Natural Fracturing of the Canol Formation Oil Shale: An Unconventional Spin on the Norman Wells Oilfield*

Thomas Hadlari[1] and Dale R. Issler[1]

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[1]Geological Survey of Canada, Calgary, AB (thomas.hadlari@nrcan.gc.ca)

Introduction

Oil was discovered at Norman Wells (Figure 1) in the Devonian Kee Scarp reef in 1920. The current phase of development began in 1985, and over 90 years the field has produced more than 220 million barrels of oil. Whereas the oilfield appears to be a straightforward conventional system, available data are not necessarily consistent. We start with the proposition that a conceptual model should incorporate all available data and find that a slightly unconventional idea helps to explain why there is oil at Norman Wells.

Geological Framework

The source rock is considered to be black shale of the Canol Formation (Snowdon et al., 1987), which overlies the reservoir. Canol Formation has TOC of up to 8.5% (Type I/II kerogen; Gal et al., 2009), and it contains chert and dolomite cement. On outcrop the Canol Formation is resistant and forms cliffs. There is another excellent source rock in the region, the Bluefish Member of the Hare Indian Formation (TOC up to 11.92%, type I/II kerogen, Gal et al., 2009), and it lies below the Ramparts Formation, but organic geochemistry suggests that it was not a source for oil at Norman Wells (Snowdon et al., 1987).

The reservoir of the Norman Wells oilfield lies within the uplifted hanging wall of an east-vergent thrust that forms the Norman Range (Figure 2), a small mountain belt east of the Mackenzie Mountains. Permeability has been enhanced by fractures that have made parts of the reservoir economic that would otherwise be uneconomic (Yose et al., 2001).

The reservoir is a reef that was built upon the flank of a Devonian paleohigh that partly defines the Keele Tectonic Zone. Devonian and Cretaceous unconformities converge over the Keele Tectonic Zone. The result is that there were kilometre-scale differences in burial between Norman Wells (less) and areas to the southwest (more) in the Cretaceous and Tertiary; this prevented the source rocks from maturing beyond the oil window.

The presence of oil, the preserved stratigraphy, and Cenozoic structural deformation suggest that source maturation, oil generation, and migration must have been relatively young, and conventional reasoning suggests Tertiary timing (Issler et al., 2005; Gal et al., 2009). Fission-track thermochronology near the Keele Tectonic Zone, however, indicates that peak thermal maturity occurred prior to a Triassic to Cretaceous exhumation event (Figure 3; Issler et al., 2005). It is inferred that a significant pile of post-Devonian to Triassic strata was eroded (Issler et al., 2005).

Discussion

Mudstone of the Canol Formation has undergone chert and dolomite cementation during diagenesis, resulting in a brittle rock. In contrast, the Bluefish Member is not siliceous and is comparatively soft and friable. That single difference between source rocks could allow for generated hydrocarbons to have been retained within the Canol Formation and expelled from the Bluefish Member. If oil was retained within Canol Formation, then peak thermal maturity and oil generation could have been significantly separated in time from migration.

As the second easternmost mountain belt in the region, the Norman Range Thrust Fault is among the youngest of structures in the area. Although the timing of initial displacement is not clear, it is known that Mackenzie Mountains are presently being translated eastward, driven by collision of the Yakutat Terrane offshore of southern Alaska that began 5 Ma (Mazzotti and Hyndman, 2002).

We propose that neotectonics of the northern Canadian Cordillera and migration of the deformation front eastward from Mackenzie Mountains have uplifted and fractured the Canol Formation, thereby releasing hydrocarbon. In that way, oil migration and filling of the reservoir in the Norman Wells oilfield would be relatively young phenomena.

Conclusions

New advancements in understanding unconventional resources have changed our view of shale and hydrocarbon systems. Rock properties of certain shales allow for retention of oil and gas within source rocks. We propose a new conceptual model for the Norman Wells oil field:

1. Deposition of Devonian Hare Indian, Ramparts, and Canol formations on the flank of a paleohigh (Keele Tectonic Zone).
2. Maximum burial and thermal maturity were reached prior to exhumation that began in the Triassic. Oil was generated at that time and a portion was trapped within pores of the Canol Formation. The majority of hydrocarbons generated from the Bluefish Member were expelled and eventually lost to the system.
3. Pre-Albian uplift and erosion left the Devonian succession of Hume-Hare Indian-Ramparts-Canol-Imperial formations exposed at the surface on the flanks of the Keele Tectonic Zone. Any conventionally trapped hydrocarbons were flushed or biodegraded.
4. During Cretaceous and Tertiary deposition, the Keele Tectonic Zone was a paleohigh onto which wedge-shaped stratal geometries onlapped. The result was much less burial than regions to the west, followed by post-Eocene uplift and erosion.
5. Strain from collision of the Yakutat Terrane beginning 5 Ma was translated across the Cordillera and drove displacement on the Norman Range Thrust Fault. During uplift, fault-related fractures released hydrocarbons trapped within Canol Formation and provided conduits for migration.
6. Migrating hydrocarbons were trapped within the Kee Scarp reef, and some migrated through fractures to the surface where they were discovered as oil seeps.

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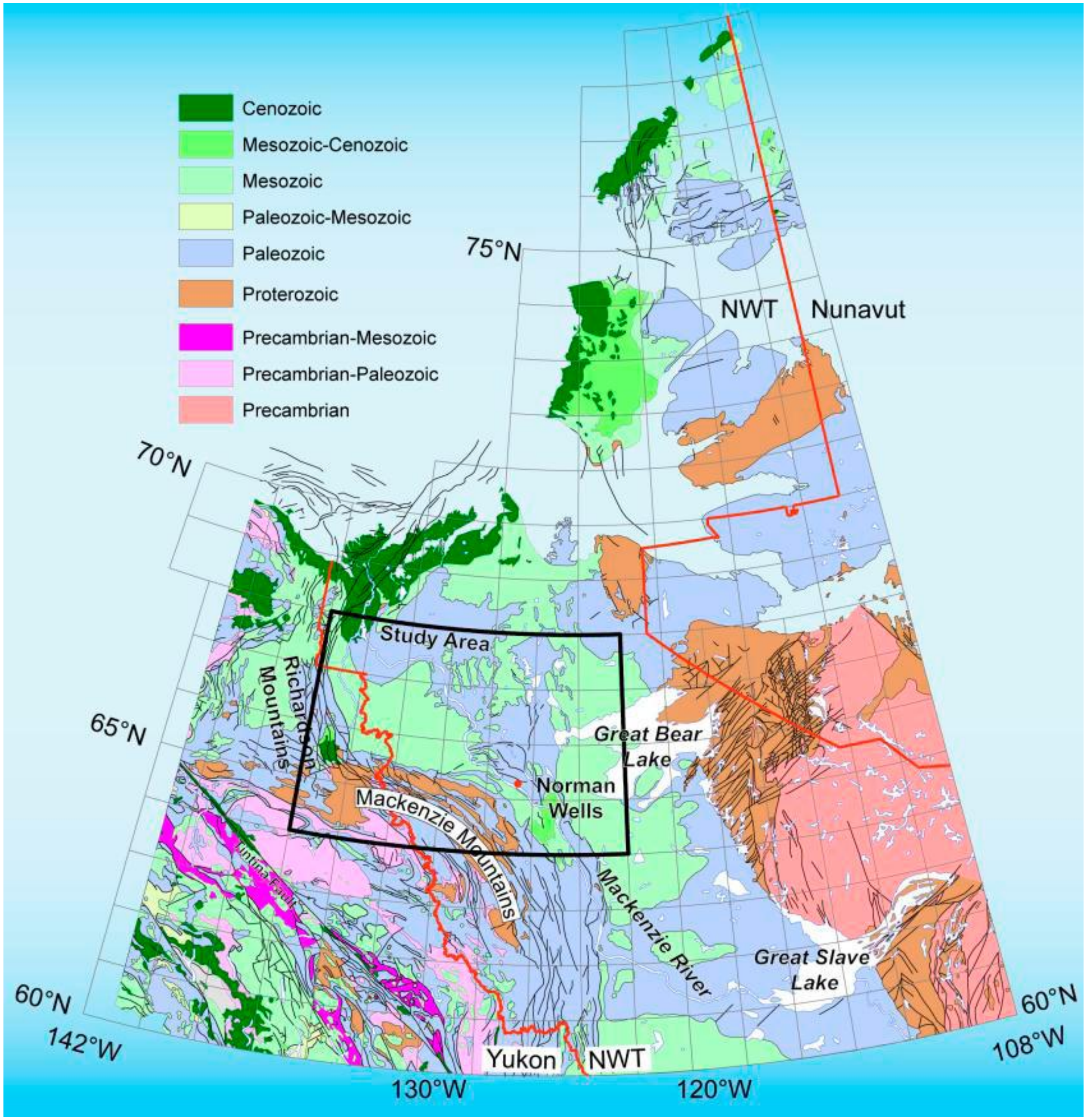

Figure 1: Geology map of Yukon and Northwest Territories, showing location of Norman Wells.

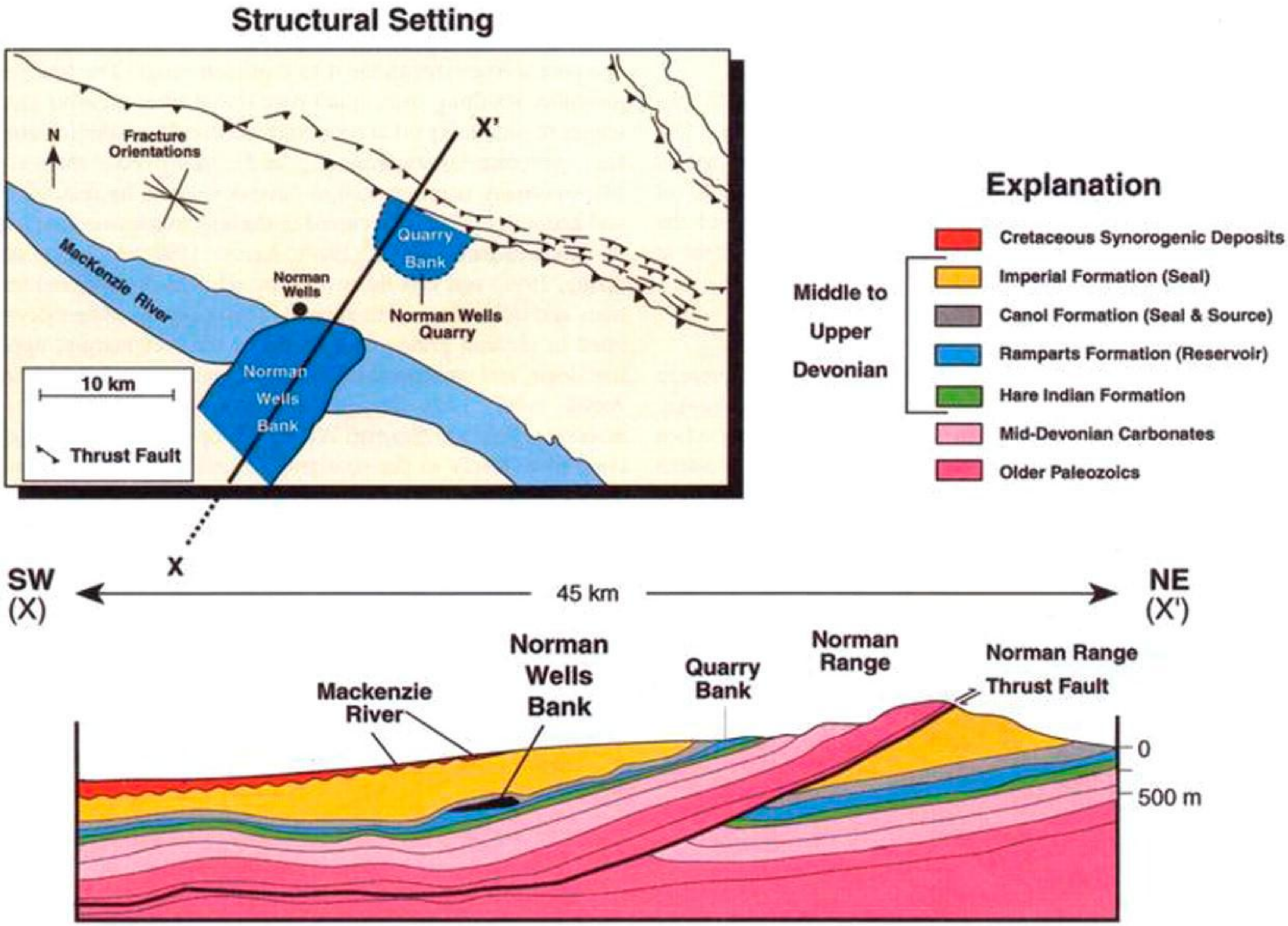

Figure 2. Structural framework of Norman Wells (reproduced from Yose et al., 2001).

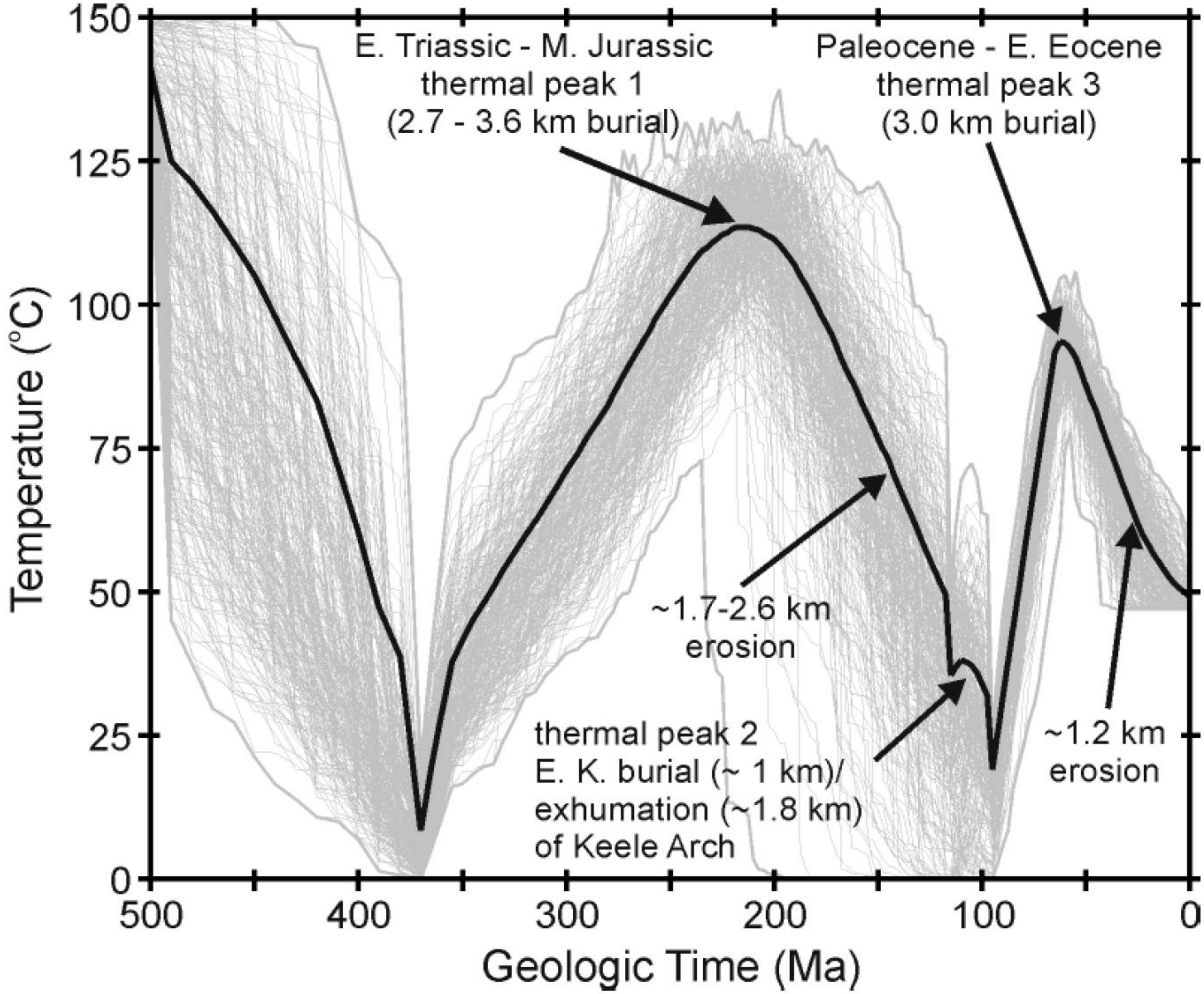

Figure 3: Apatite fission track thermal history for the East MacKay I-77 well, Keele Arch area (reproduced from Issler et al., 2005).