

CHARACTERISATION AND DISTRIBUTION OF HYDROCARBON IN SONG HONG BASIN

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Summary

Compared to other Tertiary basins of Vietnam, the Song Hong basin is less prolific. The density of oil and gas discoveries is therefore not sufficient for detailed geochemical characterisation of the petroleum in the entire basin. However, based on the available data the authors have analysed the geochemical characteristics of hydrocarbons (HC) and source rocks in the study area and got the following results:

- There are four HC groups that could be recognised in the Song Hong basin: Hydrocarbon with mainly terrestrial sources from blocks 102 and 103 (Miocene inversion zone); Hydrocarbon with mainly lacustrine sources from blocks 106 and 107 and well B10 STB-1X (NE Song Lo differential zone and Bach Long Vi zone); Hydrocarbon with mainly terrestrial sources from block 112 (Hue Da Nang sub-basin); Hydrocarbon from blocks 118 and 119 and migrated HC from block 120 (Tri Ton horst) and HC from block 113 (central sub-trough);
- The distribution of HC and source rock samples on the diagrams demonstrates the close relationship between oil and source rock on the same structural element in the basin;
- It is possible that the migration distance of HC in the Song Hong basin is not long;
- The distribution of HC suite in the structures in the Song Hong basin is to be studied in further research.

Key words: Song Hong basin, Miocene inversion zone, NE Song Lo differential zone, Benzene-Toluene-Xylene, 4-methyl C30 Sterane

1. Introduction

The Song Hong basin covers approximately 220,000km² of surface area; in Vietnamese territory, it occupies 126,000km², 4,000km² of which belongs to the onshore Hanoi trough and the shallow marine area. The remaining area belongs to the Gulf of Bac Bo and offshore Central Vietnam. Hydrocarbon exploration activities in the Song Hong basin started in the beginning of the 60s of the last century, but mainly focused on onshore areas with the first gas discovery being the Tien Hai C gas field (TH-C) in 1975. When Vietnam declared its Renovation Policy in 1988, especially with the promulgation of the foreign investment policy, the Song Hong basin was extensively investigated and explored with the signing of twelve Production Sharing Contracts (PSC) for both onshore and offshore activities [2]. This study focuses on the offshore area.

Likewise, exploration drilling in the offshore area was mainly conducted by foreign operators. Since 1990, more than 40 exploration wells have been drilled. The shallowest well on the Qua Vai structure reached 1,050m TVD and the deepest well on the Bach Tri structure reached

4,114m TVD. The density of exploration wells is about one well/3,200km². Among the wells drilled in the area, more than 70% of them had moderate to good hydrocarbon shows and discoveries.

The Song Hong basin is a Tertiary sedimentary basin formed from a NW-SE trending pull-apart graben and its flanks are bounded by strike-slip and normal fault systems. These fault systems were initiated by the collision between the Indian and the Eurasian plates during the Eocene-Early Oligocene [8]. Left-lateral strike-slip movement in the Oligocene, right-lateral movement in the Late Miocene, and pull-apart extension are the major geodynamic elements that form the Song Hong basin. Immediately following the Middle-Late Miocene tectonic inversion, the basin continued to steadily undergo thermal subsidence until the present. The Song Hong basin is a very large basin with complicated geological features, changing from the NW to the SE and from the North to the South. The basin is made up of different structural units with different hydrocarbon potential: the Northwestern margin, the Northeastern margin, the Central area and the Eastern margin (Fig.1).

The Western margin is made up of the Hanoi trough and other blocks in the west of the Song Hong basin. The prominent geological features are complicated folding structures accompanied by tectonic inversion of the Miocene succession. There are 3 structural elements in this area: Thanh Nghe shelf, Hue Da Nang sub-basin and Da Nang shelf.

The Northeastern margin is situated in northeastern Song Lo fault as well as Bach Long Vi area. The prominent geological features are folding structures accompanied by tectonic inversion in the Oligocene. This area could be divided into 4 structural elements: the Ha Long shelf, the NE Song Lo differential zone, the Bach Long Vi zone and the West Hainan shelf.

The Central basin area extends from blocks 102-103 to block 121 with water depths ranging from 10 to 120m. In this area, the basement gently dips towards the depocentre where the thickness of Tertiary section exceeds 15,000m. Structures range from drape-over (topping the basement) in the West to mud diapirs in the basin centre. The Central basin is divided into four structural elements: the Dong Quan trough, the Miocene inversion zone, the Central sub-trough and the Quang Ngai graben.

The Eastern margin, with water depths of 100 to 800m, is structurally different from the above mentioned areas. There are three structure elements in this area: the Eastern Tri Ton trough, the Tri Ton horst and the Hoang Sa differential zone.

The area is characterised by a basement high (the Tri Ton horst), which existed since the beginning of the synrift stage, uplifted at the end of the Oligocene, and thus creating favourable conditions for the formation of carbonate platforms and reef build-ups in the Middle and Upper Miocene. To the North-East and the South-East of the Tri Ton horst are the East Tri Ton trough and the Hoang Sa differential zone.

In the offshore Song Hong basin, although no oil/gas fields have been developed, HC discoveries have been made. The type of the source organic matter (OM) and the origin of HC as well as potential drainage areas (direction/distance migration of hydrocarbons) are still open questions that require additional investigations to be resolved.

2. Source rock

The analytical data of well-samples indicate that the sediments of Middle Miocene, Lower Miocene and Oligocene ages are source rocks in the Song Hong basin. The HC generation potential of these source rocks varies both vertically (stratigraphic) and horizontally (spatially). Oligocene sediments are potentially much better source rocks than the Miocene sediments [3, 5]. However, since the number of detailed analyses of Oligocene source rocks is limited, the relationship between the Oligocene source rocks and the encountered products is not fully documented.

Middle Miocene sediments in the Northern basin are fair source rocks with respect to organic richness, and contain mainly gas-prone kerogen type III, but in the central parts of the basin, palaeogeographic reconstructions indicate shallow marine deposition, which may be reflected in the composition of the generated HC [3]. In deeper basinal areas, Mid-Miocene source rocks entered the oil window in the late Miocene when hydrocarbon migration began. In the Southern basin the Lower Miocene source rocks contain gas-prone type III kerogen.

Oligocene sediments cover the entire basin and mainly contain the kerogen of type III. In places, especially in the southern basin, deposits containing a mixture of kerogen type I and III occur. With the exception of the Northeastern margin, Oligocene source rocks in the Southern basin have better oil potential than in the Northern basin. Most of the Oligocene and Miocene source rocks in the central parts of the basin have realised all of their HC generation potential and large-scale HC migration started from 20Ma [3].

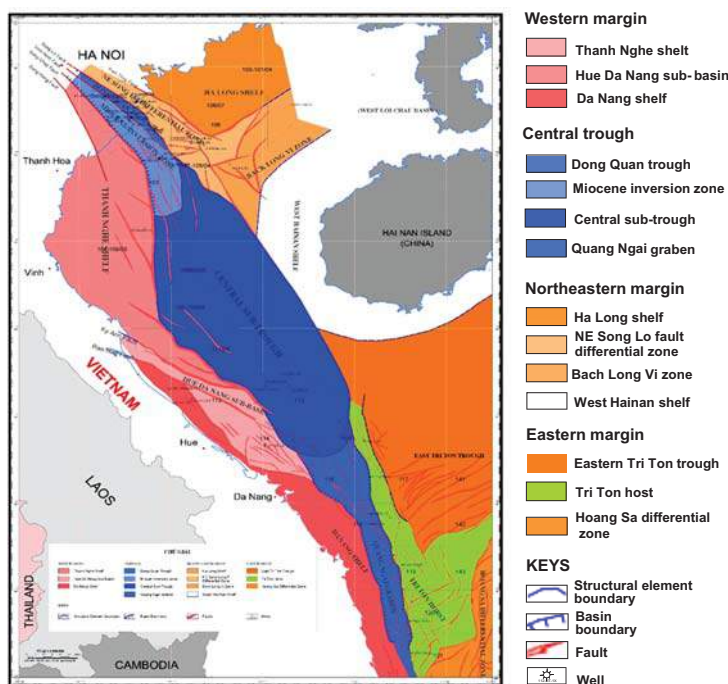


Fig.1. Main tectonic elements in Song Hong basin and adjacent area (Tru.V. and Dau N.T., 2012)

Lacustrine Oligocene source rocks that are found in outcrops at Dong Ho and on Bach Long Vi island are immature mudstones and humic coals [9, 10]. The mudstones from Dong Ho generally have a TOC content of 8 - 17%wt. and HI values of more than 500mg HC/g TOC. The organic matter is principally composed of fluorescing amorphous organic matter and liptodetrinite. The alginite with Botryococcus-morphology is present [10, 11]. The organic matter corresponds to type I kerogen. The Bach Long Vi island mudstones contain 1.55 - 7%wt. TOC and have HI values ranging from 400 to 700mg HC/g TOC. The organic matter is largely similar to that of the Dong Ho mudstones, but in addition it may contain some marine organic material (?) [6]. Studies conducted in Dong Ho area as well as offshore and onshore Bach Long Vi island (ENRECA 3 well) suggest that lacustrine shales and coaly shales of Oligocene age are excellent source rocks containing kerogen Type I and II with potential for generation of primarily oil and minor amounts of gas.

In addition, Eocene (?) source rocks may be present in the NE Song Lo fault differential zone and Bach Long Vi zone. In the neighbouring area, Eocene source rocks are present in the Chang-Liu formation in the West Weizhou basin (China) adjacent to the NE margin of the Song Hong basin. In the West Weizhou basin, source rocks are shales rich in organic matter (kerogen types I and II) with a TOC of 2.67 - 2.78%wt. and with a high petroleum potential (S1+S2 ~10 - 30mg/g; HI ~200 - 600mgHC/gTOC).

The petroleum potential of the Oligocene source rocks is better than that of the Miocene deposits. However, the number of detailed analyses of Oligocene source rocks is very limited; hence the relationship between the Oligocene source rocks and oils in the area is insufficiently documented.

The presence of source rocks in the study area is documented by analysis of rock and fluid samples from wells. The migrated oil/condensate (HC) in the wells demonstrates the following [5]:

- HC found in Devonian carbonate basement rocks in well B10-STB-1X is a proof of HC migration from source rocks into reservoir.
- The oil show in Miocene layers in the 102-CQ-1X well has a biomarker signature similar to that of one coal sample collected at a depth of 3,010 - 3,040m at the 102-HD-1X well.
- The sterane distribution of HC in the Miocene section of the 102-CQ-1X well and the sterane distribution

of DST # 3 sample (mid Miocene age) of the 103-TH-1X well are similar, but DST # 3 samples (103-TH-1X well) has a higher maturity level than samples from well 102-CQ-1X. Thus, these two HC samples can be generated from source rock which contains terrestrial organic matter (OM), but at different levels of maturation (?).

- The conspicuous even and rapid decrease in the range from C₂₂ to C₃₃ of the n-alkane distribution in extracts of samples from well 120-CS-1X is similar to that of HC extracted from carbonate rocks in well 119 CH-1X.

- In the Miocene section of the 118-CVX-1X well (1,150 - 1,570m) migrated HC were found: PI > 0.3. The source rocks in the well are immature, so the HC in the Miocene carbonate are assumed to be migrated in from thermally mature kitchens in the vicinity. Gas and oil were also encountered in carbonate in immature Miocene sections of wells 119-CH-1X, 112-HO-1X, and 118-CVX-1X.

- The 120-CS-1X well does not encounter mature source rocks, but an oil stain is present at a depth of 1,146 - 1,170m, PI = 0.45 - 0.78. C₁₅ + chromatograms of saturated HC indicate that the source rock is mature and contains mixed kerogen. These characteristics demonstrate the presence of migrated HC in the reservoir possibly sourced from Oligocene sediments of paleo-lakes in the Quang Ngai graben (?).

3. Geochemical characteristics of oil/condensate

Compared to other Tertiary sedimentary basins of Vietnam, the Song Hong basin appears less prolific with only few petroleum discoveries. Hence, available data are insufficient for a detailed evaluation of HC-geochemistry in the basin as a whole. However, recent HC analytical data from new wells in the area (blocks 103, 106 and 107) gave new interesting information on the origin of HC. Based on the chemical and physical properties, the HC-occurrences in the Song Hong basin can be grouped:

Oil/condensate samples of the Song Hong basin are characterised by very low sulfur content (< 0.1%), typical for oils generated from source rocks with non-marine organic matter. Generally, HC density in the study area is quite variable, ranging from 33°API in the B10-STB-1X well to 48°API in well 107-BAL-1X. HC in the 107-BAL-1X and 103-TH-1X wells seem to have mixed origin, including contributions from two sources, judging from biological marker data that show mixing of lacustrine oil with terrestrial condensate [7]. In the DST # 4 sample from the 103-TH-1X and 107-BAL-1X

wells the concentration of saturated hydrocarbons is high (74 - 90.68%) with very high Pristane/phytane ratio (8.18 - 30.47) indicating source rock deposited in oxic environments. Alternatively, high pristane/phytane ratio may be due to biodegradation or high maturity.

HC samples from block 112 have lower concentrations of saturates (74 - 83%) and the pristane/phytane ratio is lower, 4.8 - 7.7. Samples DST # 1 and DST # 3 from the 103-TH-1X and 106-YT-1X wells have low concentrations of saturated HC (Fig.2), and the pristane/phytane ratio is moderate (2.33 - 5.71).

Samples from wells 118-CVX-1X and 119-CH-1X have the lowest concentration of saturated HC (37.1 - 54.6%), high concentrations of aromatic HC (40.39-57%) and low pristane/phytane ratios (< 2). On the diagrams, samples from wells B10-STB-1X, 106-YT-1X, 107-BAL-1X, and 107-PA-1X are marked in green; wells in blocks 102 and 103 are marked in red; wells in blocks 112, 114 and 115 are marked in blue; and wells in blocks 118, 119, 120 and 121 are marked in purple.

On the chart of group type composition of the HC (saturate-aromatic-heavy component), all samples were concentrated to the left of the chart indicating the normal HC, not degraded (Fig.2), thus any doubts that biodegraded organisms cause high values of pristane/phytane can be erased. However, two separate groups have been recognised: 1) the sample group from blocks 118 and 119, DST # 1 and DST # 3 in well 103 TH-1X; 2) the group of samples from wells B10-STB-1X and 107 BAL-1X, DST # 4 at well 103 TH-1X and from the wells in block 112. Particularly, the sample from 106-YT-1X which is separated from the groups may be indicator of higher maturity level (?).

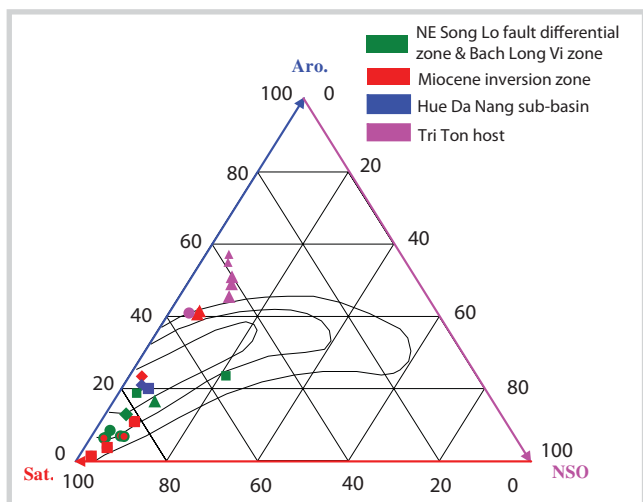


Fig.2. Group type composition of oil samples in the Song Hong basin

Fig.3 demonstrates the relationship between pristane/phytane and nC_{17}/nC_{18} , the distribution of the samples showed more clear groups. Most samples from blocks 118, 119 and 120 belong to group distribution in the transition zone, while samples from 103-TH-1X, B10-STB-1X and remaining wells are distributed into two groups even though they all belong to the terrestrial peat swamp environment. The Biomarkers from mass spectrometry analysis data (GC-MS) can further evaluate the input and maturity of original OM (source rock). The chart of $C_{27-28-29}$ sterane relationship (Fig.4) indicates that the samples from 102-CQ-1X and 112-HO-1X are distributed in the terrestrial; samples from 103-TH-1X are distributed in the

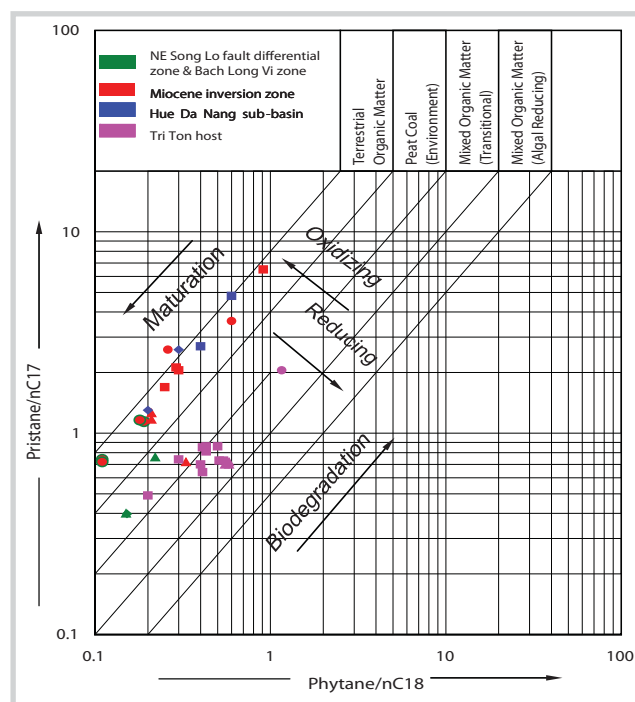


Fig.3. The correlation between Pristane/nC17 and Phytane/nC18 ratio HC samples in Song Hong basin

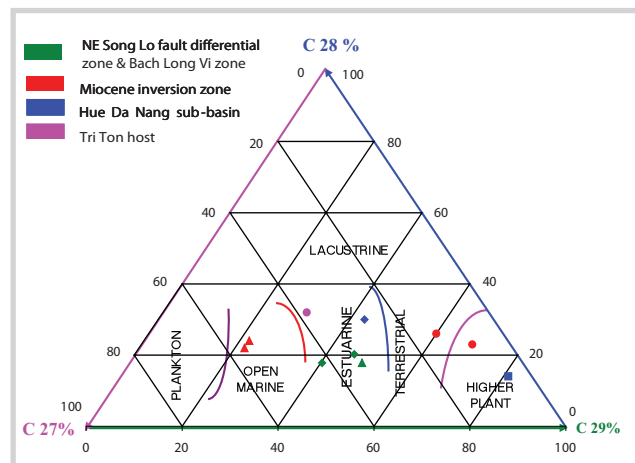


Fig.4. The correlation between C27, C28 and C29 steranes HC samples in Song Hong basin

open marine area. The remaining samples are distributed in the estuarine one.

Correlation chart of Ts/Tm ratio and Oleanane index of hopane in saturate HC (Fig.5) shows samples from the wells at blocks 106 and 107 and the B10-STB-1X well (green symbols in red ellipse line) distributed in the region of higher lacustrine than samples from blocks 102, 103 and

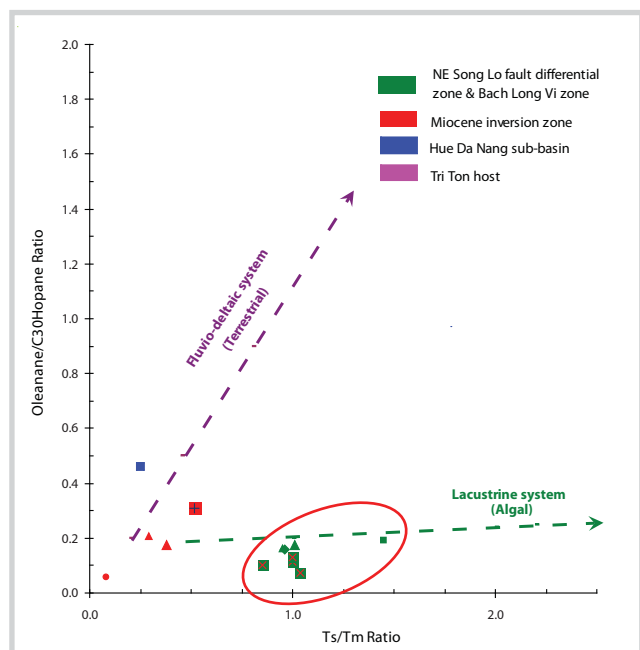


Fig.5. The correlation between Oleanane/Hopane and Ts/Tm ratio HC samples in Song Hong Basin

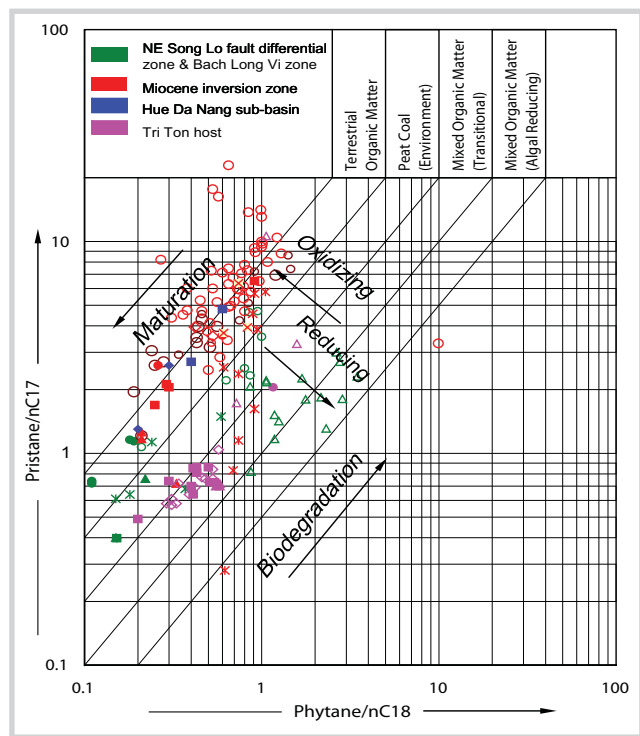


Fig.6. The correlation between Pristane/nC₁₇ and Phytane/nC₁₈ ratio HC and source rock samples in Song Hong basin

112 (red and blue symbols). This distribution is consistent with Fig.2 and Fig.3. Especially, the sample from well 106-YT-1X is distributed in the lacustrine system (algal) but separated from the group, perhaps due to its higher maturity level Tm transformed into Ts and resulting in the high Ts/Tm ratio. As the result, this sample is distributed on the right side of the chart (Fig.5).

4. Migration possibility of oil/condensate from the source rocks

In order to compare oils and source rocks, in the following oils are represented by filled symbols, whereas source rocks are represented by open symbols, with wells from the same areas shown in identical colour. The B10-STB-1X, 106-YT-1X, 107 BAL-1X, and 107 PA- 1X wells are shown in green; the wells in blocks 102 and 103 in red; the wells in blocks 112, 114 and 115 in blue; and the wells in blocks 118, 119, 120 and 121 in purple. Figs. 6 through 8 show the relationship of source rocks and HC in the study area. HC samples and extracts from source rocks in the same area (with symbols of the same colour) are often distributed along a maturity trend (Fig.6). This suggests a genetic relation between HC and source rocks. And, this distribution shows on proven migration distance of HC from source rocks to traps may not be large (?)

The preponderance of lacustrine input is clear in both oil and source rock data in the NE margin compared to other areas in the Song Hong basin (Figs.6, 7 and 8). Unfortunately no biomarker data are available for samples from the NE Song Lo differential zone and Bach Long Vi zone.

As mentioned above, five fluid samples of the 107-BAL-1X, 106-HR-1X, 106-HR-2X, and 106-YT-1X wells were

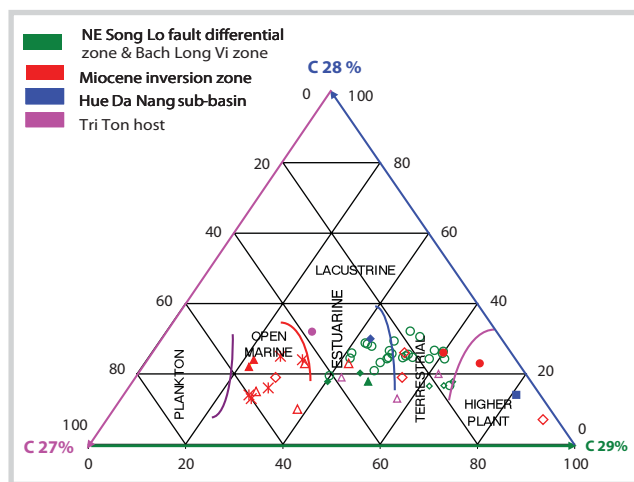


Fig.7. The correlation between C₂₇, C₂₈ and C₂₉ steranes HC and source rock samples in Song Hong basin

collected and analysed with respect to bulk properties and separated into four such fractions as saturate, aromatic, resine and asphaltene on liquid chromatography by using silica column. GC (Gas chromatography), GCMS (Gas chromatography-Mass spectrometry) and GCMSMS have been carried out on saturate and aromatic fractions.

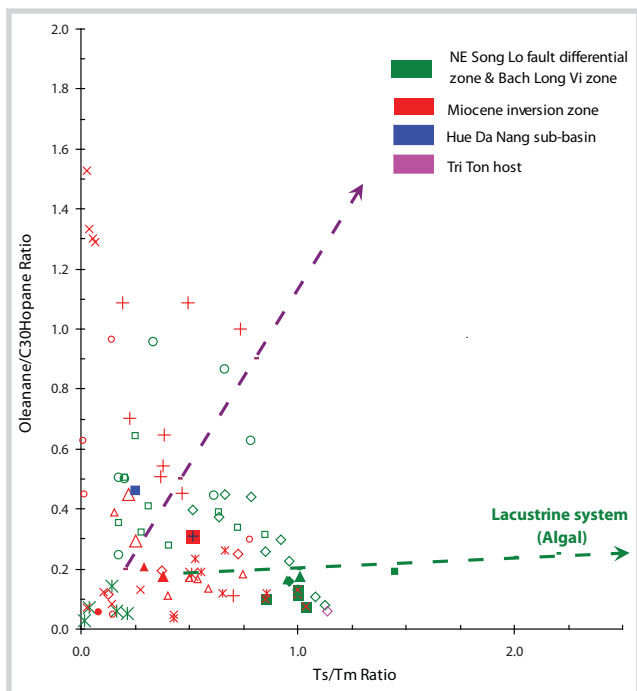


Fig.8. The correlation between Oleanane/Hopane and Ts/Tm ratio HC and source rock samples in Song Hong basin

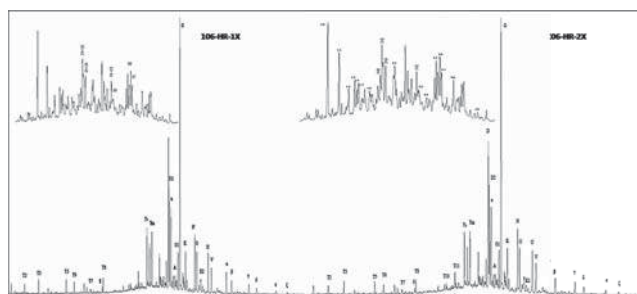


Fig.9. GC-MS chromatograms of two oil samples from 106-HR-1X and 2X wells

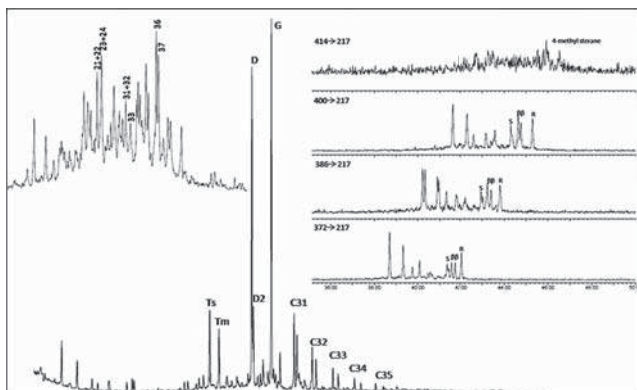


Fig.10. GCMSMS chromatograms of DST#3 from 107-BAL-1X well

The API results show that fluid samples of 107-BAL-1X and 106-YT-1X are condensates but two fluid samples of 106-HR-1X and -2X are crude oils with low sulphur contents and a group type composition in the normal oil range with respect to HC concentration (Fig.2).

The two oil samples collected from wells 106-HR-1X and -2X have similar characteristics with typical lacustrine geochemical signatures, including medium Pristane/Phytane ratios (2.95, 2.90 in each) and “lacustrine” distributions of hopanes (Fig.9). Besides, they are characterised by the presence of 4-methyl C₃₀ Sterane (peak 42), tricyclic terpane distribution with some lacustrine signature and predominance of C₂₇ and C₂₉ steranes over C₂₈ steranes (Fig.9). These features suggest that these oils are mainly derived from lacustrine algal organic matter.

The condensate fraction (< nC₂₀) of samples from well 107-BAL-1X shows very high pristane/phytane ratios (8.18 to 30.47), which is typical for the fluvio-delta depositional environment with high oxidation level. They show relatively high BTX (Benzene-Toluene-Xylene) content, high isoprenoid abundance, significant anthracene and Me-anthracene concentrations in the aromatic fraction, all of which suggest the condensates were mainly generated from terrestrial source rock [7]. In contrast, heavier fractions show evidence to suggest input from lacustrine algae, including the presence of tricyclic terpanes, 4-methyl C₃₀ sterane and “lacustrine” distribution of hopanes (Fig.10). Moreover, cross-plotting oleanane/hopane ratio versus the Ts/Tm ratio (Fig.5) shows all samples of 107-BAL-1X to distribute in the lacustrine field. The same features are found in the condensate from 106-YT-1X (Fig.2). However, this condensate has some different properties with respect to bulk composition (Fig.2) and biomarkers (Fig.5) that need more investigation to evaluate.

5. Conclusions

- Some oil groups could be recognised in the Song Hong basin:
 - + Hydrocarbon with mainly terrestrial input found in blocks 102 and 103 (*Miocene Inversion Zone*);
 - + Hydrocarbon with mainly lacustrine input encountered in blocks 106 and 107 and well B10-STB-1X (*NE Song Lo differential zone and Bach Long Vi zone*);
 - + Hydrocarbon with mainly terrestrial input distribute in block 112 (*Hue Da Nang Sub-basin*),
 - + Hydrocarbon from blocks 118 and 119 and

migrated HC found from block 120 (*Tri Ton horst*) and HC from block 113 (*Central Sub-trough*).

- Oils and source rocks were encountered in NE Song Lo differential zone and Bach Long Vi Zone with the most prominent lacustrine input compared to other structural elements of the Song Hong basin.

- The distribution of oil/condensate groups and source rocks in the different structural elements of the Song Hong basin shows close relationships, suggesting short migration distances.

- The distribution of source rocks in the Song Hong basin, as well as their geochemical characteristics, show spatial variation. The role of each source rock in supplying HC into the reservoirs in the study area is clarified only when analysing the results of geochemical modelling and geochemical characteristics of the group of oil/condensate (HC). The spatial distribution of the HC groups in relation to the geological structures of the Song Hong basin is a matter in need of further research.

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