Modeling of petroleum generation in Phu Khanh Basin by Sigma-2D software

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Abstract

The Phu Khanh Basin is a narrow, elongated basin extending from 11.5 to 14°N off the coast of central Vietnam. It is bounded to the west by the narrow Da Nang shelf and separated from the Quang Ngai Graben to the North by the Da Nang shear zone, and from the Cuu Long Basin to the South by the Tuy Hoa shear zone.

The purpose of this paper is to understand, by 2D modeling, the generation, migration and accumulation histories for oil and gas from source rocks in the Phu Khanh Basin. Several regional sections covering shallow to deep-water areas were modeled by SIGMA-2D software. In the sedimentary basin, Oligocene lacustrine source rock has generated oil since the Middle Miocene time and is in gas window in almost the entire area of the basin, with the main part in the deep water area at the present time. The Lower Miocene fluvio-deltaic source rock has generated oil since the Late Miocene time and is in gas window in the central part of the basin at the present time.

Oil and gas generated both in the Oligocene and Lower Miocene source rocks in deep water areas migrated along a regional carrier system in Lower Miocene (both sandstone and porous carbonate) after vertical migration of the Oligocene oil and gas by cap rock leakage and through faults. The oil and gas accumulated in structural highs in both deep water and in shallow water areas. Some were already found as oil seeps from onshore outcrops [1] and were encountered in exploration wells such as 124-CMT-1X.

1. Introduction

The Phu Khanh Basin is one of Vietnam's large offshore Cenozoic Basins located along the Western and Southern margins of the East Vietnam Sea. It is located at latitudes from 11 - 15°N offshore central Vietnam, as a narrow North - South trending basin approximately 250km long and 50 - 75km wide (Lee and Watkins, 1998). These basins have attracted increasing interest from the national and international oil and gas industry as significant hydrocarbon resources have been identified. While the Vietnamese sedimentary basins have generally been explored to some extent, with an open seismic coverage acquired over a period of 20 years from 1974 - 1993 [2]. In 2009, crude oil was discovered only at well 124 CMT in carbonate reservoirs, while the other well was dry in block 127.

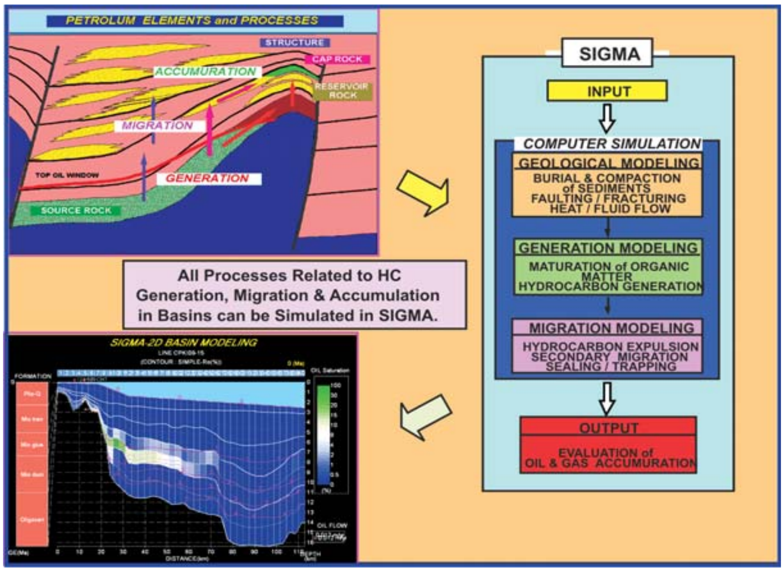

Fig.1. *Concept of SIGMA modeling*

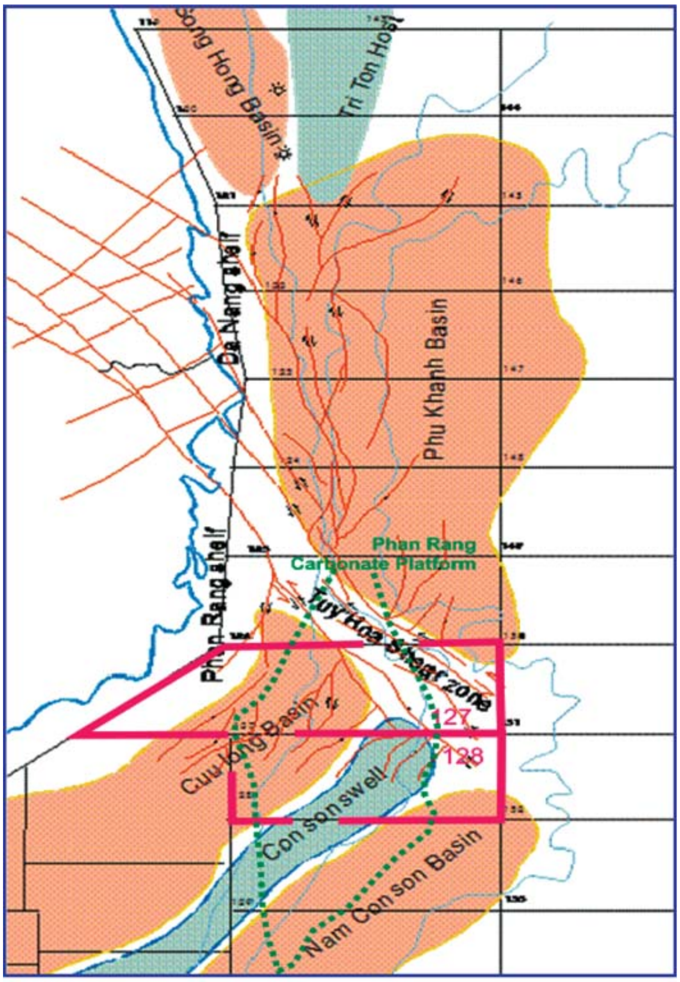

Fig.2. *Structural elements of the Phu Khanh Basin (after Nguyen Hiep, etc. 2007)*

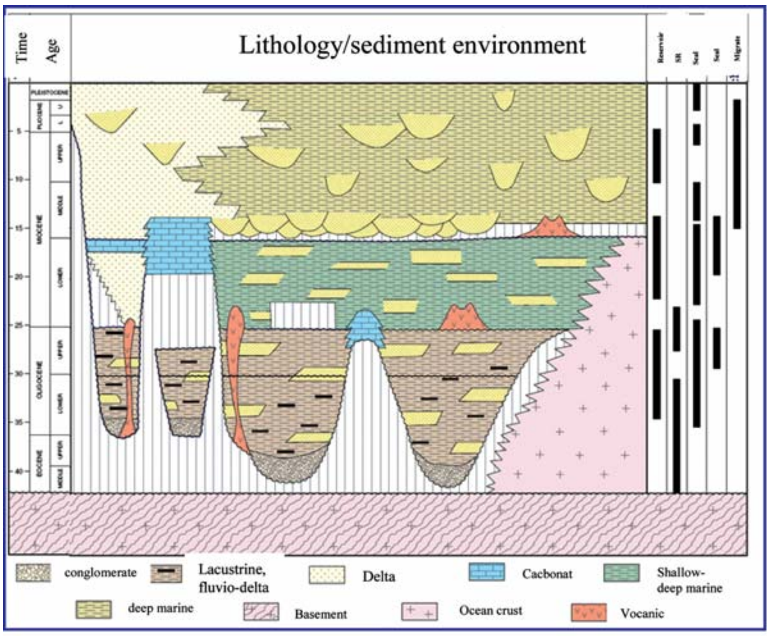

Fig.3. *General stratigraphy of the Phu Khanh Basin*

Multi-dimensional Basin modeling is a computer simulation technique, which is currently widely used for oil and gas exploration. Basin modeling can reproduce the processes relating to a petroleum system in computer simulation from past to present times thus enabling assessment of the timing and location of the generation, migration and accumulation of oil and gas (Fig.1) [7].

The basin modeling work started from the construction of input data. Depth sections for 2D modeling were created by seismic interpretation and depth conversion. Then, lithology distribution, thermal history and source-rock distribution were determined for each cross section and each map.

Two wells (120CS-1X, 121 CM-1X), were selected for the study area, these being useful to determine the above input data. Lithology at each well can be determined by electrical-logging interpretation. Routine geochemical analyses such as TOC, rock-eval and maceral analysis enables specification of source rock interval and properties at the wells. The temperature profile (geothermal gradient) and vitrinite reflectance can be used for the calibration of thermal history. New information was used only from well 124 CMT-1X (must not use original data because of sensitivity). After the construction of all input data, multi-dimensional basin modeling was conducted to reveal the history of generation, migration and accumulation of oil and gas in the Phu Khanh Basin. This enables one to pick up any prospective exploration play and its fairway in the Phu Khanh Basin. SIGMA-2D Basin modeling was conducted for regional sections from shallow to deep-water area (blocks 121 - 127 and blocks 141 - 147). At first, calibrations of thermal and pressure histories at wells were done by the comparison of the calculated results with the observed data at wells.

2. Geological setting

The Phu Khanh Basin is an elongated, narrow basin extending from 11.5 - 14°N off the coast of central Vietnam (Fig.2) [2]. The basin is about 250km long from North to South and 50km wide from East to West. It is bounded to the West by the narrow Da Nang shelf, separated from the Quang Ngai graben

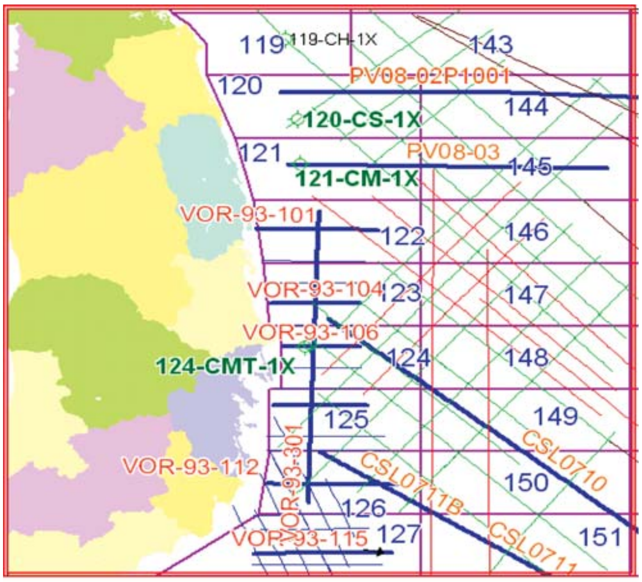

Fig.4. *Seismic lines used for SIGMA-2D modeling*

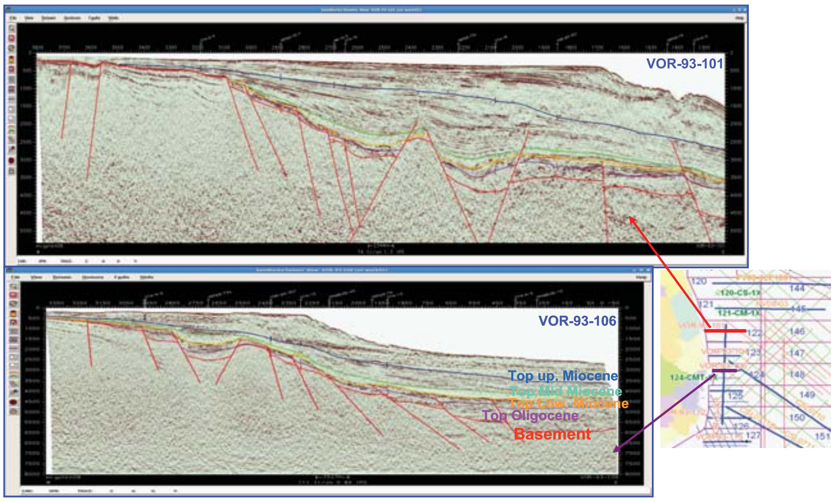

Fig.5a. *Interpreted seismic lines (VOR 93-101 and 106) in shallow water are of the Phu Khanh Basin*

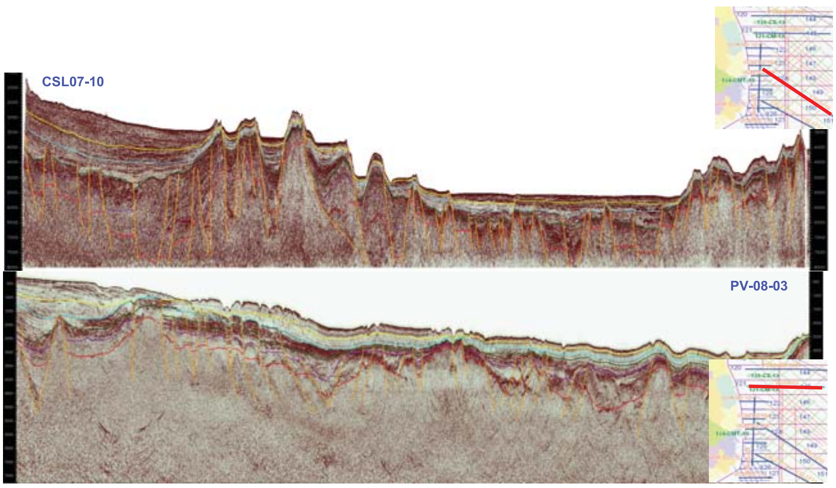

Fig.5b. *Interpreted seismic lines (PV08-03 and CSL07-10) in deep water area of the Phu Khanh Basin*

to the North by the Da Nang shear zone, and from the Cuu Long Basin to the South by the Tuy Hoa shear zone.

The water depth is less than 100m in the Western near shore areas increasing to more than 3.000m towards the deep-water basin to the East. The area comprises several major structural elements, which mainly trend from the North to the South.

The basin is a rift basin, formed during Eocene? - Oligocene times by crustal extension and stretching. Rifting and uplift appear to have resumed or to have continued locally during the Late Oligocene and Early Miocene epochs. The Oligocene and Lower Miocene sediments are covered by 100 - 3,000m of post-rift Middle Miocene - Quaternary sediments at the present time (Fig.3) [2].

3. Basin modeling

3.1. Depth Section

Seven seismic lines mainly covering shallow water areas and another 4 lines extending to deep water areas were selected for use in this study (Fig.4). These lines were merged to make regional 11 sections, which were used for 2D modeling.

Each seismic section was interrelated at 5 horizons (top of basement, Oligocene, Lower, Middle and Upper Miocene). Well tie was done at 120-CS-1X and 121-CM-1X wells. Fig.5a and 5b are the examples for such interpretations.

Depth conversion from time to depth relationship for sediments was derived from 120-CS-1X and 121-CM-1X wells.

3.2. Lithology, rock properties and fault properties

Lithology (Rock percentage) at each well was evaluated by electrical logging data (Fig.6). However, as no well drilled in the Phu Khanh Basin was permitted to use for this study, lithology was decided mainly by seismic character, basin history and settings.

Properties for each rock type such as porosity, permeability, irreducible water saturation, capillary pressure and thermal conductivity were taken from 2D modeling database (Fig.7). In addition, measured data at wells such as porosity (Fig.8) and formation pressure were used for the calibration for lithology and rock properties.

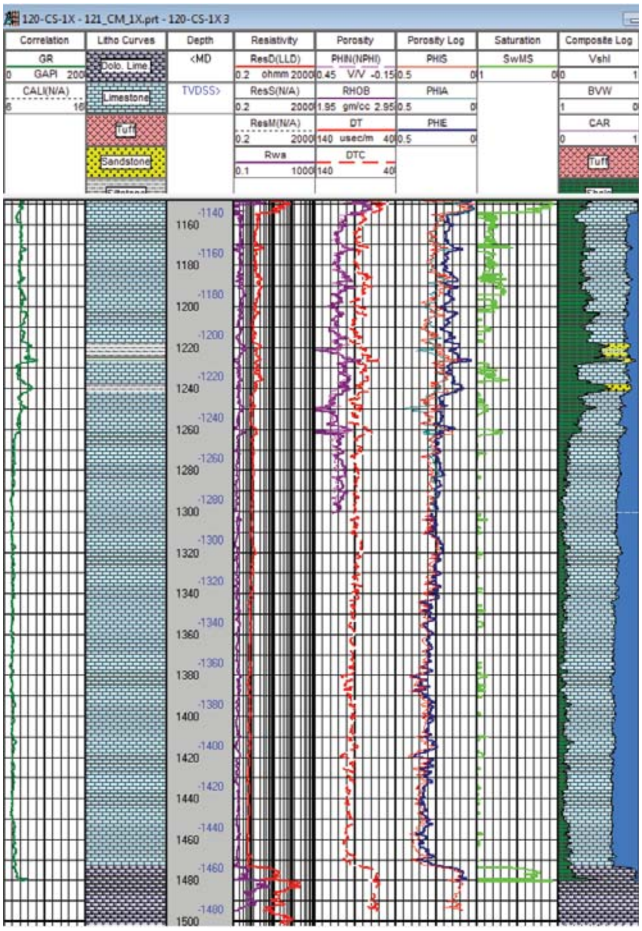

Fig.6. *Interpretation of electrical logging data at the well 120 - CS - 1X*

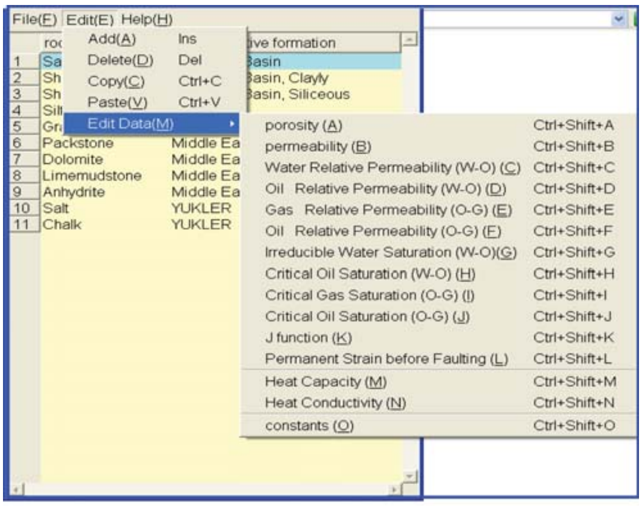

Fig.7. *Properties for each rock type used for SIGMA modeling*

Faults play important roles for vertical migration of oil and gas. Fault properties in SIGMA are defined by the duration of faulting, its width and permeability. For SIGMA Basin modeling in the Phu Khanh Basin, the duration of faulting was specified based on seismic sections and it was assumed that 10m of a fault zone has 10md permeability at maximum deformation.

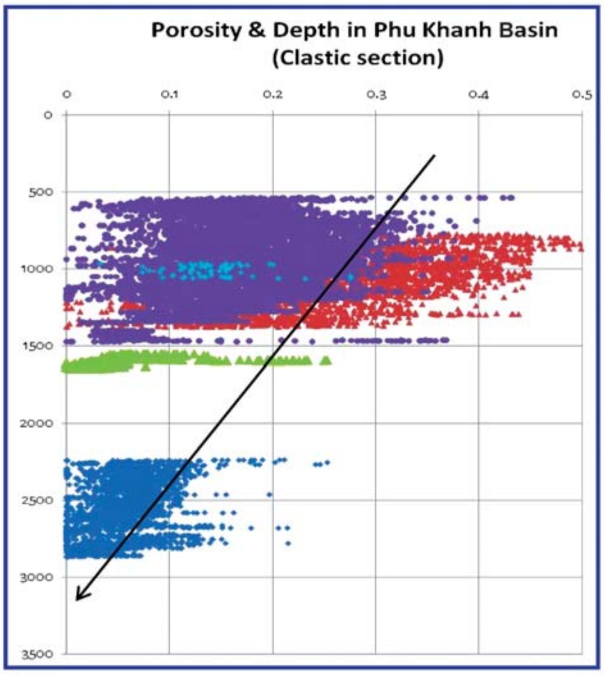

Fig. 8a. *Porosity vs. Depth relationship in the Phu Khanh Basin (Clastic section)*

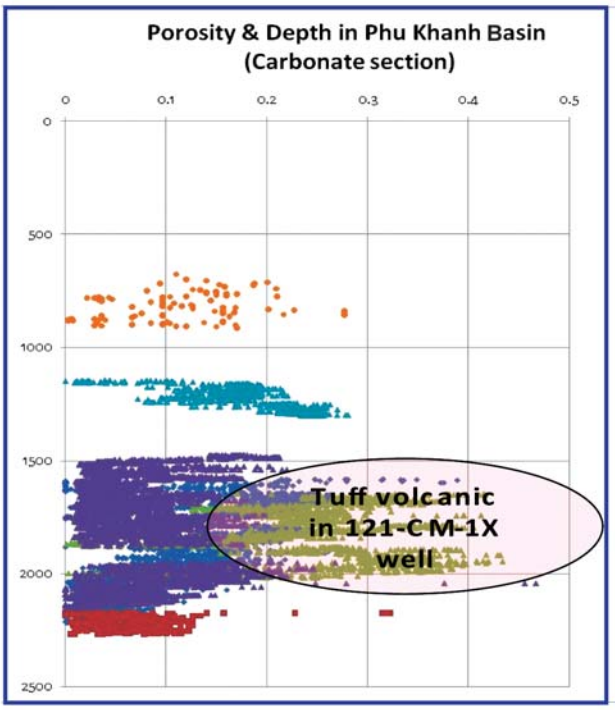

Fig.8b. *Porosity vs. Depth relationship in the Phu Khanh (Carbonate section)*

3.3. Source rock

As discussed above, no well data in the Phu Khanh Basin were allowed to be used for this study. Therefore, at first, oil seep samples collected from onshore outcrops were investigated by advanced geochemical analyses, which revealed that all the samples analyzed, originated from fluvio-deltaic source rocks [17]. Geochemical analyses result on oil seep samples). In addition, working of dual non- marine petroleum systems in the Phu Khanh Basin is consistent with adjacent basins such as the Nam Con Son [4] and the Song Hong, which have similar basin history at least until the Early Miocene before the opening of the East Sea.

Seismic data in the Phu Khanh Basin was also investigated in detail, which revealed that continuous high amplitude and low frequency events are recognized in syn-rift sequences in some parts of the Phu Khanh Basin (Fig.5a, 5b). This character is specific for good lacustrine source rock in the Upper Oligocene of the Cuu Long Basin as well as widely in Southeast Asia, and therefore there is enough reason to suppose that such kind of good lacustrine source rock develops in the Oligocene sediments of the Phu Khanh Basin.

Based on these evaluations, source rock parameters for the SIGMA modeling were constructed as Fig. 9. Lacustrine source rock was assumed in the Oligocene, which has a total thickness of 1,000m of which the upper part has better source rock potential. Fluvial source rock (coal) was assumed to develop in the Lower Miocene, which has 60% TOC and 200mgHC/gTOC hydrogen index in 20m.

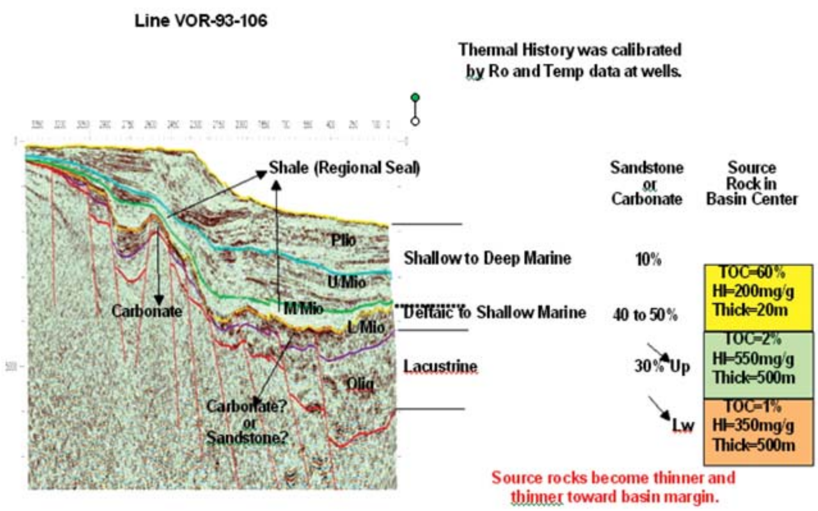

Fig.9. *Input parameter for source rocks in the Phu Khanh Basin*

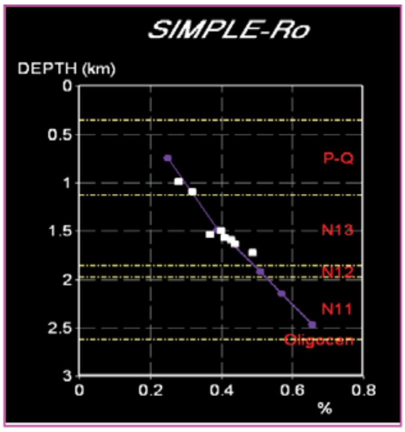

Fig.10a. *Result of Optimization of Thermal History at well 121CM-1X. White Squares: Measured pressure reflectance at hhis well, Purple Line: Calculated Vitrinite Reflectance at this well*

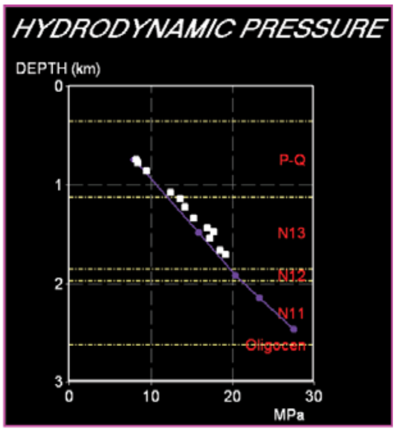

Fig.10b. *Result of optimization of pressure profile at well 121CM-1X. White squares: Measured pressure at this well, Purple line: Calculated pressure at this well*

3.4. Thermal history

Thermal history, especially heat flow, is difficult measure at wells. Therefore, these parameters are generally optimized by easily measurable data at wells. Since the present temperature gradient depends on surface temperature and basement heat flow at the present time, measured temperature data at wells were used to optimize present heat flow calculation. In addition, since vitrinite reflectance profile depends on surface temperature and basement heat flow in the past (accumulation of heat energy received until present time), analyzed vitrinte reflectance at wells is used to optimize the heat flow history.

In this study, the optimization of thermal history was conducted at 3 wells. Surface temperature was assumed as 20°C in shallow water area and was decreased to 5°C as water depth becomes larger toward the deep water area. Details of a complex heat flow history are difficult to assume and therefore a constant heat flow was assumed for this study. As the result of optimization, constant heat flow of 1.3 - 1.5 HFU (54 - 65mW/m^2) was derived (Fig.10).

4. Modeling of petroleum generation

Eleven cross sections were simulated by SIGMA-2D in the Phu Khanh Basin covering areas from shallow to deep water. The simulated generation history is different from line to line depending on the location of the section. However, the main part of the basin has the width of 150km [2], where more than 10km thickness of sediments can be seen from the seismic data. In addition, there can be seen other mini-basins on the more offshore side in the deep water area. However, sediments in these basins are thin, mostly less than 3,000m, since they are far from onshore source areas of sediment supply.

Oil and gas generations in the Oligocene source rock mainly occurred in Early Miocene time in the deepest part of the main basin, which was followed by oil and gas generations in the Lower Miocene source rock since Middle Miocene time. These generations from dual source rocks have succeeded toward the basin margin until the present time.

Generated oil and gas migrated horizontally along the sandstones in the Oligocene and Lower Miocene formations, migrated vertically through faults and by making local columns and reached traps in these horizons. Additional leakage to Middle Miocene from Lower Miocene structures was also simulated, which may result in oil and gas accumulations in turbidite fans developed in the deep marine environment [5].

In offhore mini-Basins, only the deepest part, buried by more than 3,000m, generated some oil. However, effective migration has not commenced since the generation occurred recently and the amount generated is not enough to increase oil saturation in the source rock.

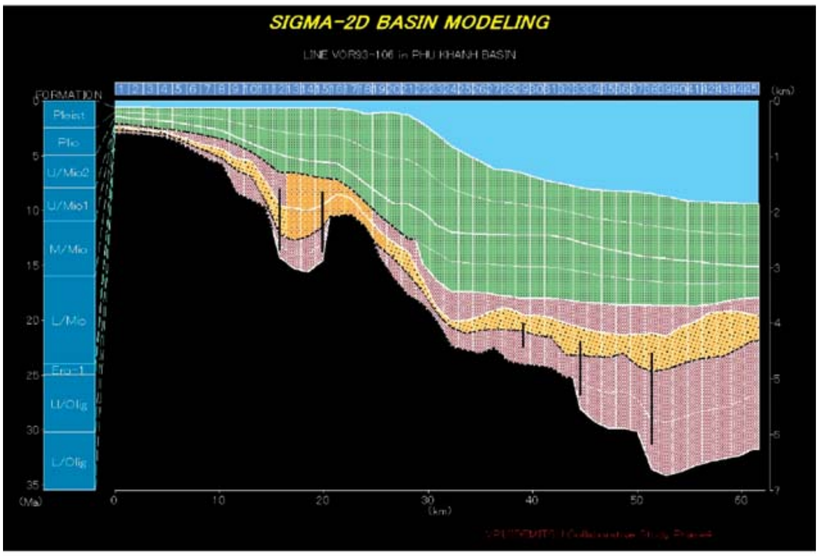

Fig.11a. Simulated section for line VOR 93-106

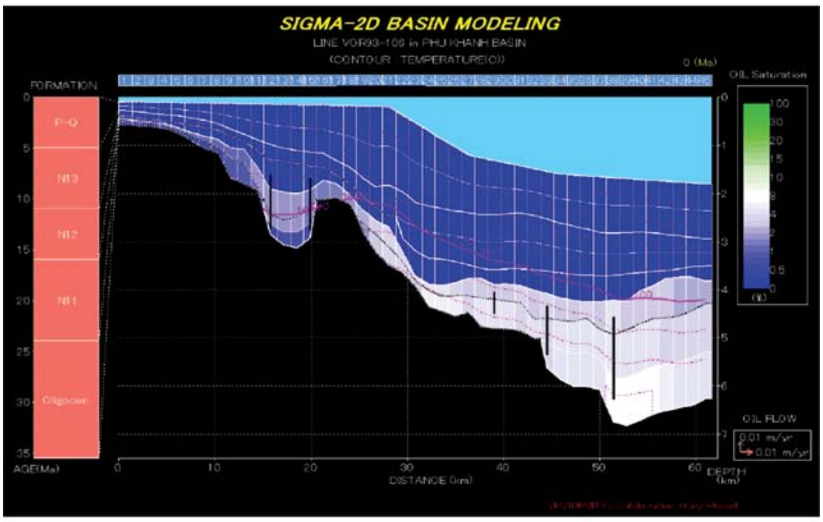

Fig.11b. Simulated result for line VOR 93-106 Color: Oil saturation, Contour: Temperature, Arrow: Oil flow

Line VOR 93-106 is extending from West to east in Block 124 covering shallow to deep water of the Phu Khanh Basin crossing the well 124-CMT-1X, where light oil was discovered from the Miocene carbonate. Input data for this section is shown on Fig.11a. The thickness of Tertiary sediments in shallow water is about 3,500m, which increases toward deep water and reaches 5,000m in this section. However, maximum thickness remains relatively thinner than in other sections since this line appears located on a ridge dividing the Phu Khanh Basin into Northern and Southern sub-basins.

Because of the location of this section, even the deepest part of the section (Column 39) reaches the temperature of 160^{o}C and Vitrinite reflectance of 1.0%, which corresponds to peak oil generation [9]. The Oligocene and the Lower Miocene source rocks are matured enough to generate certain amount of oils from Pliocene times, but its migration has just started (Fig.11b). Due to this level of maturity of source rocks, gas generation

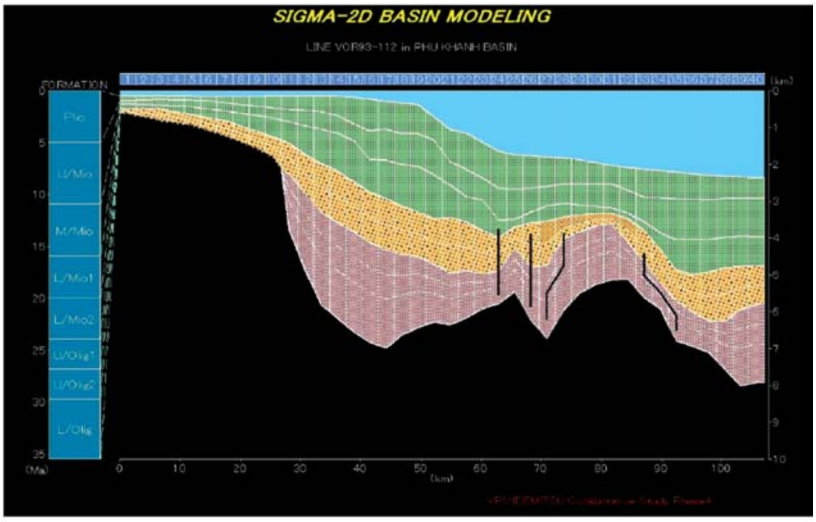

Fig.12a. *Simulated section for line VOR 93-112*

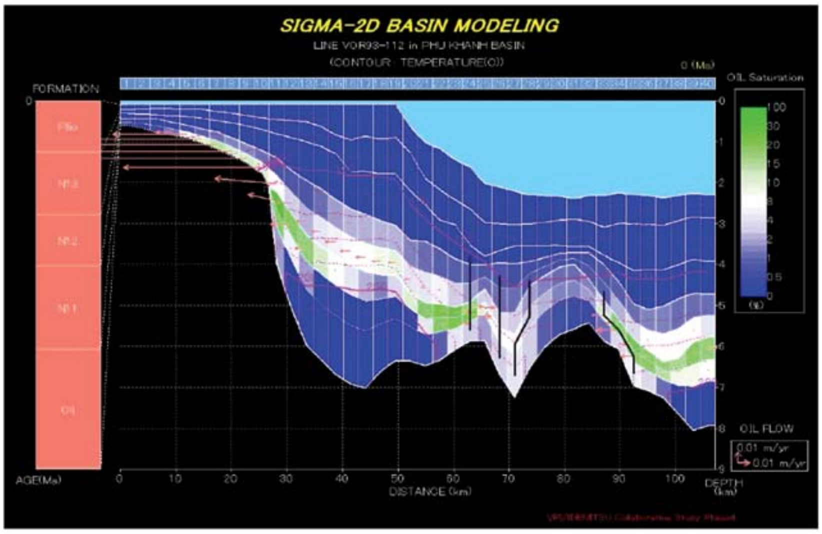

Fig.12b. *Simulated result for line VOR 93-112 Color: Oil saturation, Contour: Temperature, Arrow: Oil flow*

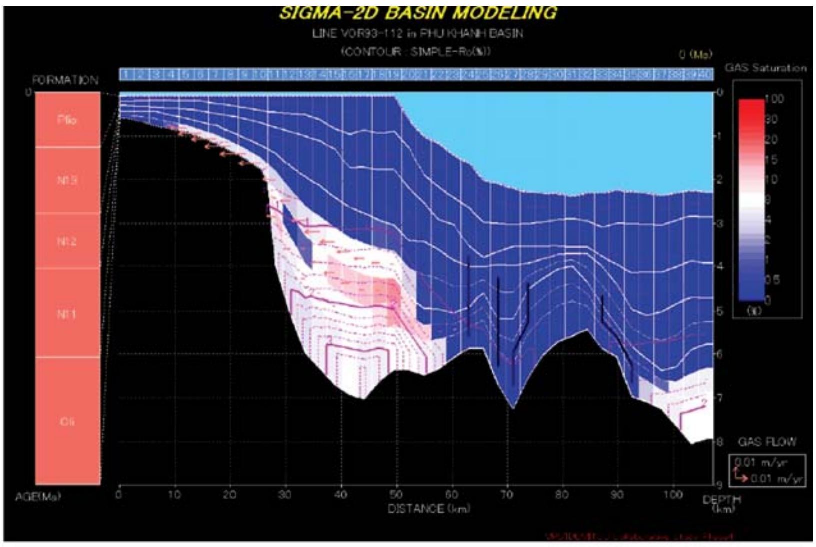

Fig.12c. *Simulated result for line VOR 93-112 Color: Gas saturation, Contour: Vitrinite reflectance, Arrow: Gas flow*

has not yet started. Oil and gas charge to the well 124-CMT-1X was not simulated on this section due to the late generation in source rocks on this section (Fig.11b). This suggested that the oil and gas charge to this structure did not occur from the East, but from the Northeast or the Southeast, which will be evaluated by the simulation on other sections.

A different oil and gas generation and migration history was simulated further to the south on the Line VOR 93-112. On this section, a thick and deep basin, whose thickness reaches about 7,000m, developed in shallow water, (Fig.12a). This basin extends to deep water with a local high in the middle. The thickness of the sediments in deep water is still 6,000m. This suggests that the main basin extends from Northeast to Southwest, and develops in shallow water on this section. Simulated results for this section demonstrate that the Oligocene lacustrine source rock is in the gas window and the Lower Miocene fluvio-deltaic source rock is in the oil window [4] in the main basin at the present time (Fig.12b, 12c). The Oligocene source rock had generated oil since Middle Miocene times (Fig.12d).

Generated oil migrated horizontally along the interbedded sandstone, and then leaked vertically to Lower Miocene by making its column in a local high where more sandstone and carbonate rocks develop as a regional carrier system below the Middle Miocene shaly section. This oil, together with the oil generated in the Lower Miocene source rock since the Late Miocene time, migrated horizontally along this regional carrier system to reach close to the coast at the present time (Fig.12b) [9].

The Oligocene source rock has been in the gas window since the Late Miocene and, therefore, any oil in source and carrier rocks were cracked to gas (Fig.12c,

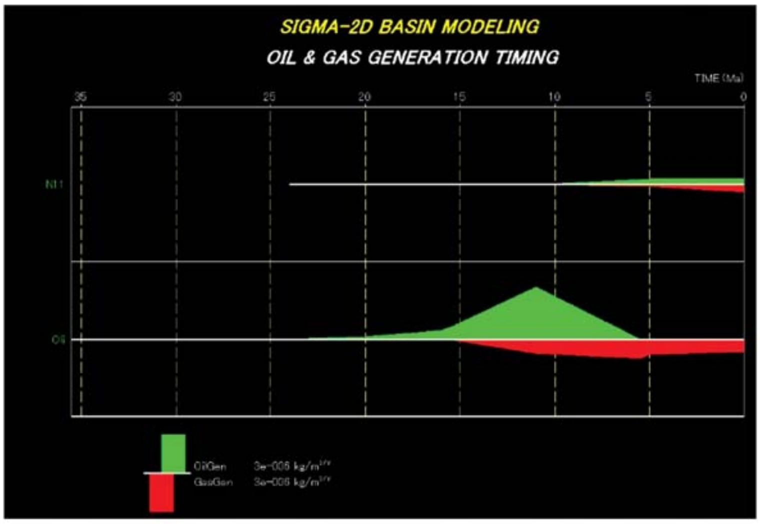

Fig.12d. *Timing of oil and gas generation in deepest part of line VOR 93-112 (Column 17). Upper: Lower Miocene source rock, Lower: Oligocene source rock*

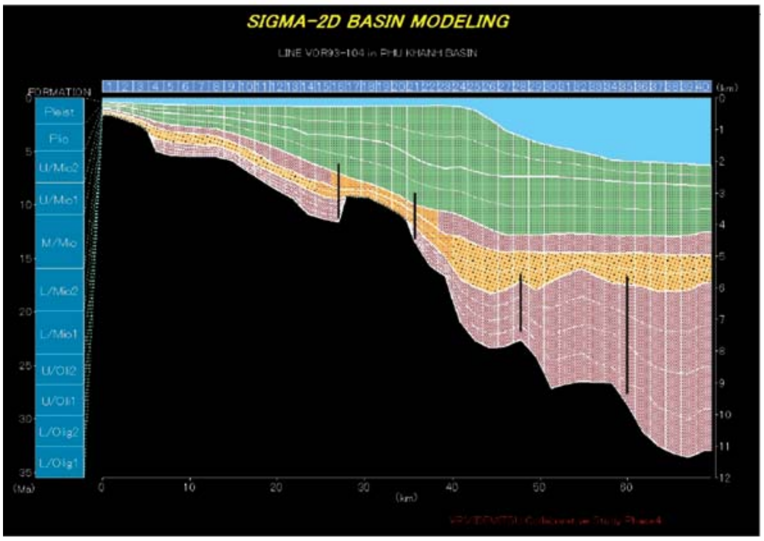

Fig.13a. *Simulated section for line VOR 93-104*

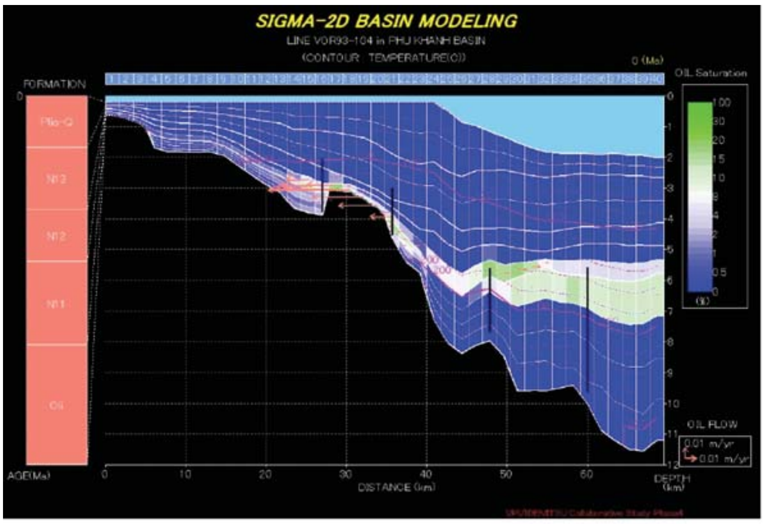

Fig.13b. *Simulated result for line VOR 93-104 Color: Oil saturation, Contour: Temperature, Arrow: Oil flow*

12d). This gas has migrated in the same way as oil and is also about to reach the coast at the present time.

4.1. Line VOR 93-104

Further to the North from Line VOR 93-106, oil and gas generation and migration history is a little different from that of Lines VOR 93-106 and 112. On this northern section the thickest part of the basin reaches 9,000m of sediments in the deep water area (Fig.13a). Around the shelf break of the section, a carbonate build-up trend developed in the Miocene section extending to Line VOR 93-106, where light oil was discovered in the well 124-CMT-1X.

The Oligocene lacustrine source rock is in the gas window and the Lower Miocene fluvio-deltaic source rock is in the oil window in the deepest part of the section at the present time (Fig.13b, 13c), which is a similar setting to the deepest part of the Line VOR 93-112. However the timing of generation is delayed on this section (Fig.14).

The main oil generation in the Oligocene source rock has occurred since Late Miocene times in the deepest part of this section (Fig.13d). In addition, oil generation in the Lower Miocene source rock and gas generation in the Oligocene source rock one has started since the Pliocene time. These timings are later than the deepest part of Line VOR 93-112 (Fig.12d).

The oil and gas migration style however is similar to that of Line VOR 93-112. At first, generated oil and gas in the Oligocene migrated horizontally along interbedded sandstone and reached local highs. Then, they leaked vertically to a Lower Miocene carrier system by forming their columns. Finally, this oil and gas, together with the oil generated in Lower Miocene source rock, migrated horizontally along sandstone to reach the carbonate build-up trend in the middle of the section (Fig.13b, 13c) [9]. In multi-dimensional direction, this oil and gas should also migrate towards the South to charge Block 124.

4.2. Line PV 08-03

This line is located at the boundary between the Song Hong and the Phu Khanh Basins so that sediment is still thin, especially for the deep water area (Fig.14). The Oligocene source rock is buried by more than 3,000m only in the shallow water area, where a narrow trough develops and some amount of oils were generated (Fig.14). The generated oil migrated along the Oligocene formation toward a high trend, where the well 121-CM-1X was drilled. Oil accumulation should be discovered if porous rock develops in this deep formation.

4.3. Line CSL 07-10

This regional line extends from the Northwest to the Southeast of the entire Phu Khanh Basin covering Blocks, 124, 149 and 150 from shallow to deep water. Since this line is distributed perpendicular to the structural trend, the geometry of the basin is clearly demonstrated (Fig.15a). The main part of the basin has a width of 150km, where more than 10km thickness of sediments can be seen from the seismic data. In addition, other mini-basins can be seen further offshore in the deep water area. However, the sediment thickness in these basins is mostly less than 3,000m since they are far from the onshore area and the sediment supply is t insufficient for a thicker accumulation.

Simulated result predicted that the Oligocene lacustrine source rock in main basin is in gas window at the present time. Deepest part reaches the temperature more than 300°C and the vitrinite reflectance more than 4%. The Lower Miocene fluvio-deltaic source rock is also in gas window except marginal part of the basin (Fig.15b, 15c) [4].

Oil and gas generations in the Oligocene source rock mainly occurred in Early Miocene time in deepest part of main basin, which had followed by oil and gas generations in the Lower Miocene one since Middle Miocene time (Fig.15d). The generations in dual source rocks have succeeded toward Basin margin until the present time. These timings are earlier than the Lines VOR 93-104 and 112, since this line is crossing deepest part of main basin.

Generated oil and gas migrated horizontally along the sandstones in the Oligocene and Lower

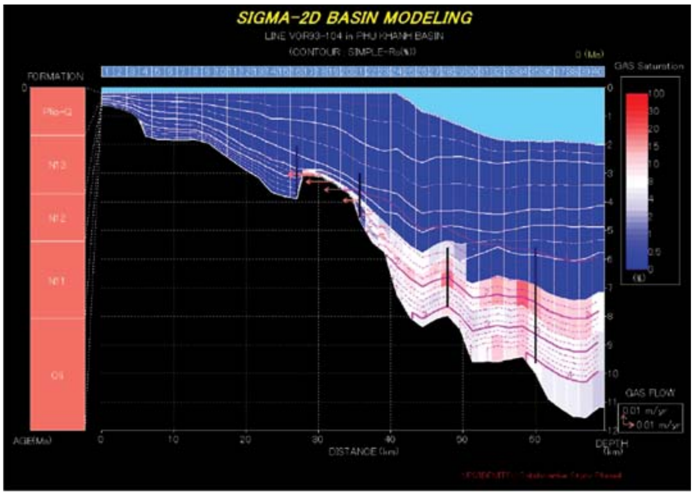

Fig.13c. *Simulated Result for Line VOR 93-104 Color: Oil Saturation, Contour: Vitrinite Reflectance, Arrow: Oil Flow*

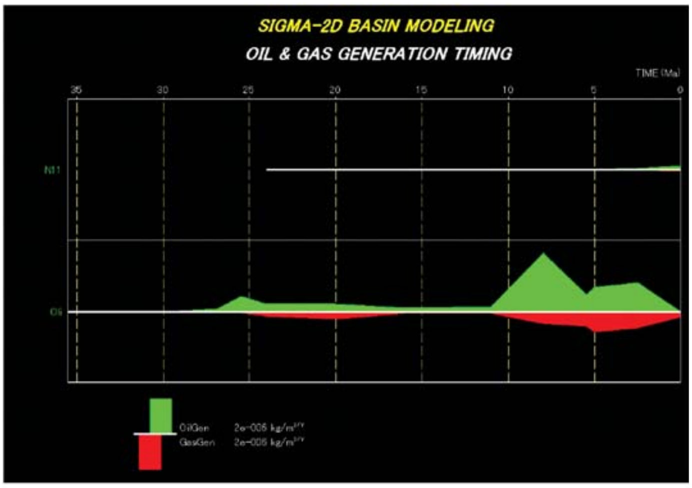

Fig.13d. *Timing of Oil and Gas Generation in Deepest Part of Line VOR 93-104 (Column 38). Upper: Lower Miocene Source Rock, Lower: Oligocene Source Rock*

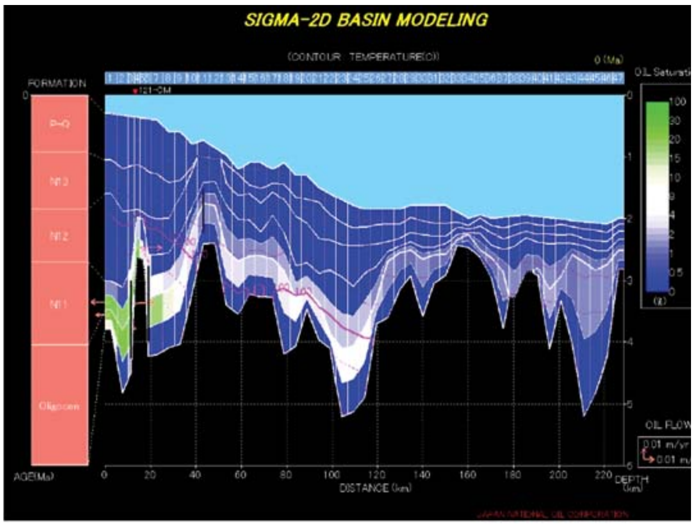

Fig.14. *Simulated result for line PV 08-03 Color: Oil saturation, Contour: Temperature, Arrow: Oil flow*

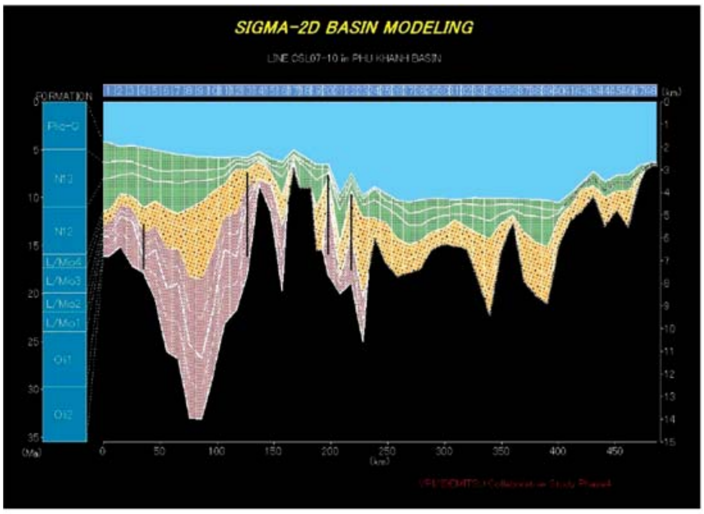

Fig.15a. *Simulated Section for Line CSL 07-10*

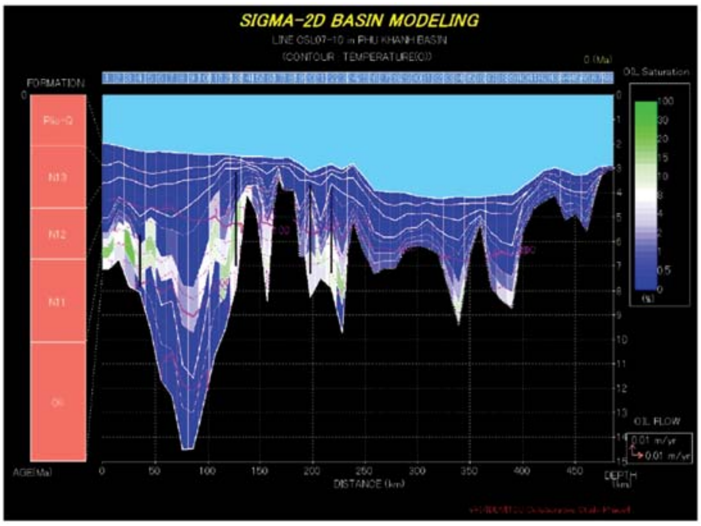

Fig.15b. *Simulated result for line CSL 07-10 Color: Oil saturation, Contour: Temperature, Arrow: Oil flow*

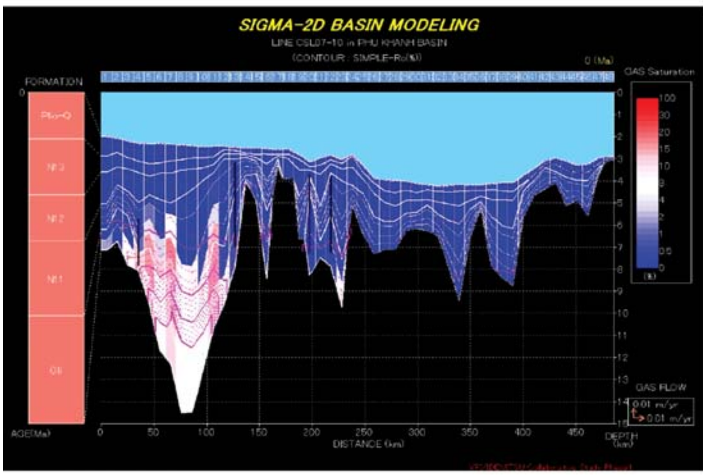

Fig.15c. *Simulated result for line CSL 07-10 Color: Gas saturation, Contour: Vitrinite reflectance, Arrow: Gas flow*

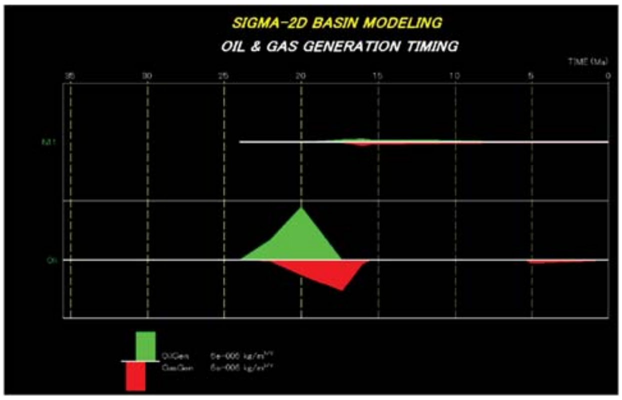

Fig.15d. *Timing of oil and gas generation in deepest part of line CSL 07-10 (Column 9). Upper: Lower Miocene source rock, Lower: Oligocene source rock*

Miocene formations, vertically migrated through faults and by making local columns and reached the traps in these horizons, as similar way to the Lines VOR 93-104 and 112, which was discussed in detail as above (Fig. 15b, 15c). Additional leakage to Middle Miocene from Lower Miocene structures was also simulated, which may result in oil and gas accumulations in turbidite fans developed in deep marine environment.

In offshore mini-basins, only deepest part which buried more than 3,000m generated some oils (Fig. 15b, 15c). However, effective migration has not been started, since the generation occurred recent and the amount generated is not enough to increase oil saturation in source rock.

5. Conclusions

The Oligocene lacustrine source rock had generated oil since the Middle Miocene time and is in gas window almost in entire area of the Basin (main part is in deep water area) at the present time. The Lower Miocene fluvio-deltaic source rock had generated oil since the Late Miocene time and is in gas window in central part of the Basin at the present time. Oil and gas generated both in the Oligocene and Lower Miocene source rocks in deep water area migrated along regional carrier system in Lower Miocene (both sandstone and porous carbonate) after vertical migration of the Oligocene oil and gas by cap rock leakage and through faults. These oil and gas made their accumulations in structural highs in deep water and in shallow water areas. Some of them were already found as oil seeps from onshore outcrops and encountered in exploration wells drilled such as 124-CMT-1X. Faults do not play main role for vertical migration, since they started healing before main oil and gas generations since the Middle Miocene time.

More oil and gas accumulations were simulated in Southern sub-basins (Blocks 125 - 127) in most of cases. This is because the Southern sub-basins is larger, deeper and closer to shallow water area, where exploration wells can be more easily drilled. This kind of settings enables to generate more oil and gas in earlier timing of basin history, which results in more migration period for oil and gas. Oil and gas can migrate further, if more migration period is allowed. However, these results solely depends on the assumptions for the multi-dimensional basin modeling such as source rock properties, heat flow history, lithology distribution, etc. Therefore, future tuning of these input data after the drilling of new well is necessary to acquire more accurate view for petroleum system in the Phu Khanh Basin.

References

1. J.A.Bojesen-Koefoed, L.H.Nielsen, H.P.Nytoft, H.I.Petersen, Nguyen Thi Dau, Le Van Hien, Nguyen Anh Duc and Nguyen Huy Quy. *Geochemical characteristics of oil seepages from Dam Thi Nai, Central Vietnam: Implications for hydrocarbon exploration in the offshore Phu Khanh Basin*. Jour of Pet Geol. 2005; 28: p. 3 - 18.

2. Science and Technics Publishing House. 2007

3. K.W.Larson, D.W.Waples, H.Fu and K.Kodama. *Predicting tectonicfractures and fluid flow through fractures in basin modeling*. A.G. Doreet al. edt NPF Special Publication 3, "Basin Modelling: Advances and Applications". 1993: p. 373 - 383.

4. A.Okui. *Characterization of non-marine "Dual Petroleum Systems" in Southeast Asia*. Jour. Japanese Association Petroleum Technology. 2005; 70: p. 91 - 100.

5. A.Okui, M.Hara and H.Matsubayashi. *The analysis of secondarymigration by two-dimensional basin model "SIGMA-2D"*. AAPGAnnual Convention Abstracts. 1994; 227.

6. A.Okui, M.Hara and H.Matsubayashi. *Three-dimensional assessmentof oil migration in a Japanese basin by two-dimensional Basin model "SIGMA-2D".* AAPG Annual Convention Abstracts, 72A. 1995.

7. A.Okui, M.Hara, H.Fu and Takayama, K. *SIGMA-2D: A Simulator forthe integration of generation, migration, and accumulation of oil and gas*. Proceedings of 8th International symposium on the observation of the continental crust through drilling. 1996: p. 365 - 368.

8. A.Okui, S.Hirahara, K.Matsubara and O.Kitamura. *Re-evaluation of Oil and Gas Migration in the Northern Sea area by 3D basin Modeling*, AAPG Annual Convention (Houston). 2002.

9. A.Okui, R.M.Siebert and H.Matsubayashi. *Simulation of oil expulsionby 1D and 2D Basin modeling - Saturation threshold and relativepermeability of source rocks.* J. Iliffe and S. Dueppenbecker edt, The geological society special publication No.141, "Basin Modeling: Practiceand Progress". 1998: p. 45 - 72.

10. A.Okui, K.Tsuji and A.Imayoshi. *Petroleum system in the Khmer trough, Cambodia*. Proceedings of the Petroleum Systems of SE Asia and Australasia Conference. May 1997: p. 365 - 379.

11. A.Okui, Y.Yokoyama and T.Fujii. *Effect of molecular-sieving onunsaturated oleanens in fluvio-deltaic sequence.* Res. Org. Geochem. 2000; 15: p. 7 - 11.

12. A.Okui, Y.Yokoyama and K.Yokoi. *Higher-plant Biomarkers in oils from Southeast Asia.* Res. Org. Geochem. 1998; 13: p. 5 - 12.

13. K.E.Peters, C.C.Walters and J.M. Moldowan. *The Biomarker Guide: Interpreting molecular fossils in petroleum and ancient sediments*. Cambridge Univ. Press. 2005; 490.

14. K.E.Peters, C.C.Walters and J.M. Moldowan. *The Biomarker Guide: Biomarkers and isotopes in Petroleum systems and earth history*. Cambridge Univ. Press. 2005; 700.

15. Phan Huy Quynh, Nguyen Xuan Vinh, Nguyen Huy Quy, Le Thi Phuong. *Report on geological survey of Dam Thi Nai, Quy Nhon*. VPI library. 1980.

16. E.Saurin. *Notice sur la feulle de Quy Nhon & complements*. Geologueprincipal au Service Geologique de l'Indochine, Service Geographique National du Vietnam, Dalat. 1964.

17. A.Okui. *Geochemical analyses result on oil seep samples*. 2011.