Engineering and Technology Journal e-ISSN: 2456-3358
Volume 10 Issue 12 December-2025, Page No.-8191-8194
DOI: 10.47191/etj/v10i12.17, I.F. – 8.482

Implication of Shale Gas in Hydrocarbon-Related Zones in the Southern Song Hong Basin, Vietnam: A Case Study

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ABSTRACT: This study focuses on the assessment of hydrocarbon generation potential of source rocks, types of organic matter, thermal maturity and mineral compositions for defining multiple hydrocarbon-related zones in SH-1X well that are integrated from the results of Rock-Eval pyrolysis, vitrinite reflectance and X-Ray Diffraction analyses in the Upper Miocene to Oligocene. Organic matters in the Upper Miocene to Middle Miocene shales show low to moderate potential of hydrocarbon generation with low contents of TOC and pyrolysis yields, mainly deriving from type III kerogen and in immature to early mature stages. Shale zones in the Lower Miocene and Oligocene are fairly good-quality source rocks with TOC values of 1.04-1.65 wt.% and S2 pyrolysis yields of 1.40-3.21 mg/g, giving moderate potential of hydrocarbon generation of type III kerogen. The organic matters preserved within the mature stage and reached peak of hydrocarbon generation phase with Ro=0.60-0.83%, Tmax=443-456ºC and PI=0.20-0.44. Mineral compositions of the Lower Miocene and Oligocene shales mainly comprise brittle minerals of over 40% such as quartz, feldspar, plagioclase, carbonate minerals that are favorable conditions for fracturing shale beddings to release gas. High pressure recorded in the Middle Miocene is early a good indicator of seal capacity around and within the shales and also providing reservoir energy needed for driving gas flow. Several hydrocarbon-related zones were defined in the whole well with an implication of weak to effective shale gas-bearing found in the Upper Miocene-Middle Miocene, and significant gas-bearing with a little oil-bearing in Lower Miocene-Oligocene.

KEYWORDS: Hydrocarbon-related zone, Shale gas, Song Hong basin, Source rock, Vitrinite reflectance, X-Ray Diffraction

1. INTRODUCTION

As oil and gas become harder and more expensive to find in Vietnam in recent years, petroleum geologists endeavor to reduce exploration risk by using modern technology to the extent possible. They look not only for traps and petroleum accumulations, but also try to assess the probability that oil and gas were generated in a particular source rock and migrated into those traps. They work to determine if the petroleum generated in a source rock might have escaped from a trap or been destroyed by thermal processes during deep burial.

The organic-rich, fine-grained source rocks themselves are the target of intense exploration and drilling for natural gas. So-called thermogenic shale-gas reservoirs comprise an exciting new kind of unconventional energy resource. The main geochemical and geological features of shale gas play are generally essential for assessment of the resource, development and environmental governance. A gas shale is firstly rich in organic matters and thermal mature source rock that probably generates gas. The surface of gas shale likely needs seal formations to keep the leakage of gas. The seals, which are also considered the reservoirs and traps of the shale gas plays, are often missed or ignored but they are really important [1]. Overpressure is a key indicator of the high yields of shale gas and a major factor for assessing preservation conditions and for moving the flow of gas during production.

The Song Hong (SH) basin is one of the best candidate for gas accumulations from shales by favorable conditions such as rapid sedimentation rate, very thick sediments and high geothermal gradient. Conventional petroleum system has generally been confirmed in the whole basin, especially, with the estimation from oil companies last decades that a largest amount of gas and condensate has probably being preserved in the sandstone and carbonate reservoirs. With the interesting local geology in the southern basin, this study is to imply if gases are probably retained in shale zones from Oligocene to Miocene of SH-1X well.

2. GEOLOGICAL SETTINGS

The Song Hong (SH) basin is located between 105º30’-110º30’E longitudes and 14º30’-21º00’N latitudes (Figure 1). It is an elongated basin spreading from the Northwest to the Southeast direction, about 850 km long and 150 km wide with the sediment thickness of more than 10 km at its depocenters. This basin has boundaries with neighbor basins in the South China Sea such as the Northeastward with the Beibuwan basin, the Southeastward with the Qiongdongnan basin [2].

The SH basin was formed throughout Early Tertiary period because of the impact of plates known as Eurasian and Indian, initiating the re-activation of fault systems in SH, and then rotating in clockwise, and strike slipping of the Indochina plate in Southeast direction. In addition to the continuing regional pulling apart activities, therefore, the SH baxxxxsin was formed with the properties of an extension rift basin. The sinistral movement along the fault systems caused the beginning of the formation of the SH basin. The moves of strike-slip mainly taken place alongside Song Lo-Song Chay faults. The past local fault systems were enlarged in the Northwest to Southeast and under the meridional ward, while young fault systems were trending in East-West and sub-parallel directions that importantly contribute to the migration as well as accumulation of petroleum [3]. The activities of the system of geological faults were almost ending before Pliocene (Fig. 1). The tectonic evolution of the study area can be divided into the following periods according to PetroVietnam (2009): (i) Late Paleocene-Early Eocene, (ii) Early Eocene-Middle Eocene, (iii) Late Oligocene-Early Miocene, (iv) Middle Miocene, (v) Late Miocene, (vi) The Pliocene-Quaternary [4]. The SH basin consists of three different parts with different in geological events in the northern, central and southern areas.

The southern basin spreads alongside the Da Nang shelf, along the coastline to the Phan Rang shelf in the west Phu Khanh basin. Its Pre-Tertiary basement is characterized by Paleozoic to Mesozoic sediments with Middle-Upper Miocene platform carbonates in some places. This area is generally considered as low hydrocarbon generation potential due to thin Cenozoic sediments. Quang Ngai graben, located in the end of southern part of the Song Hong basin, which is a narrow graben with the thicknesses of Eocene to present day sediments up to 9 km. Volcanic activities strongly occurred in Upper Miocene-Pliocene. Miocene submarine sand bodies are considered as good reservoirs in the Quang Ngai graben and one of the major kitchens in the southern area of the Song Hong basin. Tri Ton High is a basement that is covered by Oligocene clastics, carbonate platforms, carbonate and reef build-up of the Middle-Upper Miocene (Fig. 2) [5].

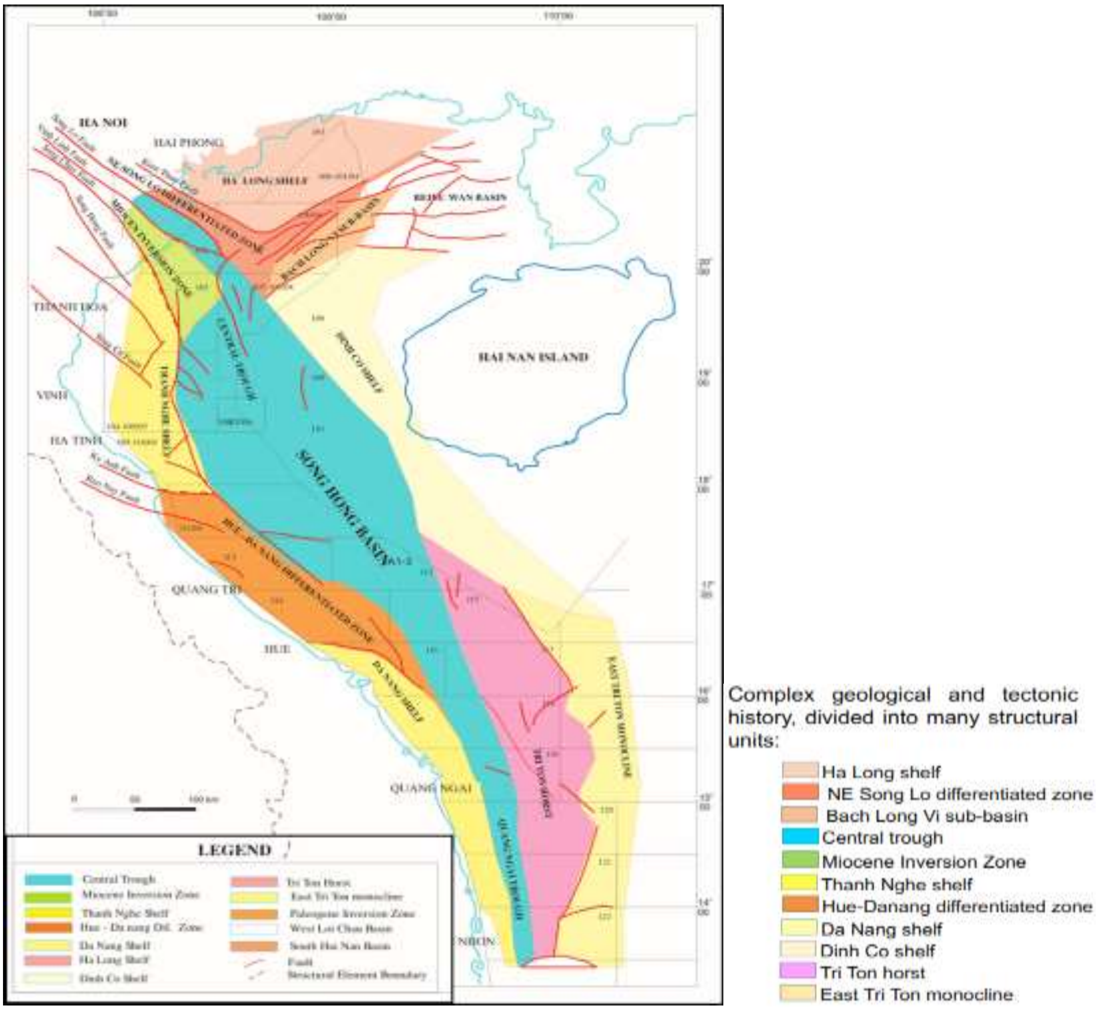

Fig. 1 Structure elements of Song Hong basin [4]

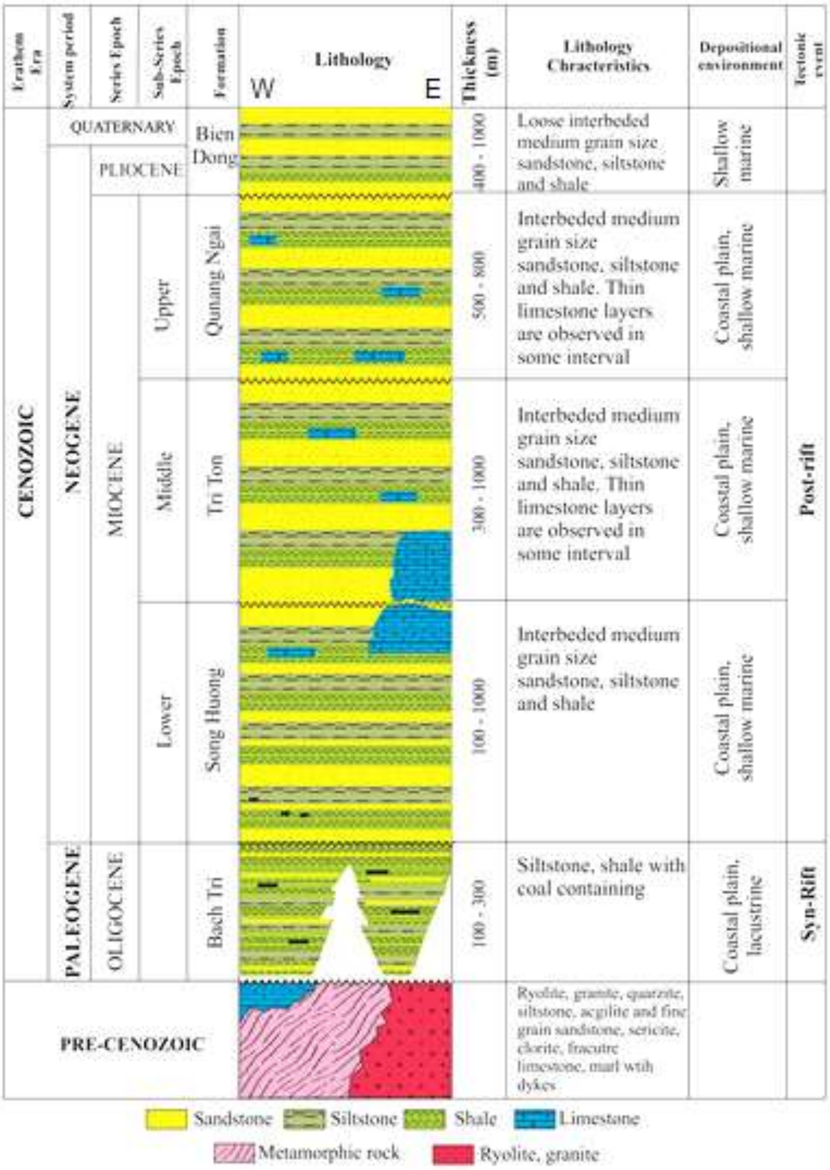

Fig. 2 Stratigraphic columns in the southern Song Hong basin [6]

3. DATA AND METHODS

SH-1X well was drilled from Pliocene to Oligocene with the water depth 271 m and total depth 3750 m, going through very thick shale beds interbedded with thin sandstones and siltstones in the Upper Miocene (1000-1960 m), Middle Miocene (1990-3010 m), Lower Miocene (3010-3520 m), and Oligocene (3520-3750 m). Ninety-three (93) cutting samples were selected for geochemical and petrologic analyses such as Rock-Eval pyrolysis (RE), vitrinite reflectance measurement (Ro) and X-Ray Diffraction (XRD). In addition, well log data and analysis result of fluid inclusion from 518 samples of the whole well spanning from 770-3750 m were also used as a reference for the interpretation.

3.1. Rock-Eval Pyrolysis (RE)

The Rock-Eval 6 pyrolysis is applied for source rock characterization. The instrument is a completely automated device consisting of two micro-ovens which can be heated up to 850°C controlled by a thermocouple located in contact with the rock sample. Basically, the analysis consists of weighing a sample of ground rock, typically 50-100 mg, placed it into a crucible that goes into the RE's pyrolysis oven. The rock is heated in helium atmosphere to 300°C and held isothermally for up to 5 minutes. During this time the volatile organic material is measured by a flame ionization detector and is recorded as the peak S_1. Following this isothermal heating step, samples were heated linearly from 300°C to 650°C at 25°C/minute, yielding a peak S_2. The temperature at peak S_2 can be converted to the thermal maturity parameter, Tmax (°C). The S_3 curve corresponds to the amount of CO_2 (mg CO_2/g of initial rock), which is monitored by infrared (IR) cells, generated from organic matter during the initial isothermal heating step and the programmed heating phase up to 400°C. CO_2 generated between 400°C and 650°C is from the thermal decomposition of carbonate minerals. Pyrolysis mineral carbon is determined from the high temperature portions of the CO and CO_2 pyrolysis curves. The total organic carbon (wt. %) is the sum of the pyrolysis organic carbon [7].

3.2. Vitrinite Reflectance (Ro)

Kerogen, which is isolated from organic matters of shale samples, i.e. cuttings, cores, sidewall cores, is blocked in epoxy resin. The surface of block is fully polished and then measured under CRAIC 308™ spectrometry microscope with oil immersion. Good vitrinite particles are selected for measurement in a random mode under reflected light. Statistic method is applied for defining the reliable value based on total vitrinite particles after excluding 2 groups of caving and reworked vitrinite particles in the sample. About 50 measurement readings are enough for getting final reliable value (Ro, %). The thresholds of thermal maturity are shown in Table 2.

3.3 X-Ray Diffraction (XRD)

A standard XRD analysis for whole rock and shale is performed at VPI-Labs to define quantitative and qualitative mineral compositions which are needed for determination of the brittleness shale. The XRD analysis is carried out on the D8-Advance automatic system with alternative system 40 (kV) and 40 (mA), using Copper K-α radiation with Nickel filter, step width of 0.04° and counting time 1 second per step. Whole rock analysis is carried out using approximately 1g of sample that is ground by micronizing mill; powder sample is then packed to plastic sample holder and run from 3°2θ-50°2θ. The XRD analysis for clay fraction runs from 2°2θ to 30°2θ including four traces are done following steps: (i) drying the clay mount at room temperature and humidity; (ii) ethylene glycol solvation for 24 hours at 50°-60°C in order to identify swelling clays in sample; (iii) immediately following heat to 300°C for 30 minutes. This causes illite-smectite and smectite to concur at 10 (Å); (iv) heat to 550°C for 1.5 hours, causing the destruction of brucite and kaolinite minerals within chlorite [8].

Table 1 Rock-Eval parameters [9]

Quantity	TOC (wt. %)	S1 (mg HC/g rock)	S2 (mg HC/g rock)
Poor	<0.5	<0.5	<2.5
Fair	0.5-1.0	0.5-1	2.5-4
Good	1-2	1-2	4-10
Very good	2-4	2-4	10-20
Excellent	>4	>4	>20
Quality		**HI (mg HC/g TOC)**	**Kerogen type**
Non hydrocarbon		<50	IV
Gas		50-200	III
Gas and oil		200-300	II/III
Oil		300-600	II
Oil		>600	I

Table 2 Parameters of source rock maturity [10]

Level of maturity	Ro (%)	Tmax (°C)	PI
Immature	0.2-0.55	<435	<0.10
Marginal mature	0.55-0.60	-	-
Mature			
Early mature	0.60-0.65	435-445	0.10-0.25
Peak mature	0.65-0.90	445-450	0.25-0.40
Late mature	0.90-1.35	450-470	>0.40
Post mature	>1.35	>470	-

4. RESULTS AND DISCUSSION

4.1 Results of laboratory tests

Organic carbon content is an indicator of potential hydrocarbon source rocks. Organic matters can be subdivided into several types representing sources of the material. Organic carbon content in gas shales is usually of type I/II, and some type III kerogens. Parameters from the RE pyrolysis and vitrinite reflectance are used for assessing the quantity, quality, and thermal maturity of organic matters of source rocks, i.e. TOC, S2, HI, PI, Tmax, Ro. XRD result is used to define mineral compositions and the brittleness of shales. In unconventional petroleum system, TOC of over 0.5 % is necessary for quantity of organic matter to be a good source rock, and brittleness of shale of over 40% is a necessary condition for hydraulic fracturing. The result from XRD analysis is to define how much the brittle a rock is [11, 12]. Quartz, feldspar and carbonate minerals are expressed as the brittle components of tight shaly rocks and generally comprise high quantity and the least clay contents.

4.1.1 Upper Miocene shales (1000-1960 m)

The obtained data show that the Total Organic Carbon (TOC) contents are low to medium values, ranging from 0.25 to 0.80 wt.%. This indicates most analyzed samples in this formation seem to be poor to fairly good-quality source rocks. The pyrolysis yields (S1+S2) vary from 0.08 to 2.27 mg/g, showing poor potential of hydrocarbon generation of the source rocks. In addition, plot of TOC and total hydrocarbon generation potential (S1+S2) of these samples falls in the gas-prone (Fig. 3). The organic matters are mainly derived from types III and II kerogen, mostly generating gas with HI ranging from 9 to 181 mg/g (Figs. 3 and 4). Tmax and vitrinite reflectance values show that the shales are in immature to low mature stages, varying between 406-431ºC and 0.32-0.42 %, respectively. However, PI values ranging from 0.11-0.82 indicate that the shales reached peak hydrocarbon generation and post mature stages (Fig. 7).

4.1.2 Middle Miocene shales (1960-3010 m)

The analyzed shale samples contain medium contents quantities of organic matters with TOC ranging from 0.50 to 0.84 wt.%. The pyrolysis yields (S1+S2) vary from 0.86 to 1.90 mg/g, indicating poor hydrocarbon generation potential of the source rocks. The organic matters are mainly derived from type III kerogen and mixing with a minor amount of materials from type II kerogen that mostly generating gas with HI ranging from 9 to 222 mg/g (Figures 3-4). Cross-plot of TOC and total hydrocarbon generation potential (S1+S2) shown in Figure 7, it can be deduced that the shales have low hydrocarbon generation potential in gas-prone. Measured vitrinite reflectance values and Tmax ranging from 0.40-0.51 % and 427-436ºC, respectively indicate the organic matters are in low to early mature stages. However, PI values ranging from 0.11-0.42 show the organic matters are within the mature to late mature stages (Figure 7). Generally, active source rocks are currently existing in the petroleum systems that little amount of gas has probably been generated and released to the local reservoirs. In addition, high pressure was recorded in the Middle Miocene based on well logging data that shows early a good indicator of seal capacity around and within the shales and also providing reservoir energy needed for driving gas flow. Therefore, the Middle Miocene shales consist of favorable conditions for both effective source richness and self-sources, therefore, an amount of gas is still retained in the shales.

4.1.3 Lower Miocene shales (3010-3520 m)

The lithology in this section comprises the relative thick shale beds interlayered with siltstones, thin sandstones and volcanic clastic rocks. The selected shale samples contain high quantities of organic matters with TOC varying from 1.11 to 1.49 wt.% and moderate potential of hydrocarbon generation with pyrolysis yields (S1+S2) varying from 2.60 to 4.84 mg HC/g rock. The organic matters are mainly originated from type III kerogen and mixing with a very little amount of materials from type II kerogen that are sufficient for generating gas with HI ranging from 141 to 219 mg/g (Figs. 3-4). These shales are effective source rocks with fair to good potential for gas generation that displayed on plot of TOC and total hydrocarbon generation potential (Fig. 7). Thermal mature thresholds are defined from Tmax, PI and Ro parameters that show a good match with values in ranges of 444-450ºC, 0.20-0.44 and 0.60-0.75%, respectively. These indicate the organic matters entered the mature stage and reached strong hydrocarbon generation phase (Fig. 7). Generally, the organic matters in the Lower Miocene have sufficient conditions for generating a significant amount of gas and probably released to the reservoirs.

Depending on the well log curves, volcanic clastic rocks have been found through the lithology of Lower Miocene section including glassy minerals, i.e. tuffs, crystal tuffs and crystal fragments, i.e. quartz, biotite, feldspar, plagioclase. K-feldspar. Twenty-four (24) samples were selected for X-Ray diffraction (XRD) analysis in whole rock and clay fraction. The analytical results show that brittle minerals (15-83.70 %) including quartz, K-feldspar and plagioclase are mostly more dominant than clay minerals (6-16.70 %), i.e. illite, kaolinite, chlorite. Illite mineral is the most abundant following kaolinite and chlorite in clay minerals, whereas, smectite is also detected in the composition of clay minerals with a little amount (Figs. 8-9).

4.1.4 Oligocene shales (3520-3750 m)

The lithology in this section mainly comprises shales and siltstones interbedded with sandstones and some volcanic clastic rocks. The obtained shale source rocks containing high quantities and fairly good qualities of organic matters have moderate potential of hydrocarbon generation with TOC of 1.04-1.65 wt.% and pyrolysis yields (S1+S2) of 2.02-3.48 mg/g. The organic matters are mainly originated from type III kerogen that sufficient for generating gas with HI ranging from 117 to 152 mg/g (Figs. 3-4). TOC and total hydrocarbon generation potential (S1+S2) are plotted on Figure 7 showing these effective source rocks falling into fair to good potential zones for gas generation. Tmax values of 443-456ºC, vitrinite reflectance values of 0.75-0.83% and PI values of 0.31-0.43 indicate that the organic matters reached peak of hydrocarbon generation phase (Fig. 9). Generally, the organic matters in the Oligocene have convenient conditions for generating a sufficient amount of gas and migrated to the reservoirs.

In comparison with the Lower Miocene, thin volcanic clastic rock beds have been found sometimes in Oligocene. XRD results from sixteen samples present that these samples mainly comprise brittle minerals (66.60-91 %) including quartz, K-feldspar and plagioclase and clay minerals (6-25.70 %) consisting of illite, kaolinite and chlorite (Figs. 8-9). In clay fraction, illite is the most abundant in comparison with kaolinite, chlorite and smectite minerals.

4.2 Discussion

Each shale gas play has proper characteristics and different from basin to basin. Changes of shale properties in hydrocarbon-related zones with depth from the Miocene to Oligocene indicate that the organic matters are more dominant and higher levels of maturity in the Lower Miocene and Oligocene than those in the Upper Miocene and Middle Miocene. Moreover, the bottom hole temperature of about 147°C, very high geothermal gradient of about 4.3°C/100m, and the presence of volcanic clastic rocks in these formations indicate that the organic matters have mainly been controlled by thermogenic origin and most likely formed by indigenous hydrocarbons as illustrated on the cross plot of TOC and S1 (Fig. 6).

S1 values are low in the Upper Miocene and Middle Miocene shales and higher in the Lower Miocene and Oligocene shales, implying a little amount of hydrocarbons in the Upper Miocene and Middle Miocene shales are thought to be retained in the shales, it means that the hydrocarbons could be generated from these potential source rocks but not expelled yet. In addition, the ratio of S1/TOC is implied for distinguishing between migrated hydrocarbons, contaminants and indigenous hydrocarbons and possibly predicting reservoir interval. When the organic matters contain high S1 and low TOC contents, migrated hydrocarbons occurred [13]. Plot of S1 vs TOC shows the Upper Miocene and Middle Miocene shales are mostly distributed in indigenous organic sources (Table 3 and Fig. 6). The thermal maturity of organic matters in the shallow depths vary from the low mature to mature stages and the maturity increasing with depths, indicating the effects of geological activities on both sedimentation process and thermal maturity. These evidences are probably found in the in-situ gas from shales of the Upper Miocene (1560-1960 m) and Middle Miocene (1990-3010 m), whereas, the organic matters of the Lower Miocene and Oligocene shales distribute in non-indigenous and indigenous hydrocarbon zones (Fig. 6). It means the hydrocarbons were partly released from these source rocks and the current hydrocarbon generation potential of the source rocks is still good for gas generation.

In addition, the brittleness of a mineral is controlled by the temperature, effective stresses from the burial, diagenesis textures and organic matter sources. Kaolinite, a non-swelling clay is able to absorb hydrocarbons while illites are able to absorb pore water which increases the wettability of a sample [14]. The abundance and preservation of silicate minerals in the analyzed samples of well SH-1X show the predominance of quartz contents affecting to the brittleness of the shales interbedded with sandstones during catagenesis stage of Lower Miocene and Oligocene shales. XRD data of the Upper Miocene and Middle Miocene are not available that could not be defined the brittleness of the shales. However, based on the above results, the Upper Miocene and Middle Miocene shales are probably playing roles as partly active self-sources and local seals for sandstone reservoirs.

Table 3 Rock-Eval, vitrinite reflectance and calculated parameters

Parameters	Upper Miocene (33 samples)	Middle Miocene (35 samples)	Lower Miocene (17 samples)	Oligocene (8 samples)
TOC, wt.%	0.25 - 0.80 0.49	0.50 - 0.84 0.64	1.11 - 1.49 1.32	1.04 - 1.65 1.32
S1, mg/g rock	0.05 - 1.42 0.37	0.09 - 0.79 0.33	0.54 - 1.63 1.02	0.62 - 1.42 1.12
S2, mg/g rock	0.02 - 1.07 0.49	0.67 - 1.29 1.00	1.66 - 3.21 2.31	1.40 - 2.06 1.70
HCgen, mg/g rock	0.33-3.35 1.64	1.29-3.22 2.12	2.19-3.25 2.52	1.84-2.55 2.14
HI, mg/g TOC	9 - 181 91	97 - 222 159	141 - 219 174	117 - 152 130
PI	0.11 - 0.82 0.43	0.11 - 0.42 0.24	0.20 - 0.44 0.31	0.31 - 0.43 0.39
Tmax, °C	406 - 431 416	427 - 436 431	444 - 450 447	443 - 456 450
Ro, %	0.32 - 0.42 0.38	0.40 - 0.51 0.45	0.60 - 0.75 0.68	0.75 - 0.83 0.78
Calculating Ro from Tmax, %	0.36 - 0.42 0.39	0.53 - 0.69 0.60	0.83 - 0.94 0.89	0.81 - 1.05 0.93
S2/S3, mg/g	0.01-3.34 0.85	0.43-2.68 1.34	1.91-13.95 4.74	1.11-4.38 2.47
S1/TOC	0.14 - 1.98 1.73	0.15 - 1.34 0.53	0.44 - 1.36 0.77	0.56 - 1.03 0.84

*Note: (min-max)/average; PI = S1/(S1+S2); HCgen = hydrocarbons had been generated = (S1+S2)/TOC; Est. Ro=0.018*Tmax-7.16*

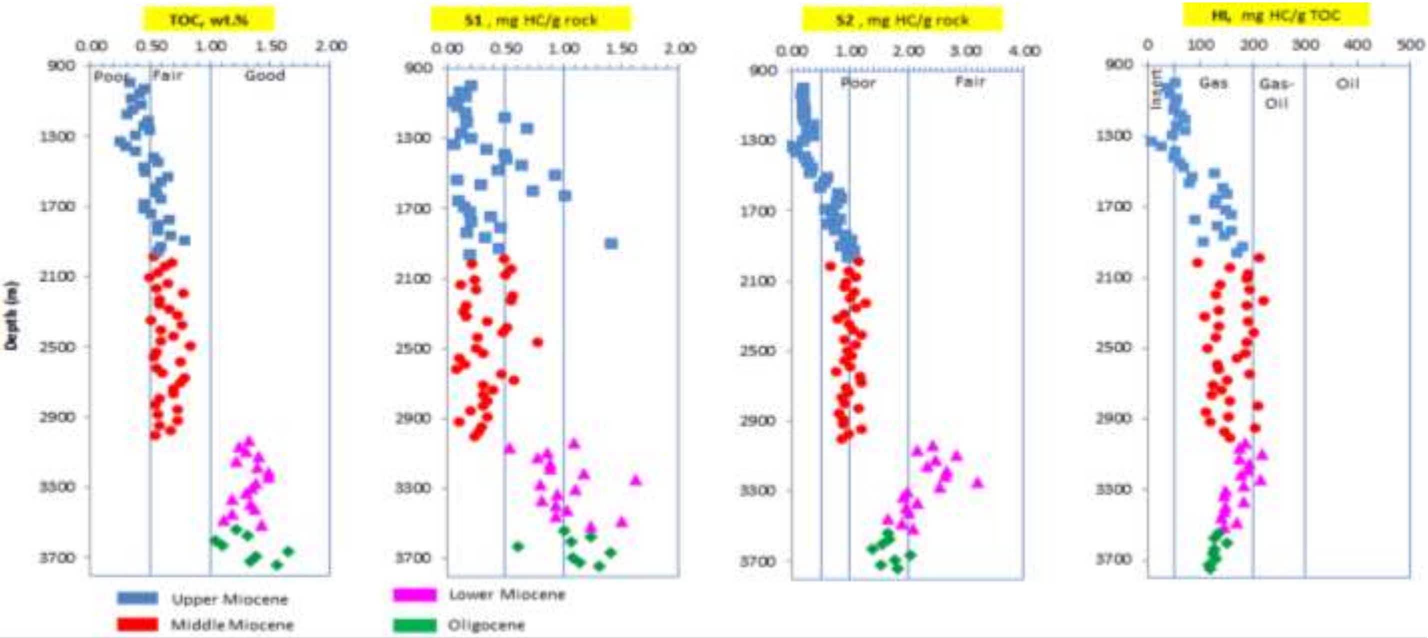

Fig. 3 Rock-Eval parameters change with depth

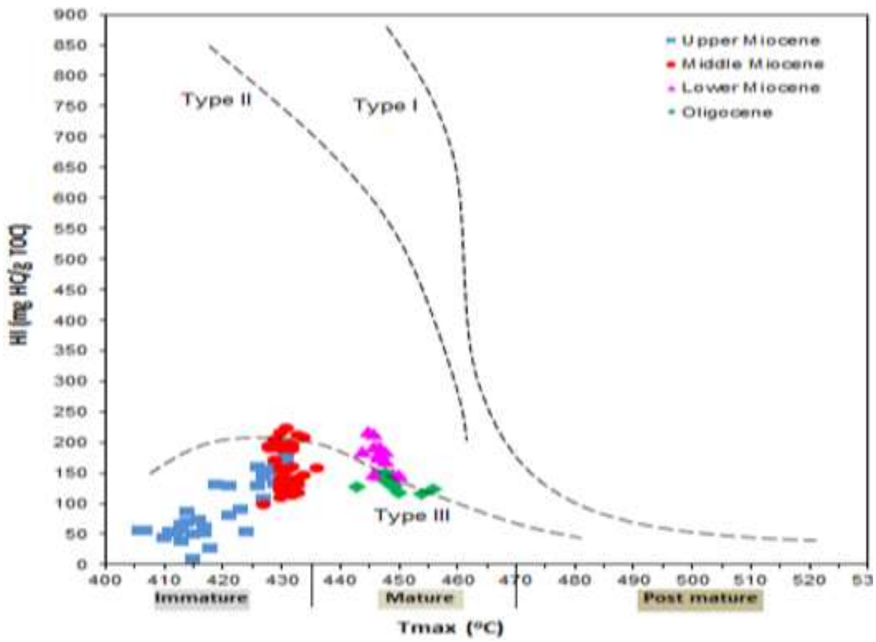

Fig. 4 Types of organic matter

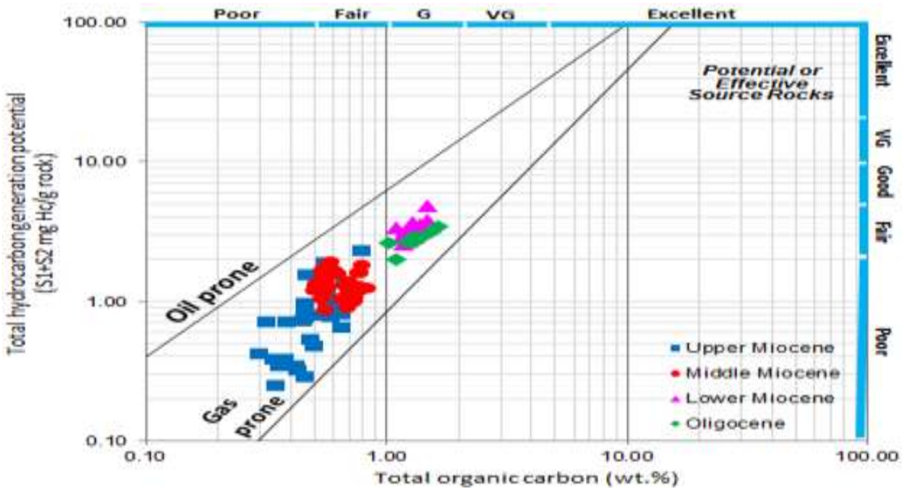

Fig. 5 Total hydrocarbon generation potential

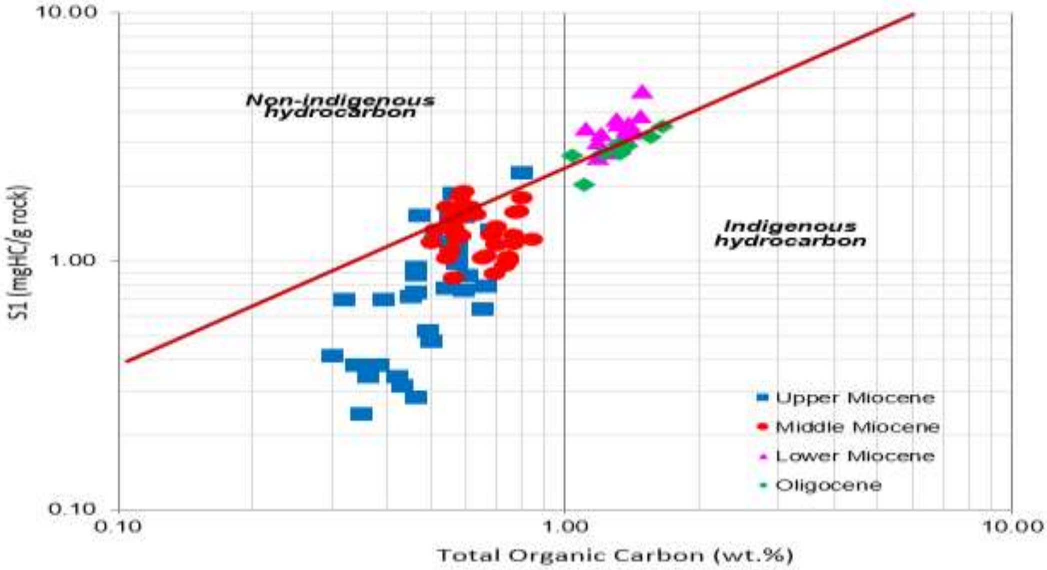

Fig. 6 TOC vs S1 for determination of migration or indigenous hydrocarbon

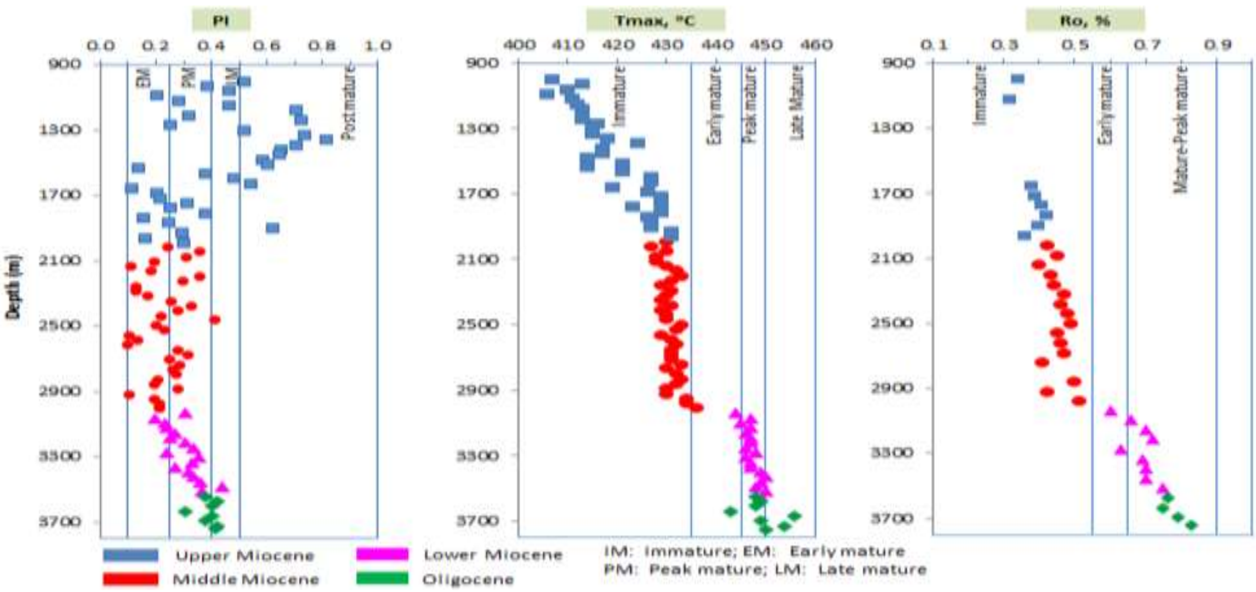

Fig. 7 Thermal maturity parameters change with depth

Table 4 Mineral compositions of the whole rock

Depth (m)	Quartz	K-Feldspar	Plagio-clase	Clay minerals	Calcite	Dolomite	Siderite	Pyrite	Riebe-cite	Zeolite	Barite
2905-2920	70.7	5.4	3.3	11.60	2.1	2.2	0	0	0	0	4.7
2920-2930	47.2	3.8	2.6	21.9	2.9	0	4.3	4	0	0	13.3
2985-2995	18.8	2	2.1	11.0	49.4	3.4	3.6	2.5	0	0	7.2
2995-3005	17.5	2.2	1.8	11.2	51.8	3.3	2.8	0.0	1.7	4	3.7
3020-3030	25.0	7.4	2.1	15.3	26.6	6.5	0.0	0.0	0	0	17.1
3140-3150	18.1	4.0	1.9	19.4	24.8	4.2	0.0	0.0	3.7	8.1	15.8
3150-3160	54.5	3.7	8.4	13.5	2.8	12.0	0.0	0.0	0	0	5.1
3165-3175	49.4	4.0	2.6	16.9	9.0	5.2	0.0	3.6	0	0	9.3
3310-3320	54.9	4.4	3.5	16.2	3.4	4.1	0.0	3.1	0	0	10.4
3320-3330	64.2	3.3	12.6	10.6	4.3	0.0	0.0	0.0	0	0	5.0
3405-3415	64.7	3.7	4.5	14.7	4.1	5.0	0.0	0.0	0	0	3.3
3415-3425	59.2	5.5	3.8	13.1	3.5	4.2	0.0	0.0	0	0	10.7
3425-3435	56.1	5.2	3.9	13.3	5.6	3.0	0.0	0.0	0	0	12.9
3435-3445	49.7	3.1	2.2	15.6	3.3	13.4	2.6	0.0	0	4.8	5.3
3480-3490	30.1	5.6	2.2	21.2	2.7	5.9	5.0	0.0	0	7.9	19.4
3490-3500	31.2	5.7	3.0	13.6	6.5	4.2	3.2	0.0	0	0	32.6
3500-3510	21.6	0.0	2.3	28.5	5.1	6.2	0.0	0.0	0	0	36.3
3515-3525	53.8	3.6	2.2	11.9	10.9	6.7	0.0	0.0	0	0	10.9
3585-3590	51.4	3.0	3.7	18.9	6.5	4.6	3.7	0.0	0	4.7	3.5
3590-3603	27.8	7.0	11.4	22.8	2.9	5.3	4.5	0.0	0	5.5	12.8

Table 5 Clay mineral compositions of clay fraction

Depth (m)	Kaolinite	Chlorite	Illite	Illite-Smectite
2905-2920	23.7	35	37.7	3.6
2920-2930	27.1	25.7	41.5	5.7
2985-2995	21.7	27.1	46.5	4.7
2995-3005	23.4	24.8	47.4	4.4
3020-3030	19.4	20.5	56.5	3.6
3140-3150	15.4	15.3	64.5	4.8
3150-3160	17.1	17.8	61	4.1
3165-3175	12.9	15.8	67	4.3
3310-3320	19.3	27.3	49.2	4.2
3320-3330	0	36.6	56.6	6.8
3405-3415	0	34.3	61	4.7
3415-3425	0	53.5	42.8	3.7
3425-3435	0	51.4	44.5	4.1
3435-3445	0	57.5	36.9	5.6
3480-3490	14.9	6	71.9	7.2
3490-3500	20.6	14.5	59.5	5.4
3500-3510	16.5	10.1	66.7	6.7
3515-3525	23.1	28.4	43.3	5.2
3585-3590	12.2	5.8	74.1	7.9
3590-3603	10	5.5	78.6	5.9

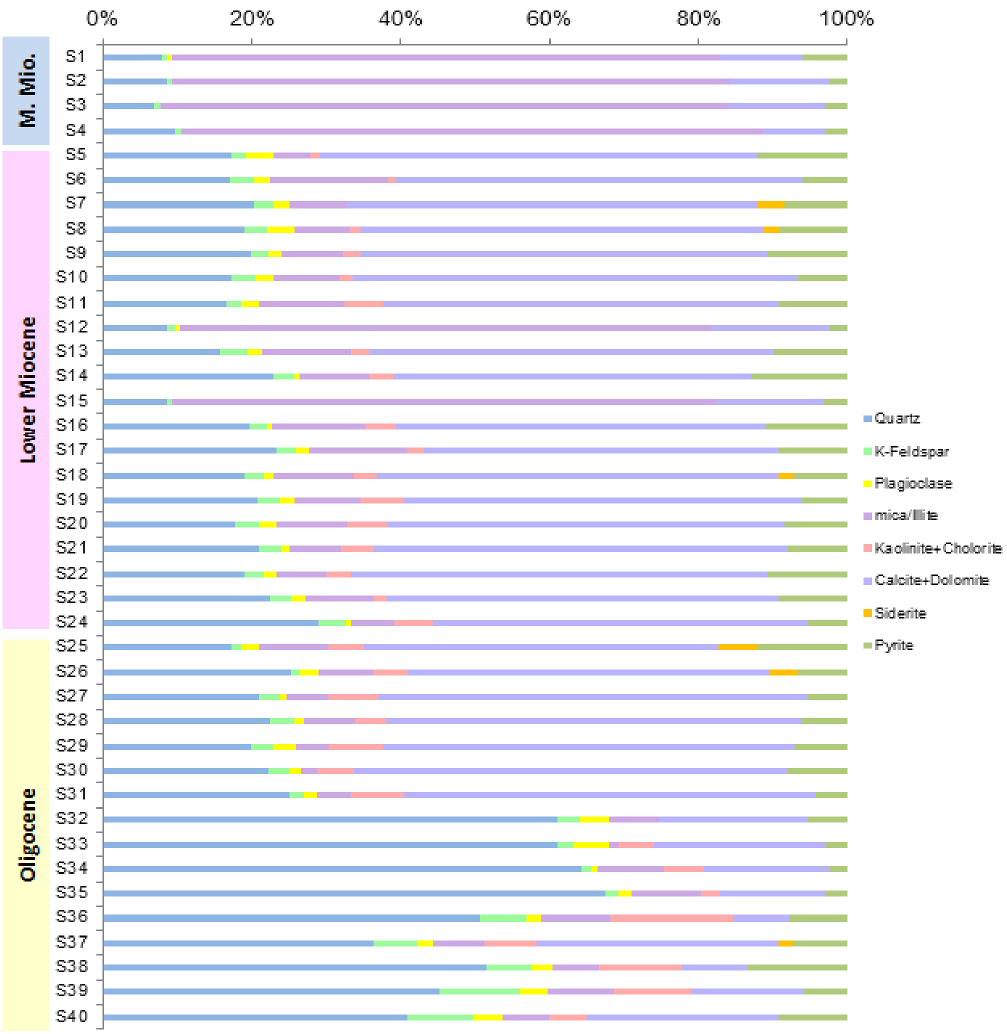

Fig. 8 Mineral compositions of the whole rock fraction

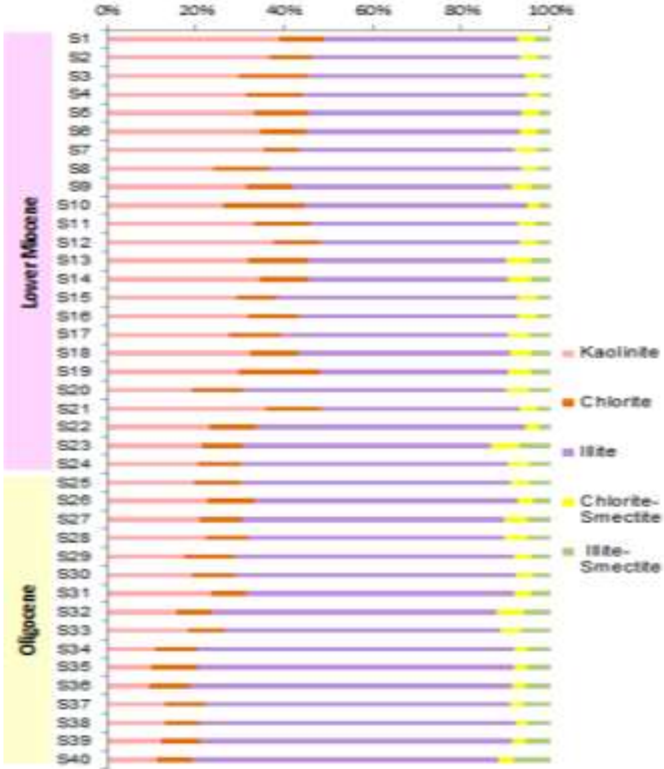

Fig. 9 Clay mineral compositions of clay fraction

5. CONCLUSIONS

Geological evolution in the southern Song Hong basin had strongly affected on the compaction of depositions during the diagenesis with a rapid sedimentation rate and highly increasing geothermal gradient in catagenesis through metamorphic stages that formed very thick shales up to several hundreds of meters in the Middle Miocene-Upper Miocene, therefore, organic matters entered the mature stage in short period of time. These are favorable conditions for oil and gas accumulations in this area. Evaluation of potential source rocks indicates the presence of active shale source rocks in this well based on main properties such as: (i) containing moderate quantities of organic matters that mainly originated from type III kerogen with a small amount of type II kerogen; (ii) having fair to good potential of hydrocarbon-related zones, mainly for gas; (iii) organic matters preserved in immature to early mature stages in the Upper-Middle Miocene and reached peak of hydrocarbon generation in the Lower Miocene-Oligocene; (iv) high pressure in the Middle Miocene is early a good indicator of seal capacity around and within the shales and also providing reservoir energy needed for driving gas flow; (v) high composition of brittle minerals is a favorable condition for creating fractures in the shale formations to release the gas; (vi) several hydrocarbon zones could be defined such as weak gas-bearing in the Upper Miocene, weak to effective gas-bearing in the Middle Miocene and significant gas-bearing and probably a little oil-bearing in the Lower Miocene-Oligocene.

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