Thermal Maturation Considerations and the Significance of Phytoclasts in the Upper Member of the Lodgepole Formation in the Northwestern Williston Basin*

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Abstract

The study represents the first attempt to provide palynological data to help with the analysis of hydrocarbon source potential of the upper marker bed of the Lodgepole Formation (herein referred as the Upper Lodgepole). This study covers the southeast corner of Saskatchewan, Canada and northwest corner of North Dakota, USA. In this area, the Upper Lodgepole is a calcareous source rock that reaches a maximum thickness of roughly 30 m. X-ray diffraction calcite values range from 68-94%, total organic carbon (TOC) content from pyrolysis reaches a maximum of 9.06 wt. %, and vitrinite reflectance equivalence values from pyrolysis range from 0.76–0.87%. Based on Rock-Eval pyrolysis data, both from this study and others, it has been postulated that the Upper Lodgepole is a mature, kerogen type-II source rock that is well within the oil window. However, previous published studies have suggested that such elevated thermal maturity indicated from Rock-Eval pyrolysis is rather a result of lower hydrogen index (HI) and higher degree of oxidation. Palynological kerogen analysis of both core and cuttings unequivocally confirms the aforementioned hypothesis that organic material is indeed highly degraded. Furthermore, a detailed point count of the palynomorphs also shows the interval to contain 100% phytoclasts, a predominantly gas-prone, type-III kerogen.

Introduction

The focus of this study is on the uppermost organic-rich marker bed of the Lodgepole Formation in southern Saskatchewan, Canada and northwestern North Dakota – herein referenced as the “Upper Lodgepole”. The Upper Lodgepole has long been speculated as a significant source rock in the Williston Basin. Osadetz and Snowdon (1995) claimed that the samples analyzed in the Lodgepole have “consistently higher hydrocarbon yields suggesting marginal to excellent potential, better than other sources at comparable maturities”. Osadetz and Snowdon (1995) also reported the Upper Lodgepole to have up to 14.47 wt.% TOC with upwards of 444°C T_{max} northwest and up-dip of the present study area (Figure 1, Geological Survey Canada data points). Numerous penetrations while exploiting the underlying Bakken Shale show significant gas shows and solvent ultraviolet cuts on mud logs adding to the assumption that this could be a significant oil play worthy of being exploited. Published T_{max} values from the underlying Bakken shales tend to be on the magnitude of roughly 10°C lower than samples from the

overlying Lodgepole Formation (Osadetz and Snowdon 1995; Gaswirth et. al. 2013). In addition, core extract data collected through this study show a marine source with a Vitrinite Reflectance Equivalent (VRo-eq) of 0.7 and 0.75 in the Oungre and Sparks wells, respectively (Figure 1). This study not only incorporates new pyrolysis data from the Sparks and Oungre cores, but also utilizes palynological data from the Oungre core as well as cuttings from the Gulbranson 1-1H, Gulbranson 2-1H, and Wolter 15-8H (Figure 1) to help resolve the elevated thermal maturities seen from pyrolysis.

Methodology

Samples for palynological analysis from the Oungre core were taken from the same core plugs that were taken to perform Rock-Eval and Hawk pyrolyses, allowing for accurate data correlation. Cuttings were collected from the Upper Lodgepole as dictated on mud logs. Sample thicknesses varied based on the amount and availability of samples. Palynological organic matter extraction was conducted following the standard technique outlined in Traverse (2007). Ten microscopic slides were examined in transmitted light. Seven of the slides represent different intervals in the Oungre core in addition to one slide from each of the Gulbranson 1-1H, Gulbranson 2-1H, and Wolter 15-8H wells. Three hundred sedimentary organic matter (SOM) particles were point counted from each slide. These particles were separated into categories to determine the kerogen type as well as the overall level of organic matter degradation.

Rock-Eval pyrolysis was initially performed on two samples from the Sparks core and seven samples from the Oungre core. Initial pyrolysis of samples through commercial lab 1 was cleaned first with an azeotropic mixture of chloroform-methanol (89:11 v/v) for 24 hours. Samples were then Soxhlet extracted for 48 hours with an azeotropic mixture of DCM-methanol (87:13 v/v). After that, samples were run through a Rock-Eval 6. Samples from the Oungre core were then rerun through commercial lab 2 utilizing a Hawk pyrolysis and two different cleaning methods. Method A involved cleaning the samples in DCM after being crushed with a ball mill. The samples were agitated three times at a 10-minute interval between each agitation. After all agitations, samples were air-dried and then run through Hawk pyrolysis. If S1 carryover was seen to the S2 peak, the process was repeated. Method A was run on only two samples from the Oungre core. Method B involved the samples being homogenized through the same ball mill process but were then loaded immediately to the Hawk pyrolysis. In addition to the above analyses, samples were also subject to core extract, XRD and MICP analyses at commercial laboratories.

Results

Palynomorph point counting resulted in statistically 100% terrestrial phytoclasts. Of these, 90-99% being degraded dark brown phytoclasts (Figure 2, no. 1), and 1-10% being equant, opaque phytoclasts (Figure 2, no. 2). One sample from the Oungre core at a depth of 2249.7 m did contain a statistically insignificant amount of amorphous marine organic material, which was not seen in the other samples. Pyrolysis values were significantly impacted by the change in sample preparation methods. It is evident that S2 values increased with the less aggressive cleaning on five out of seven samples (Figure 3). Additionally, VRo-eq decreased on all but one sample bringing the range of values from 0.76-0.87 (average 0.81) from commercial lab 1 to 0.73-0.83 (average 0.78) from commercial lab 2, Method B (Figure 4). TOC showed an increase on all but one sample (Figure 5).

Discussion

XRD analysis performed on the studied samples showed up to 90% calcite content. Core extract analysis revealed evidence for marine source materials. Such unequivocal marine (type II kerogen) influence was not seen during palynological examination, since type I/II kerogen materials are preferentially converted to bitumen and oil leaving type III/IV kerogen behind (cf. Hackley and Cardott 2016). Samples cleaned aggressively prior to pyrolysis were likely stripped of all mobile hydrocarbons, however it is probable that a portion of the bitumen was also extracted during cleaning lowering the amounts of type II source constituents and biasing the analysis towards the remaining phytoclasts (type III materials). The remaining heavily degraded phytoclasts would then contribute to higher T_{max} values. Samples cleaned with an aggressive solvent prior to MICP analysis showed a greater permeability and porosity value than those cleaned with a lighter solvent. This is due to stripping of bitumen from the pore space and therefore giving confidence to the idea that samples could be biased due to invasive cleaning methods. To further confirm this, samples were run again through a separate, commercial lab 2, which utilized a lighter solvent (Method A) or no cleaning at all (Method B). The new results came back showing a higher S2 peak; which proves that the more invasive cleaning from commercial lab 1 did indeed strip some of the organics. Additionally, an increase in the HI pushed samples towards more of a Type II-III source rock and lowered the VRo-eq to a range of 0.73-0.83% (average of 0.78%). Therefore, the thermal maturity is closer to the range of the core extract data and the underlying Bakken shales.

Conclusion

In conclusion, the studied Upper Lodgepole samples contain type II/III source materials. This is drawn from the identification of degraded phytoclasts from palynomorph analysis as well as the pyrolysis data. Thermal maturity from the original analysis through commercial lab 1 was high due to their invasive cleaning method that stripped type II daughter materials from the analysis. The new values from commercial lab 2 cleaning methods A and B place the thermal maturation in line with maturity values from both the underlying Bakken shales as well as the core extract values. No signs of marine organisms were observed through microscopic work, which is likely because Type II organic materials were preferentially converted to hydrocarbons leaving only the degraded phytoclasts behind. A greater concentration of low-hydrogen terrestrial material in extracted Lodgepole samples drove the apparent VRo-eq maturity higher relative to less- or unextracted samples. Extracted pyrolysis also made the overlying Lodgepole appear more mature than the extracted Bakken Shale when maturity for both is calculated using the same VRo-eq (Jarvie) equation. The discrepancy is explainable as a difference in the organic matter type, its starting hydrogen content and its kinetic pathway during catagenesis.

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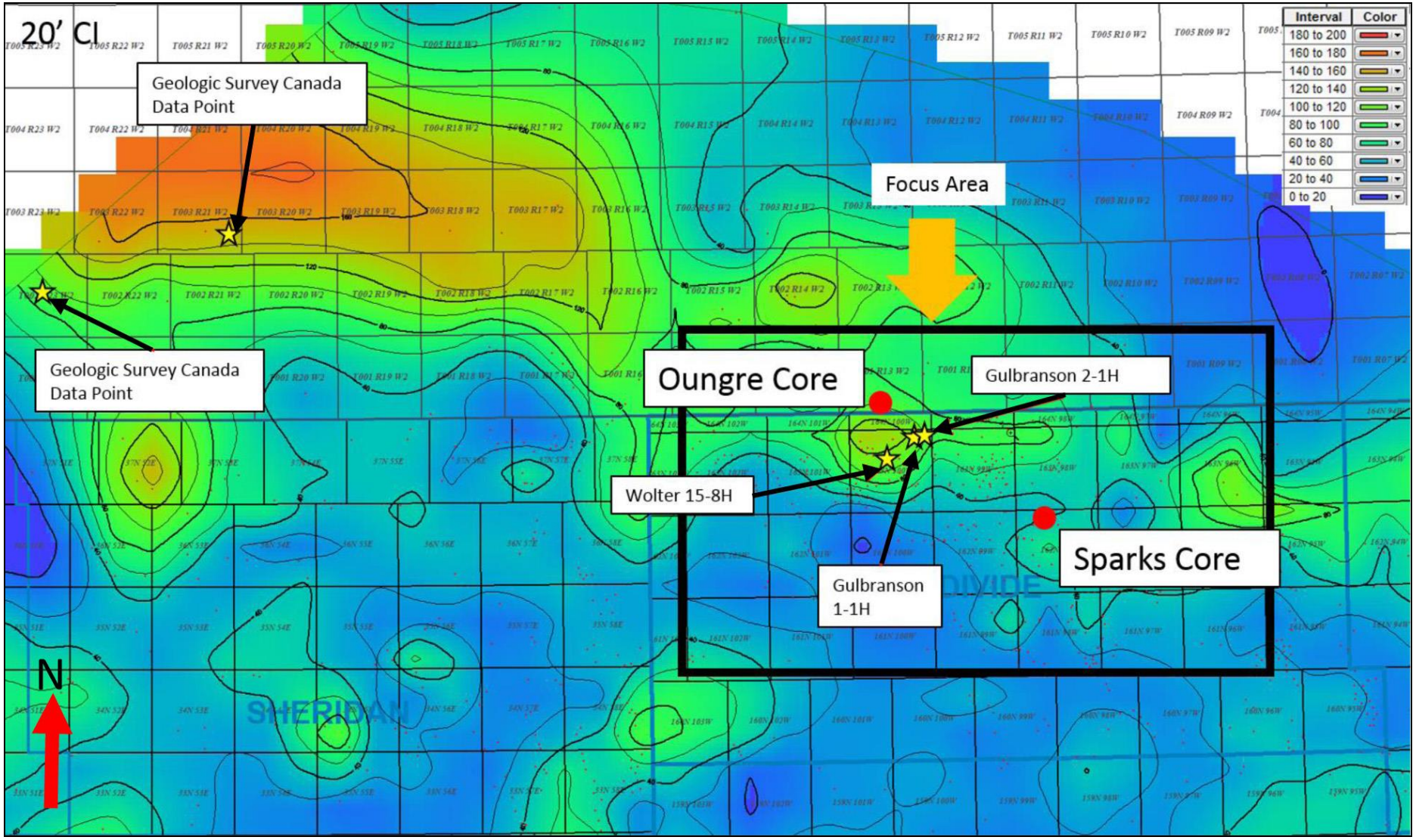

Figure 1. Isopach Map of Upper Lodgepole in the Williston Basin with locations of key wells discussed in the present study.

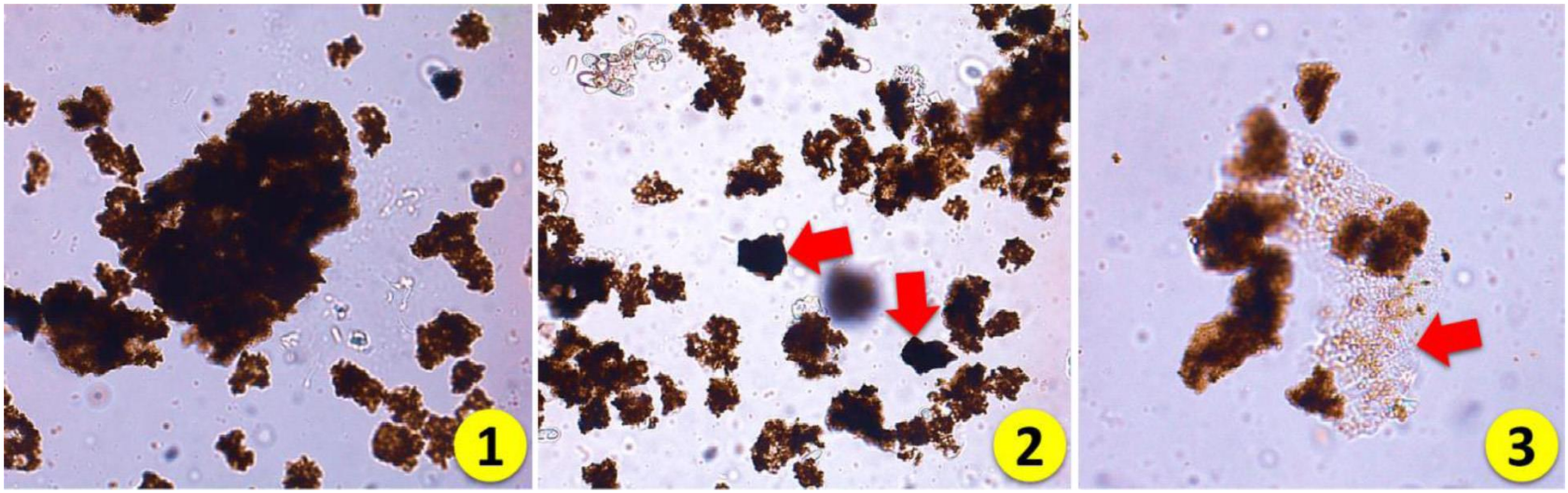

Figure 2. Photomicrographs of example SOM particles recorded from the Upper Lodgepole in the studied Oungre core samples. All images are taken from sample 5, depth 2249.7 m (7380.91 ft), at 40x magnification. 1) Dark brown degraded phytoclasts. 2) Equant opaque phytoclasts (red arrows). 3) Amorphous marine organic matter, possibly algal (red arrow).

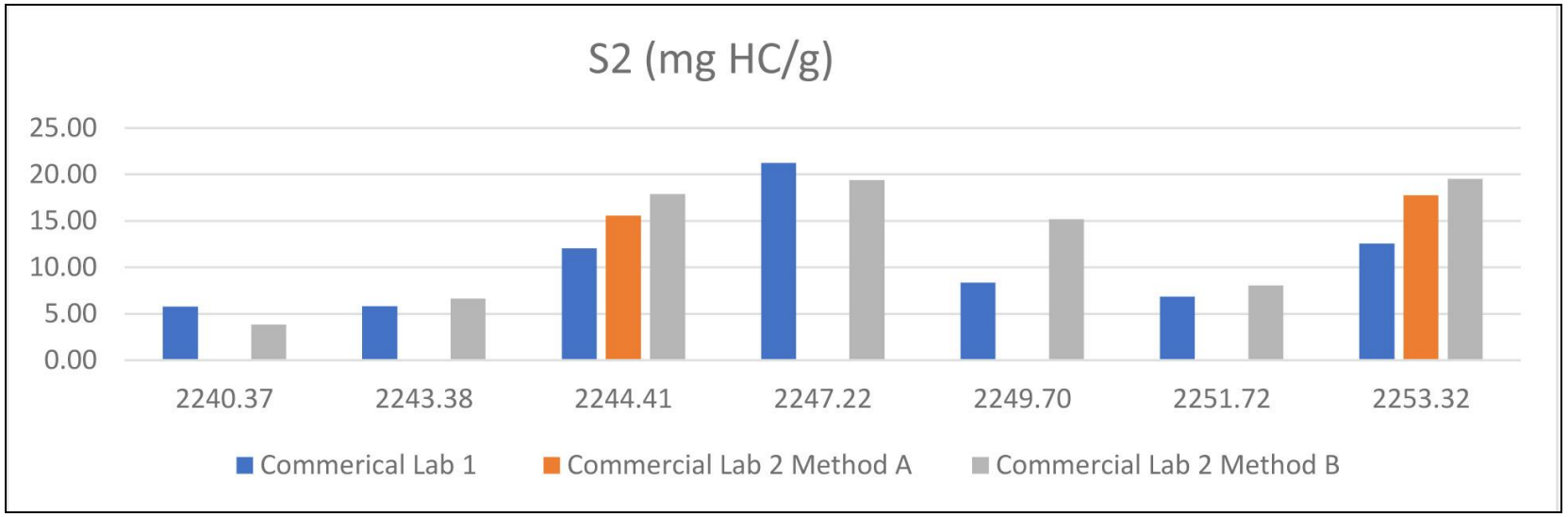

Figure 3. Comparison of S2 values of the Oungre core samples obtained from the two commercial labs using variable cleaning methods. The most aggressive cleaning method was used in commercial lab 1, a less aggressive cleaning was used in commercial lab 2, Method A, and no cleaning was applied in commercial lab 2, Method B.

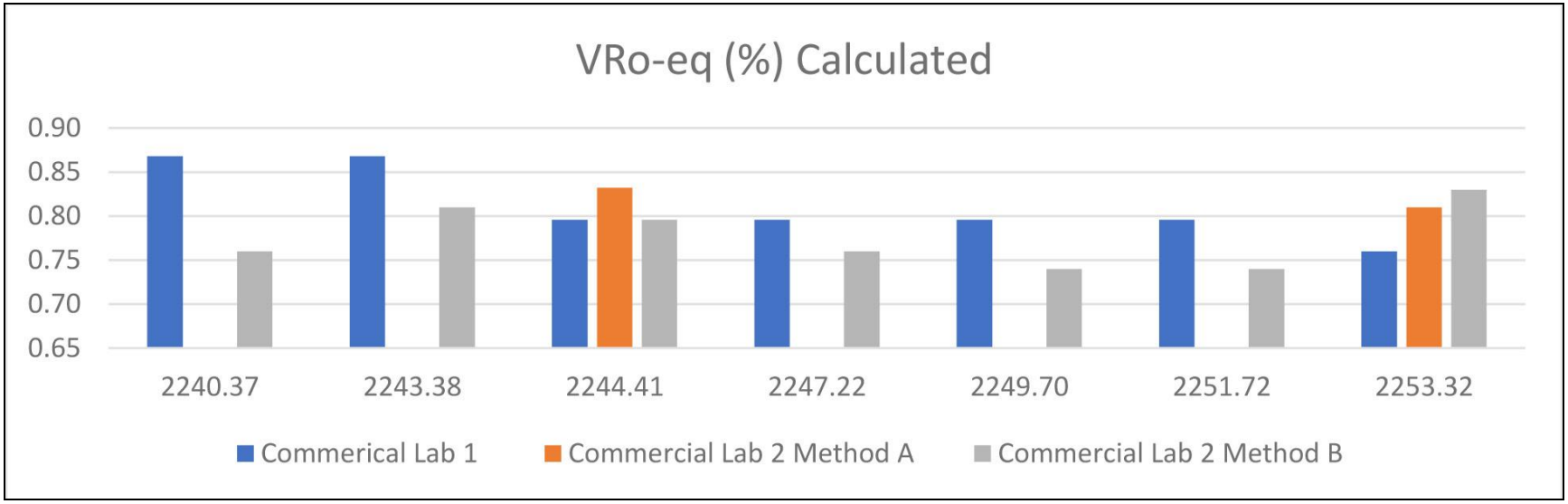

Figure 4. Comparison of VRo-eq values of the Oungre core samples obtained from the two commercial labs using variable cleaning methods.

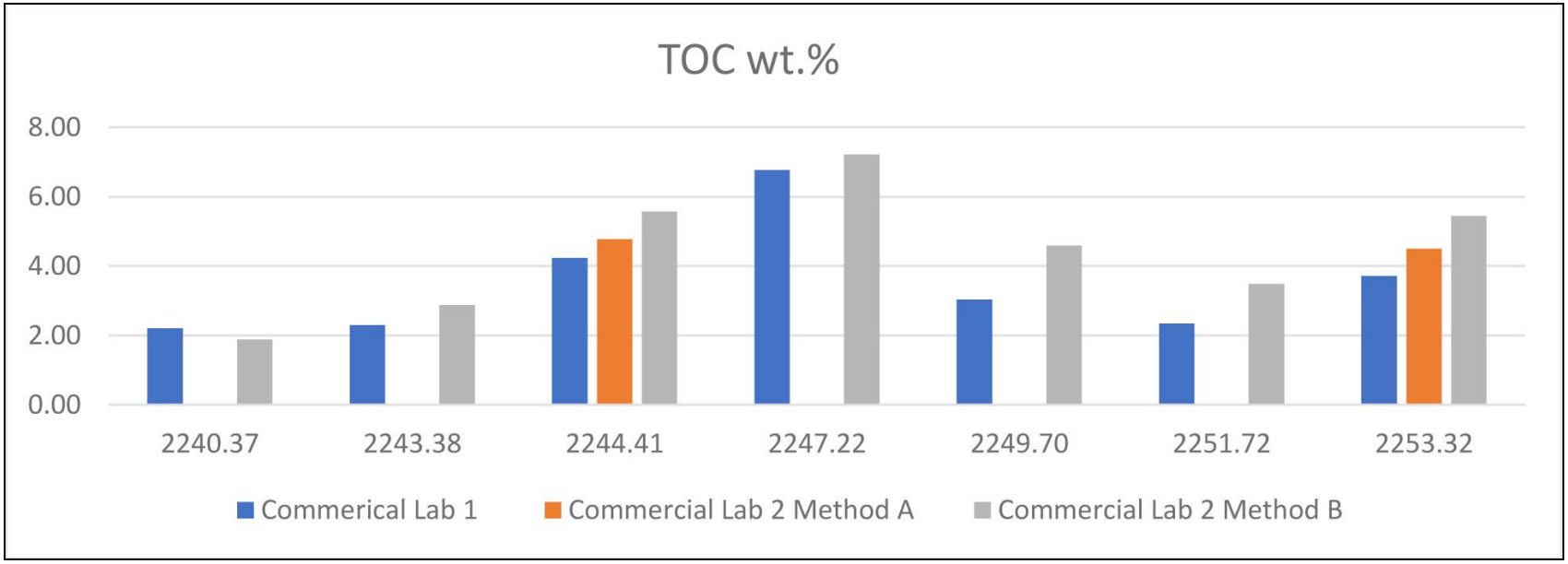

Figure 5. Comparison of TOC wt.% values of the Oungre core samples obtained from the two commercial labs using variable cleaning methods.