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# Geochemical Analyses of Potential Source Rocks and Light Oils in Pan Yu Low Uplift and Bai Yun Depression, Pearl River Mouth Basin, South China Sea

Sani A.M. Bachir, Sheng He, Guo Xiao Wen and Xiao Qi Lin
China University of Geosciences, Wuhan

**Abstract:** Eocene and Oligocene source rocks together with light oils from the Bai Yun depression and Pan Yu Low uplift have been analyzed by various organic geochemical techniques. The potential source rocks investigated include En Ping and Zhu Hai. The En Ping Formation, which is an important source in the study area, was used as a laboratory standard in this study. The oils examined in this study were obtained from the reservoir formations of various ages from throughout the northern margin of Pearl River Mouth Basin (PRMB). The source rocks screening analysis indicated that lower and middle subfacies of the Zhu Hai, especially from the southern part of the Bai Yun depression has substantial oil-generation potential. Wen Chang and En Ping have substantial oil and especially gas-generation potential. The result of this study supports the multiple sources point of view of oil and gas generation in this area. Selected source rocks and oils were characterized in more detail and the distributions and concentrations (both relative and absolute) of various biomarkers in different source rocks and oils were combined with other geochemical and geological data to check the source and the depositional environments. Oil-oil, oil-source rock correlations were made between two source rock samples and six light oils based on qualitative and quantitative biomarker distribution. There was a fair to good correlations between oil-oil and oil-source rock. The source rocks evaluations supported the multiple source rock concept. The correlations are also supported by carbon isotopes data.

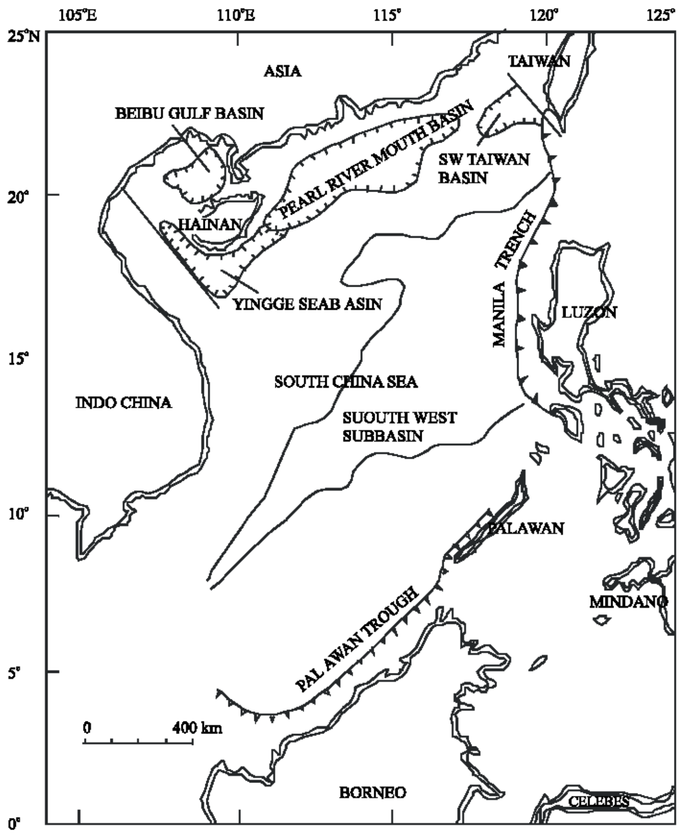
**Key words:** Screening analyses, oil-source rocks correlations, Pan Yu Low uplift and Bai Yun depression, Pearl River Mouth Basin, South China Sea

## INTRODUCTION

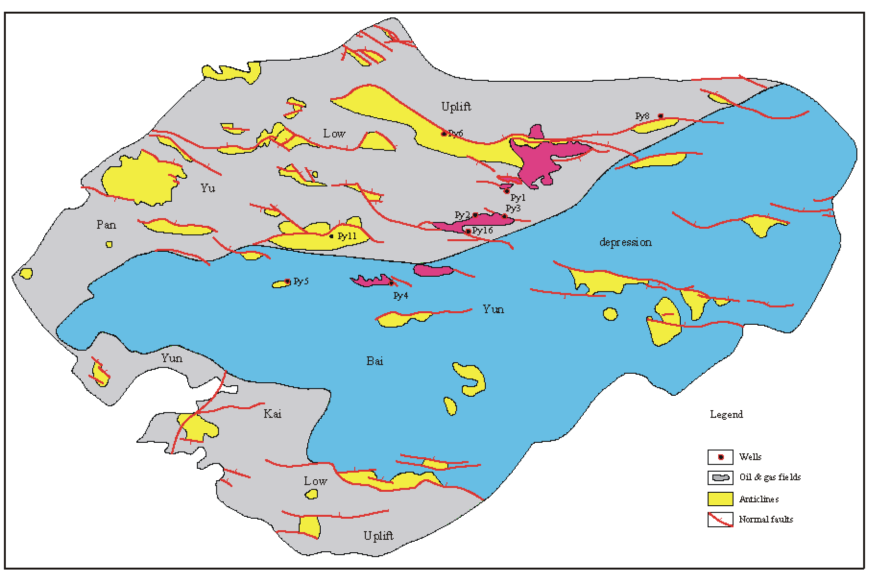
The South China Sea is a large continental marginal sea bounded to the north by the China mainland, to the south by the Palawan Trough and to the west by the Manilla Trench (Fig. 1A and B).

Due to the likelihood of large reserves of oil and gas being found on the margins, the structure and evolution of the region has attracted considerable interest. Much of the current exploration is focused on the north margin where there are four major sedimentary basins-The southwest Taiwan basin, the Pearl River Mouth Basin, the Beibu Gulf Basin and the Yingge Sea Basin (Xing, 1980; Li, 1984). The basins are thought to have been formed by extension during the early Cenozoic (Ru and Pigeott, 1986). Subsequently, spreading commenced to the south forming the main part of the South China Sea Basin (SCS) as a result of northward subduction below the Philippines back-arc (Taylor and Hayes, 1980; Taylor and Hayes, 1983). The Pearl River Mouth Basin (PRMB) is a passive margin rift system located on the northern shelf of the South China Sea; it contains three large depressions (Zhu-1, Zhu-2 and Zhu-3) interconnected by half-graben sub-basins separated by intervening ridges (Ru Ke and Pigott, 1986). These sub-basins can be further subdivided into several sub-units: The Pan Yu Low uplift and Bai Yun depression are located within Zhu-2, the southernmost of the sub-basins. The Pearl River Mouth Basin formed over the Mesozoic continental crust and inherited the preexisting tectonic zones of weakness in that crust. Paleogene extensions that formed the depocenters of the Pearl River Mouth Basin occurred mainly between the Late Eocene to Late Oligocene and include a component of dextral shear (Chen and Li, 1987). The shear may originate from reactivation of NW-SE trending strike slip faults. The Shear trend also seems to influence the Paleo-Pearl River drainage. Bai Yun depression is the deepest unit (over 12000 m) in thickness. Even in the shallower northern portion of the basin (Pan Yu Low uplift), the sedimentary sequence still ranges between 3000-8000 m in thickness (Zhu *et al*., 1999).

**Corresponding Author:** Sani A.M. Bachir, China University of Geosciences, Wuhan




A. South China Sea




B. Study Area

Fig.1A and B: South China Sea Basin and the location map of Pan Yu Low uplift and Bai Yun depression

The evolution of the northern margin of the South China Sea has been divided by most researchers into 3 periods of rifting and/or uplift (Ru and Pigott, 1986; Chen and Li, 1987; Su, 1987; He *et al*., 1988). From the Late Cretaceous to Paleocene, widespread crustal thinning and normal faulting, accompanied by uplift and erosion, is thought to have occurred. This episode resulted in the formation of a series of NE-SW trending horsts and graben (He, 1988). Small amounts of alkaline volcanism occurred at the same time (Chen and Li, 1987; Ru, 1987). Widespread volcanism commenced at about 12 Ma and still continues in the vicinity of Hainan Island (Barr and MacDonald, 1981). Throughout the basin, small amounts of normal faulting disrupt the sea-bed suggesting that extension has recommenced more recently (Daquan Su *et al*., 1989). In the western part of the basin close to Hainan Island, a considerable amount of recent normal faulting with offset of up to 400 m is evident (He *et al*., 1980).

A second period of more rapid rifting (the "Nan Hai movement") occurred in the Early Oligocene. Subsidence then followed while oceanic spreading occurred further south in the main part of the South China Sea during the Oligocene and Early Miocene. A third stage, known as the Dongsha movement, occurred during Middle to Late Miocene. Many researchers regard this as a period of uplift and erosion, based on evidence for reworked calcareous nannofossils in the Han Jiang Formation (Middle- Miocene). In contrast, Ru and Pigott (1986) suggested hat rifting was important at this time.

The present study focused on the following formations and associated light oils.

- Two rocks samples from Py5 well were collected from En Ping and Zhu Hai Formations, respectively;
- Six light oil samples were collected at wells (Py1, Py2, Py3 and Py4) mainly from Zhu Jiang Shang, Zhu Jiang Xia and Zhu Hai Formations, respectively from top to bottom as in the stratigraphic column of Pearl River Mouth Basin (PRMB) (Table 1).

The purpose of this study was to assess and characterize the nature and quality of the potential source rocks in Bai Yun depression and Pan Yu Low uplift and evaluate any relationship between the potential source rocks and the presence of oil and gas under the light of the new concepts of organic geochemistry.

Table 1: Analyzed source rock and oil samples from various wells

| No. | Well | Type of samples | Sources rocks | Depths (m) |
|---|---|---|---|---|
| 1 | Py5 | Black mudstone (Core) | En Ping | 4295.54-4296.55 |
| 2 | Py5 | Black mudstone (Core) | En Ping | 5090.80-5091.62 |
| 3 | Py1 | Light oil | Zhu Jiang Xia | 2511.50 |
| 4 | Py2 | Light oil | Zhu Jiang Shang | 2249 |
| 5 | Py3 | Light oil | Zhu Jiang Xia | 2711-2726 |
| 6 | Py3 | Light oil | Zhu Jiang Xia | 2743-2758 |
| 7 | Py4 | Light oil | Zhu Jiang | 3612-3633 |
| 8 | Py4 | Light oil | Zhu Jiang | 3650-3660 |

## STRATIGRAPHY

In the Pearl River Mouth Basin, nine formations have been recognized ranging from the Paleogene to Quaternary in age (Fig. 2). The summary presented here was drawn from the work of Duan and Huang (1987), Wu (1988), He (1988), Feng and Zheng (1982), Wang (1982), and Zhang *et al*. (1983).

Sediments are mainly of continental and shallow marine facies. The pre-rift basement is composed of Mesozoic granites and metamorphic rocks (Roberts, 1988).

At the base of the sequence, the Shen Hu, Wen Chang and En Ping Formations are thought to be terrestrial. Fossils, including spores and pollen, are rare. The Shen Hu Formation is dominated by red or mottled sandy conglomerates of fluvial fan facies, associated with igneous and volcanoclastics debris. The Wen Chang Formation consists of grey to black lacustrine mudstones, with thin sandstones and siltstones. In contrast, the En Ping Formation is dominated by floodplain and stream sandstones with some swamp and lacustrine mudstones. Palaeowater depths range between 0 and 20 m (Wang *et al*., 1985).

The upper Oligocene Zhu Hai Formation comprises a sequence of grey gravelly sandstones and grey silty mudstones. Spores and pollen are abundant, but foraminifera are absent (Duan, 1985).

The Lower Miocene Zhu Jiang Formation consists of brownish-grey silty mudstones, sandstone and conglomerate. Foraminifera occur in a few layers, but are poorly preserved. This formation was deposited in a shallow marine, inner shelf environment and comparison with modern foraminifera suggests a water depth of 0-50 m (Wu, 1988).

The Middle Miocene Han Jiang Formation consists of grey silty mudstone, gravelly sandstones and shale. The paleobathymetry of the Han Jiang Formation is variable. From Early to Middle Miocene the transgression reached its climax. As transgression and regression occurred several times during the Middle Miocene, so a

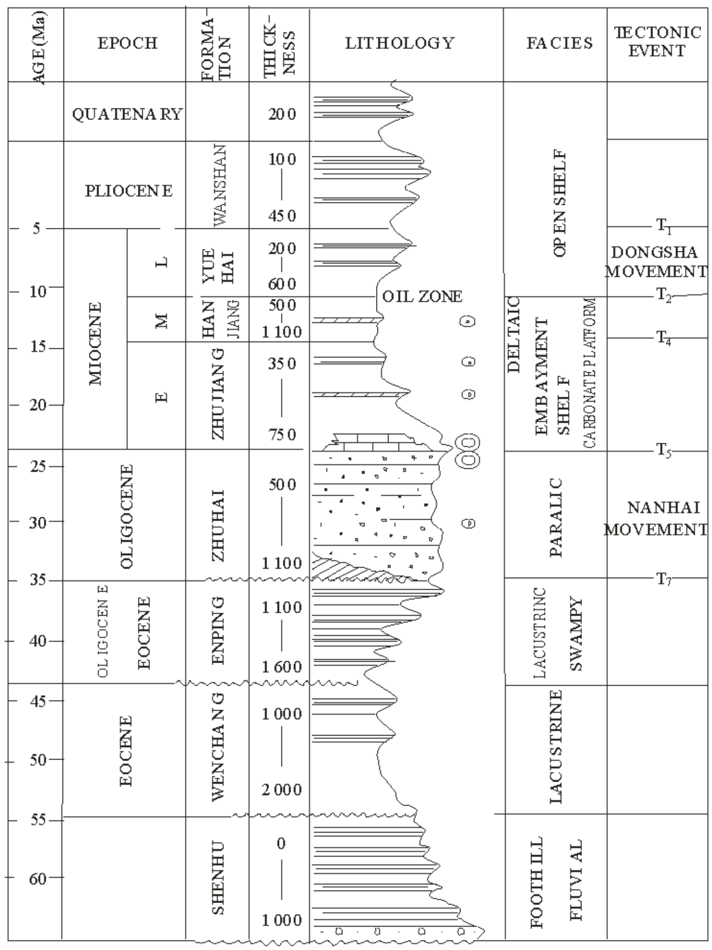



Fig. 2: Stratigraphic column of the Pearl River Mouth Basin

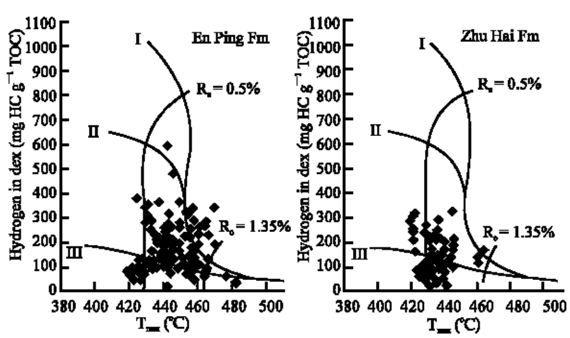



Fig. 3: A Kerogen type plot based on HI versus $T_{max}$

relatively large range of water depth (0-150 m) is appropriate (Duan and Huang, 1987) and He (1988). In the Upper Miocene Yue Hai Formation, planktonic foraminifera were abundant. The water depth is estimated at 50-200 m by comparison with the ranges of modern foraminifera (Wood, 1982).

The Pliocene Wan Shan Formation consists of grey silty mudstone, with conglomerates occurring in the upper part. The environment is shallow marine, with an estimate of water depth of 50-200 m (Feng and Zheng, 1982; Wang 1988; Zhang *et al*., 1983).

Recently a number of sea-level curves have been proposed by Watts and Steckler (1979), Haq *et al*. (1987), Wu (1988) the differences between each being considerable. Fortunately, this study is only concerned with the period from 60 Ma to the present and during this period the differences between the proposed curves are relatively small. The sea-level variation shown by Watts and Steckler's (1979) curve is from 100 to 6 m and that of Haq *et al*. (1987) varies by about + 250 and -250 m Wu (1988), gives no quantitative estimates, but his curve is generally similar to the other two.

## MATERIALS AND MATERIALS

The sample treatment and analysis were carried out at Wuxi Xinxing Petroleum Corporation in the Experimental Geological/Geochemical Research Institute in May/June, 2005.

Total organic carbon (TOC describes the quantity of organic carbon in a rock sample and includes both kerogen (insoluble organic matter) and butimen (soluble organic matter in organic solvents) of the source rock samples was determined with a LecoCS-200 carbon determinator. Following the TOC analysis, the rock samples were pyrolysed to determine the Rock-Eval parameters such as: $S_1$ (free hydrocarbons mg HC $g^{-1}$ rock), $S_2$ (pyrolysable hydrocarbons mg HC $g^{-1}$ rock), $T_{max}$ (temperature of the top of $S_2$ peak) and HI (Hydrogen Index S2*100/TOC) values. On the basis of these parameters, selected source rock samples were extracted with methylene chloride-methanol-9. The asphaltene fractions of the source rock and oils were precipitated with n-pentane and deasphaltened samples were separated into saturates, aromatics and polar fractions (NSO) using Thin Layer Chromatography (TLC). A portion of each saturates fraction was treated with AG-285 molecular sieve to remove n-alkanes. The branched and cyclic saturates fractions obtained were used for chromatography-mass spectrometry (GC-MS).

Stable carbon isotope ($\delta^{13}C_{PDB}$ (‰)) values of saturates and aromatics fractions of oils and source rocks extracts were determined using a Delta $^{Plus}$ XL mass spectrometer as shown in the Table 2. Selected rock samples were pyrolysed using Agilent 5973-I system equipped with a mass spectrometer as a mass detector to obtain biomarker distribution in kerogen and asphaltenes (asphaltic material soluble in carbon disulphide).

These experiment results were combined together and compared with other ones conducted by previous workers and when suitable, the results were adopted and used in this study.

## RESULTS AND DISCUSSION

**Geochemical characteristics of the source rocks:** Based on previous studies, there are mainly three source rock formations in Pan Yu Low uplift and Bai Yun depression: Eocene Wen Chang, Eocene-Oligocene En Ping and Oligocene Zhu Hai. The Miocene Zhu Jiang Formation has also a capacity for producing hydrocarbons (Su, 1987). The Wen Chang Formation is not penetrated by any well in this study.

Two core samples (from En Ping Formation dark shale) were used from well Py5 and six light crude oil samples from four other wells. Many other geochemical data were supplied by China National Offshore Oil Corporation, Guangzhou and were used in this study (Table 1).

A kerogen type plot based on HI versus $T_{max}$ (Fig. 3) from Pan Yu Low uplift and Bai Yun depression showed that, the samples under our study from Zhu Hai Formation contained kerogen type 3, whereas, the samples from En Ping dark mudstone is a mixture of kerogens 3 and 2.

$T_{max}$ is the temperature at which the $S_2$ (mg HC $g^{-1}$ rock) peak its reaches it maximum amount of hydrocarbon generation during Rock-eval pyrolysis (Tissot *et al*., 1987). $T_{max}$ values here range between 414 and 480°C. This plot indicates that the organic matter is relatively uniform in the dark mudstone and its maturity is well advanced. In addition to other geochemical data available Zhu Hai limestones subfacies may also be regarded as a good source rock with a high content of organic matter and oil generation potential.

**Total organic carbon concentration:** The plots of TOC (Total Organic Carbon) frequency distribution for the five Formations from Pan Yu Low uplift-Northern margin of Bai Yun depression are shown in Fig. 4. The number of treated samples is the 141 samples from the En Ping Formation. They include dark shales, carbonate shales and coal beds. In the En Ping coal, bearing, the maximum measured TOC value is 63.31%. Nine samples show measured TOC values which ranged between 16.04% and 63.31%. In addition, there are 106 measured TOC values is 0.4% from dark shale samples. The average value is 1.67%.

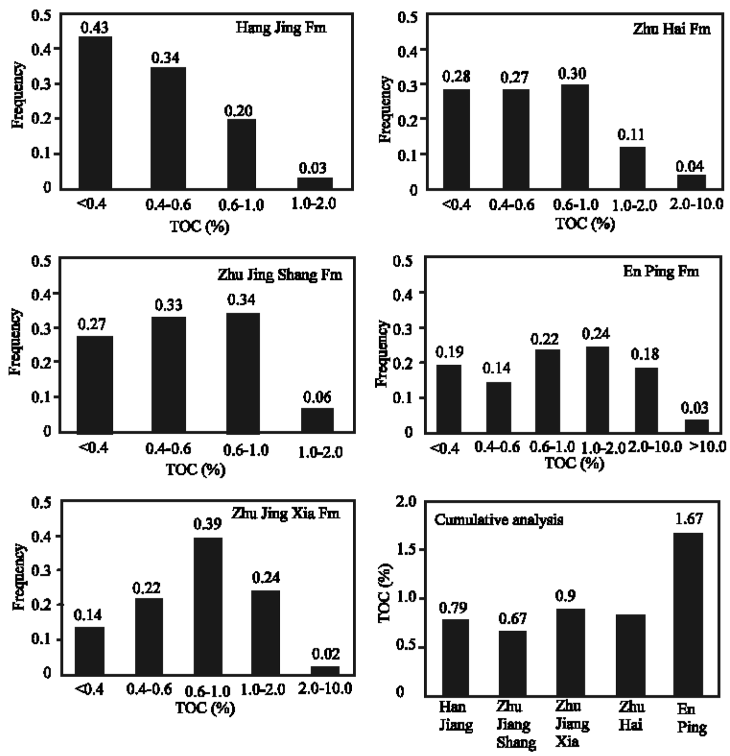



Fig. 4: Total organic carbon (TOC) frequencies distribution of various samples from different formation

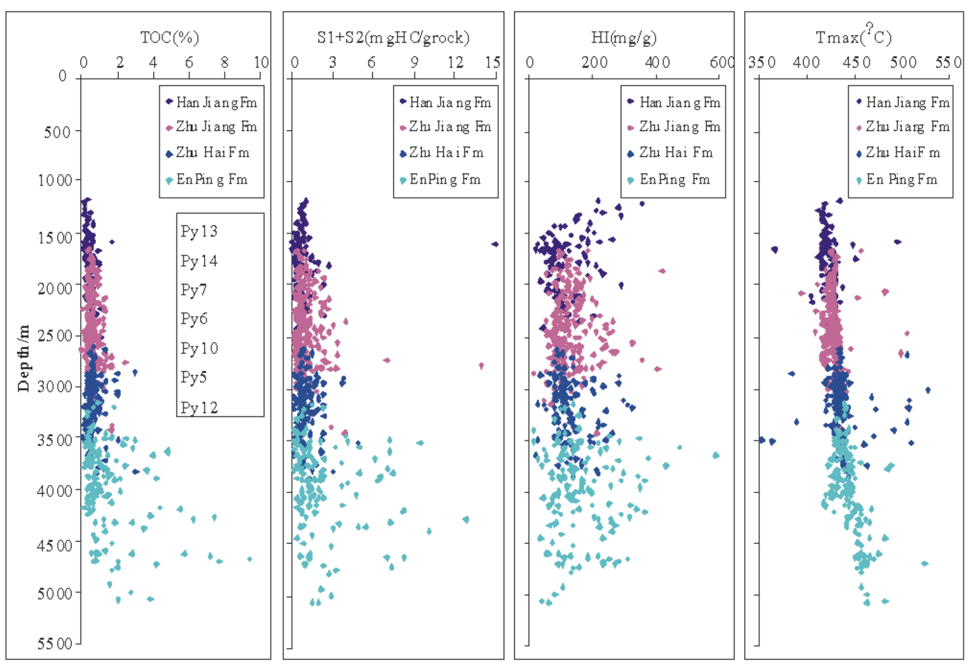



Fig. 5: Total organic carbon (TOC), $S_1$+$S_2$ (mg HC $g^{-1}$ rock), Hydrocarbon Index (HI = $S_2$ *100/TOC) and rock-eval $T_{max}$ values depth for 141 samples

The measured samples from Zhu Hai Formation all together are 142 and those with their TOC lower than 0.4% are 40 samples; the others are greater than 0.4%. The maximum measured TOC value is 0.3%. The average measured value is 0.83%. Fifty nine samples of Lower Zhu Jiang Formation were treated and 51 samples show a TOC higher or equal to 0.4%; the remaining ones showed values lower than 0.4%. The maximum is 2.42% while the average is 0.9%.

In the Upper Zhu Jiang Formation, the total number of samples measured is 172 and there are 47 samples with (TOC<0.4%) and 125 with (TOC>0.4%). The maximum TOC is 1.65% and the average is 0.67%.

Based on these statistics, we note that the En Ping Formation dark shale samples with (TOC>1.0%) represent 45% of the all the samples combined together.

**Hydrocarbon occurrence potential:** $S_1$ is the dissolved hydrocarbon quantity in rock samples and $S_2$ is the quantity of pyrolysable hydrocarbons. Hydrocarbon occurrence potential ($S_1$+$S_2$) changes sharply in the strata of the Pan Yu Low uplift mainly between 0.05 mg $g^{-1}$ and 30 mg $g^{-1}$. The average is 2.0 mg $g^{-1}$. This means that the hydrocarbon occurrence potential in this area is good. Figure 5 shows that ($S_1$+$S_2$) in a few dark shale samples collected from the En Ping Formation ranges between 3-6 mg $g^{-1}$ and 6-12 mg $g^{-1}$.

Correspondingly, these total organic carbon concentrations are greater or equal to 1%; the hydrogen Index (HI, mg HC $g^{-1}$ TOC) ranges between 200 and 400 which may suggest that the organic matter type is a transitional type 2-3.

Note that $T_{max}$ values from all samples show a relatively uniform trend. This trend showed a progressive increase in values with depth.

The hydrocarbon index (HI = $S_2$*100/TOC) from all four formations range from 18 to 410 and follow a relatively progressive trend as show in Fig. 5.

**Gas chromatography analysis of dissolved saturated hydrocarbons:** Gas chromatography analyses of saturated hydrocarbons can reflect the source and thermal maturity features of the original organic matters.

Usually these parameters are used as distribution shapes of n-alkyl hydrocarbons, carbon numbers of highest peak, ratio of light/weight hydrocarbons ($C_{21}^{-}/C_{22}^{+}$ and $(C_{21}+C_{22})/(C_{28}+C_{29})$), distribution ranges of carbon numbers and "odd and even predominance index"(OEP) to determine mixture features for biological sources, to study sedimentary environments and maturity of organic matter. Figure 6 showed distribution graphs of n-alkyl hydrocarbons in two source rock samples collected from the En Ping Formation and the six samples of light oil. They are the front peak type of distribution shapes for n-alkyl hydrocarbons with their carbons number ranging from $C_{11}$ to $C_{36}$ and carbon numbers of main peak is $C_{16}$, ratios of $C_{21}$-/$C_{22}$+ and $C_{21}$+$C_{22}$/$C_{28}$+$C_{29}$ is about 2.

The ratio of Pr/Ph (Pristane and Phytane) for the source beds in the En Ping ranges from 1.821-5.837; Peters (1986) pointed out that there was terrestrial organic matter input into oxygen depositional environments. Maturity can cause an increase in the Pr/Ph ratios and thus for deeply buried samples, Pr/Ph ratios may be quite high as a result of source deep burial and not from the nature of the depositional environment (Alexander *et al*., 1981). The CPI (Carbon preference index) values for the samples from the En Ping are close, to or slightly less, than 1.0. While on the other hand the computed even/odd predominance of n-alkanes of some samples from Zhu Hai source bed is a characteristic feature of carbonate source rocks. Bimodal distribution of n-alkanes is very common in the Zhu Hai source rock which can be interpreted to result from the contribution higher plants or bacteria.

**Vitrinite reflectance ($R_o$%):** The percentage of the light reflected by the vitrinite particules could be correlated with coal rank measured by other methods and because vitrinite particules also occur in kerogens, the technique called vitrinite reflectance, has been widely applied in assessing kerogen maturity.

Vitrinite reflectance values ($R_o$) were plotted against burial depths. Three trends of measured $R_o$ were observed changing with burial depth as shown in Fig. 7.

The first trend (represented by the filled triangles): It is generally the same trend in well Py6 which is located in the Pan Yu Low uplift, as well as in the local structures in well Py7 and Py8. This trend showed that the vitrinite reflectance ($R_o$) increased slowly with burial. However there are some individual high values.

The second trend (represented by filled diamonds) is shown by measured data in well Py3. This trend revealed that the increase of $R_o$ with burial is relatively fast.

The third trend (represented by filled squares) shows that the $R_o$ changing with burial depths is basically the same in well Py5 as of Bai Yun depression and the following wells: Py9, Py10, Py11 and Py12 located in the Pan Yu Low uplift and Yun Kai Low uplift, respectively.

When $R_o$ threshold is 0.6%, based on the plot from the first trend, the depth is about 3700 m and the temperature is about 130°C; but from the second trend we noted that the depth is about 2200 m and the temperature is 86°C at the threshold of $R_o$. From the third trend plot, we can observe that the depth is merely about 3000 m and the

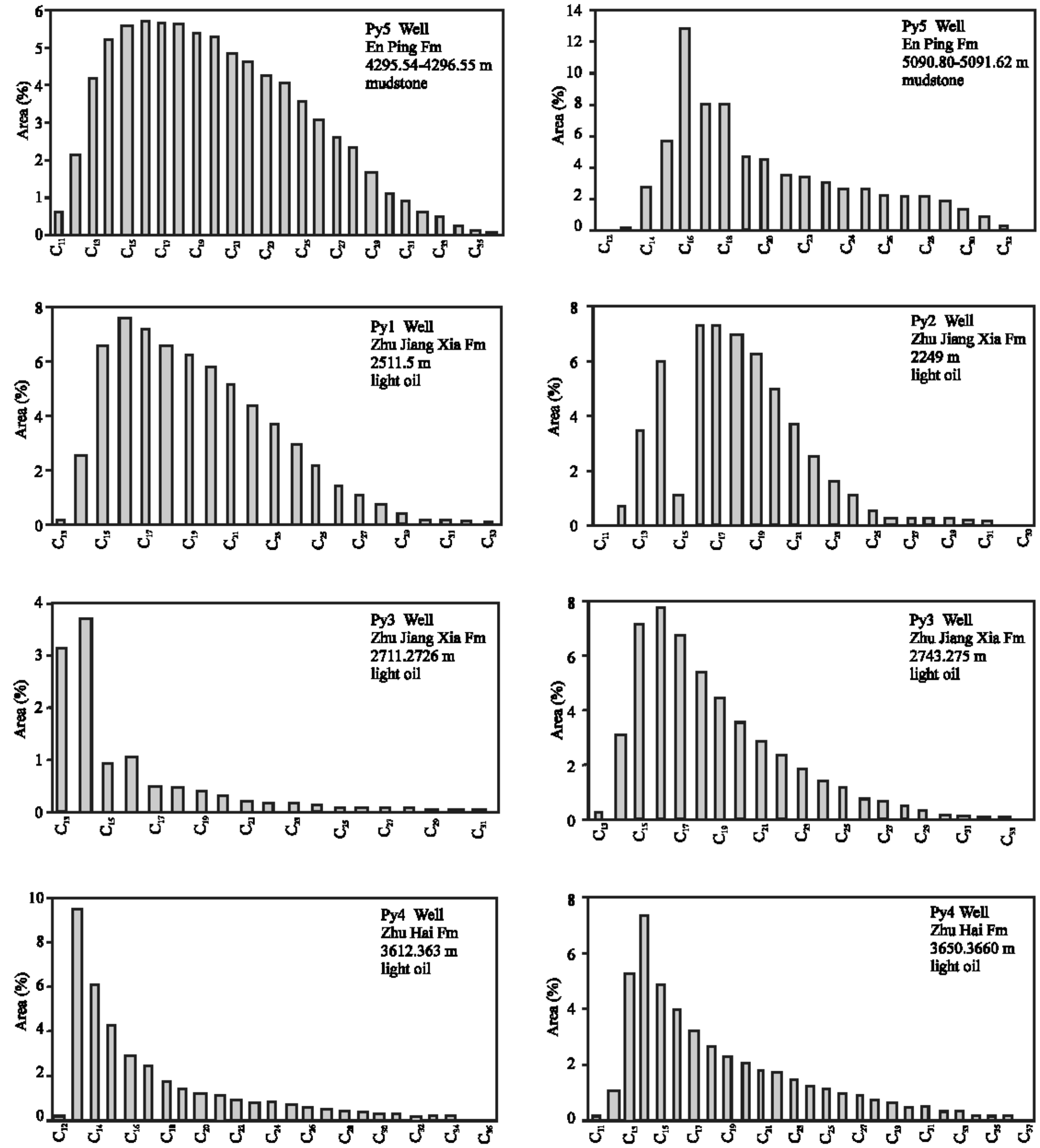



Fig. 6: Distribution graphs of n-alkyl of hydrocarbons from the two source rocks Samples from En Ping Formation and six light oil samples

temperature is equal to 110°C at the threshold of $R_0$. The vitrinite reflectance ($R_0$) is equal to 1.5% when burial depth is 5000 m, which corresponds to a temperature of 170°C.

## OIL-SOURCE CORRELATIONS

**Characteristics of steranes compounds:** The ternary diagram of $C_{27}$, $C_{28}$ and $C_{29}$ sterane compounds from the oils and sources are frequently used to identify the type or origin of the initial organic matters. The main source of $C_{27}$ steranes is marine and that of $C_{29}$ steranes are mostly the inputs from advanced plants, $C_{28}$ steranes consist of a mix of advanced plants and algaes. From Fig. 8, we observed that two data points of black shale core samples collected from the En Ping bed occupied the area 5 which shows that the major source rock is mainly from terrestrial plants. The area occupied by the oil sample in area 4 was

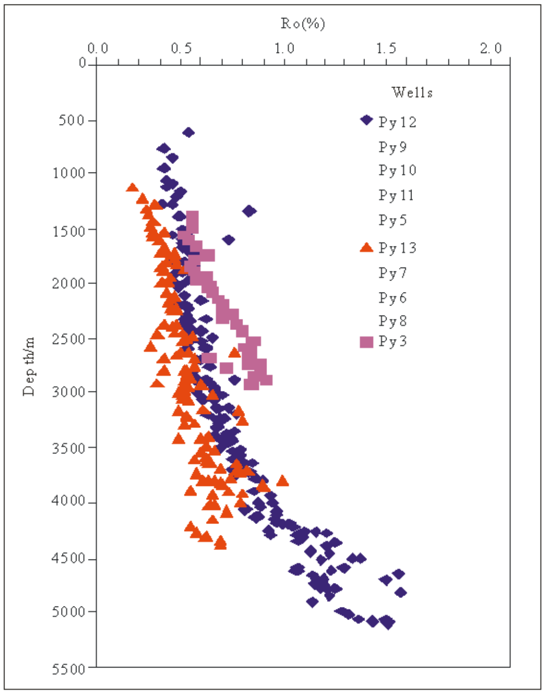



Fig. 7: Plot of vitrinite reflectance ($R_o$) with depths at different Wells

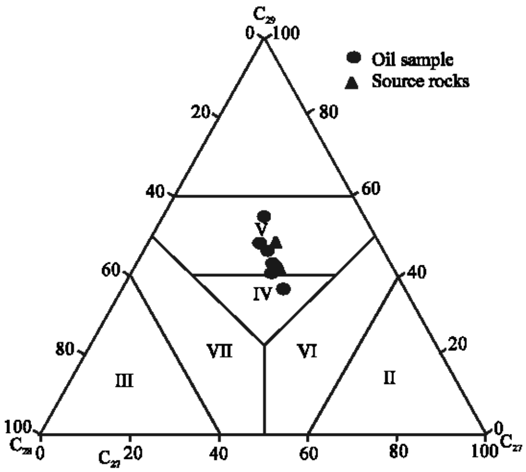



Fig. 8: Sterane ternary diagram, showing the correlation between oils and source rocks

interpreted as a sample from a mix source rock. The five oils which occupied the area V in the ternary diagram show a good correlation with the En Ping source rock.

But the correlation with the oil sample in area 4 with their suspected source rocks is not well established.

Oil-source correlations include parental relationship, correlation between oils/gases and source rocks and correlation between oils/gases preserved in various reservoirs. Based on oil-source rock correlations, we were able to predicted the petroleum migration directions. Since petroleum can flow in the subsurface, the original similarities between oil-oil and oil-source rock may be affected by physical, chemical and biological factors in the processes of reservoir forming such as, adsorption, dissolution, diffusion, admixture and oxygenation by water washing, separation by gravity, thermal corrosion, petroleum migration and biodegradation. Therefore, reasonable selection of correlation parameters and synthetic application of organic geochemical indicators are comparatively critical. For the oil-oil and oil-source rock correlations in the study area, a series of compounds were selected, with a wide distribution within source rocks and petroleum. They were not affected by processes of petroleum migration, biodegradation and sub-alteration and can be available by distinguishing their characterizations between different source rocks and different original petroleum. Parameters of serial compounds were chosen based on their distribution models and ratios. Biomarkers for steranes and terpanes in light crude oils were influenced by the original organic matter and thermal maturity. The distribution features of steranes and terpanes showing the original source and their deposited environments are relatively stable. Light to middle biodegradation has little Influence on most parameters. From the analyses of the data measured by GC-MC (Gas chromatography-Mass Spectrometry) for six light crude oils from the Zhu Hai and Zhu Jiang Formations and elution data of two dark shales from the En Ping Formation, we selected some parameters to check oil-oil and oil-source correlations. They include a series compound ratio for $C_3$-$C_9$ light hydrocarbons including normal and isomers of alkyl hydrocarbon, cyclalkylhydrocarbon, ratios for series compounds and distribution models for relative contents for steranes and terpanes in the Zhu Hai and Zhu Jiang Formations and elution compounds of dark shales in the En Ping ratios for series compounds and relative contents distribution models of aromatics and non-hydrocarbons and stable carbon isotope data.

**Steranes-terpanes series correlation:** On the basis of relative percentage contents of 17 steranes series compounds in six light oils and 2 samples of dark mudstones from En Ping Formation, the correlations of distribution models of steranes series compounds are shown in Fig. 9 and 10. From these two plots, it clear that the distribution models are similar. Comparing with that of 2 samples of dark shales from the En Ping Formation, the similarity is relatively good between light oils and dark shale at the depth between 4295.54-4296.55 m in Well Py5.

## CARBON ISOTOPES DISTRIBUTION

Carbon isotope analyses were carried out with 2 light oils samples of the Zhu Hai Formation from Well Py5 and lower Zhu Jiang Formation from Well Py3 and their family components (except asphaltum as no asphaltum was eluted), chloroform asphaltum "A" of 2 samples of dark shale of the En Ping from Well Py5 and their family components, the measured data are shown in the Table 2.

From the type curves of carbon stable isotopes and their components from four light crude oils and 2 dark shales of the En Ping Formation, we can see carbon stable isotopes of light crude oils and their family components from Zhu Hai and Zhu Jiang Formations, the lightest are those of saturated hydrocarbons and the heavier are the aromatic hydrocarbons. From Fig. 11, it is obvious that the curve type of carbon stable isotopes followed this trend: saturated hydrocarbons? chloroform bitumen "A" (or light crude oils) to aromatic hydrocarbon and

Table 2: Carbon isotopes analyses data with 2 light oils samples of Zhu Hai Formation from Well Py4 and lower Zhu Jing Formation at Well Py3 and their family components (no asphaltum was eluted), choroform asphaltum "A" of 2 sample of dark shale from En Ping Formation from Well Py5 and their family components

| Wells | Fm | Depth (m) | Samples type | $\delta^{13}C_{PDB}$ (‰) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | oil | Bitumen "A" | Saturates | Aromatics | Nonhydrocarbons | Asphaltene | Kerogen |
| Py5 | En Ping | 4295.54-4296.55 | Dark mudstone | | -27.38 | -27.94 | -26.64 | -27.5 | -27.48 | -27.36 |
| Py5 | En Ping | 5090.80-5091.62 | Dark mudstone | | -27.34 | -28.22 | -26.71 | -27.96 | -27.87 | -27.05 |
| Py3 | Zhu Jiang Xia | 2711-2726 | Light oil | -27.09 | | -27.1 | -26.46 | -26.92 | | |
| Py3 | Zhu Jiang Xia | 2743-2758 | Light oil | -26.83 | | -27.28 | -26.41 | -27.24 | | |
| Py4 | Zhy Hai | 3612-3633 | Light oil | -26.48 | | -27.2 | -26.11 | -26.49 | | |
| Py4 | Zhy Hai | 3650-3660 | Light oil | -27.03 | | -27.55 | -26.02 | -26.65 | | |

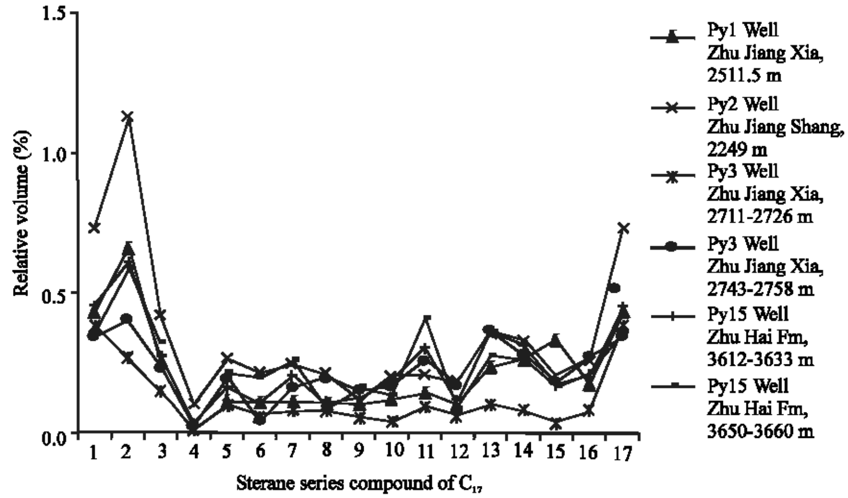



Fig. 9: Quantitative biomarker ($C_{17}$) distributions for six (6) light oils

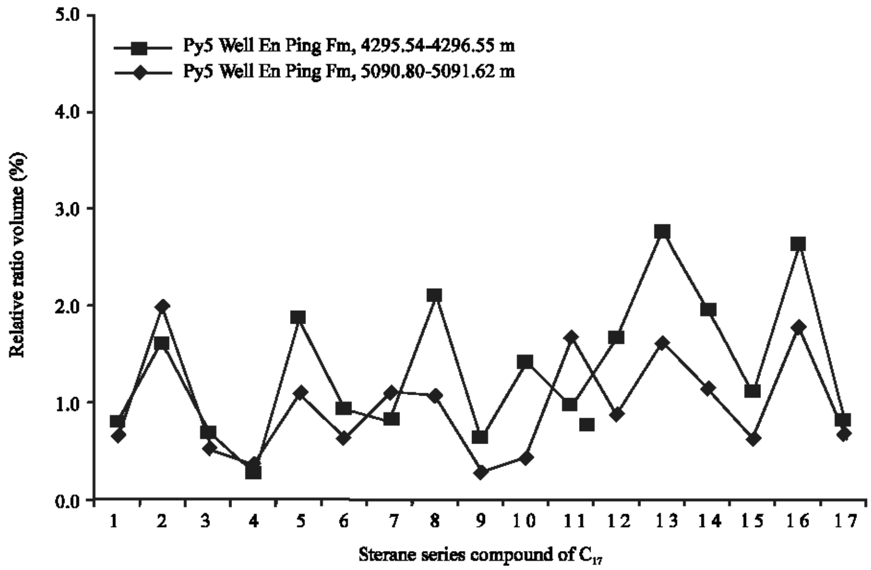



Fig. 10: Quantitative biomarker ($C_{17}$) distributions of two source rocks

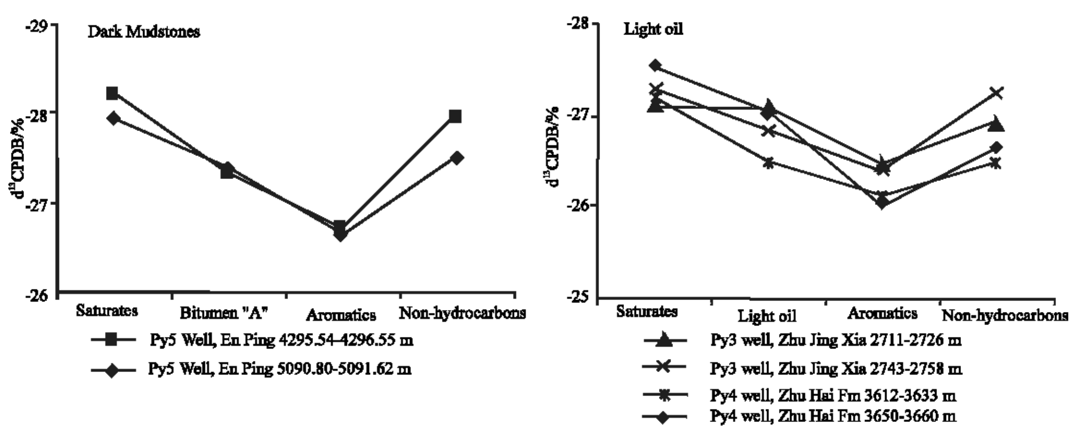



Fig. 11: Carbon isotopes distribution of two samples from the source rockes and three oils (after Sheng He, 2005)

then to non-hydrocarbons. This type of trend may suggest at a large scale that the collected light oil samples shared the same source rocks. Other workers have pointed out that there is a parental relationship between light oils from the Zhu Hai and Zhu Jiang reservoirs beds and dark shales from the En Ping subfacies.

## CONCLUSIONS

The source rock evaluations, as determined in this study, support the multiple source rock concept in the Pan Yu Low uplift and Bai Yun depression. Though based on the various type of geochemical data used, it appeared that the En Ping dark mudstone remained the principal source rock due to its source potential. The En Ping dark mudstone contained mainly type 3 to 2 kerogens and this contributed significantly to the natural gas generated in the Pearl River Mouth Basin in general and specifically in Pan Yu Low uplift and Bai Yun depression. From the limited data available the Zhu Hai limestones subfacies may also be regarded as a good source rock with a high content of organic matter and oil generation potential.

The multiple source rock concept is also supported by biomarker characterization and distribution.

Correlation between source rocks and light crude oils were made on the basis of biomarker distribution graphs. The various correlations are well supported by carbon isotopes data and other geochemical properties from source rocks and light oils.

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