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Geochemical characterization and evaluation of the Upper Cretaceous petroleum source rock of Donga in the Termit Basin (East Niger)

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ABSTRACT: The oil potential of Niger is mainly located in two large sedimentary basins: the Iullemeden Basin in the West and the Eastern Niger Basin in the East. These two basins cover 90% of the National Territory. Nowadays, exploration and exploitation activities take place in the Eastern Niger Basin, more particularly in the Termit-Basin.
Despite the development of some deposits and recent discoveries, the Termit Basin, one of the largest Cretaceous to Tertiary trenches belonging to the West and Central African Rift System (WCARS), remains under-explored.
The overall objective of this study is to assess the petroleum potential and kerogen type contained in the Donga bedrock of the Termit Basin.
This study, which follows previous organic geochemical work, is based on the Rock-Eval6 method and Gas chromatography (CG-SM) method of analysis of source rock samples and crude oil from the Upper Cretaceous of Donga formation. The samples come from the following wells: Trakes N-1D, Minga-1, Douwani N-1, Kanga-1, and Koulele Deep-1.
The Source rock evaluation of Well Douwani N-1 and Trakes N-1D, suggests that, the Donga Formation contains more Type II2 and II1 organic matters in the eastern basin than in the western basin, and is generally considered the moderate to good source rock.
Pr/Ph is 1.57, the Tricyclic terpane content is higher than the Pentacyclic terpane content, the Gammacerane content is high, the ratio of Gammacerane to C30 Hopane is 1.05.
The Donga Formation crude oil from Well Trakes N-1D is different from those from Well Trakes-1, as shown in the triangular chart of C27-C28-C29 Regular steranes, and hence is defined as Class IV. The cross plot of Gammacerane/C30 Hopane and C27/C29 Regular steranes provides a good approach to distinguish these four classes of crude oil.

KEYWORDS: Source Rock, Donga Formation, Termit Basin.

1 INTRODUCTION

The Termit Basin is a sub-basin belonging to the Eastern Niger Basin. It is one of the largest trenches belonging to the Cretaceous-Tertiary Rift in the West and Central African Rift System (WCARS) (Fairhead, 1986; Genik, 1992, 1993; Guiraud et al, 2005).

The Termit basin is located in the southeastern part of the Republic of Niger, about 1400km from the capital (Niamey).

In Niger, it is the first hydrocarbon-rich basin (Xue et al., 2014; Wan et al. 2014). The hydrocarbons currently discovered are from marine formations of the Upper Cretaceous (thickness ranging from 500 to 2000 m) and Paleocene formations (Genik, 1992, 1993; Harouna and Philp, 2012; Liu et al. 2015).

The objective of the present work is to characterize and evaluate the petroleum potential of the Donga source rocks of the Termit Basin, using the rock-Eval 6 pyrolysis method developed by LAFARGUE.all and the Gas chromatography method.

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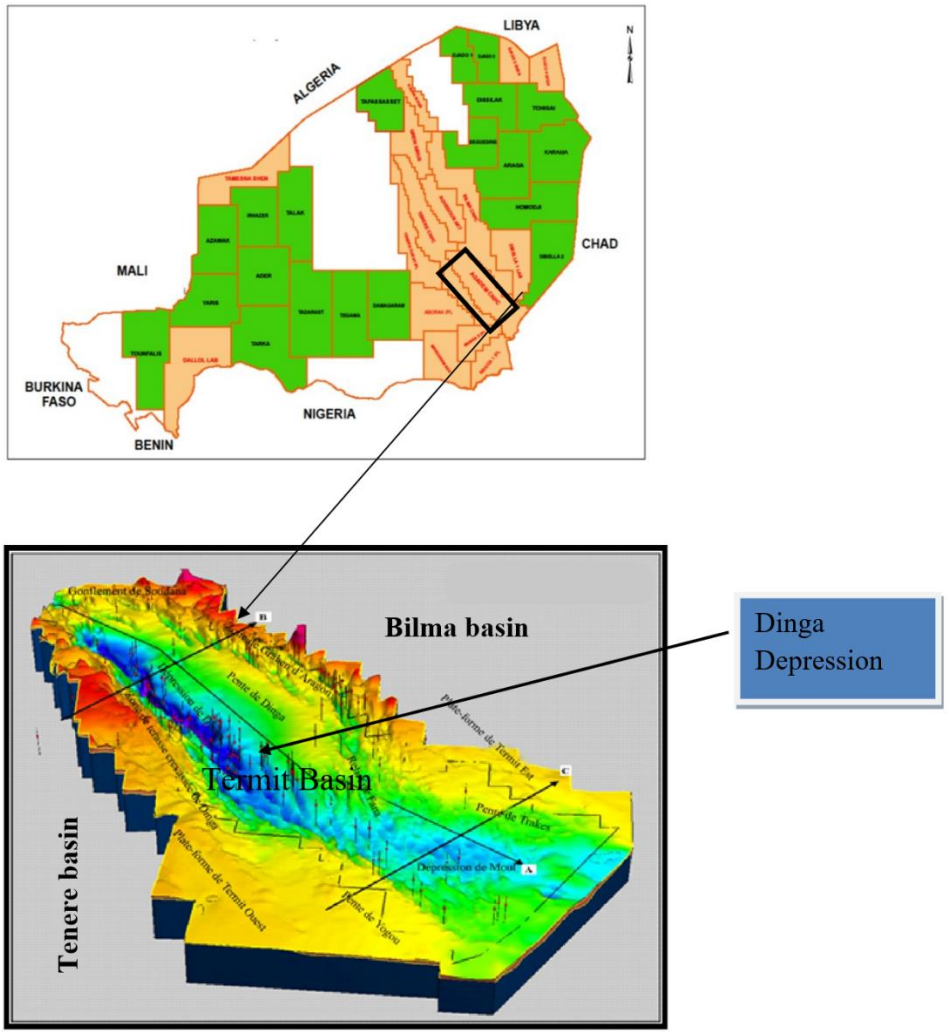

Fig. 1. Geographic location of Termit Basin

2 GEOLOGICAL CONTEXT OF THE STUDY AREA

The Termit Basin is an intracontinental basin between Niger, Chad and Nigeria. It is one of the largest basins in eastern Niger straddling the Borno Basin in Nigeria and the Doba-bongor Basin in Chad.

The Termit Basin was developed during the opening of the Atlantic Ocean in the Cretaceous period.

From the beginning of the Aptian to the end of the Albian; the Africo-Arabian plate extended in a northwestward direction; the pre-Pan-African metamorphosed zone and the Pan-African folded belts moved in northwest and southeast directions.

The rifting of the Intracontinental Basin east of Niger, Chad and Sudan is entering their first syn-rift period; the subsidence in the vicinity of the major NW-SE trending fault shows a rapid filling of sandstone and clay that can reach thousands of meters.

In the early Cretaceous period, syn-rifting activities weaken within the Africo-Arabic Plate. When sea level peaks in the Phanerozoic Eon and seawater from the Neo-Tethys and South Atlantic Oceans caused large-scale marine transgression.

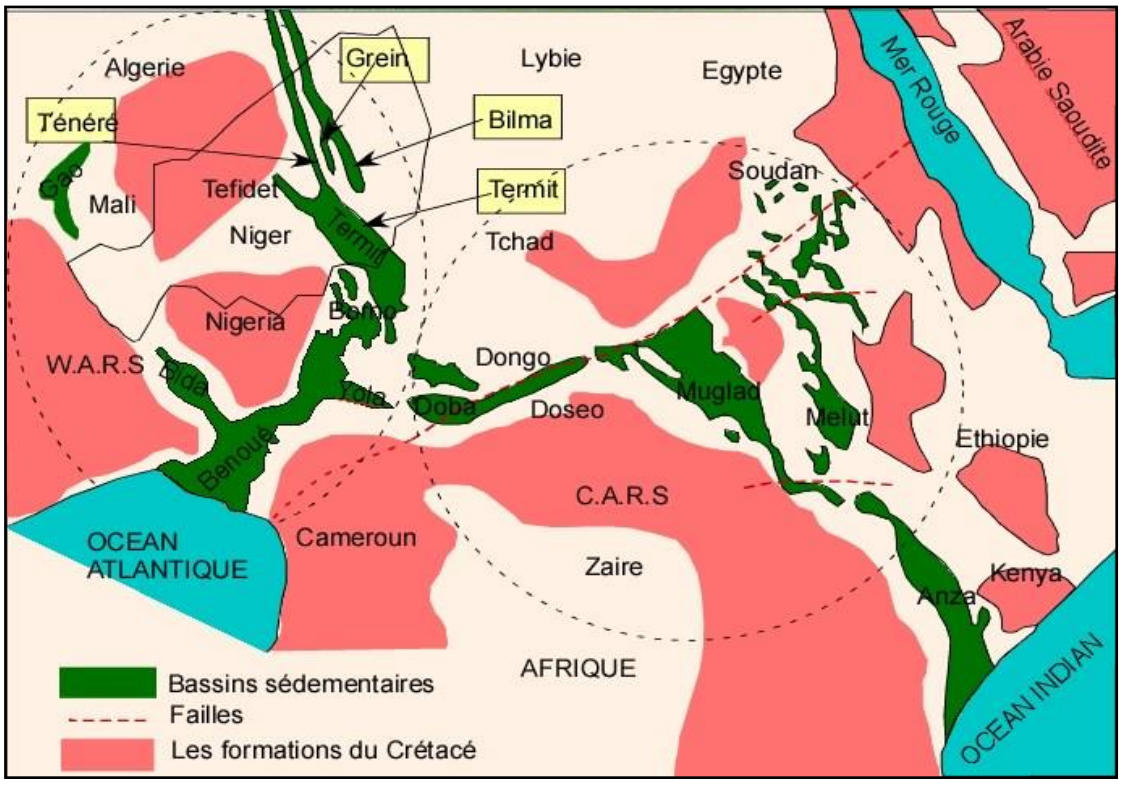

Fig. 2. Tectonic evolution of WCARS (Genik 1992, modified)

3 LITHO-STRATIGRAPHIC OF THE TERMIT BASIN

From its formation to the present day, the Termit Basin has undergone two depositional episodes: one (1) in the Upper Cretaceous accompanied by a marine transgression and the other (2) in the Paleocene.

This Basin is composed of sandstones and marine and continental clays whose maximum thickness of deposition can exceed 12,000 m.

According to seismic reflection data, drilling data, paleontological data and the stratigraphy of the Termit Basin is presented from the base to the top as follows:

- The Basement: The Precambrian Basement and the Cambrian-Jurassic Metamorphic Basement composed of biotite gneiss, pegmatite, quartz, mica and phyllite.
- Cretaceous formations which are composed of Lower Cretaceous K1 formation, Upper Cretaceous K2 formation (Donga formation, Yogou formation, Madama formation).
- The formation of the Paleocene
- The formation of Neocene
- The recent formation of the quaternary

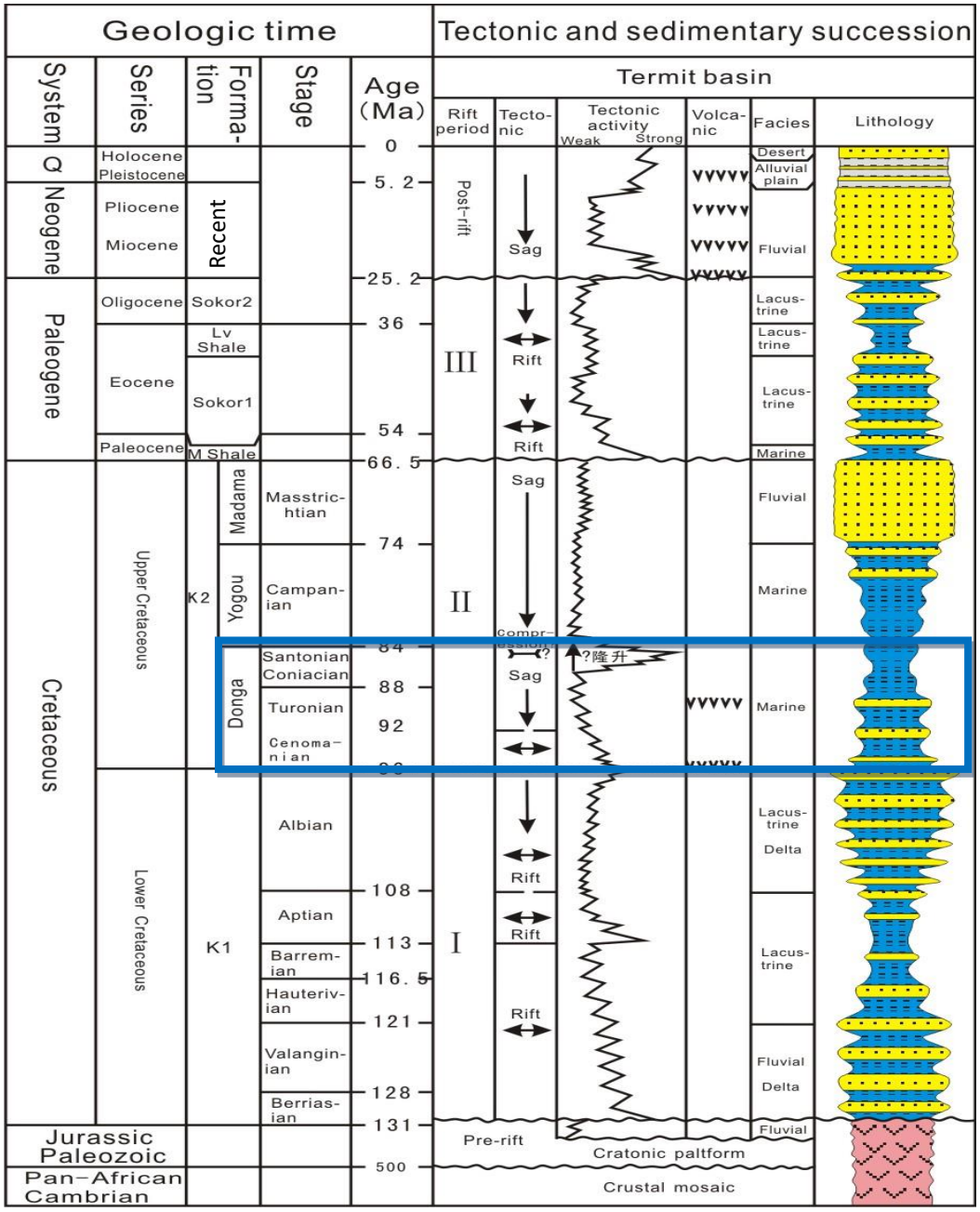

Fig. 3. Column litho-Stratigraphic of the Termit Basin (modified after Genik 1993)

4 MATERIALS AND METHODS

In this study, 40 samples were collected. These samples come from five wells of Termit basin of the study area and belong to the following wells:

- 10 samples from the Trakes N-1D
- 5 samples from the Minga-1
- 5 samples from the kanga-1
- 10 samples from the Douwani N-1
- 10 samples from the Koulele Deep-1

All those samples are analyzed by Rock-Eval pyrolysis (Rock-Eval6) according to the method developed by E. LAFARGUE and All of the French Petroleum Institute (IFP).

Two crude oil of the Donga formation were selected: the crude oil of Trakes N-1D and the crude oil of Trakes-1.

All of those two crudes oils were analyses by the Gas Chromatography and MS method

PREPARATION OF THE SAMPLES

The sample preparation is as follows: the crushing of samples (core) with a diameter between 2 and 3 mm before pyrolysis, the sieving to select the seeds whose size is less than 2 mm in diameter, sorting under the magnifying glass of soluble and pasty pollutants and finally the taking of 500 mg of sample to submit analysis

5 RESULTS AND DISCUSSIONS

5.1 EVALUATION OF DONGA FORMATION SOURCE ROCK

Two reservoir-caprock assemblages were formed in the Donga Formation in the Termit Basin: the upper and lower assemblages.

The upper reservoir-caprock assemblage is an alternating sequence of sandstone and mudstone in the upper section of the Donga Formation, with the thick-bedded mudstone and shale that are present in the middle and upper sections of the Yogou Fm serving as caprocks.

This assemblage has been proved by exploration in Block Lake Chad to be effective. The lower reservoir-caprock assemblage is an alternating sequence of sandstone and mudstone in the lower section of the Donga Formation, with the mudstone and shale of the Donga and K1 formations acting as source rocks, the Lower Donga Formation sandstone as reservoir and the Middle Donga Formation mudstone as caprock. This assemblage has been proved by drilling the Trakes N-1D well to be effective.

The source rock evaluation of the Donga Formation was carried out in five wells of this study: Minga-1, Kanga-1, Douwani N-1, Koulele Deep-1 and Trakes N-1D. Through a variety of analytical tests (rock pyrolysis and saturated hydrocarbon GC-MS), source rock potential, maturation threshold depth and scope of currently matured source rock were analyzed, providing the basis for further understanding the hydrocarbon accumulation law of the Donga Formation.

5.2 GEOCHEMICAL CHARACTERIZATION OF THE DONGA SOURCE ROCK

5.2.1 GEOCHEMICAL ANALYSIS OF DONGA SOURCE ROCK IN WELL MINGA-1

Well Minga-1 was drilled in the southern part of the Dinga fault terrace belt. Rock pyrolysis analysis of this well indicates that, the Donga Formation has Type III-II2 organic matter, and is considered poor source rocks. Peak temperature of pyrolysis indicates that, the maturation threshold of source rock in this well is about 1800 m (Fig.4)

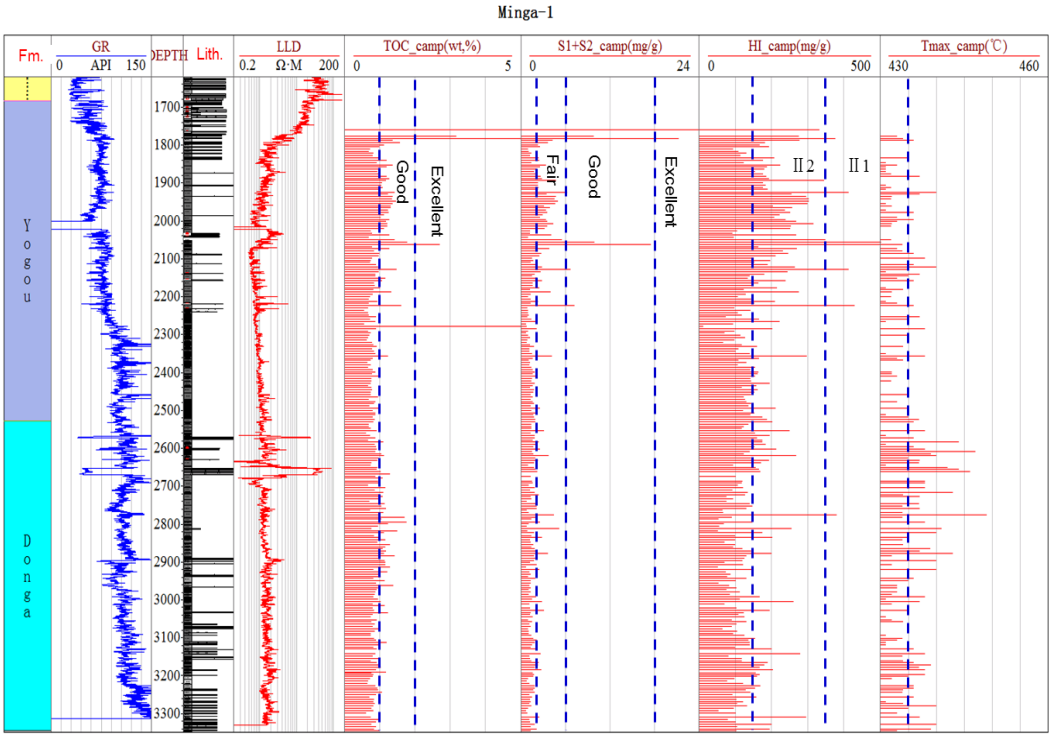

Fig. 4. Geochemical profile of Well Minga-1

5.2.2 GEOCHEMICAL ANALYSIS OF SOURCE ROCK IN WELL DOUWANI N-1

Well Douwani N-1 was drilled in the eastern part of the Moul depression in the basin. The Rock pyrolysis analysis of this well indicates that, the upper section of the Donga Formation has Type II-III organic matter, and is considered moderate to good source rock. Peak temperature of pyrolysis indicates that, the Donga source rock in this well is thermally mature (Fig.5).

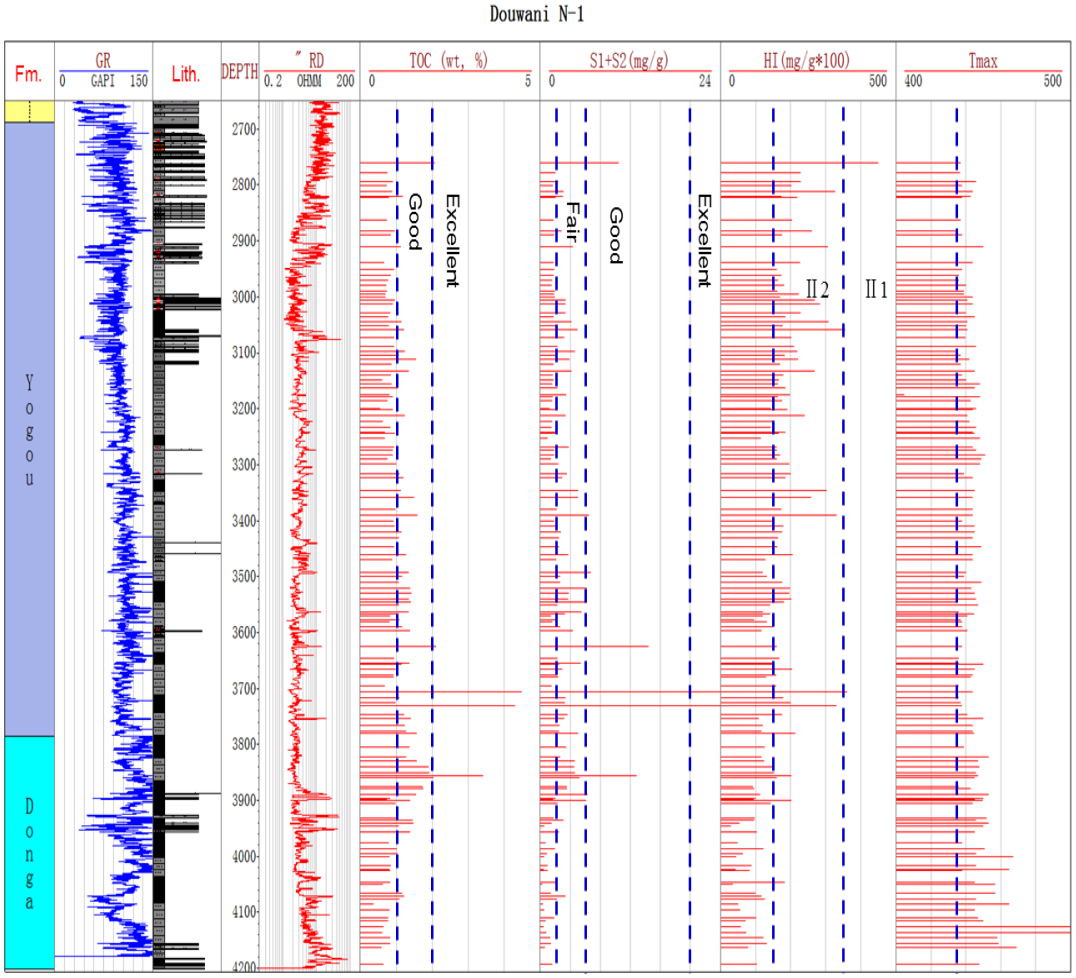

Fig. 5. Geochemical profile of Well Douwani N-1

5.2.3 GEOCHEMICAL ANALYSIS OF SOURCE ROCK IN WELL TRAKES N-1D

Well Trakes N-1D was drilled on the Trakes slope in the eastern basin. Rock pyrolysis analysis of this well indicates that, good source rock intervals are present in both the upper and lower sections of the Donga Formation, with Type II2 to II1 organic matter. Peak temperature of pyrolysis indicates that, the maturation threshold depth of the Donga Formation source rock in this well is about 2100 m (Fig.6).

The Source rock evaluation of Well Douwani N-1 and Trakes N-1D, both of which were drilled on the structural belt in the eastern basin, suggests that, the Donga Formation contains more Type II and II organic matters in the eastern basin than in the western basin, and is generally considered the moderate to good source rock.

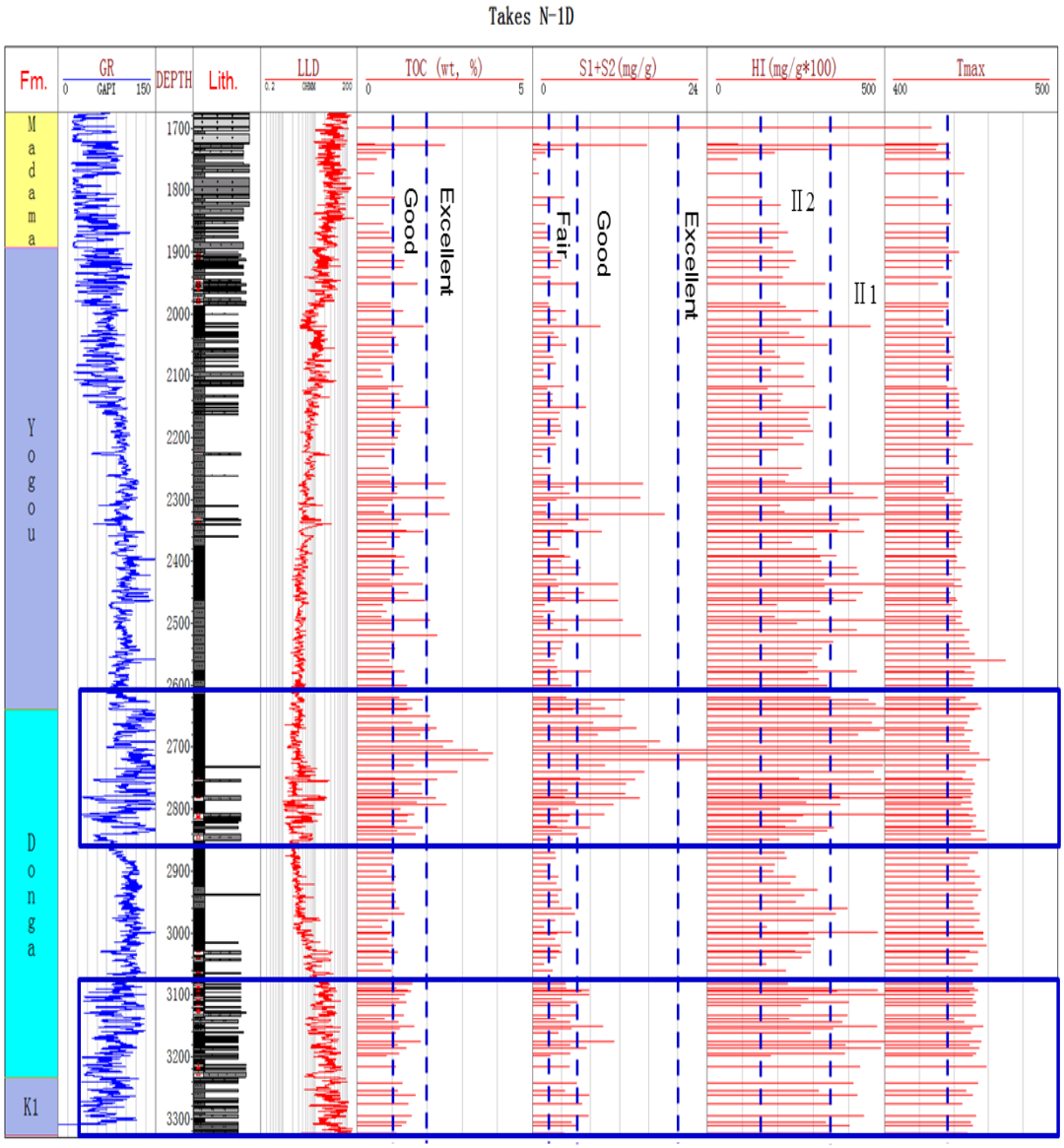

Fig. 6. Geochemical profile of Well Trakes N-1D

5.2.4 Scope Of Currently Matured Donga Formation Source Rock

Gas logging value derived from mud logging provides an opportunity to roughly determine the maturation threshold depth of a source rock. It is generally believed that, the depth at which the C4 component and above are present corresponds to the present maturation threshold depth of the source rock. Gas logging of Well Trakes N-1D indicates that, the presence of the C4 component is firstly recorded at a depth of 2070 m (TVD) (Fig.7), which matches well with the maturation threshold depth (2100 m) given by the indication of peak temperature of rock pyrolysis (Fig.8).

In accordance with the result of the well-seismic synthetic seismogram record calibration for Well Trakes N-1D, the depth of 2100 m corresponds to the TWT of 1750 ms (Fig.9). This figure shows the scope of the area exceeding 1750 ms on TWT structural map of Top Donga Formation, which corresponds to the scope of the currently matured Donga Formation source rock.

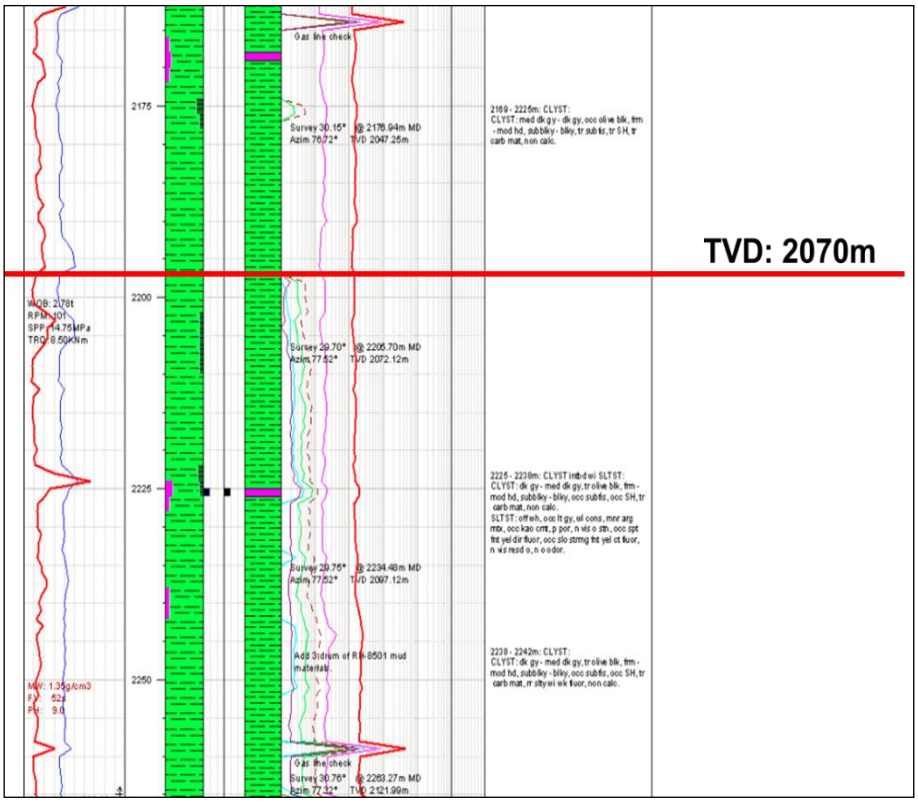

Fig. 7. Comprehensive mud-logging diagram of Well Trakes N-1D

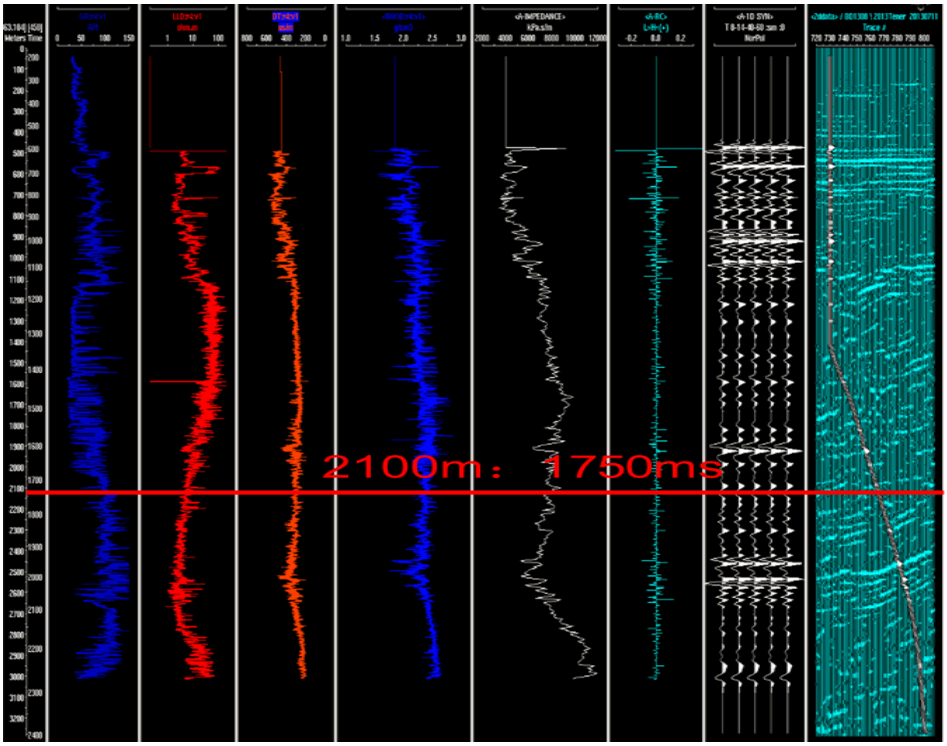

Fig. 8. Well-seismic synthetic seismogram calibration for Well Trakes N-1D

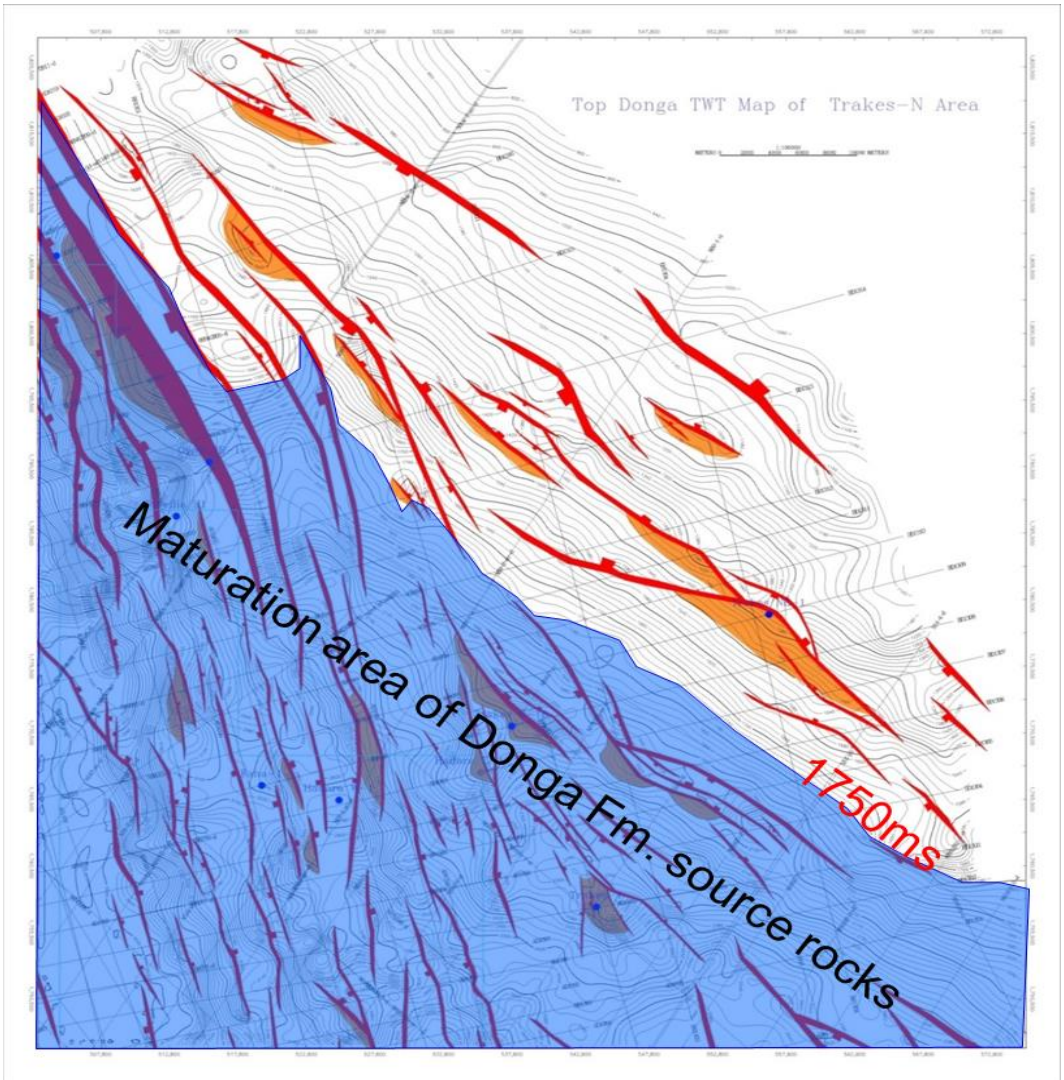

Fig. 9. Scope of the matured Donga Formation source rock in the Termit Basin

5.3 CRUDE OIL GEOCHEMICAL ANALYSIS

The study area of oil flow has been recorded only in Well Trakes N-1D from the hydrocarbon accumulation assemblage in the Donga Formation across the Termit Basin.

The GC and GC-MS analyses were carried out using the samples recovered from this well by oil testing. On the basis of the existing crude oil geochemical analysis of Well Trakes-1 made by this study, the crude oil geochemical features and crude oil types of the Donga Formation were analyzed, and the source of the crude oil trapped in the Donga Formation was studied through the oil source correlation, thereby providing the basis for further understanding the hydrocarbon accumulation law of the Donga Formation.

5.3.1 CRUDE OIL SAMPLE FROM DONGA FORMATION

There are only two crude oil samples available from the hydrocarbon accumulation assemblage in the Donga Formation in the Termit Basin: samples of Well Trakes N-1D and Well Trakes-1. Of particular note is Well Trakes-1, where analytical test was performed by ex-operator. Crude oil sample of Well Trakes-1 was recovered from an oil layer that is present in the upper section of the Donga Formation, and that of Well Trakes N-1D from the lower section. Well Trakes N-1D produced 169.5bbl per day of API 33 crude oil while DST1 oil testing. API 39.4 Crude oil from Well Trakes-1was recovered with RFT.

5.3.2 GEOCHEMICAL FEATURES OF DONGA FORMATION CRUDE OIL

Geochemical features of the Donga Formation crude oil in Well Trakes-1 are as follows: Pr/Ph is 1.57, the Tricyclic terpane content is higher than the Pentacyclic terpane content, the Gammacerane content is high, the ratio of Gammacerane to C30 Hopane is 1.05 (Fig.10), and C27-C28-C29 Regular steranes show the C27 predominance and C27>C28>C29, with C27/C29 of 1.5.

Geochemical features stated above suggest that, the source rock of this crude oil was deposited in a saline water environment, where numerous lower hydrobionts acting as oil-generating kerogen.

Geochemical features of the Donga Formation crude oil in Well Trakes N-1D are as follows: Pr/Ph is 0.98, the Tricyclic terpane and Gammacerane contents are relatively high, ratio of Gammacerane to C30 Hopane is 0.35 (Fig.11), C27-C28-C29 Regular steranes show the C29 Sterane predominance in content and C29>C27>C28 (Fig.12), with C27/C29 of 0.85, and the Pregnane and Homopregnane contents are high. Geochemical features stated above suggest that, the source rock of this crude oil was deposited in a saline water environment, where oil-generating kerogen is dominated by terrigenous higher plants, followed by a certain amounts of lower hydrobionts.

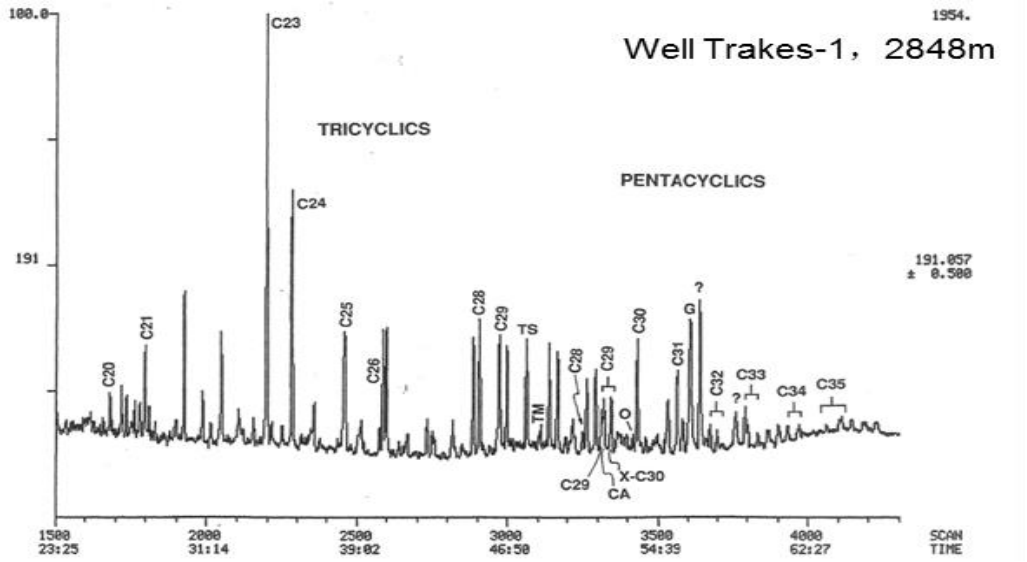

Fig. 10. m/z191 GC-MS of the Donga Formation crude oil in Well Trakes-1

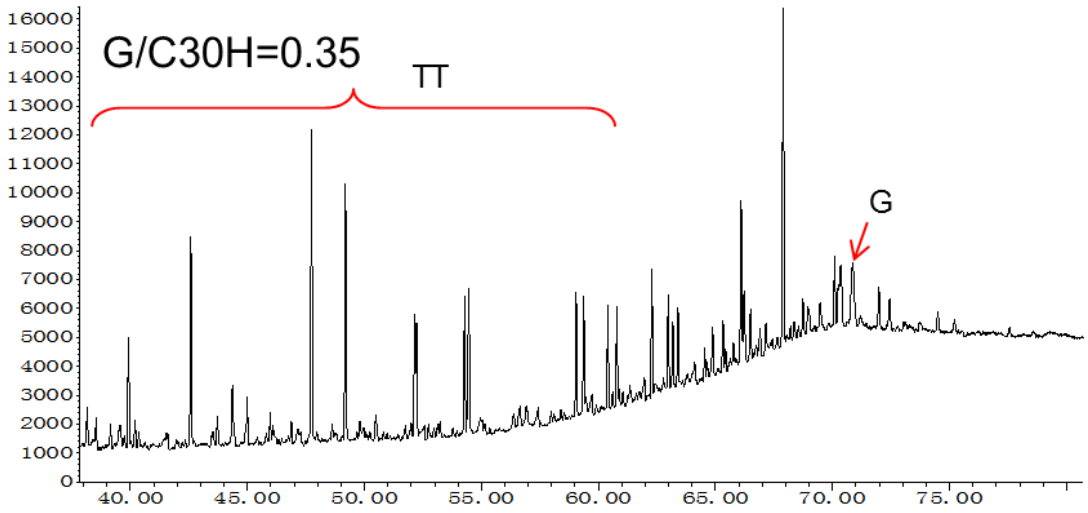

Fig. 11. m/z 191 GC-MS of the Donga Formation crude oil in Well Trakes N-1D

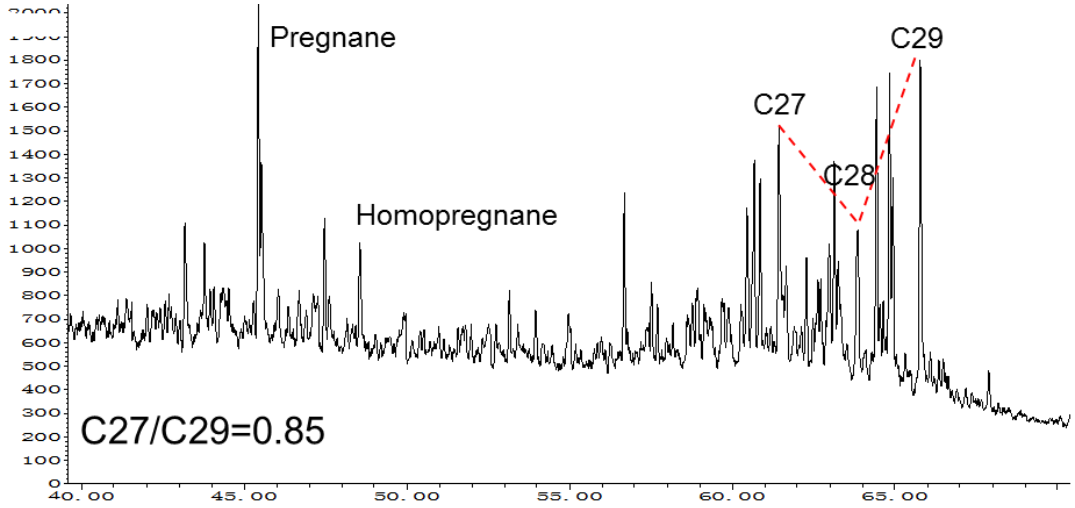

Fig. 12. m/z 217 GC-MS of the Donga Formation crude oil in Well Trakes N-1D

5.3.3 CRUDE OIL TYPE

The crude oil in the Termit Basin was divided into three classes before we perform the analysis of the Donga Formation crude oil recovered from Well Trakes N-1D. The majority of crude oil discovered in the basin is defined as Class I, those recovered from the Dinga Deep-1, Tairas-1 (E0), Goumeri (E0) and Dinga-1 (E0) are Class II, and the Donga Formation crude oil from Well Trakes-1 is Class III.

In addition, the Donga Formation crude oil from Well Trakes N-1D is different from those from Well Trakes-1, as shown in the triangular chart of C27-C28-C29 Regular steranes, and hence is defined as Class IV. The cross plot of Gammacerane/C30 Hopane and C27/C29 Regular steranes provides a good approach to distinguish these four classes of crude oil (Fig.13).

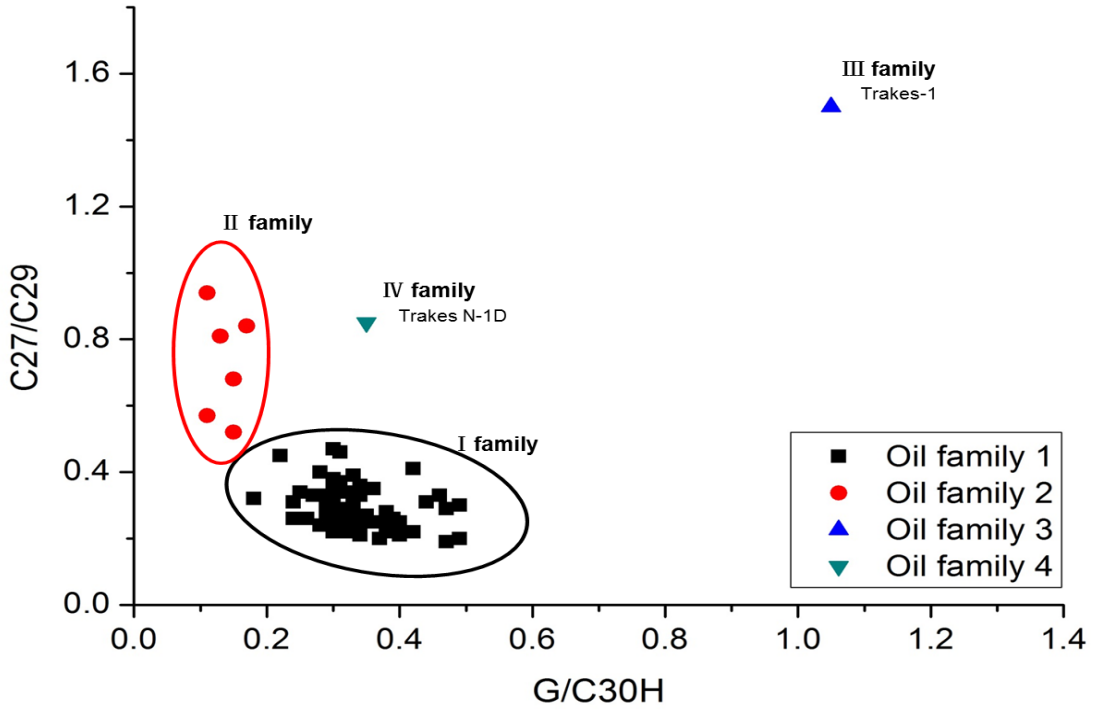

Fig. 13. Crossplot of Gammacerane/C30 Hopane and C27/C29 Regular steranes of crude oil in the Termit Basin

5.3.4 OIL SOURCE CORRELATION

In this study, the Donga Formation crude oil of Well Trakes N-1D and the Donga Formation mudstone of Well Koulele Deep-1 are selected for oil source correlation. The study indicates that, the Terpane and Sterane distribution features of the crude oil sample is consistent with the that of the mudstone sample, exhibiting high contents of Tricyclic terpane, Pregnane and Homopregnane, with C29>C27>C28 Regular steranes (Fig.14, 15, 16 and 17).

In the crossplot of the Gammacerane/C30 Hopane and (Pregnane +Homopregnane/Regular steranes), the Donga Formation crude oil samples of Well Trakes N-1D and the Donga Formation mudstone samples of Well Koulele Deep-1 fall within the same zone (Fig.18), indicating that the Donga Formation crude oil is sourced from the Donga Formation source rock.

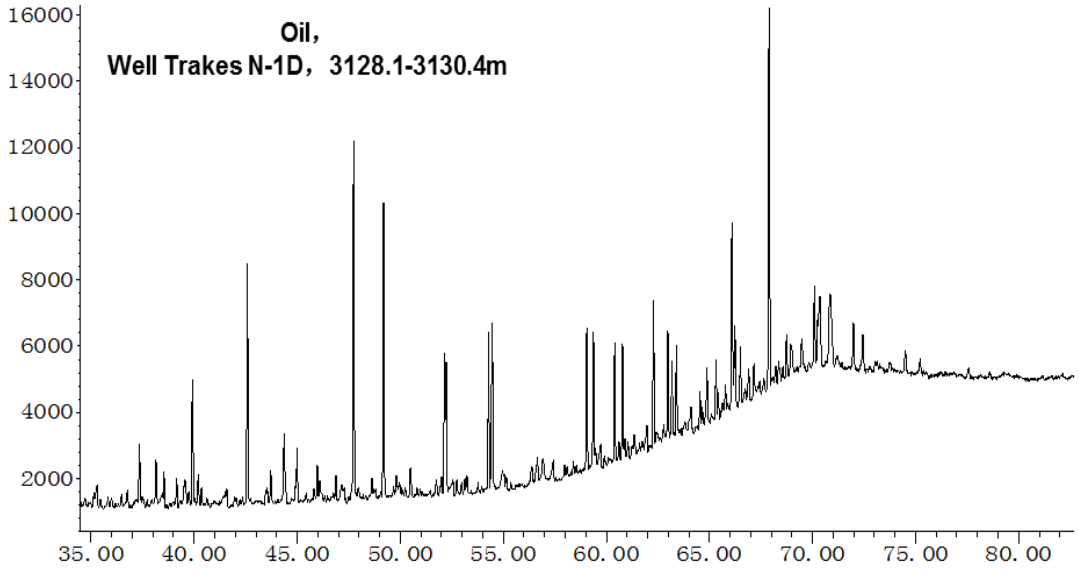

Fig. 14. m/z 191 GC-MS of the Donga Formation crude oil of Well Trakes N-1D

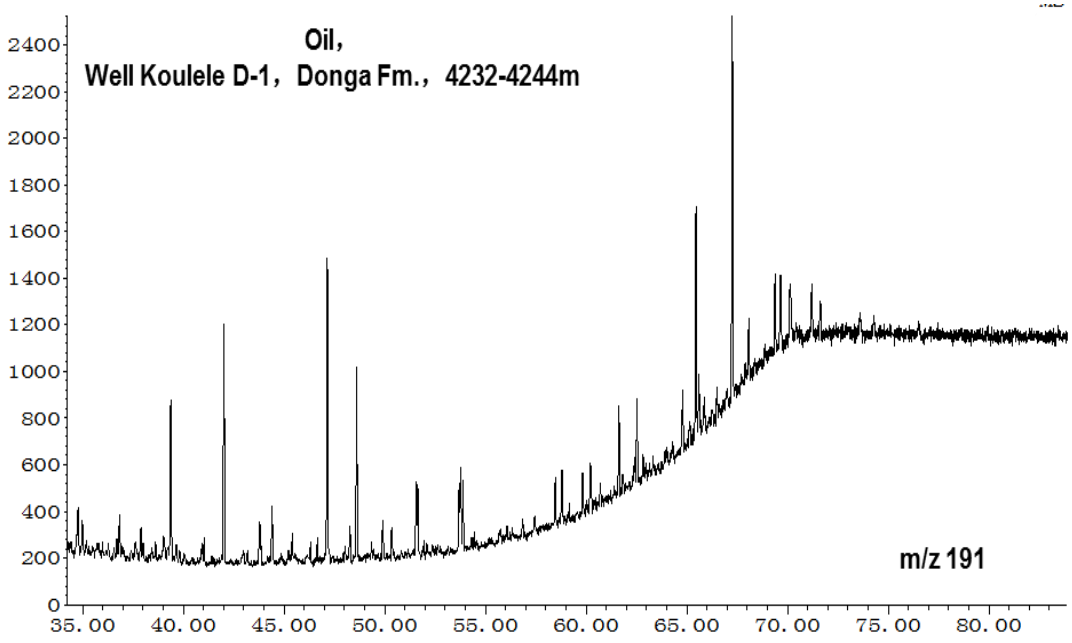

Fig. 15. m/z 191 GC-Ms of the Donga Formation mudstone of Well Koulele Deep-1

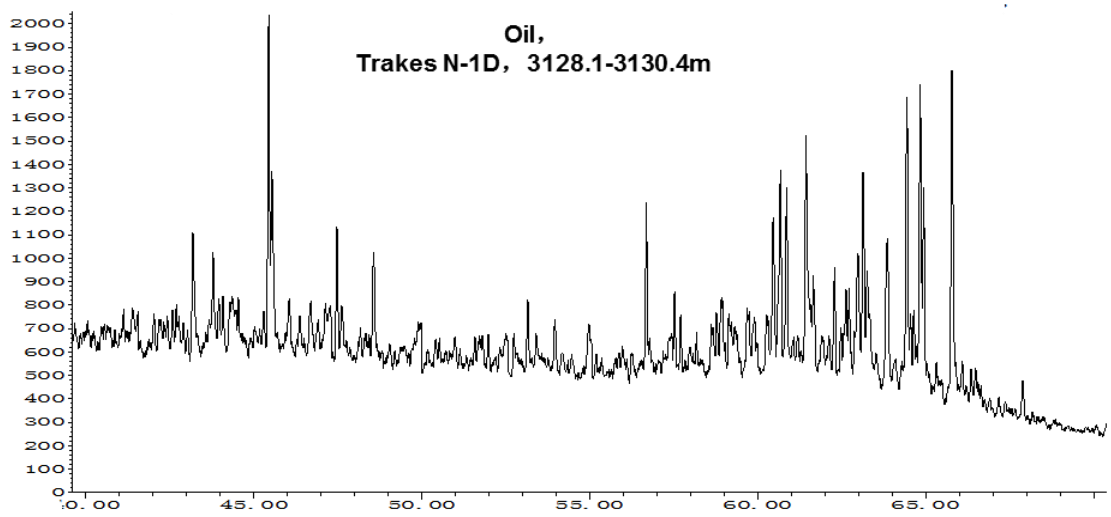

Fig. 16. m/z 217 GC-MS of the Donga Formation crude oil of Well Trakes N-1D

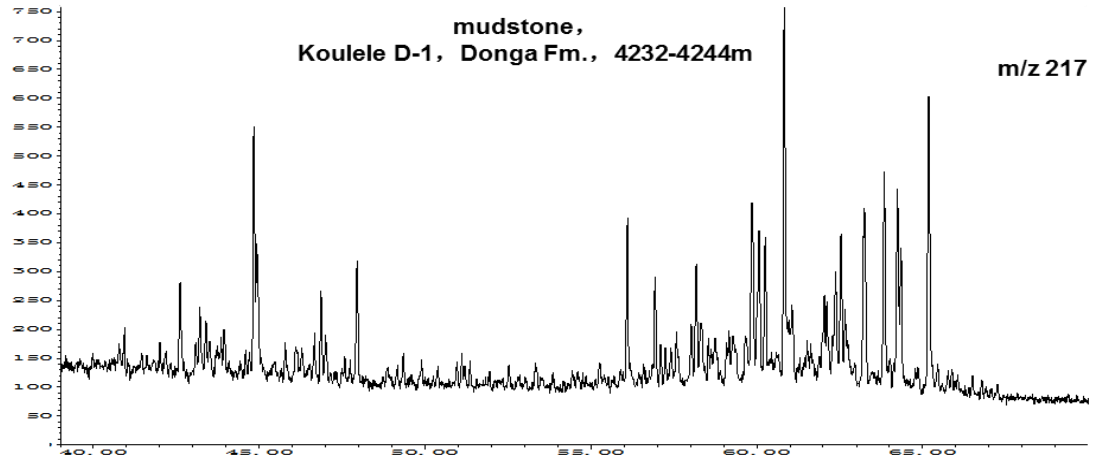

Fig. 17. m/z 217 GC-MS of the Donga Formation mudstone of Well Koulele Deep-1

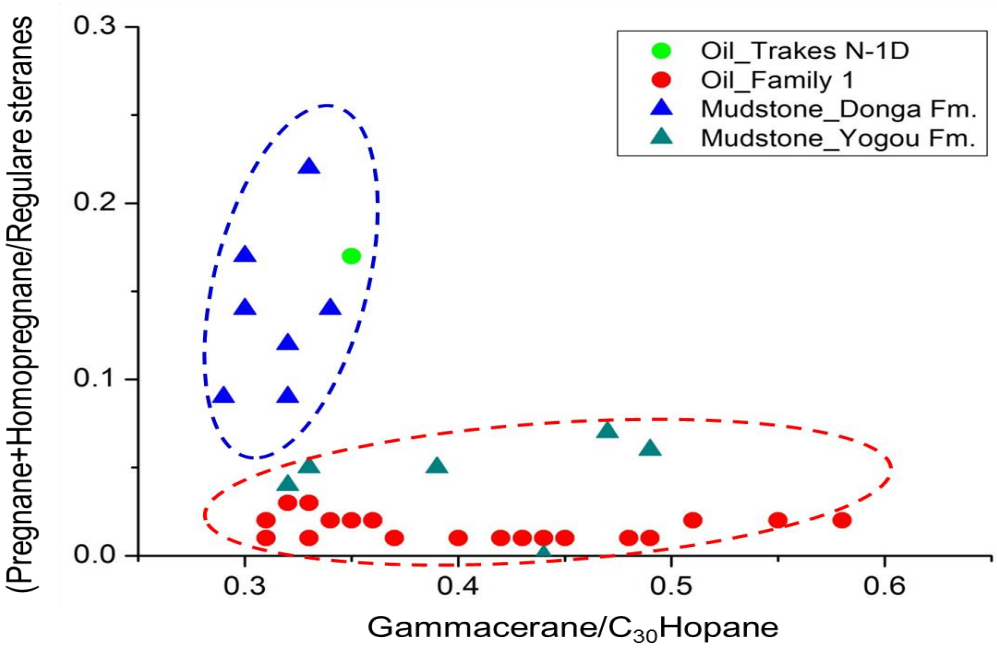

Fig. 18. Crossplot of Gammacerane/C30 Hopane (Pregnane+Homopregnane) /Regular steranes of the crude oil in the Termit Basin

6 CONCLUSION

The geochemical characterization and evaluation of the donga source rock of the Termit basin show that:

The Source rock evaluation of Well Kanga-1 and Well Minga-1, both of which were drilled on the structural belt in the western basin, suggests that, the Donga Formation has Type III-II organic matter and is generally considered poor to non-source rock.

The Source rock evaluation of Well Douwani N-1 and Trakes N-1D, both of which were drilled on the structural belt in the eastern basin, suggests that, the Donga Formation contains more Type II2 and II1 organic matters in the eastern basin than in the western basin, and is generally considered the moderate to good source rock.

The Donga Formation crude oil from Well Trakes N-1D is different from those from Well Trakes-1, as shown in the triangular chart of C27-C28-C29 Regular steranes, and hence is defined as Class IV. The cross plot of Gammacerane/C30 Hopane and C27/C29 Regular steranes provides a good approach to distinguish these four classes of crude oil.

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