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Organic petrology and Rock-Eval characteristics in selected coal samples of the Cau Formation, block 07 Nam Con Son Basin

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ABSTRACT

The liptinitic-rich coal and other organic-rich sediments from the Cau Formation in block 07 Nam Con Son basin is believed to be a major source rock. The coal is dominated by vitrinite, with moderate by bituminite, suberinite, sporinite and resinite and low amounts of inertinite. The rock-eval analysis shows that the coals are enriched in hydrogen (hydrogen index up to 410 mg HC/g TOC) and depleted in oxygen (oxygen index up to 10 mg CO_2/g TOC). The value of Tmax ranges from 427 to 439 °C, indicating a low level of thermal maturity, the vitrinite reflectance is between 0.44 and 0.79% consistent with the The Tmax.

1. Introduction

Block 07 is located in the SouthEast marginal of Nam Con Son basin, the nominal water depth of 320 meters. A total of eleven wells have been drilled to date. The CRD Field in block 07 is the furthest from shore and the deepest water development to date within Vietnam. The Cau formation is Oligocene in age and comprises thinner sands, often with a coarsening-up profile, inter-stratified with shales and coals is considered the main source rock in this area.

In this paper, the organic geochemical characteristics of selected coals of two wells in the CRD and CRV area are examined.

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2. Geological setting

The Nam Con Son is predominately an extensional basin associated with the opening of the Bien Dong (East Sea). The Tertiary-age clastic section in the Nam Con Son Basin has undergone two rift events, each of which has an associated post-rift unconformity. The first rift event formed as a result N-S extension, which was a precursor to the initiation of sea floor spreading in the East Sea Basin about 32 Ma (Figures 2). A classic break-up unconformity is seen in the Nam Con Son Basin at the top for the Lower Oligocene section. From Late Oligocene to Early Miocene there was a period of tectonic quiescence which coincides with the sea floor spreading in the East Sea. In the Middle Miocene, sea floor spreading ceased and the second rift event began, with NW-SE extension. Following the rifting phase, the Middle Miocene Unconformity (MMU) formed at the top of the Middle Miocene section. The MMU is seen over the entire East Sea Basin and is related to thermal uplift related to the end of sea floor spreading about 16 Ma (Figure 2). After the MMU, the asthenosphere cooled resulting in widespread subsidence throughout the East Sea Basin and resulted in the moderately deep water setting of the Cá Rồng Đỏ (CRD) Field (Figure 1).

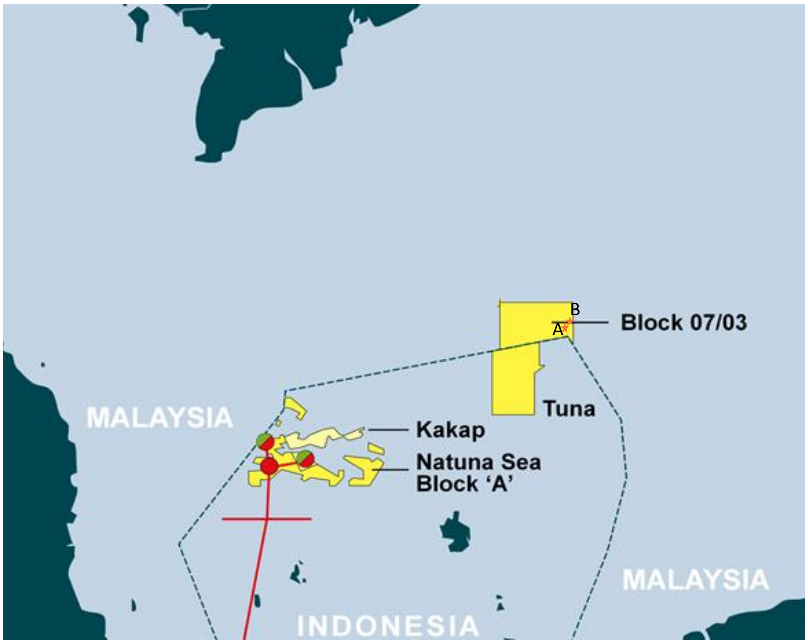

Figure 1. Location of Study area.

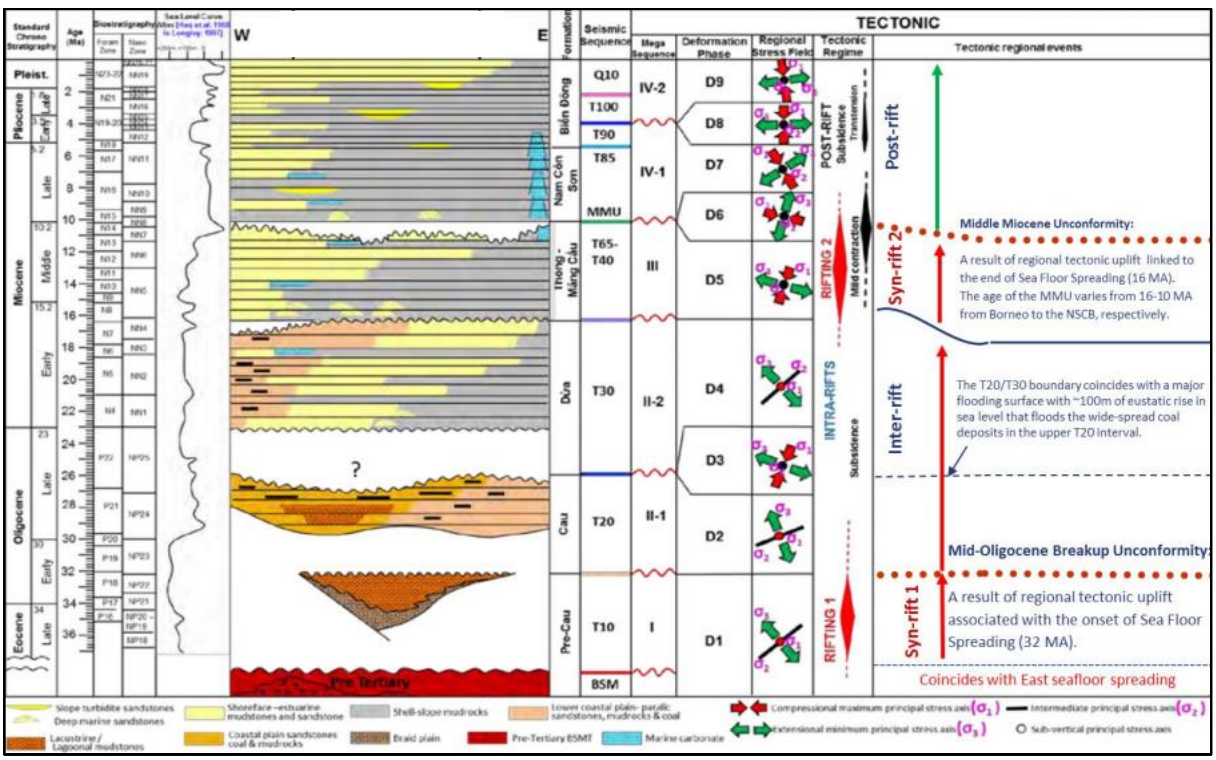

Figure 2. Nam Con Son Basin Chrono-Stratigraphic Chart showing two rifting events and associated regional unconformities (Rosneft_TNK Vietnam).

The basin-fill contains from base to top: Pre Cau - Oligocene Cau formation (T10 and T20 sequences); Early Miocene Dua formation (T30 sequence), Middle Miocene Thong/Mang Cau formation (T65 sequence), Late Miocene Con Son formation (T80 and T85 sequences) and Pliocene – Pleistocene Bien Dong formation (T90, T100 and Q10 sequences). A stratigraphic column of the Nam Con Son basin area is provided in Figure 2.

3. Material and method

The sixteen cutting samples were collected from Cau formation of two wells (A & B) in block 07. The locations of the samples are shown in Figure 1.

Pyrolysis analysis was performed using a Rock-Eval 6 analyzer following guidelines by (Peters 1986). Samples were prepared for maceral analysis according to the standard method: Preparing coal samples for microscopical analysis by reflected light (ASTM, 2007). Microscopic analysis was performed using polished blocks, a Leica DMR microscope, and oil immersion objectives. Maceral analysis was performed using reflected white and fluorescent light and a 25X objective. 250 points per polished block were counted using the single scan method. Maceral nomenclature for the liptinite, vitrinite, and inertinite maceral groups is according to the International Committee for Coal and Organic Petrology (ICCP) (ICCP 1998; ICCP 2001; Sýkorová, Pickel et al., 2005; Pickel, Kus et al., 2017).

Bitumen extractions were performed on the powdered samples using a Soxhlet apparatus for 72 h using an azeotropic mixture of dichloromethane (DCM) and methanol (CH_3OH) (95:5).

4. Results

4.1. Source rock properties

Source rock generative potential was evaluated using total organic carbon content (TOC wt.%) and pyrolysis S1 plus S2 yields (Figure 3). As expected, the 14 coal samples contain high total organic carbon content (TOC) ranging from 63.23 to 85.23 wt.%; the two coaly-claystone samples contain 13.13-31.65 wt.%. In the pyrolysis analysis, free hydrocarbons (S1) in the rock and the number of hydrocarbons (S2) expelled from pyrolysis of kerogen are measured. It is a useful measurement to evaluate the generative potential of source rocks (Peters 1986). The samples have pyrolysis S2 yield values in the range of 104.66–349.07 mg HC/g rock. Such values meet the accepted standards of a source with excellent generative potential (Peters and Cassa, 1994) (Figure 3).

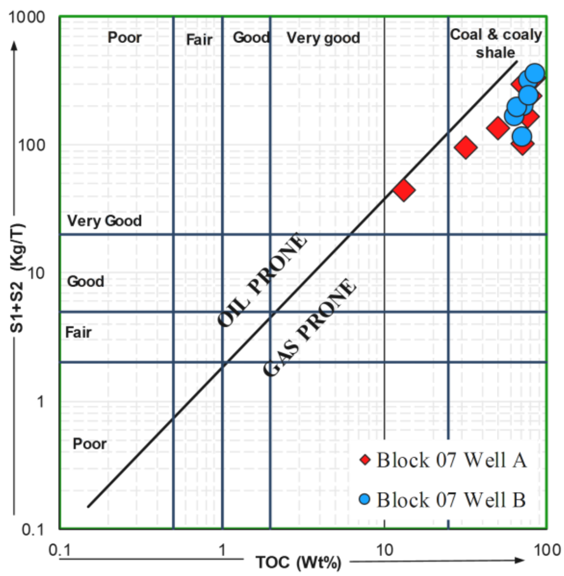

Figure 3. Generation potential of Oligocene coals in block 07 Nam Con Son.

The quality of Oligocene coals is also clearly demonstrated by the organic content extracted from the samples. The total soluble organic matter from samples ranged from 48 600 to 104 388 ppm - which can be classified as an excellent hydrocarbon potential source rock. On the plot of soluble organic matter vs. TOC (Figure 4), all the samples were located in the oil source rock field indicated that bitumen is indigenous.

Hydrogen index (HI) values range from 202 to 410 mg HC/g TOC. A plot of hydrogen index (HI) and pyrolysis Tmax (Figure 5), which can be used to classify the maturity and type of organic matter (Mukhopadhyay, 1995), shows that the coals are mixed Type III-II kerogens.

4.2. Maceral/kerogen assemblages

The proportions of the macerals in coals reflect the organic source materials contributing to the accumulation of peat and the conditions

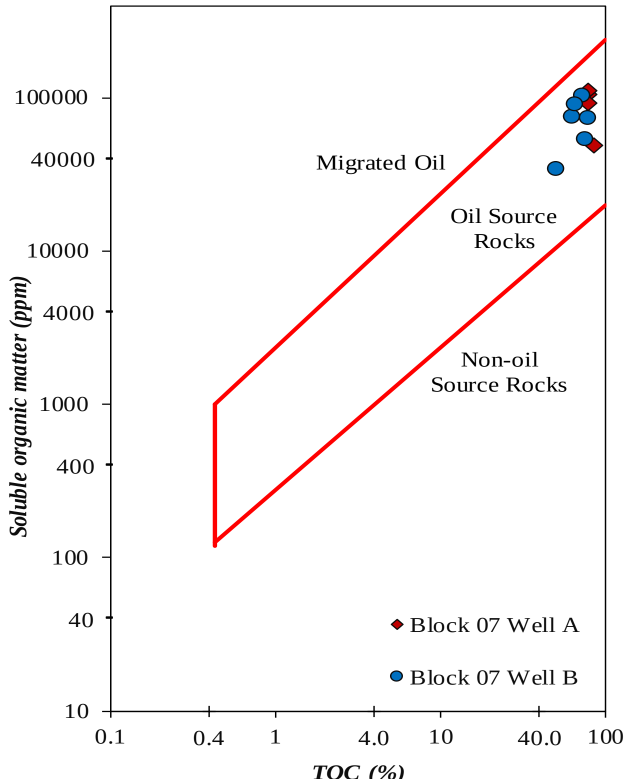

Figure 4. Soluble organic matter vs. TOC plots of coal samples in block 07 Nam Con Son basin.

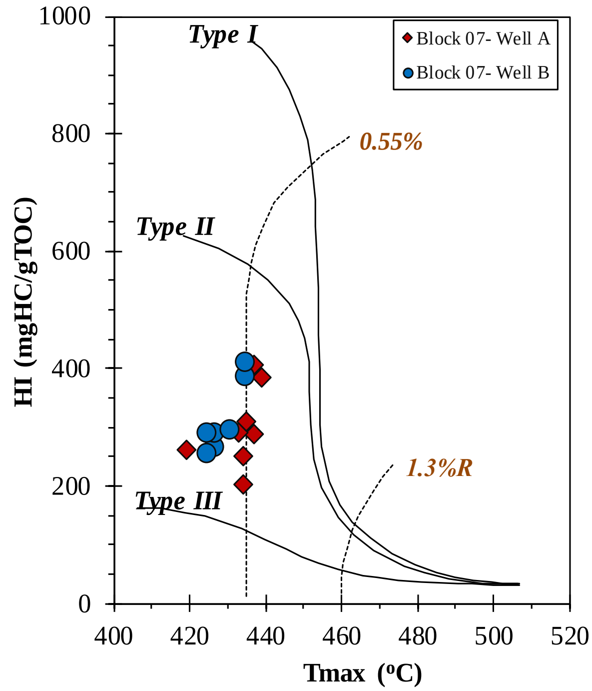

Figure 5. HI versus Tmax plot of coal samples in block 07 Nam Con Son basin.

during accumulation. Data related to the maceral composition of the coals are shown in Figure 6.

Most of the coal samples are dominated by vitrinite (66.48-83.52%) and classified as humic with significant amounts of liptinite and inertinite macerals. The vitrinite macerals (Kerogen type III) are mainly Collotelinite and Collodetrinite. Collotelinite is a maceral of the vitrinite group, subgroup telovitrinite, with a homogeneous, more-or-less structureless appearance. It is derived from the parenchymatous and woody tissues of roots, stems, and leaves, composed of cellulose and lignin and originating from herbaceous and arborescent plants. (ICCP 1998). Collodetrinite is a maceral of the maceral subgroup detrovitrinite within the maceral group vitrinite occurring as a mottled vitrinitic groundmass binding other coal components. Collodetrinite is derived from parenchymatous and woody tissues of roots, stems, and leaves, composed of cellulose and lignin. The original plant tissues are destroyed by the strong decomposition at the beginning of the peat stage.

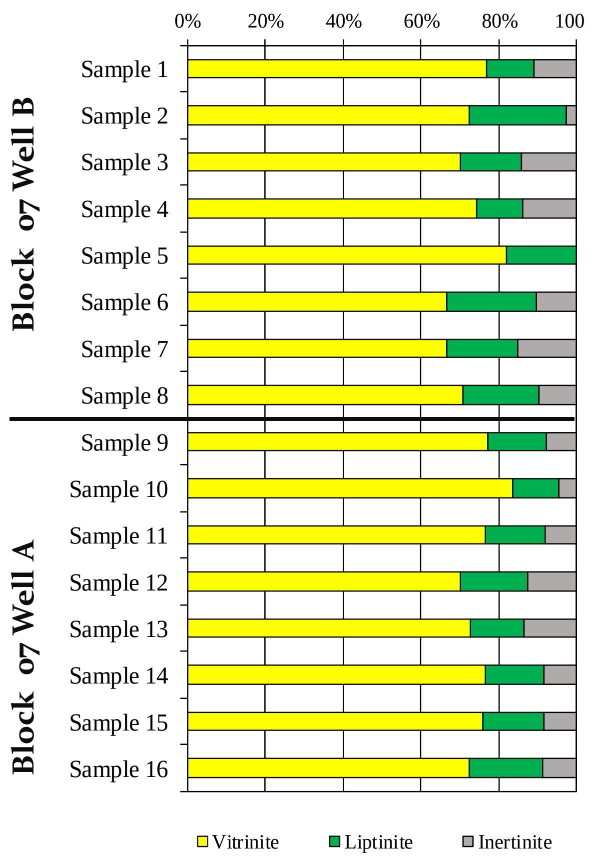

Figure 6. Maceral composition in Oligocene coal samples at well A and well B, block 07 Nam Con Son basin.

The small particles are cemented by humic colloids within the peat and subsequently homogenized by geochemical gelification (vitrinitization). Cellulose-derived substances may be more commonly the source of collodetrinite than lignin-rich wood. (ICCP 1998). Thus, the change of two maceral portion reflects the change of the environment as well as the source of materials.

At well A, vitrinite components of collodetrinite, vitrodetrinite dominate in the samples from the sample 1 to sample 5. The structured vitrinite maceral groups (telovitrinite, telinite) that predominate in coal samples 6 to sample 9. The phenomenon of changing the above components is repeated twice in the coal sample 9 to 16 at well A shows the cyclical change of the environment as well as the source of materials in the Oligocene period.

Inertinite (kerogen type IV) contents are mainly fusinite, inertodetrinite and sclerotinite, and range from 0-13%. Fusinite is a maceral of the inertinite maceral group, showing highly reflecting, well preserved cellular structure of at least one complete cell of parenchyma, collenchyma, or sclerenchyma. Funginite is a maceral of the inertinite maceral group, consisting of mainly high reflecting single or multi-celled fungal spores, sclerotia, hyphae and mycelia (stromata, mycorrhiza), and other fungal remains (ICCP 2001). Funginite in this area sample includes a unicellular form (which usually thrives when environmental conditions are moist - hot) and multicellular (thrives when conditions are colder).

All analyzed samples contain significant amounts of liptinitic macerals (kerogen type II) (11.93-24.83%). The most dominant liptinite macerals are bituminite, suberinite, sporinite and resinite whilst fluorinite, cutinite, exsudatinite are fairly common.

The coal maceral bituminite was defined by M. Teichmüller (Stach, Mackowsky et al., 1975), the name bituminite for an unfigured autochthonous maceral of the liptinite group, occurring in lignite and bituminous coals and in

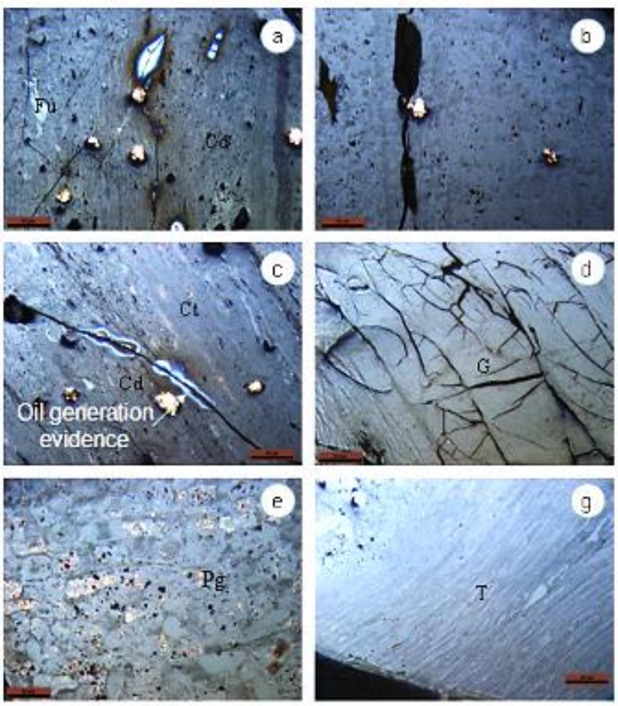

Figure 7. Vitrinite maceral in coal samples well B block 07 under reflectance white light, objective x50. Collodetrinite (Cd) in humic coal sample 1(a), sample 2 (b) ; Coporgelinite (Cg) in sample 2 (b); Gelinite (G) in sample 4 (d). Porigelinite (Pg) in sample 4. Telinite (T) in sample 6 (g).

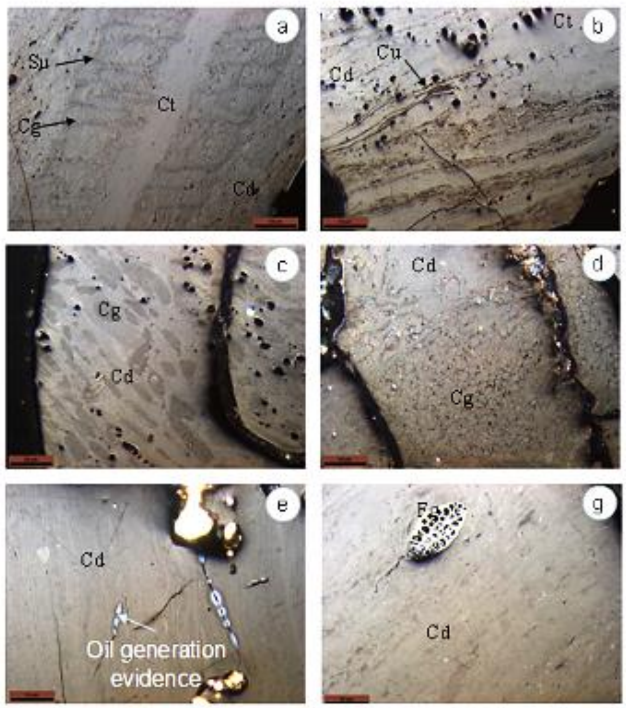

Figure 8. Vitrinite maceral in coal samples well B block 07 under reflectance white light, objective x50. Collodetrinite (Cd) in samle 11 (b), sample 12 (c, d), sample 13 (e), sample 14 (g) ; Coporgelinite (Cg) in sample 12 (c).

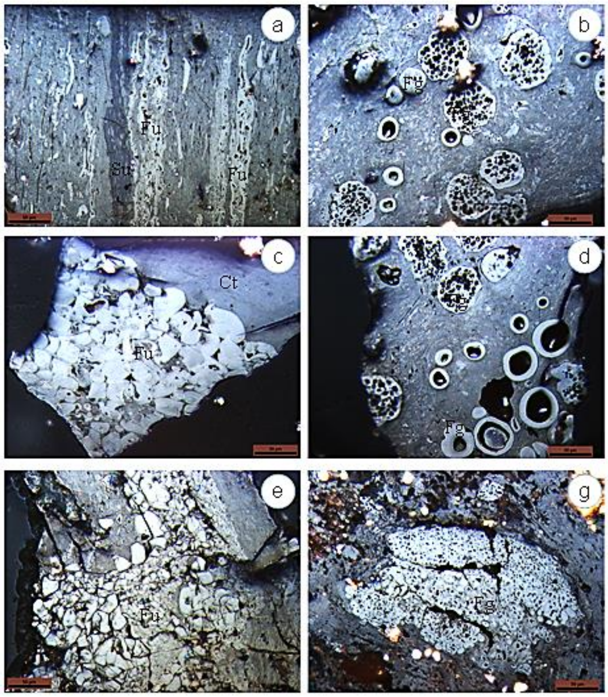

Figure 9. Inertinite maceral in well B under white light, objective x50 in oil. Fusinite (Fu) in sample 1 (a), sample 2 (c,e), sample7 (h), sample 8 (i). Funginite (Fg) in sample 2 (b), sample 7 (g, h).

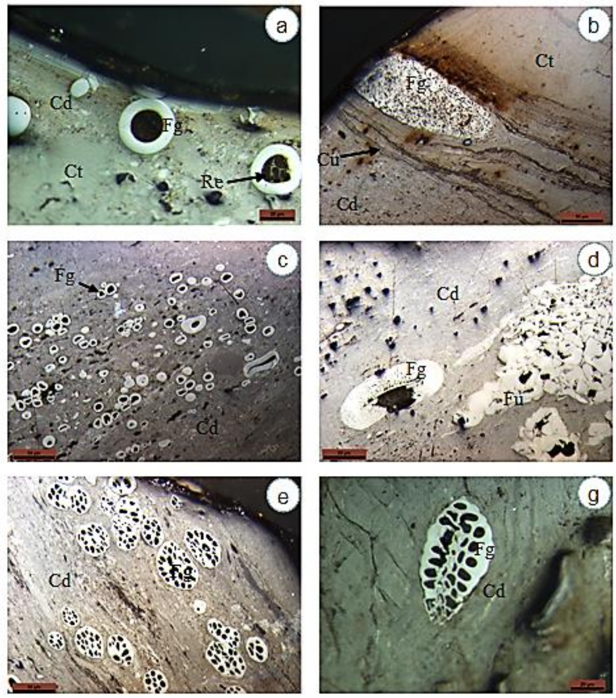

Figure 10. Inertinite maceral in well A under white light, objective x50 in oil. Single cell Fuginite (Fu) in sample 10 (a) and sample 13 (c). Multi-celled Funginite in sample 12 (b), samle 13 (d), samle 14 (e), sample 15 (g). Fusinite (Fu) in sample 13 (d).

sedimentary rocks (Pickel, Kus et al., 2017). Suberinite occurred as cell wall tissues and was characterised by a yellow to brownish-yellow fluorescence (Figure 11 g,h; Figure 12 a,b). Resinite appeared mostly as filling in the dimension of plant cells and yellow to brownish-yellow in fluorescent light (Figure 12 h, i). Fluorinite (Fu) is considered as a variety of resinite. Fluorinite can be easily distinguished when found associated with the cutinite from the essential oil-bearing leaves and by its striking bright fluorescence (Pickel, Kus et al. 2017). In these coals, fluorinite show greenish-yellow fluorescence (Figure 11 e,f). A number of petrographic features that are also considered to indicate oil generation from the studied samples have been recognized. The most significant of these features is the occurrence of exsudative, a secondary maceral commonly considered to represent the very beginning of oil generation in coal. Exsudatinite appeared as crack fillings and was yellow to brownish-yellow in fluorescent light (Figure 11 a, b).

4.3. Thermal maturity

Tmax values are fairly uniform, ranging from 427 to 439 °C, which commonly reflects on maturity but may also be influenced by kerogen type (Hunt, 1996), thus the defined maturity windows on this diagram are only approximate. The Tmax values are consistent with the mean vitrinite reflectance data (0.44–0.79%). The maximum temperature (Tmax) versus Hydrogen Index (HI) diagram (Figure 5) shows that thermal maturity of the organic matter from the two wells tend to occur between an immature to early mature zone; the coal samples in well A more mature than those in well B. The presence of oil generation evidence in cleat of vitrinite maceral proves that. Base in coal ranked classification, it is rank as subbituminous A to high-volatile bituminous C coal (Crelling).

4.4. Coal as petroleum source rock

It is said that vitrinite was gas-prone, liptinite was oil-prone, and inertinite had no petroleum generation potential (Tissot and Welte, 1984; Hunt, 1991). Many authors have focused on the critical importance of liptinites in estimating the potential of coal for oil generation (Tissot and Welte, 1984; Wilkins and George, 2002). There have been several opinions about volume percentage level of liptinite (exinite) in a coal for it to be considered to be capable of generating oil ((Hunt 1991) - "15 – 20% liptinite+ resinite"; (Snowdon 1991) - "as little as 10% H-rich maceral"; (Mukhopadhyay and Hatcher 1993) - a minimum of 15 - 20% liptinite). In this case study, coal samples contain 11.93 - 24.83% liptinite maceral, TOC content is 63.23 to 85.23%wt, hydrogen index range from 202 to 410mg/g. This coals can be referred as petroleum source rock with both oil and gas prone.

5. Conclusion

Based on geochemical investigation and detailed petrographic study, the following findings are highlighted:

(1) Coals composition dominated by humic material and significant amounts of liptinite; minor inertinite macerals.

(2) The organic matter is identified as Type II kerogen and mixed Type II–III kerogens as indicated by hydrogen index values (202 to 410mg HC/g TOC).

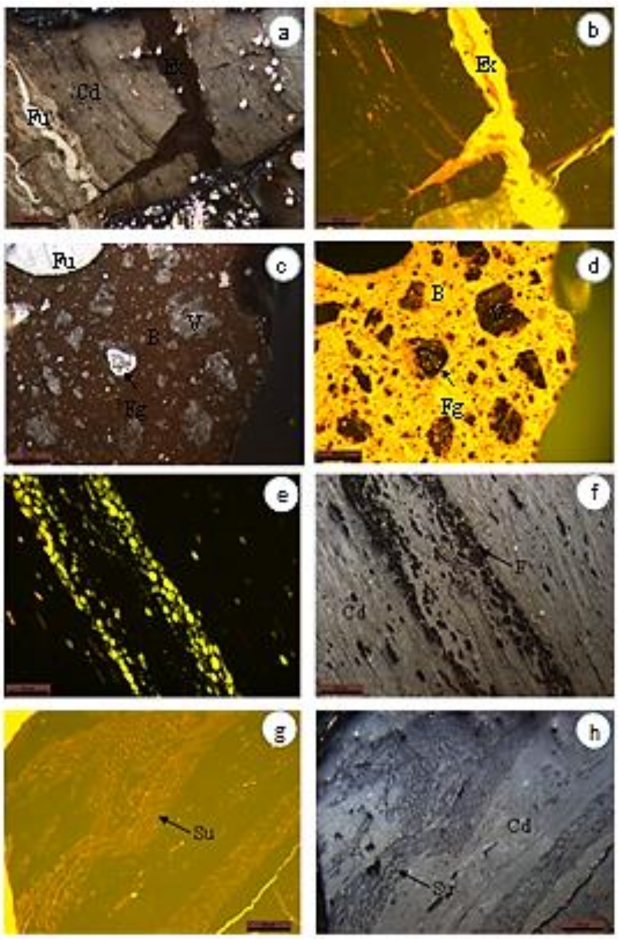

Figure 11. Liptinite maceral in well B under incident light (a, c, f, h) and fluorescent light (b, d, e, g), objective x50 in oil. Exudatinite (Ex) fill in cleat of Collodetrinite (Cd) in sample 16 (a, b). Funginite (Fg), Fusinite (Fu) and vitrinite fragments float in Bituminite (B) sample 9 (c, d). Fluorinite (F) in sample 14 (e, f). Suberinite (Su) in sample 12 (g, h).

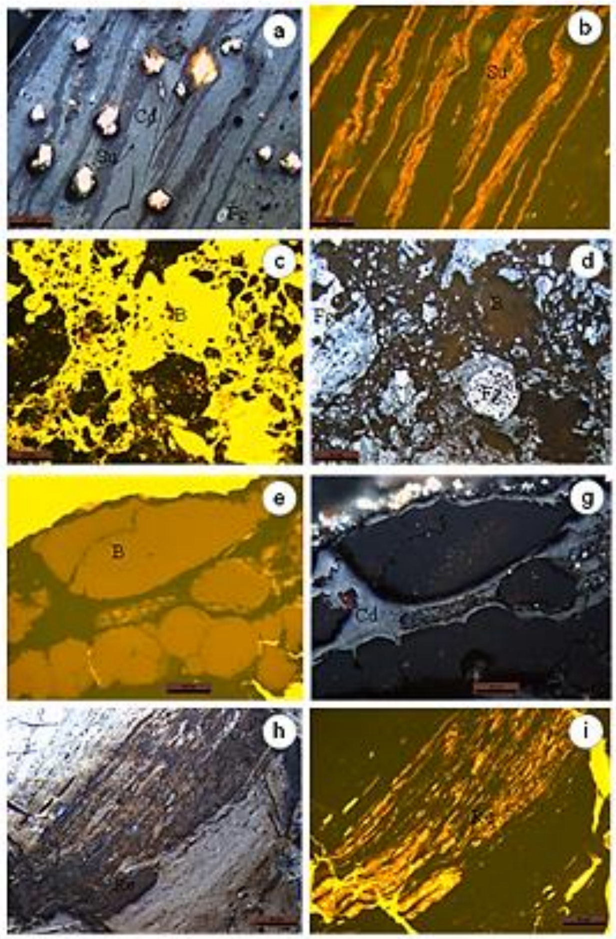

Figure 12. Liptinite maceral in well A under incident light (a, d, g, h) and fluorescent light (b, c, e, i), objective x50 in oil. Suberinite (Su) and Collodetrinite (Cd) sample 01 (a, b). Bituminite (B) in sample 02 (c, d) and sample 06 (e, g). Resinite (Re) in sample 02 (h, i)

(3) Thermal maturity classification based on pyrolysis data and vitrinite reflectance values suggests that the coals generally are thermally immature to early-mature for petroleum generation and range from subbituminous A to high-volatile bituminous C rank.

Although these coal samples are immature to early-mature for petroleum generation, the stratigraphic equivalent of these sediments are known to have been buried to a deeper depth and therefore act as a source rock for oil and gas in block 07.

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