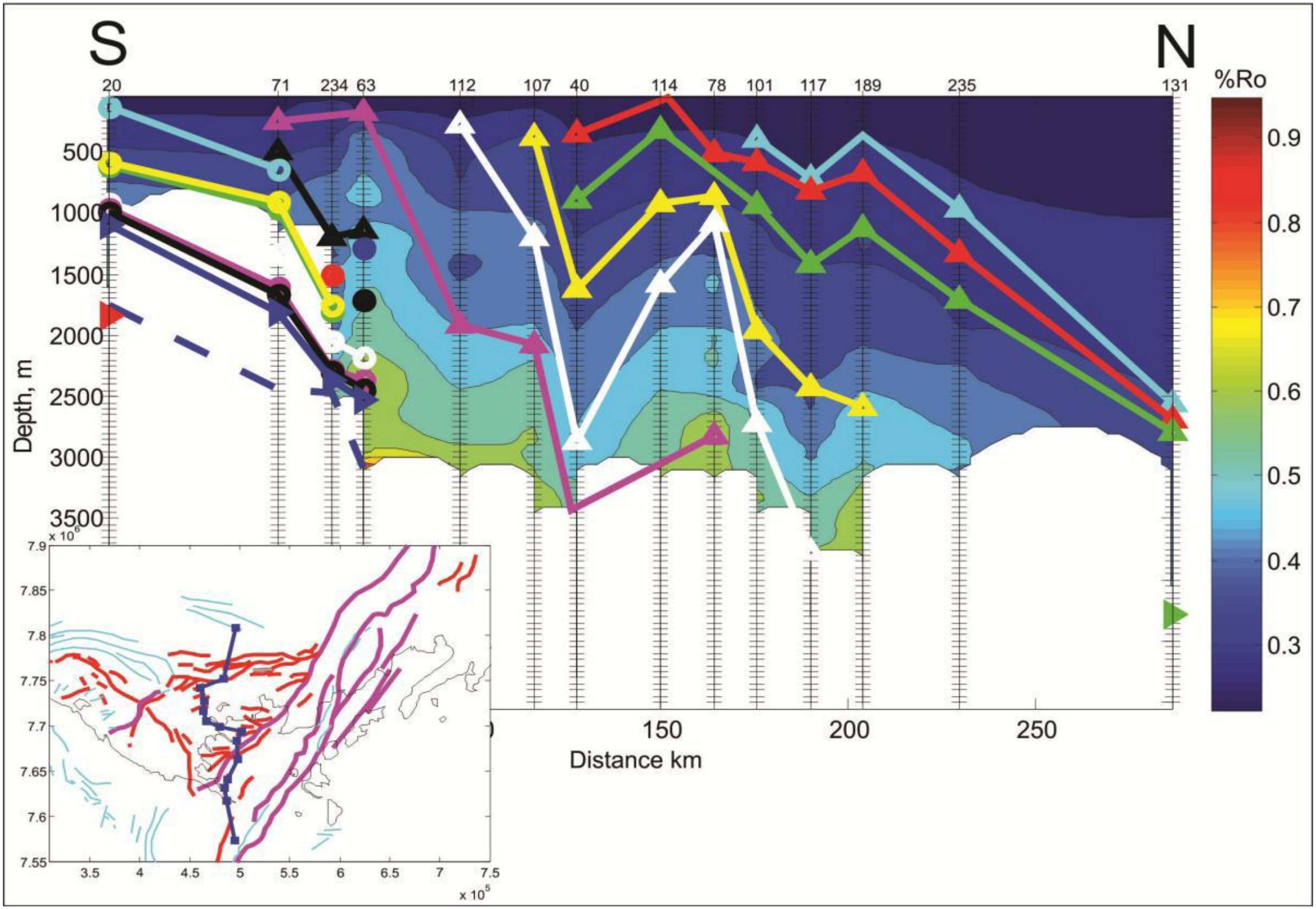


Figure 3. North-south cross section through Beaufort-Mackenzie Basin (blue line on inset map) showing %Ro trends with respect to various stratigraphic successions (coloured lines on cross section).