Geochemical Analysis and Evaluation of Exploration Wells in the Beetaloo Sub-Basin, Onshore Australia: Application of Real-Time Elemental Measurement on Cuttings with Source Rock Mapping and Lateral Geosteering Implications*

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Abstract

The scope of this paper is to illustrate the successful application of the Advanced Cuttings Characterization (ACC) service at the Amungee NW-1 vertical well and Amungee NW-1H horizontal well drilled onshore in the Northern Territory, Australia (Figure 1).

The prospective organically enriched mudstones of the Mesoproterozoic-aged Velkerri Formation Amungee Member and Kyalla Formation have Total Organic Carbon (TOC) contents ranging from 4 to 8 %wt and 2 to 3%wt, respectively. The organic matter present within organically enriched intervals is oil-prone, type I / II, but deep burial in the center of the Beetaloo Sub-Basin has resulted in the generation of commercially significant quantities of late maturity gas from the thermal cracking of retained oils and bitumen. In addition to thick organically enriched intervals, the Velkerri Formation Amungee Member and Kyalla Formations also contain hundreds of meters of interbedded siltstones and mudstones with minor sandstone.

The primary objective of the Amungee NW-1 vertical exploration well was to technically assess the Velkerri Formation Amungee Member as a potential regional shale gas play, by testing the lateral extent, facies variation, and physical reservoir properties of the organically-enriched mudstones. The primary objective of the Amungee NW-1H horizontal well was to appraise the organically enriched B shale of the Amungee Member, which was identified following comprehensive wireline logging as having the best combination of reservoir and geomechanical properties for initial horizontal and hydraulic fracture stimulation appraisal. To fulfill the well objectives, Origin Energy decided to use ACC, by combining Energy Dispersive X-ray fluorescence (ED-XRF) and high-resolution microscopy, to provide an accurate geochemical and mineralogical characterization while drilling both Amungee NW-1 and Amungee NW-1H.

The ACC approach of measurement on drilled cuttings was a valuable formation evaluation tool to provide near real-time information to better characterize drilled reservoir in this study. The ED-XRF was calibrated for majors and traces elements present in the drilled rock from sodium (Na) up to uranium (U) with a resolution down to the ppm level, to deliver accurate elemental quantification. Rock elemental composition provided by ED-XRF allowed delineation of subtle formation changes, identification of formation tops, characterized paleo-depositional environment changes including intervals with higher primary productivity and preservation, i.e., using redox proxies-elements (U, V, Mo). High-resolution digital photography of drilled cuttings assisted in capturing main physical characteristics of the rock such as colour, texture, and accessory minerals. This provides further guidance about main lithological and depositional changes.

Specific goals for the employment of the ACC were to: i) in the Amungee NW-1 vertical well, improve identification of lithofacies and paleo-environmental deposition indicators, assist with core point and well termination decision-making by using the specific ED-XRF elemental ratios diagnostic of the Velkerri Formation Amungee to Kalala Member transition; ii) in the Amungee NW-1H lateral well, use information from the pilot well to land and steer the well into the organic rich source rocks intervals.

The bulk lithology for clastics formation can be quickly defined qualitatively by cross plotting the log of (SiO_2/Al_2O_3) vs. the log of (Fe_2O^3/ K_2O) (Herron et al., 1998). According to the ED-XRF lithology proxy, Amungee NW-1 penetrated fine-grained sediments ranging from shale to wacke (siltstone) generally controlled by the relatively high abundance of Al_2O_3 in the bulk rock composition. This reflects the relatively high mudstone or finely interbedded mudstone-sandstone of Roper Group package penetrated by Amungee NW-1. Local deviations from the general trend occur within the Bukalara sandstone, the Jamison Sandstone and Moroak sandstone where lithologically mature, quartz-rich sandstones of dunal terrestrial to marginal marine and upper deltaic higher-energy depositional environments occur (Figure 2).

The petrophysically defined zone that was targeted for the Amungee NW-1H horizontal appraisal well, the Amungee Member B Shale, was well defined by and limited to a general litharenite composition.
Lithofacies were defined by utilizing the Interactive Petrophysics Self-Organizing Map (IPSOM) methodology: five lithofacies were identified based on indicative ED-XRF elements in both wells. These elements were classified in four groups: i) clay mineral proxies (K, Th, Al); ii) sand/silt mineral proxies (Si, Zr, Ti); iii) redox sensitive proxies (Co, Mo, U, V); and iv) productivity sensitive proxies (Cd, Cu, Ni, Zn). Among those, only K, Al, Si and Ti are major elements (% wt), while the remaining ones are trace elements (ppm). The five lithofacies characterized the Amungee NW-1 well (Figure 3) as follows:

Facies 1: Predominantly sandstone. Occurs in the Bukalara and Jamison Sandstone, and upper part of the Moroak Sandstone. It has high amounts of Si, and very low amounts of clay mineral proxies.
Facies 2: Organic rich clay-shale intervals of the Amungee Member. These facies contain very high amounts of the redox sensitive and productivity-sensitive elemental proxies.
Facies 3: Sandy siltstone/clay-shale. It occurs over various intervals of the well and contains relatively comparable amounts of clay mineral proxies and sand/silt mineral proxies.
Facies 4: Silty clay-shale intervals of the Amungee Member, which are not organic rich. These facies contain moderate amounts of the redox sensitive and productivity sensitive elemental proxies, and lower amounts of clay mineral proxies compared to facies 2.

Facies 5: Clay-shale. It is confined to the Hayfield Formation. It has high amounts of clay mineral-proxy elements, and low-moderate amounts of sand/silt mineral-proxies.

To assist core point decision making at Amungee NW-1, studies were undertaken on the offset Amungee Member penetrations to determine the diagnostic elemental ‘fingerprints’ of the organically-enriched mudstone of the Amungee Member (Figure 4). The diagnostic ‘fingerprint’ included elevated Mo, V, Cu, Ni, Zn (Anoxia and paleo-productivity elements) coupled with a diagnostic decrease in the Al / Si ratio from the higher bulk silica content of the target intervals. When picking the coring point at Amungee NW-1 the diagnostic fingerprint was able to positively identify the penetration of the Amungee Member and enabled 100% of the core to be cut over the highest quality reservoir. To assist vertical well termination decision making at Amungee NW-1, offset penetrations were studied, specifically to identify diagnostic elemental ratio changes from the Amungee to Kalala Members. It was identified that sharp increases in the Th/U and Zr/V ratios were the most diagnostic of the transition and were utilized for the successful and optimal well termination with the Kalala Member after full penetration of the Amungee Member.

In terms of paleo organofacies, while drilling Amungee NW-1, ED-XRF revealed diagnostically high redox sensitive elemental proxies (Co, Mo, U, V) and productivity-sensitive elemental proxies (Cd, Cu, Ni, Zn) within the organically-enriched mudstones of the Velkerri Formation Amungee Member. These proxies indicated the organically enriched mudstone intervals were likely deposited under strongly reducing conditions with high biogenic organic carbon input. The measured increased abundance of these diagnostic elements over the prospective organically-enriched mudstones of the Amungee Member in Amungee NW-1 (Vertical pilot), was used to assist geosteering of the Amungee NW-1H lateral (Figure 6) into the highly prospective Amungee Member B Shale.

Another useful output of the ED-XRF analysis is the computation of real time pseudo gamma curves from quantitative measurement of potassium, thorium and uranium. Computed pseudo gamma curves exhibited strong correlation to wireline and Logging while Drilling (LWD) Gamma Ray logs at both Amungee NW-1 and Amungee NW-1H. This correlation permitted robust quality control of the cutting lag depth, confirming cuttings provenance, and enabled regional correlation updates and the updating of formation prognosis depths in real time (Figure 5).

The high-resolution photography of drilled cuttings permitted real-time streamed imaging of drilled lithology, empowering office located geoscience staff with a real time visual representation of the lithology drilled (Figure 7). This would be correlated to the ED-XRF data set.

Following the successful drilling of Amungee NW-1H within the B Shale of the Velkerri Formation Amungee Member, and subsequent fracture stimulation a 57-day production testing recovered 66 mmscf gas at an average of 1.15 mmscf/day, with a final rate of 1.12 mmscf/day.

In summary, the combination of the ED-XRF and high-resolution digital photography, included in our ACC methodology, proved to be a reliable, robust, and low-risk formation evaluation tool in the Amungee NW-1 and Amungee NW-1H wells. The methodology developed in both wells provided real-time data measurement and interpretation, guiding the horizontal geosteering within the Velkerri Formation Amungee Member. The data can be used for detailed post-well analysis for greater local or regional geochemical studies of penetrated geological formations.

Reference Cited

M. M. Herron et al., 1998, Quantitative Lithology: Open and Cased Hole Application Derived from Integrated Core Chemistry and Mineralogy Data Base: Core-Log Integration, No. 136, p. 81-95.

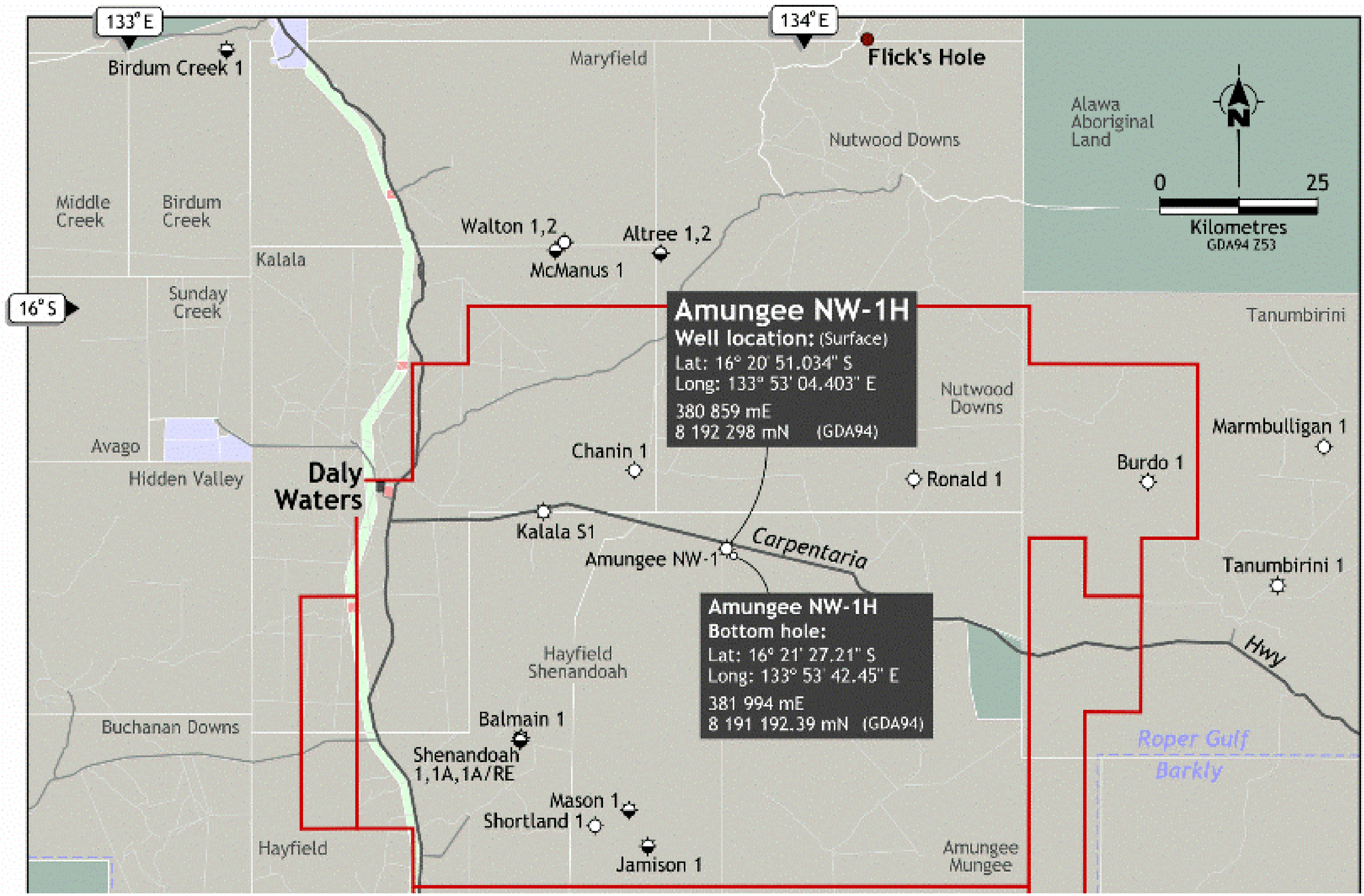

Figure 1. Location of Amungee NW-1 and Amungee NW-1H.

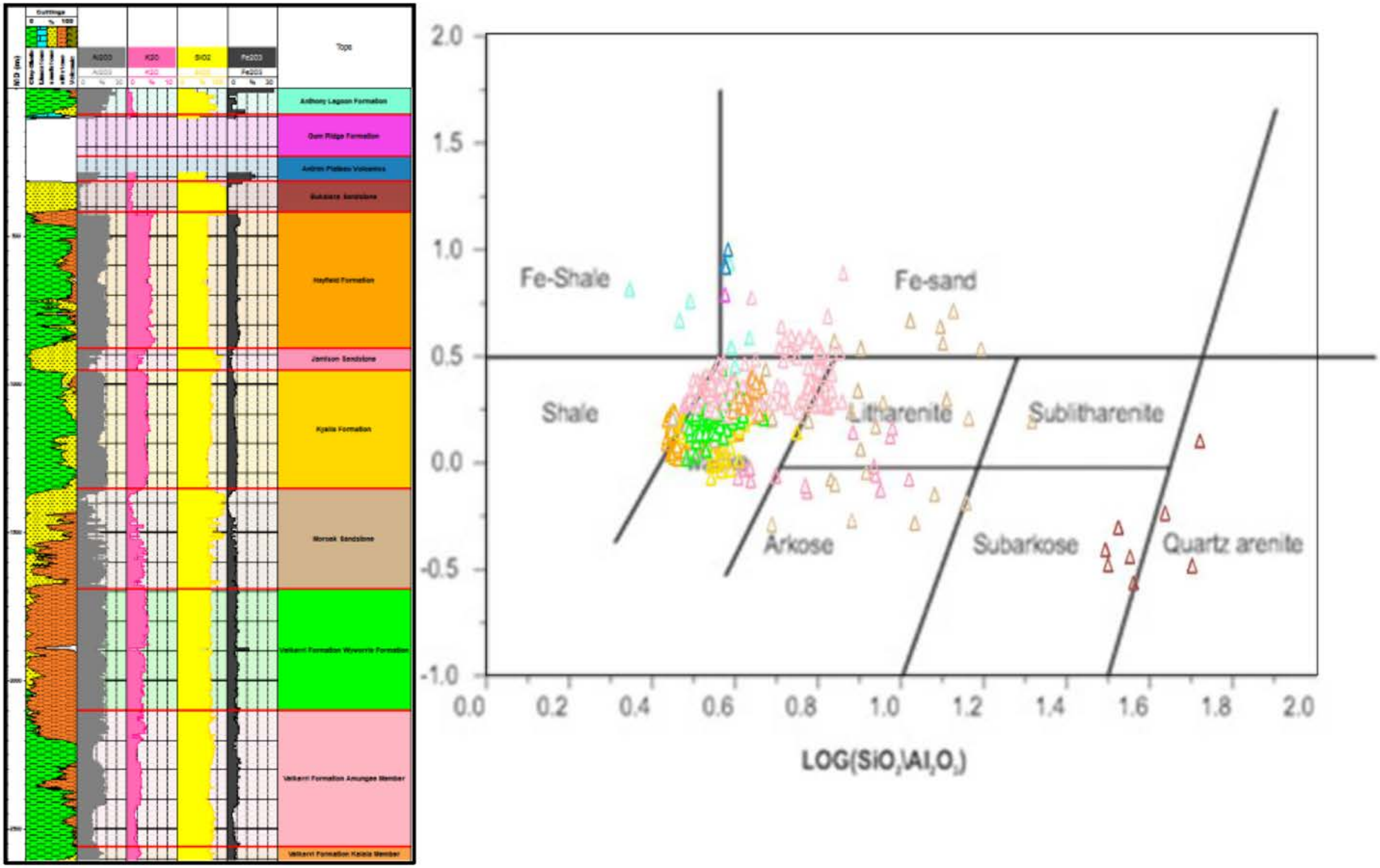

Figure 2. Amungee NW-1 sediments maturity by Herron et al., 1998.

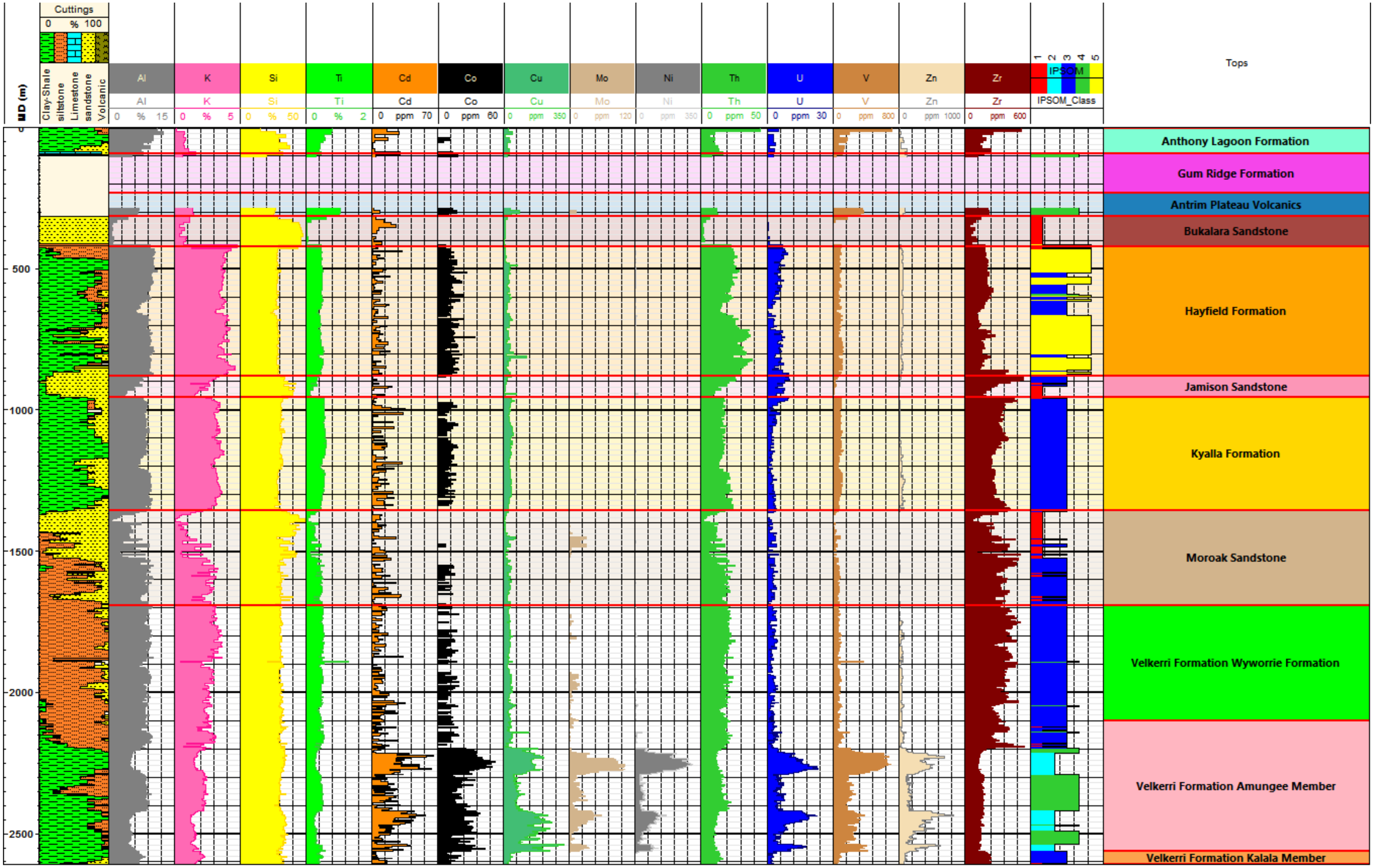

Figure 3. Amungee NW-1 depth distribution of IPSOM facies and corresponding ED-XRF data.

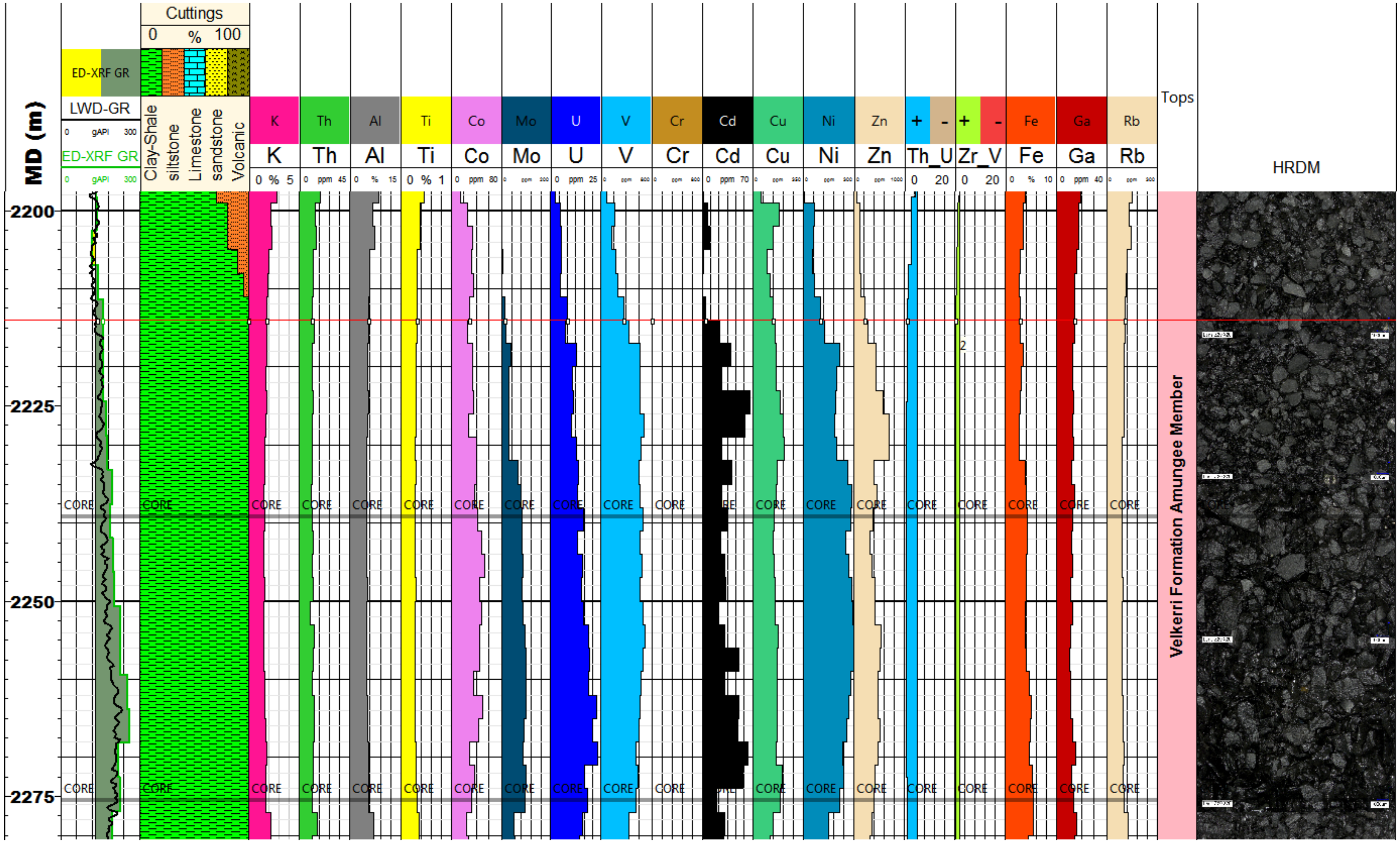

Figure 4. ED-XRF assisting coring point decision via positive identification of the Amungee member.

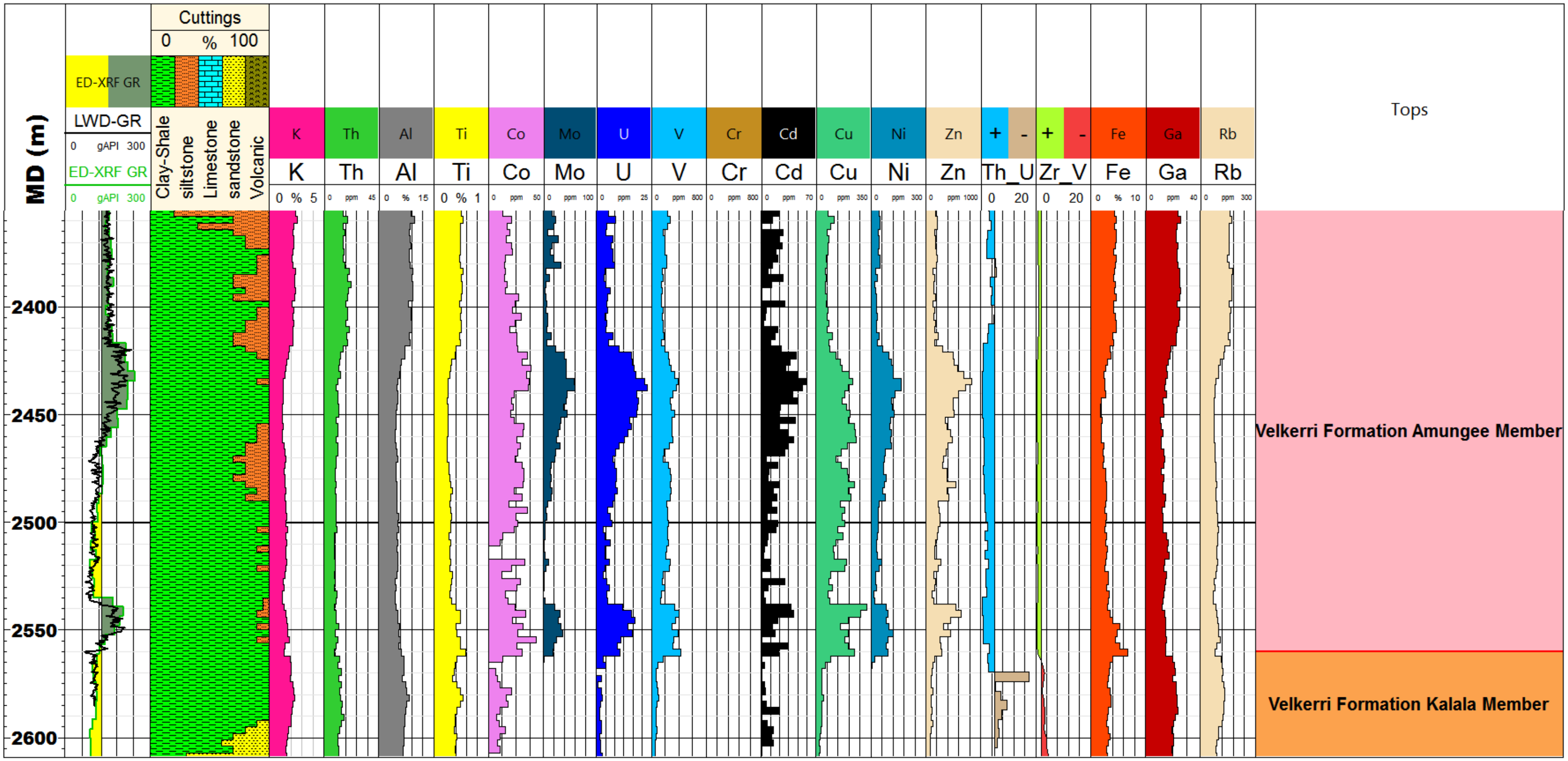

Figure 5. Amungee NW-1 target Velkerri Formation Amungee Member (organic-rich shale) with ED-XRF data.

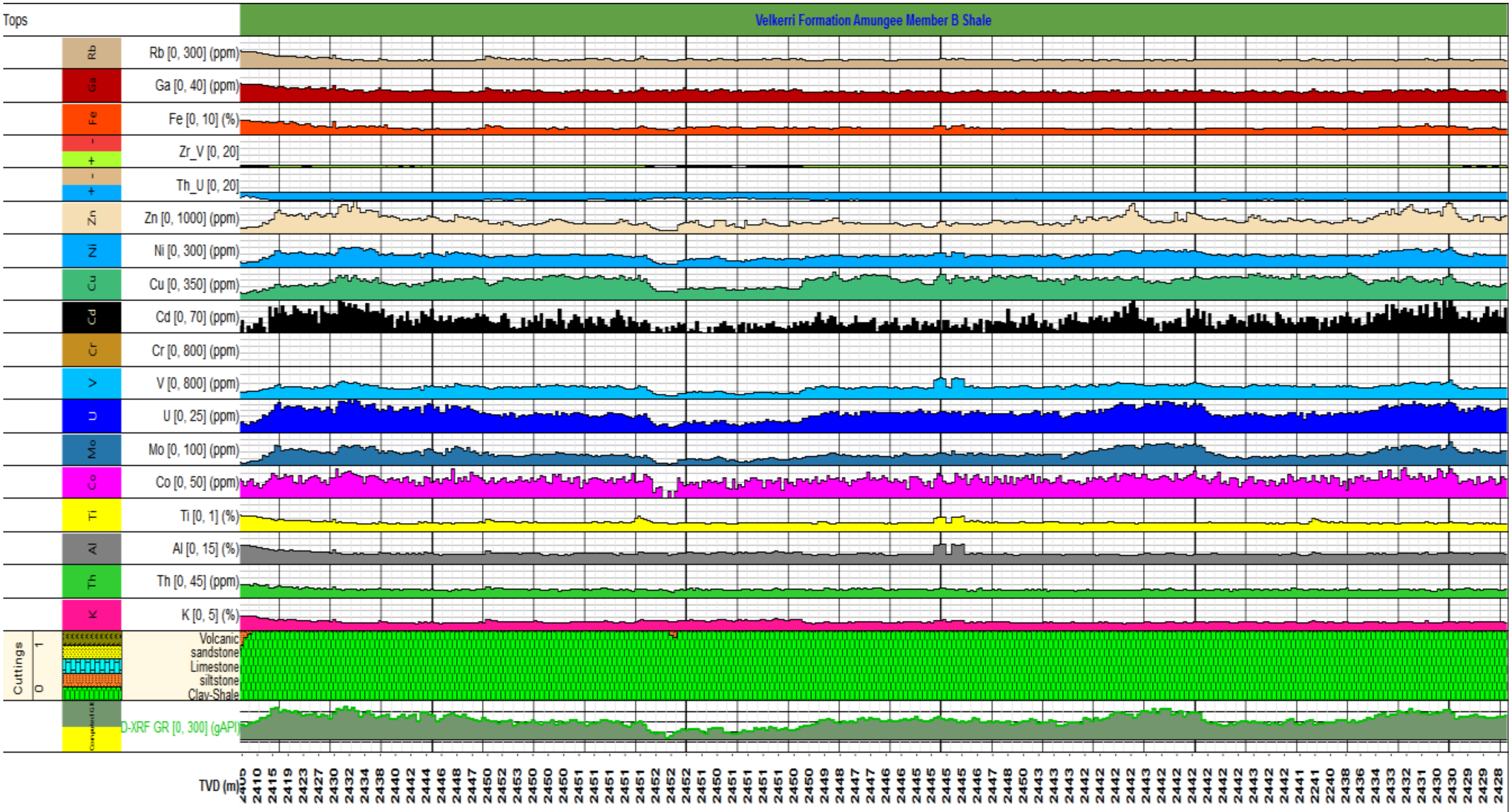

Figure 6. Amungee NW-1H target Velkerri Formation Amungee Member (organic-rich shale) with ED-XRF data.

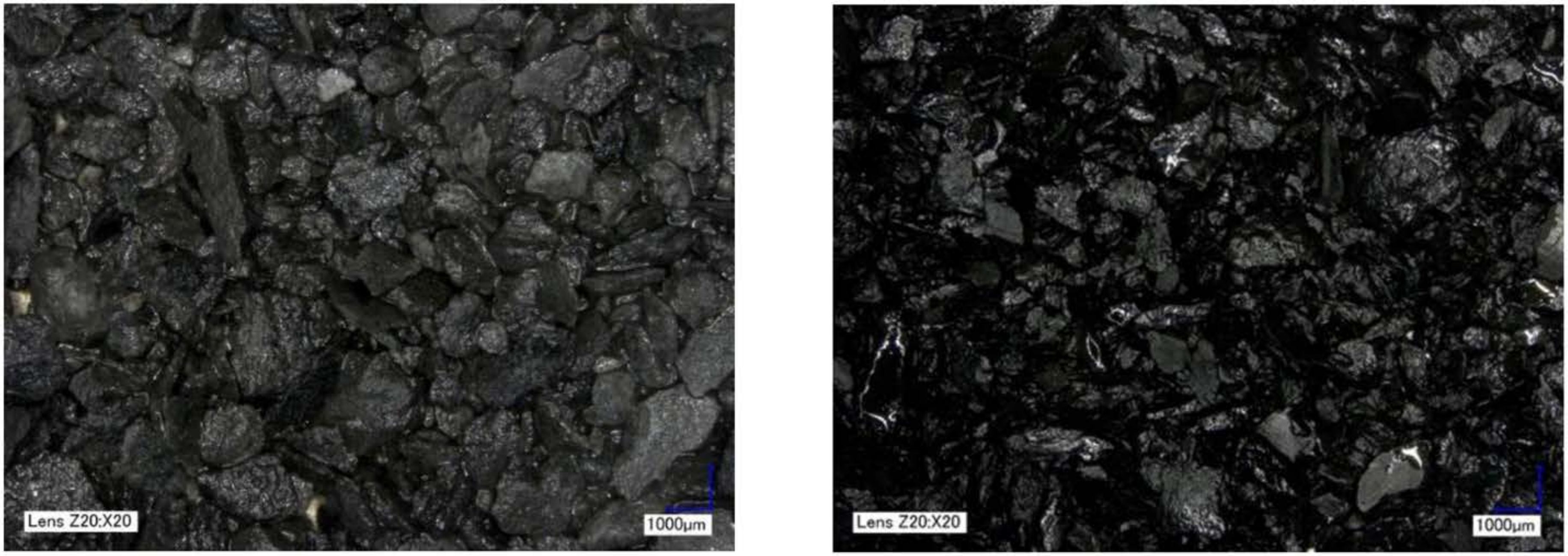

Figure 7. Velkerri Formation Amungee Member organic-rich shale. Left: Amungee NW-1; Right: Amungee NW-1H.