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## Abstract

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## Integrated Thermal History Analysis of Sedimentary Basins Using Multi-Kinetic Apatite Fission Track Thermochronology: Examples from Northern Canada

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Apatite fission track (AFT) thermochronology is a powerful thermal history analysis approach that is well suited to the study of sedimentary basins. It originated as a geochronological dating method in the 1960s but has been continually evolving as new insight has been gained concerning the time-temperature conditions and mineral compositional factors influencing the thermal annealing of fission tracks in apatite. Fission tracks are linear zones of crystal damage that result from the spontaneous fission of  $^{238}\text{U}$ . They are revealed by polishing and etching mounted grains, allowing their orientations and lengths to be measured. The nominal initial length of fission tracks in apatite is approximately 16  $\mu\text{m}$ . AFT annealing, or shortening of the track lengths, is well characterized through lab and field studies allowing annealing kinetics to be extrapolated to geological timescales. On such timescales, annealing occurs within and somewhat below the temperature range for petroleum generation and can thus be used to constrain petroleum generation histories through numerical modeling. State-of-the-art methodology is being applied to thermal history studies of northern Canadian basins (Beaufort-Mackenzie and Mackenzie Valley regions in the Northwest Territories) and much has been learned that challenges existing data analysis and modeling approaches. In these regions, mixed AFT compositional populations greatly complicate data analysis and thermal modeling.

New concepts of multi-kinetic AFT annealing (Ketcham *et al.*, 1999) based on published laboratory heating experiments (Carlson *et al.*, 1999) have been incorporated into an inverse AFT thermal history model (AFTINV) that was developed in-house. Statistically distinct AFT kinetic populations can be defined successfully using the  $r_{\text{mro}}$  parameter (Ketcham *et al.*, 1999) which integrates the results of elemental analyses for individual

apatite grains. This kinetic parameter method is superior to widely used single-parameter methods based on apatite solubility (Dpar or AFT etch figure width) and Cl content. Under this scheme, different AFT kinetic populations act as separate thermochronometers that, when modeled simultaneously, enhance the resolution of the thermal history. For the Beaufort-Mackenzie region, mixed AFT populations are mainly the result of compositionally-related differences in AFT annealing kinetics. Joint inversion of AFT and other thermal maturity data (e.g. %R<sub>o</sub>) yields information on the post-depositional heating and cooling histories of the Cretaceous-Cenozoic successions comprising the Beaufort-Mackenzie Basin and the cooling histories of the exhumed source areas from which these sediments were derived. An understanding of these histories is essential to constraining regional tectonics and the timing of petroleum generation.

For the Mackenzie Valley region, Cl content was used previously to define different AFT kinetic populations in a Devonian sample from an exploration well in the Tulita area south of the Norman Wells oil field (Issler *et al.*, 2005). Reanalysis of this data using the  $r_{\text{mro}}$  parameter indicates that the Cl-based results were misleading; new interpretations indicate that low Cl Cretaceous volcanic apatite was mixed with Cl-rich Devonian detrital apatite due to previously unrecognized contamination of drill cuttings. Subsequent data modeling yields thermal histories that are similar to published ones, underscoring the value of an integrated thermal history analysis approach where multiple geological constraints provide a more robust solution. These results highlight the importance of obtaining complete elemental data for the proper characterization and interpretation of AFT data.

### References

- Carlson, W.D., Donelick, R.A. and Ketcham, R.A. 1999. Variability of apatite fission-track annealing kinetics: I. Experimental results. *American Mineralogist*, v. 84, p. 1213-1223.
- Issler, D.R., Grist, A.M. and Stasiuk, L.D. 2005. Post-Early Devonian thermal constraints on hydrocarbon source rock maturation in the Keele Tectonic Zone, Tulita area, NWT, Canada, from multi-kinetic apatite fission track thermochronology, vitrinite reflectance and shale compaction. *Bulletin of Canadian Petroleum Geology*, v. 53, p. 405-431.
- Ketcham, R.A., Donelick, R.A. and Carlson, W.D. 1999. Variability of apatite fission-track annealing kinetics: III. Extrapolation to geological time scales. *American Mineralogist*, v. 84, p. 1235-1255

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# Quantitative Analysis of Petroleum Systems of the Beaufort-Mackenzie Basin, Arctic Canada: An Integrated Approach

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The Beaufort-Mackenzie Basin is a petroleum exploration frontier region in Arctic Canada that has attracted considerable industry attention and investment. It contains more than 14 km of post-rift Upper Cretaceous to Cenozoic deltaic and marine sediments and is underlain in part by Jurassic to Lower Cretaceous syn-rift strata and Triassic to Proterozoic pre-rift carbonate and clastic sediments. Published resource assessments for significant conventional discoveries yield estimates of  $277.3 \times 10^6 \text{ m}^3$  (1.744 billion bbl) recoverable crude oil and  $332.4 \times 10^9 \text{ m}^3$  (11.74 TCF) of recoverable natural gas and estimates for the remaining undiscovered recoverable petroleum are  $856.5 \times 10^6 \text{ m}^3$  (5.39 billion bbl) and  $1.5 \times 10^{12} \text{ m}^3$  (53.3 TCF) for crude oil and natural gas, respectively (Dixon *et al.*, 1994). Gas hydrates form an immense unconventional gas resource with estimated volumes of raw natural gas in place exceeding total conventional gas estimates by a factor of approximately 2.3 to 5.6, depending on gas hydrate saturation (Osadetz and Chen, 2005).

For over eight years, the Geological Survey of Canada has been involved with an industry-government funded quantitative study of Beaufort-Mackenzie petroleum systems and has assembled and interpreted digital seismic data, and log and drilling data for over 250 exploration wells. In addition, specialized analyses were undertaken on an extensive set of core, cuttings and oil samples. Study activities include biostratigraphy, palynology, organic geochemistry, organic petrology, geophysics, structure, stratigraphy, log analysis, petrophysics, water geochemistry, apatite fission track thermochronology, basin modeling, and petroleum resource assessment and mapping. This integrated work has led to new ideas on oil source rocks

and an improved understanding of the geological factors controlling pore pressure and temperature for this area.

Ice-bearing permafrost (defined by log, temperature and velocity survey data) varies by over 700 m in thickness across the basin and forms an important upper thermal boundary for constraining basin geotherms and the gas hydrate stability zone. It is thinnest along the southern (landward) basin margin and in the deformed and erosionally exhumed western part of the basin, and is thickest in rapidly deposited Cenozoic strata of the eastern shelf beneath the Beaufort Sea. Geothermal gradients (from drill-stem tests and corrected bottom-hole temperatures) vary between 25 to 35 EC/km across most of the basin; higher gradients (30 to 50 EC/km) are associated with major fault zones and thicker crust on the southeastern basin margin. Primary overpressure (defined by log, mud weight and pore pressure data) is associated with thick, undercompacted Cenozoic strata; the depth to overpressure varies by more than 3 km and is controlled by basin structure and sedimentation rate. Hydrocarbon leakage is documented by thick gas hydrate zones above conventional petroleum accumulations (Osadetz and Chen, 2005) and by gas chimneys and the presence of diagenetic minerals and foraminifera alteration above breached petroleum reservoirs. New oil-source studies suggest that a significant contribution from deep Cretaceous and older sources (mature marine organic matter) has been overlooked due to extensive biomarker contamination from Tertiary rocks (lower maturity terrestrial organic matter). These results suggest a dynamic petroleum system with deep, active petroleum generation and vertical migration and mixing of petroleum in shallower reservoirs.

## References

- Dixon, J., Morrell, G.R., Dietrich, J.R., Taylor, G.C., Procter, R.M., Conn, R.F., Dallaire, S.M. and Christie, J.A. 1994. Petroleum resources of the Mackenzie Delta and Beaufort Sea. Geological Survey of Canada, Bulletin 474, 52p.
- Osadetz, K.G. and Chen, Z. 2005. A re-examination of Beaufort Sea-Mackenzie Delta Basin gas hydrate resource potential using a petroleum play approach. In: Exploration, Resources and Environment. Proceedings of the Fifth International Conference on Gas Hydrates (ICGH 5), v. 3, 3048, p. 1022-1032.

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## Dr. Dale R. Issler

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### Education:

- 1982 B.Sc., Honours Co-op Earth Sciences, University of Waterloo, Waterloo, Ontario
- 1987 Ph.D., Oceanography, Dalhousie University, Halifax, Nova Scotia



### Experience:

- 1990-Present Research Scientist, Geological Survey of Canada, Calgary, Alberta
- 2001-09 Project leader for industry-government collaborative research on petroleum systems of the Beaufort-Mackenzie Basin, northern Canada

- 1988-90 Canadian Government Laboratory Visiting Fellow, Geological Survey of Canada, Calgary, Alberta
- 1978-82 Several years of co-op work term experience with mining and oil companies across Canada

### Awards:

- Canadian Society of Petroleum Geologists Volunteer and Service Awards: 2008, 2006, 2002, 2001, 1995
- 2006 Earth Sciences Sector Merit Award
- 2000 Geological Survey of Canada Division Merit Award
- 1993 Canadian Society of Petroleum Geologists Medal of Merit for best paper in Canadian Petroleum Geology

### Selected Publications:

- Authored or co-authored over 60 scientific journal and government publications

- Grasby, S.E., Chen, Z., Issler, D. and Stasiuk, L. 2009. Evidence for deep anaerobic biodegradation associated with rapid sedimentation and burial in the Beaufort-Mackenzie Basin, Canada. *Applied Geochemistry* (in press).
- Chen, Z., Osadetz, K.G., Issler, D.R. and Grasby, S.E. 2009. Pore pressure patterns in Tertiary successions and hydrodynamic implications, Beaufort-Mackenzie Basin, Canada. *Bulletin of Canadian Petroleum Geology* (in press).
- McNeil, D.H., Dietrich, J.R., Issler, D.R., Grasby, S.E., Stasiuk, L.D., and Dixon, J. 2009. A New Method for Recognizing Subsurface Hydrocarbon Seepage/Migration Using Altered Foraminifera from a Gas Chimney in the Beaufort-Mackenzie Basin. *American Association of Petroleum Geologists, Memoir on Shale Tectonics* (in press).
- Issler, D.R., Hu, K., Lane, L.S. and Dietrich, J.R. 2009. GIS Compilations of Depth to Overpressure, Permafrost Distribution, Geothermal Gradient, and Regional Geology, Beaufort Mackenzie Basin, Northern Canada. *Geological Survey of Canada, Open File 5689* (in press).
- Chen, Z., Osadetz, K.G., Issler, D.R. and Grasby, S.E. 2008. Hydrocarbon migration detected by regional temperature field variations, Beaufort-Mackenzie Basin, Canada. *American Association of Petroleum Geologists Bulletin*, v. 92, no. 12, p. 1639-1653.
- Stasiuk, L.D., Sweet, A.R. and Issler, D.R. 2006. Reconstruction of burial history of eroded Mesozoic strata using kimberlite shale xenoliths, volcanoclastic and crater facies, Northwest Territories, Canada. *International Journal of Coal Geology*, v. 65, p. 129-145.
- Issler, D.R., Grist, A.M. and Stasiuk, L.D. 2005. Post-Early Devonian thermal constraints on hydrocarbon source rock maturation in the Keele Tectonic Zone, Tulita area, NWT, Canada, from multi-kinetic apatite fission track thermochronology, vitrinite reflectance and shale compaction. *Bulletin of Canadian Petroleum Geology*, v. 53, no. 4, p. 405-431.
- Issler, D.R., Hu, K., Bloch, J.D. and Katsube, T.J. 2002. Organic carbon content determined from well logs: examples from Cretaceous sediments of Western Canada. *Geological Survey of Canada, Open File 4362*.
- Issler, D.R., Katsube, T.J., Bloch, J.D. and McNeil, D.H. 2002. Shale compaction and overpressure in the Beaufort-Mackenzie Basin of northern Canada. *Geological Survey of Canada, Open File 4192*, 10 p.
- Issler, D.R., Willett, S.D., Beaumont, C., Donelick, R.A., and Grist, A.M. 1999. Paleotemperature history of two transects across the Western Canada Sedimentary Basin: Constraints from apatite fission track analysis. *Bulletin of Canadian Petroleum Geology*, v. 47, no. 4, p. 475-486.

**Professional Memberships:**

American Association of Petroleum Geologists  
Canadian Society of Petroleum Geologists

**Professional Interests:**

Quantitative basin analysis including model and methods development and applications  
Apatite fission track thermochronology  
Petrophysics and log analysis  
Compaction and abnormal formation pressure  
Petroleum generation kinetics