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# Hydrocarbon Resource Evaluation and Favorable Area Screening of Khorat Plateau Basin, Thailand

**Yufeng Xiao[1,2*], Hongyan Wang[2], Yiping Wu[2], Zongan Xue[3]**
[1]China University of Petroleum, Beijing, 102249, China
[2]Research Institute of Petroleum Exploration and Development, Beijing, 100083, China
[3]Oil and Gas Survey Center, China Geological Survey, Beijing, 100083, China
*Corresponding Author.

***Abstract:***

In this paper, with the study focus on the progressive controlling roles of tectonic evolution, sedimentation filling and hydrocarbon accumulation on hydrocarbon play, we have divided the sequence interfaces and identified the hydrocarbon plays in Khorat Plateau Basin. With subjective probability method, we have calculated the undiscovered reserves, and predicated the favorable exploration areas. The study results show that Sunda Block was the earliest shaped tectonically in the area of Southeast Asia, and was spliced by sub-continental blocks including Indo-China, Mid Myanmar and West Myanmar. In terms of tectonic location, Khorat Plateau Basin is located in Indo-China sub-continental block, which is affiliated to Sunda continental Block, being a large-scale intracontinental craton basin (Fig.1). Since the Late Devonian, the basin has experienced two tectonic stages, including the drifting of Paleo-Tethys Ocean during Neopaleozoic and splicing of Sunda Block during Mesozoic. Controlled by the regional tectonic deposition, the sedimentary sequence of the basin can be divided into two mega-sequences of TS1 and TS2 (Fig. 2), of which TS1 is marine sedimentary sequence, filled with the deposits of the shallow marine shoreland, the continental shelve and carbonate tableland. In TS1 sequence, the major reservoir is the Permian Pha Nok Khao Formation, and the regional Seals are Permian Pha Nok Khao Formation mudstone and Permian Upper Clastic Formation. The major source rocks are Permian Saraburi Group mudstones, which had entered into gas generation stage during the Middle to Late Cretaceous. The TS2 sequence is Mesozoic continental deposits, filled with continental alluvial fan, river and lacustrine deposits, in which the Triassic secondary reservoir of fluvio-lacustrine sandstones are well developed, the regional seal of Maha Sarakham Formation and the internal seal of Huai Hinlat Formation are also developed. According to the definition of hydrocarbon play, two Class I hydrocarbon plays (the proved Permian play and prospective Triassic play) and four Class II hydrocarbon plays have been identified. The distribution range of hydrocarbon plays has been determined with multi-

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factor superposition method. In Permian, the undiscovered reserves in Class I hydrocarbon play are 124 million barrels, and the undiscovered natural gas reserves are 2 trillion cubic feet, which are mainly distributed in the middle of Phu Phan Uplift and its peripheries. In Triassic, the undiscovered reserves in Class I hydrocarbon play are 444 million barrels, and the undiscovered natural gas reserves are 91 trillion cubic feet, which are mainly distributed in the north of Khorat Subbasin and the west of Sakhon-Nakhon Subbasin.

***Keywords****: Hydrocarbon Play, Sedimentary sequence, Multi-factor superposition, Subjective probability method, Favorable area.*

## I. INTRODUCTION

The concept of hydrocarbon play emerged in response to the requirements for fast discovery of large-scale reserves in areas with low exploration degree. Based on the systematic analysis about 2000 oil & gas fields in oil and gas bearing basins in the world, White D A proposed the concept of "hydrocarbon play" for the first time, and defined it as the exploration object which is relevant geologically, with similar source rock, reservoir and trapping conditions [1]. Some foreign scholars have adopted this concept, and further developed this concept in later researches [2-6]. Some Chinese scholars have adopted this concept into their scientific researches and gave their own definition for hydrocarbon play [7-16]. This paper uses the definition of hydrocarbon play from Tong Xiaoguang, i.e. hydrocarbon play is a group of prospective traps or oil & gas reservoirs under similar geological background, which have experienced similar development and evolution history, especially in hydrocarbon charging, reservoir development, and trap structures, assemblages of hydrocarbon gention, migration and accumulation [17]. The keys to the play are reservoirs and seals, which can be divided into proven play and prospective play. Among them, the proven play includes single or multiple pools with a certain amount of oil and gas reserves, as well prospective play has no commercial discovery yet. A through study has been conducted on the hydrocarbon plays of Khorat Plateau Basin, with focus on the progressive control roles of structure-sedimentary evolution and hydrocarbon accumulation. This study is significant to evaluation of oil and gas reservoirs in the area of Southeast Asia.

## II. STRUCTURAL CHARACTERISTIC

Khorat Plateau Basin is a large-scale intracontinental craton basin. Geographically, this basin is across Khorat Plateau in the northeast of Thailand, Laos and Cambodia, with an area of $22.5 \times 104$ km$^2$. In terms of tectonic location, the basin is in the Sunda Block, which is the largest and most significant structural unit in the area of Southeast Asia, and is the earliest shaped tectonically in the area of Southeast Asia, mainly spliced by sub-continental blocks

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including Indo-China, Mid Myanmar and West Myanmar. Khorat Plateau Basin is mainly located in Indo-China sub-continental block in Sunda Block (Fig. 1). The basin has a long-term relatively stable geological background, developed multiple sets of source rock, reservoir and seal assemblages and various types of traps. Activated or alternately active faults are beneficial to hydrocarbon migration and redistribution. The oil and gas are mainly enriched in the paleo-tectonic belt of the craton basin. The western boundary of the basin is Loei-Phetchabun Fold Belt, and eastern boundary is Annamitic Fold Belt. The basin is roughly divided into 5 secondary structural units, i.e. Loei-Phetchabun Fold Belt, Khorat Subbasin, Phu Phan Uplift, Sakhon-Nakhon Subbasin and Savannakhet Subbasin [18].

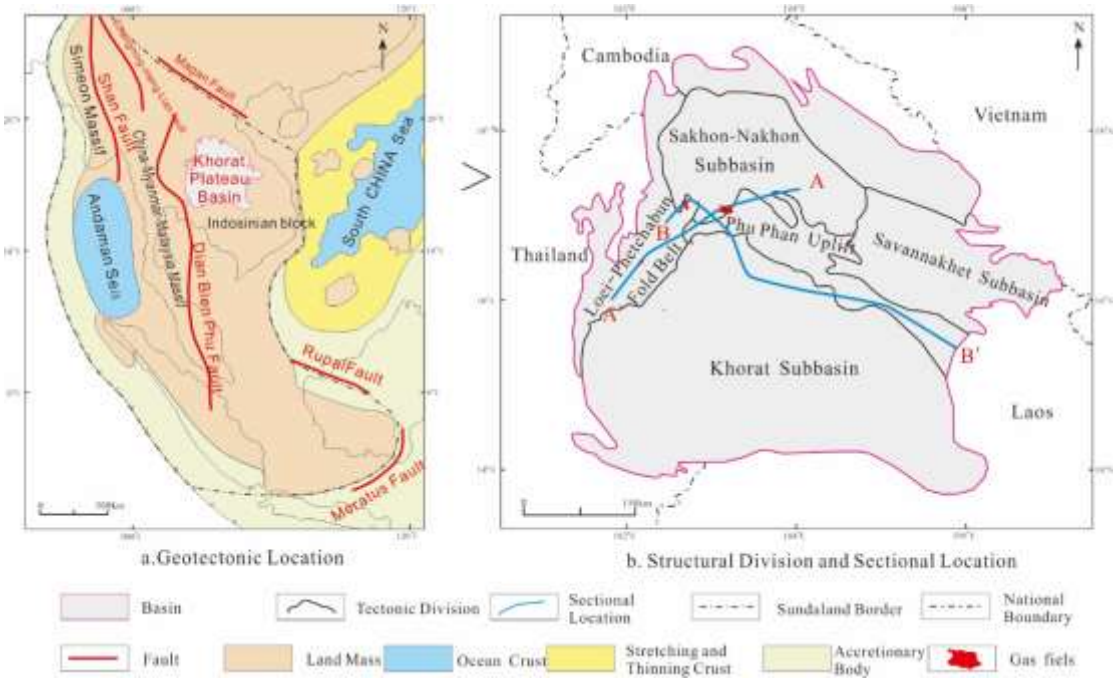


Fig.1: tectonic location map of Khorat Plateau Basin (Madon M B H et al. 1999, modified)

Since Late Devonian, the Khorat Plateau Basin has experienced two tectonic stages, including the drifting stage as an independent plate on Paleo-Tethys Ocean along with Mid Myanmar Plate and West Myanmar Plate during Neopaleozoic and the splicing of Sunda Block in Mesozoic.

During the Paleozoic , the Indo-China Block drifted in Paleo-Tethys Ocean, being submerged under water, and was separated from South China Block by the ocean (Fig. 2a). During Mesozoic, Indo-China Block drifted northward, and was pieced together with South China Block and Mid Myanmar Block, being the most significant event for the forming of Sunda Block. Since the Early Triassic, the Indo-China Block, South China Block and Mid

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Myanmar Block drifted in the ancient Tethys Ocean began to drift northward. Due to the Indo-China movement I during the early Triassic, all these blocks were pieced together, forming a stable area, namely Sunda Block on the southeast edge of Eurasia, and the Holayayu Plateau craton basin is formed. The Indo-China movement II during the early Triassic resulted in close of Paleo-Tethys Ocean and further expanding of Neotethyan Ocean (Fig. 2b) [19], the sedimentary environment of the Khorat Plateau Basin changed from Marine to continental.

According to the major tectonic events and development characteristics of strata in the basin, Khorat Plateau Basin can be divided into 2 tectonic megasequence: TS1 from Late Devonian-Late Permian and TS2 in Middle Triassic- Late Cretaceous (Fig. 3).

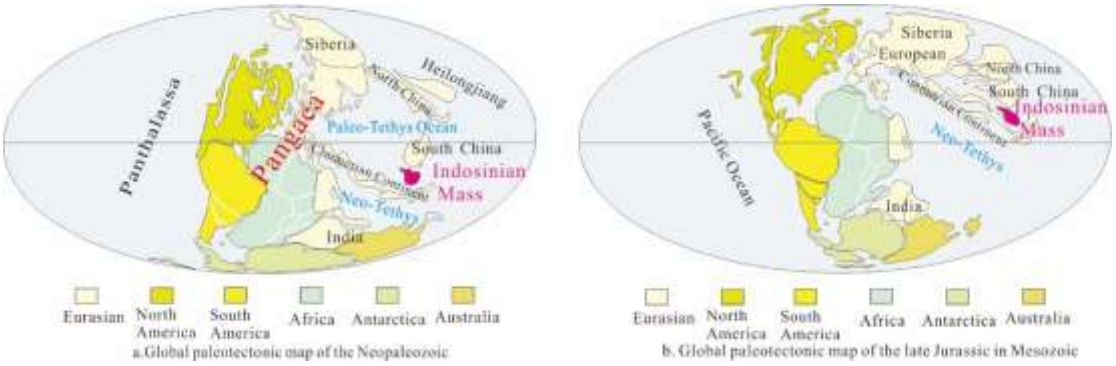


Fig.2: history of tectonic evolution of Indo-China plate from Neopaleozoic to Mesozoic (Zhu Weilin, et al. 2012)

## III. SEDIMENTARY EVOLUTION CHARACTERISTICS

From the Northeast-southwest section of Khorat Plateau Basin (Fig. 4), it can be seen that the Palaeozoic TS1 Sequence is marine deposits. During the marine regression stage (the depositional stage of Lower Clastic interval), shoreland- shallow sea environment was dominated in the basin, with the gravel shoreland conglomte and offshore continental shelf mudstones developed. During the transgression stage (the depositional stage of Pha Nok Khao-Upper Clastic), the sea level rose, and the shallow sea environment was dominated in the basin, with restricted- evaporative platform dolomite developed. The Mesozoic TS2 Sequence is continental deposits. During the lacustrine regression period (i.e. the depositional stage of Huai Hin Lat Formation), the river- lacustrine environment was dominated, with alluvial fan, shore lacustrine and shallow lacustrine deposited from east to west. During the lacustrine transgression stage (i.e. the depositional stage of Nam Phong Formation), the lacustrine level changed alternatively, and flood plain mudstone was widely developed in the basin.

From East-West section (Fig. 5), it can be seen that the marine deposits are dominated in

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Palaeozoic TS1 Sequence. During the marine regression stage, shoreland environment was dominated, with gravel shoreland and offshore continental shelf deposits developed, associated with eruptive andesite. During the transgression stage (i.e. the depositional stage of Pha Nok Khao Formation to Upper Clastic Member), the majority of the basin was covered by shallow warm sea water, and restricted platform limestone was widely deposited. Volcanic breccia was developed around Well Pakse1 on the east edge of the basin. Continental deposits are dominated in Mesozoic TS2, where lacustrine transgression and regression alternated frequently, with flood plain, distributary channel and delta front widely deposited, providing high-quality sandstone reservoirs including Huai Hin Lat Formation and lower Nam Phong Formation.

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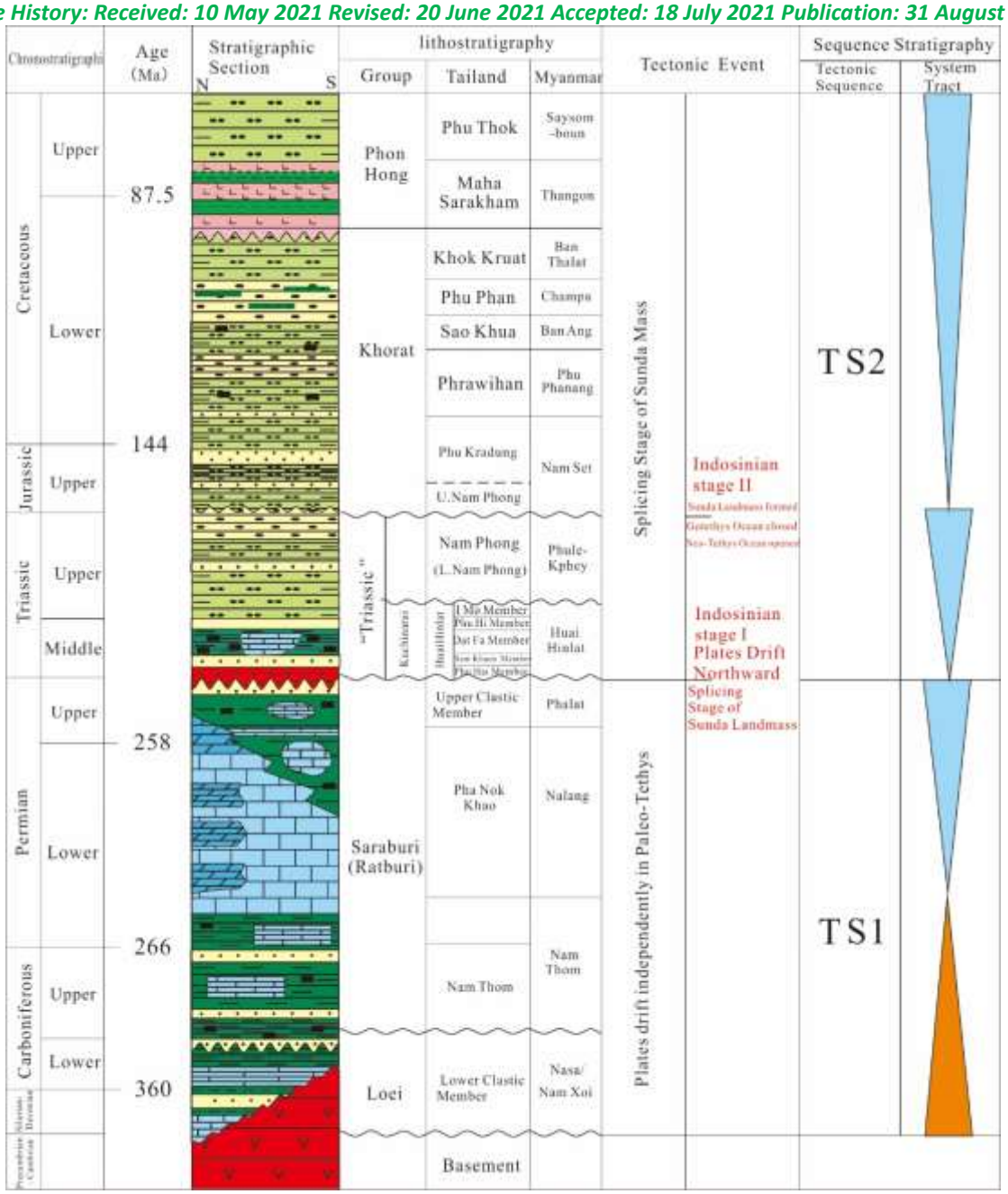


Fig.3: tectonic sequence division map of Khorat Plateau Basin

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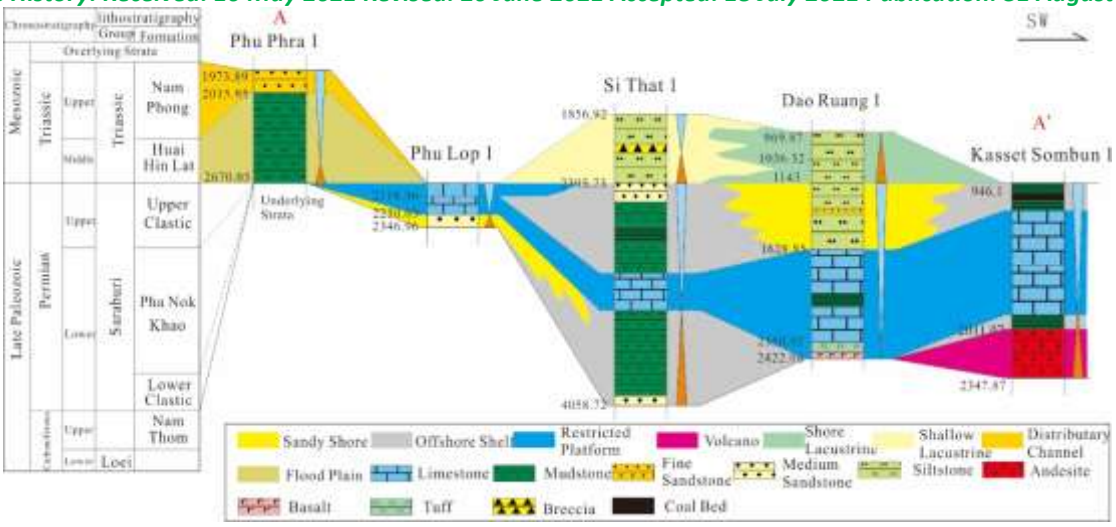


Fig.4: NE-SW well correlation of tectonic sequence and sedimentary facies in the basin

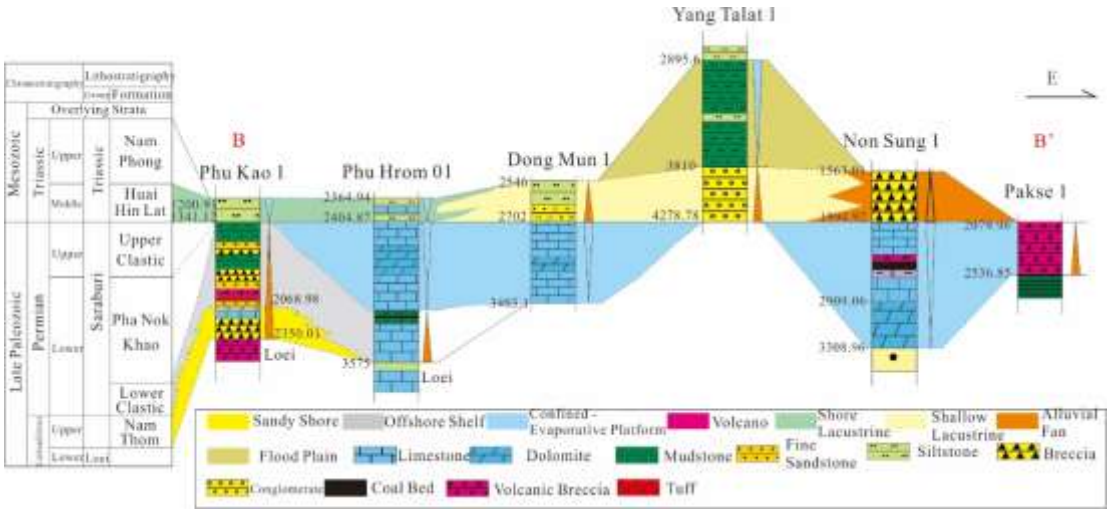


Fig5: W-E well correlation of tectonic sequence and sedimentary facies between Well Phu Kao1 and Well Pakse1 in the basin

The paleogeographic map has been made for Khorat Plateau Basin according to the facies section result and regional data, as showed in Fig. 6. In horizontal direction, controlled by tectonic evolution, the sedimentary evolution of Khorat Plateau Basin can be divided into two periods. Different sedimentary systems have been developed during different periods.

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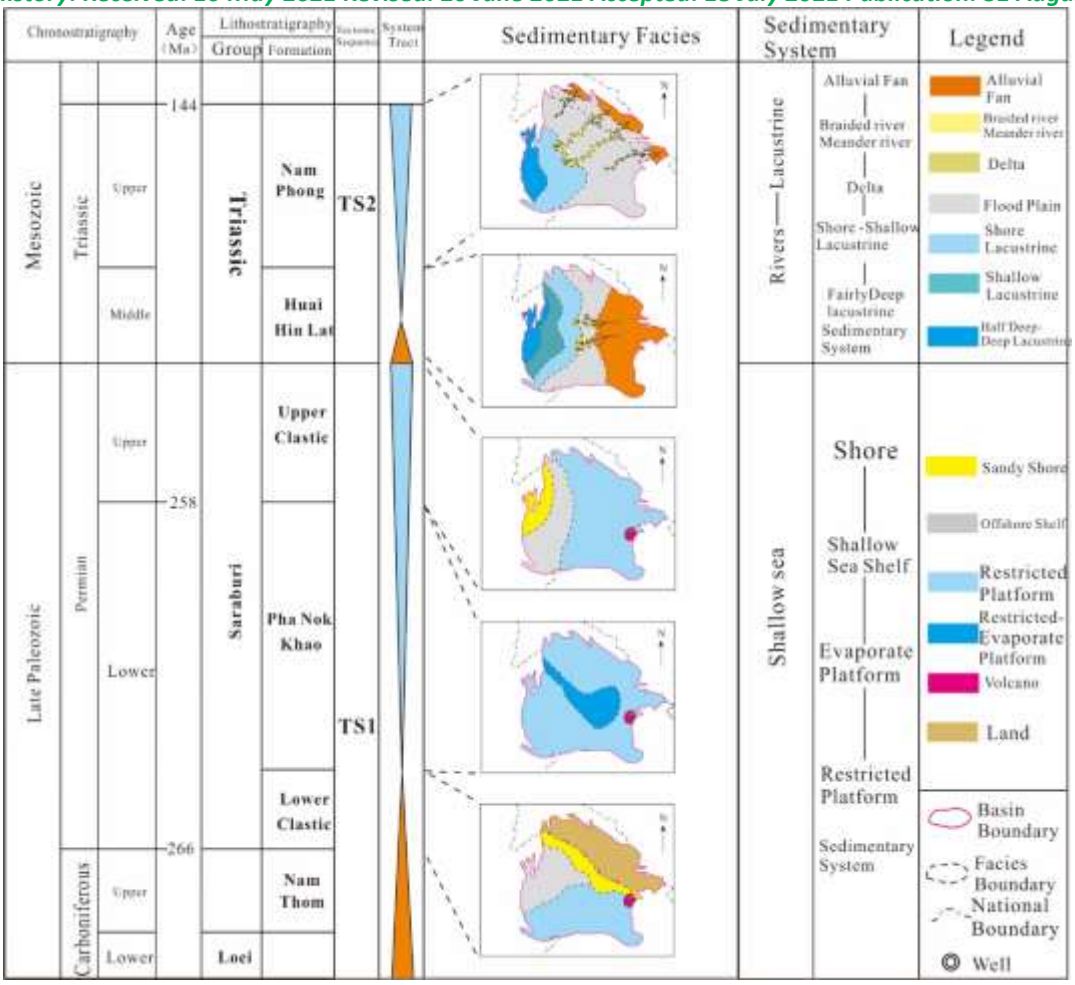


Fig.6: sedimentary evolution map of Neopaleozoic to Mesozoic in the basin

The first stage is the Paleozoic progression-regression sedimentary cycle. From the late Devonian in the early Paleozoic to the late Permian, there was a progression period, the relative sea level rose, the coastline pushed toward the land, resulting in the overlapping phenomenon, and the sediments were coarse below and fine above. The center and eastern Sakhon-Nakhon subbasin and Savannakhet subbasin were above sea level. In other parts of the basin, in the Upper Clastic member a set of assemblages in arenaceous shoreland -shallow sea shelf - confined platform developed from northeast to southwest, with shallow-bathyal face mudstone at the top (Figure 6). During Pha Nok Khao Formation, due to the falling of the relative sea level, the coastline pushed towards the sea, the sedimentary range decreased, the sediments were fine below and coarse above, and a set of restricted- evaporative platform dolomite developed in the whole basin. However, due to exposed erosion during two periods of Indo-China movement and inversion during the period of Cretaceous, the distribution range of the strata deposited during this period continued to shrink, with Phu Phan Uplift and Loei-

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Phetchabun Fold Belt dominated. During Upper Clastic member, the relative sea level further fell, and the shallow sea facies gradually transferred to the land-sea interchange, and a set of restricted- evaporative platform and sandy shore developed from west to east, which was still dominated by the shallow sea facies.

The second stage is the Mesozoic lacustrine progression-regression sedimentary cycle. During the Huai Hin Lat Formation of the Middle Triassic, the lake level rose, and a set of sedimentary facies assemblage developed from west to east, including semi-deep lakeshore shallow lake-delta-braided river-alluvial fan clastic rock depositional system (Fig. 6). From the bottom up, the granularity changes from fine to coarse. In the west, the lacustral carbonaceous shale of progressive system was taken as the end sign, and is the favorable source rock of Huai Hin Lat formation play. Lithology in the Well Dong Mun 1 of the center basin is mainly shore and shallow lake siltstone, as well in the Well Yang Talat1 of the center mainly delta front conglomerate or coarse sandstone, and in the well Non Sung1 of the eastern transitioned to the alluvial fan breccia with poor sorting. In Nam Phong Formation of the Late Triassic, the lake level decreased and the sedimentary range narrowed. The sedimentary system of shore shallow lake, delta and meandering river detritus developed from southwest to northeast in the basin. The granularity changed from fine to coarse, and Lithology became mudstone and siltstone in the southwest. In the Well Non Sung1 of the East, the formation is missing.

## IV. HYDROCARBON ACCUMULATION CHARACTERISTICS

### 4.1 Source Rock

The main indicators of hydrocarbon generation include organic matter type, vitrinite reflectance (Ro) and total organic content (TOC). The higher Ro is, the higher maturity is, in which the oil generation range is 0.5-1.3% and the gas generation range is greater than 1.3%. TOC is the proportion of organic matter in the mass of sedimentary rock, reflecting the abundance of the source material. The higher the abundance, the greater the hydrocarbon generation potential. The paleogeographic maps of lithofacies shows that the main source rock are river- lacustrine facies mudstone in Huai Hin Lat Formation of the Middle Triassic and shallow sea mudstone in Upper and Lower Clastic Member, Saraburi group, Permian system (Fig. 7).

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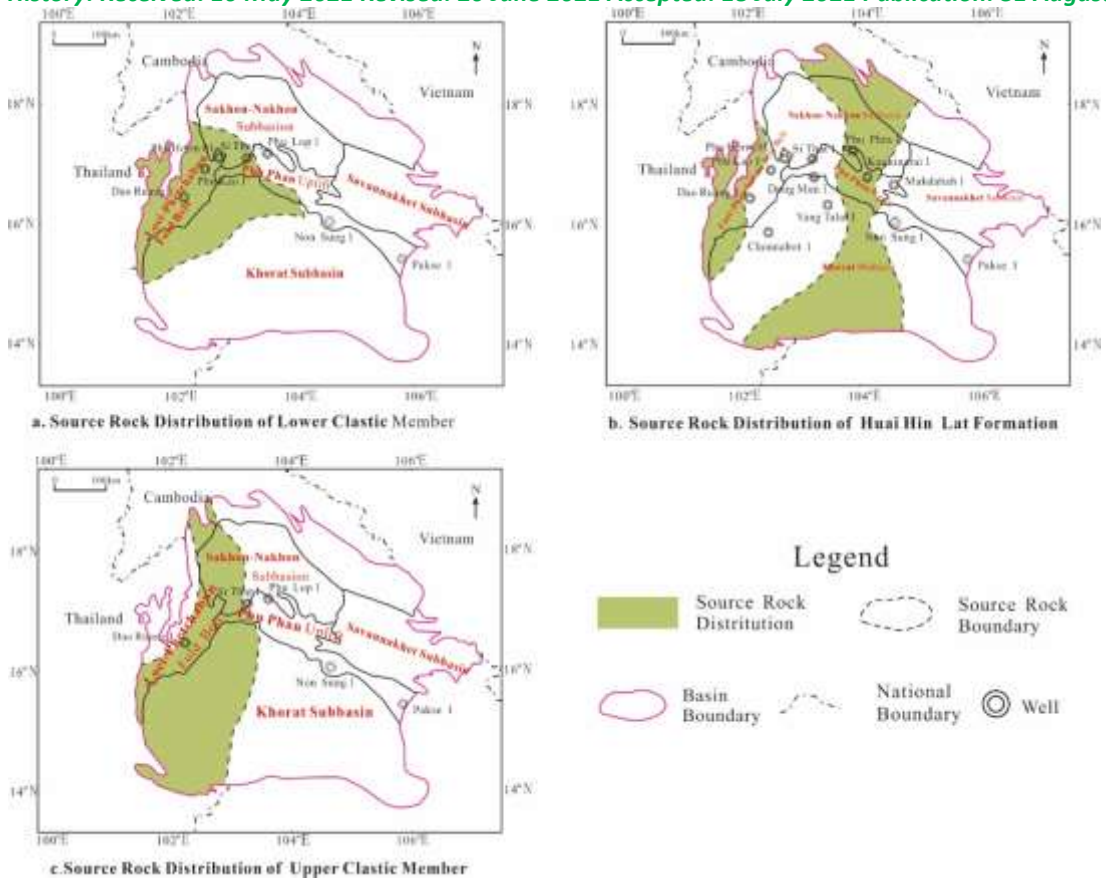


Fig.7: distribution map of the major source rocks in the basin

Dat Fa carbonaceous shale Member in Huai Hin Lat Formation is the most significant source rock in the basin and widely distributed in the west and middle of the basin (Fig. 7). The abundance of organic matter is middle to excellent, and the Total Organic Carbon Content (TOC) ranges from 1.8% to 6.6%. Type I-II kerogen is dominated. Vitrinite reflectance (Ro) ranges from 1.2% to 4.9%, indicating that the source rock is at high-mature to over-mature stage, which is mainly distributed in the west of the basin, and the current hydrocarbon discoveries in the basin are mainly natural gas.

The Permian Saraburi source rock is deposits of shallow sea, and distributed at a limited range due to the influence of denudation during Indo-China I cycle, mainly in the west of the basin. The Permian source rock is mainly Upper Clastic source rock, its Vitrinite reflectance (Ro) ranges from 1.2 to 4.5%, in the high-mature to over-mature gas generation stage. Ro is higher in the central and western parts of the basin, as well is less than 0.5% in the eastern uplift area. The kerogen type belongs to II-III. Organic matter abundance is medium to good, and TOC ranges from 1.5% to 3.6%, up to 7.3%.

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4.2 Reservoirs

The Permian carbonate rock of Pha Nok Khao Fm in Saraburi Group is the most significant and the only proved reservoir in the basin. The Triassic river- lacustrine facies sandstones of Phu Hi Member in Huai Hin Lat Formation and the lower member of Nam Phong Formation are secondary reservoirs.

The Permian Pha Nok Khao Fm reservoir is distributed in most of the basin (Fig. 8a). The dominated lithology includes shallow sea dolomitized algal limestone, packstone, bioaccumulated limestone and reef limestone, with a thickness over 1250m in the south-central part of the basin. In the northern and central uplifts of the basin, the thickness is relatively thin, generally 200 m. Pha Nok Khao Fm reservoir is a typical low porosity low permeability reservoir, with porosity around 2%, permeability ranging from 0.009 to 1000md, and median permeability of 0.1md. The reservoir quality has been improved significantly in the areas with dolomitization and fracture development, where Class I reservoir is developed, with porosity up to 12-19%. The improved reservoir is distributed in a banded shape in Sakhon-Nakhon Subbasin, Phu Phan Uplift and Khorat Subbasin in northwest-southeast direction.

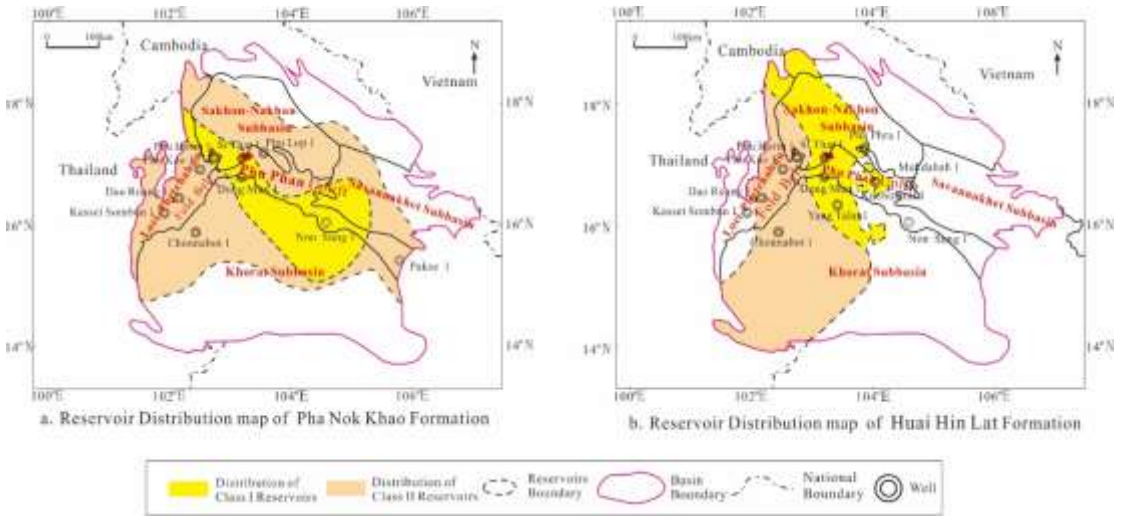


Fig.8: the distribution of the key reservoir rocks in Khorat Plateau Basin

The Triassic secondary reservoirs include river-lacustrine facies sandstones in Huai Hin Lat Formation and lower Member of Nam Phong Formation. Huai Hin Lat Formation is mainly distributed in Phu Hi Member, which is located below Dat Fa source rock in the same formation. Meandering river, delta, shore shallow lake sandstone developed from east to west in the middle west of the basin. Commercial gas flow has been acquired from Well Nam Phong1, Chonnabot1 and Phu Horm1 in meandering river sandstone reservoirs, with the richest

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prospects for gas production. Class I reservoirs in the formation are mainly composed of delta front sand body, meandering river point bar and core beach, with porosity of 12-17% and maximum thickness of 600m, and distributed mainly in Sakhon-Nakhon Subbasin and Phu Phan Uplift. Class II reservoirs are mainly composed of shoreline and shallow lake sandstones with porosity of 9-14%, and distributed in Loei-Phetchabun Fold Belt and Khorat Subbasin (Fig. 8b).

The Lower Member of Nam Phong Formation is mainly braided river siltstone, which is distributed at limited range, and mainly developed in the northeast of the basin. The composition of the reservoir is complex and poorly sorted with primary porosity ranging from 0 to 4.5%, average porosity of 1.5%, secondary porosity ranging from 0 to 11.5%, and average secondary porosity of 3.2%. Although the secondary porosity is well developed, the effective porosity is low due to the poor connectivity.

### 4.3 Seals

The only regional seal in the basin is the Jurassic mudstone of the upper Member of Nam Phong Fm in Khorat Group, above the unconformity caused by Indo-China II cycle movement. The Pha Nok Khao carbonate reservoir is covered and sealed by the widely distributed lacustrine mudstone in the upper Member of Nam Phong. Overpressure condition exists at the bottom of Khorat Group in Jurassic system in LNam Phong Gas Field and well Channabot1, indicating that Nam Phong Formation has provided effective top seal for Phan Nok Khao reservoir. The seals are widely distributed with thick layer. The Yang Talat1 and Non Sung1 Wells in the central and eastern parts witnessed meandery river mudstone and silty mudstone with a thickness of 600m, while the Phu Phra1, Channabot1 and Phu Wiang 1 Wells in the central and western parts drilled mainly shallow lacutrine mudstone with a thickness of more than 900 m. This set of mudstone becomes the favorable seal of structure-unconformity trap in Phan Nok Khao Formation.

In the middle east of the basin, the Triassic mudstone of the Lower Member of Nam Phong Fm in Triassic Group can act as local seal, providing top seal and effective sealing for Huai Hin Lat Fm alluvial fan-fluvial facies reservoir.

### 4.4 Trap Characteristics

There are two types of traps in Khorat Plateau Basin, i.e. structure-stratigraphic-unconformity and structure- unconformity traps.

Pha Nok Khao Formation belongs to shallow sea carbonate deposits, and the reservoirs are

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widely and stably distributed. In the complex structure- stratigraphic - unconformity trap in Pha Nok Khao Formation, the stratigraphic traps are mainly traps due to pinching out associated with basement lifting, and the structural traps are mainly anticlines, which have been encountered during drilling of Wells Yang Talat1, Si That1 and Dong Mun1. The structure-unconformity trap is the major trap type in Pha Nok Khao Formation, Pha Nok Khao Formation in the upliftsof the basin was directly sealed by laculacine mudstone of Nam Phong Formation, which formed effective gas reservoirs in the basin. The only gas field, LNam Phong Gas Field, has been discovered in Pha Nok Khao Formation, with major trap types of fault block- unconformity traps and faulted anticline- unconformity traps.

Huai Hin Lat Formation belongs to continental deposits of alluvial fan- river- delta-lacustrine, and the sandstone reservoirs are unstable, with poor continuity. In Huai Hin Lat stratigraphic-structure- unconformity trap, the stratigraphic traps are mainly traps due to pinching out associated with updipping faults or buried hills, in which no oil and gas has been discovered. Huai Hin Lat Fm structure-unconformity trap has been encountered in Wells Nam Phong1 and Chonnabot 1, and the major trap types are tilted fault block- unconformity traps and reversed fault block- unconformity traps and faulted anticline- unconformity traps.

## V. HYDROCARBON PLAY STUDY

### 5.1 Division of Hydrocarbon Play

In this study, the division of hydrocarbon play is focused on the progressive controlling roles of structure- sedimentary evolution- hydrocarbon accumulation. The division process includes two steps. The first step is to divide Class I hydrocarbon plays. The second step is to divide Class II hydrocarbon plays according to trap types.

The following are the main principles in the division process:

(1) A set of Class I hydrocarbon play includes at most one set of regional seal or unconformity covering the whole basin. Because the hydrocarbon is significantly different above and below the regional seal or unconformity covering the whole basin, it is unreasonable if there are two or more than two sets of regional seal (unconformity at basin scale) in one Class I hydrocarbon play. Therefore, it is necessary to separate them.

(2) One set of Class I hydrocarbon play only has one set of major reservoir, and the reservoir lithology should be consistent. If there is more than one set of main reservoirs, the division of hydrocarbon plays is rough, which has no guiding function for exploration. Reservoir rock is closely related to sedimentary environment and depositional time. The

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reservoir characteristic or resource potential are quite different for reservoirs deposited at different time or different sedimentary environments, and the exploration methods are also quite different.

At present, in Khorat Plateau Basin, the discovered hydrocarbon is mainly distributed in Lower Permian and Middle Triassic. According to division principles, two sets of hydrocarbon plays have been identified, including the proved Permian Class I hydrocarbon play and the prospective Triassic Class I hydrocarbon play. Based on that, four Class II hydrocarbon plays are have been identified, including Triassic structure-unconformity, Triassic stratigraphic-structure- unconformity, Permian structure-unconformity and Permian stratigraphic-structure-unconformity.

5.2 Distribution and Characteristics of Hydrocarbon Play

According to the definition of hydrocarbon play by Tong Xiaoguang [17], one set of hydrocarbon play must be located in the same effective oil and gas bearing range, with effective reservoir and regional seal, and located in two or three structural belts in the basin. The four requirements basically limit the horizontal distribution range of a set of hydrocarbon play [20].

5.2.1 The proved Permian Class I hydrocarbon play

The Permian Class I hydrocarbon play is the only proved hydrocarbon play in the basin, The keys to the play is the Pha Nok Khao Formation reservoir developing in TS1 structural sequence and the regional unconformity widely distributing in the whole basin. The discovered oil reserves of the play account for 57% of the total reserves of the basin, and the natural gas accounts for 85%. Oil and gas are mainly located in lower part of the Permian system.

According to the trap type, the Permian Class I hydrocarbon play can be further divided into two sets of Class II hydrocarbon plays, i.e. Pha NoK Khao structure- unconformity hydrocarbon play and Pha Nok Khao lithology- structure- unconformity hydrocarbon play. Pha Nok Khao structure- unconformity is the primary target for most wells in the basin. The only gas field with commercial gas flow, LNam Phong Gas Field has been discovered in the hydrocarbon play.

As showed in Fig. 9, hydrocarbon accumulation of the Permian Class I hydrocarbon play is chartered by the following:

(1) The hydrocarbon sourced mainly from mudstone in Upper Clastic Fm. and also from

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mudstone in the lower part of the Lower Clastic Fm. Unconformity-fractures are the major migration pathway for hydrocarbon;

(2) The reservoirs are mainly restricted platform limestone and diamictite, mixed with evaporative, restricted limestone and dolomite, with relative good physical properties in the areas with dolomitization and fracture development;

(3) The seal is mainly the regional mudstone seal of the upper Member of Nam Phong Fm, covering the unconformity caused by Indo-China II movement at the end of Triassic. The hydrocarbon play is partly sealed by Upper Clastic mudstone in Upper Permian.

(4) The formation time of traps is the key factor for reservoir formation. At present, the discovered oil and gas are concentrated in the traps in the Lower Permian and Triassic for the whole basin. Trap type for Class II hydrocarbon play in Pha NoK Khao structure- unconformity mainly includes reversed fault traps, tilted fault block, faulted anticlinal traps and folded traps. Trap type for Class II hydrocarbon play in Pha Nok Khao lithology- structure- unconformity mainly includes the carbonate rock updipped pinching out associated with buried hills.

(5) The Permian Class I hydrocarbon play is mainly distributed in Loei-Phetchabun fold, Sakhon-Nakhon Subbasin and Phu Phan Uplift in the west of the basin (Fig. 10a).

5.2.2 The prospective Triassic Class I hydrocarbon play

Triassic Class I hydrocarbon play is prospective. The keys to the play is the Huai Hin Lat Formation reservoir developing in TS2 structural sequence and the regional seal of Nam Phong Formation mudstone in the whole basin. Oil and gas have been discovered at two places in this hydrocarbon play, but with no commercial value. The discovered oil reserves of the play account for43% of the total reserves of the basin, and the natural gas accounts for 15%. Oil and gas are mainly located in the Middle and Upper Triassic system.

The Triassic Class I hydrocarbon play can be divided into two sets of Class II hydrocarbon plays according to trap type, i.e. Huai Hin Lat Fm. structure- unconformity and Huai Hin Lat Fm. stratigraphic-structure- unconformity.

As showed in Fig. 9, hydrocarbon accumulation of the Triassic Class I hydrocarbon play is chartered by the following:

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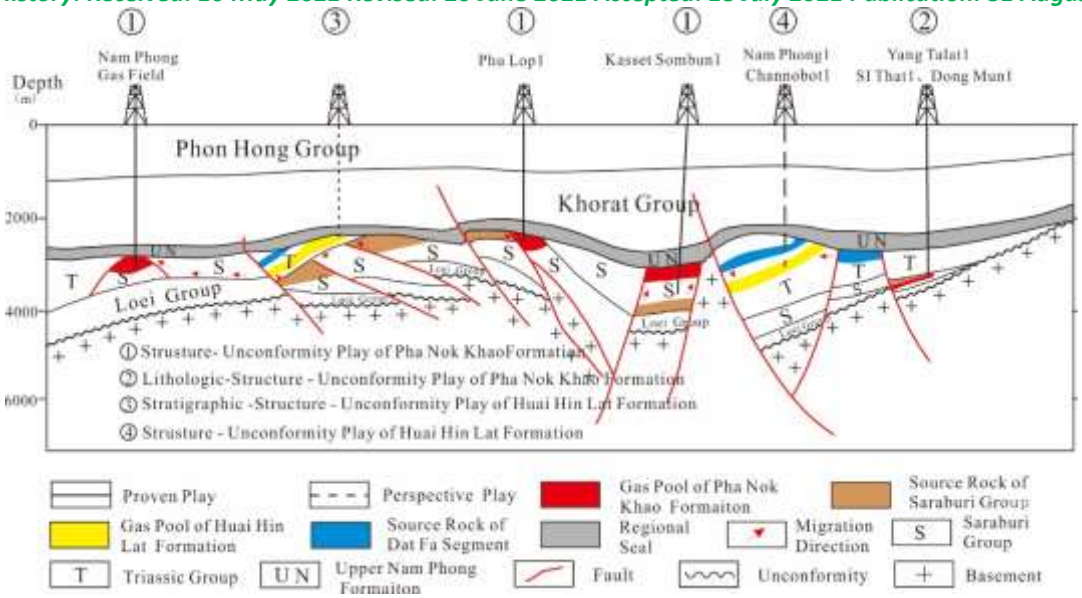


Fig.9: the model of hydrocarbon play in Khorat Plateau Basin

(1) Hydrocarbon mainly comes from Source rock of Dat Fa coal members in Huai Hin Lat Formation, hydrocarbon migrated along faults and unconformities and accumulated in the Huai Hin Lat Formation traps;

(2) Reservoirs are mainly alluvial fan, fluvial and shallow lacustrine sandstone;

(3) Seal is mainly Upper Nam Phong mudstone on the bottom of Khorat group in Jurassic system, with regional distribution. Part of play is sealed and capped by Lower Nam Phong mudstone;

(4) Trap type for Class I hydrocarbon play in Class I hydrocarbon play in Triassic system mainly includes reversed fault Block trap, tilted fault Block trap, faulted anticlinal trap, folded trap and Stratigraphic-structure- unconformity trap formed by the reservoir with horizontal normal- reverse fault, which reopened with respect to compression at the end of Triassic system;

(5) Class I hydrocarbon play in Triassic system is mainly distributed in the west of Phu Phan Uplift, Sakhon-Nakhon Subbasin and Khorat Subbasin in the northeast of the basin (Fig. 10b).

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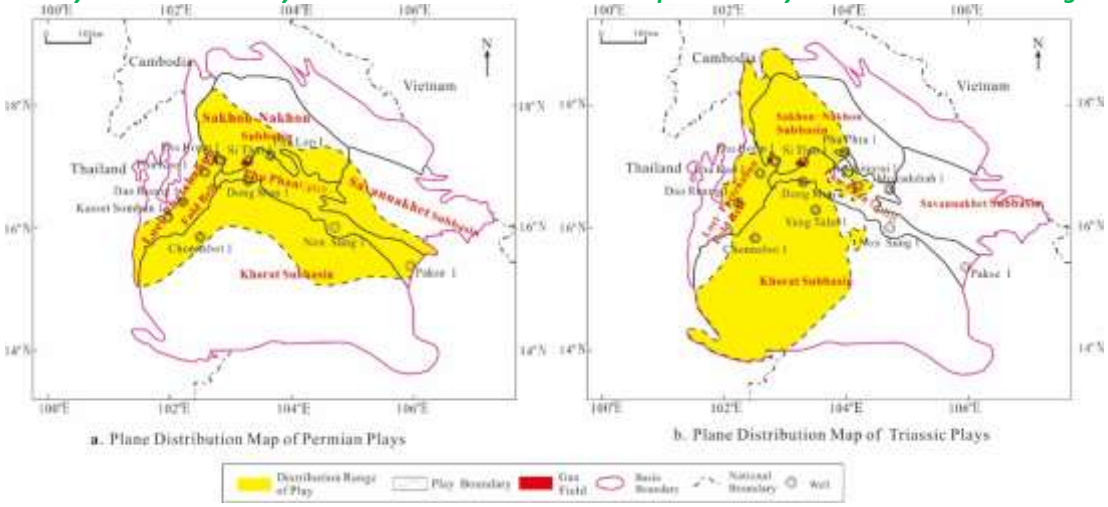


Fig.10: planar distribution of hydrocarbon play in the basin

## VI. ANALYSIS OF HYDROCARBON RESOURCE POTENTIAL

The only gas field with commercial hydrocarbon flow in the basin, LNam Phong Gas Field, is at production decline stage at present, it's urgent to find the suitable alternative targets for the next phase. Even though the exploration results achieved in Khorat Plateau Basin are limited in historical exploration, it is predicted that the basin still has high exploration potential to be excavated.

Because of uncertainty of the resource potential of the basin, the probability method is used to calculate the undiscovered resources of the basin [21]. Objective probability describes the inherent objective properties of an object, and its correctness can be tested experimentally or statistically for completely repeatable events. However, the calculation of the undiscovered resources mainly depends on the evaluator's understanding of the exploration potential, and it is difficult to test its correctness through test or statistical methods, and cannot be applied to completely repeatable events. Therefore, the subjective probability method is adopted in the evaluation of resources to be discovered.

The paper proposes that the next step exploration should focus on the following aspects:

(1) The Permian Class I hydrocarbon play is the largest in resource potential, followed by the Triassic Class I hydrocarbon play;

(2) It is predicted that natural gas will still be dominated in future oil and gas discovery in this basin, which is mainly concentrated in Permian Class I hydrocarbon play. Oil and

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condensate oil will be discovered mainly in Triassic Class I hydrocarbon play;

(3) In horizontal direction, in Permian Class I hydrocarbon play, excellent source rocks and reservoirs are developed in the west of the basin, and Indo-China I unconformity acting as regional seal is widely distributed in most part of the basin, except for Savannakhet Subbasin. Therefore, Class I Pha Nok Khao dolomite reservoir is the most favorable oil and gas exploration area in Permian system, which are well developed in Phu Phan Uplift, south of Sakhon-Nakhon Subbasin and restricted platform- evaporative platform area in the north of Loei-Phetchabun fold and acts as (Fig. 11a). Its undiscovered reserves are 124 million barrels of oil and 2 trillion cubic feet of natural gas. Its undiscovered resources are 124 million barrels of oil and 2 trillion cubic feet of natural gas. Because the gaseous hydrocarbons in the basin are mainly derived from kerogen directly generating cracking gas of natural gas, petroleum and bitumen, the peak gas generation is located at the vitrine reflectance of Ro1.8%. The peak of kerogen gas in the over-mature stage is over. So exploration risk mainly comes from whether the source rock are over-mature.

(4) In Triassic Class I hydrocarbon play, the excellent source rock is distributed in a banded shape in the middle of the basin. Continental alluvial fan- lacustrine reservoir is well developed in Savannakhet Subbasin. The Nam Phong Formation regional seal is widely distributed in the basin. Therefore, the most favorable oil and gas exploration area in Triassic system is located in the middle and western part of Phu Phan, northern part of Khorat Subbasin and western part of Sakhon-Nakhon Subbasin, where braided river sandstone reservoir, meandering river sandstone reservoir and delta sandstone are developed (Fig. 11b). The amount of oil undiscovered resources in the Triassic Class I hydrocarbon play is 444 million barrels and 91 trillion cubic feet of natural gas.

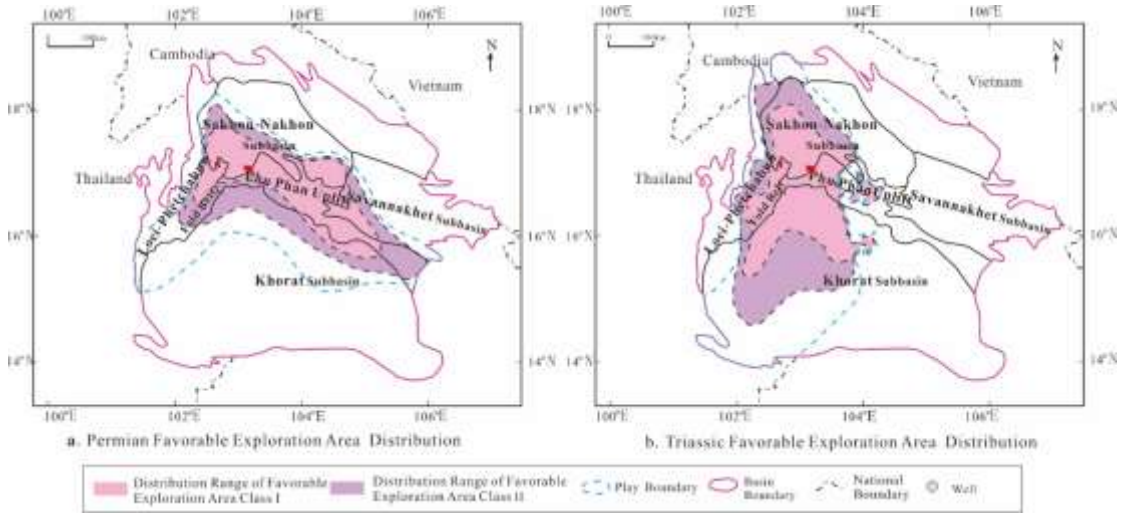

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Fig.11: distribution of favorable exploration area in the basin

## VII. CONCLUSIONS

(1) Hydrocarbon play has been investigated, with focus on the progressive controlling roles of structure, sedimentary evolution and hydrocarbon accumulation. The tectonic sequences in this basin can be divided into TS1 and TS2 according to the tectonic movement and evolution history of the plate to which the basin belongs.

(2) Controlled by tectonic evolution, the sedimentary evolution of the basin can be divided into two periods, during which different sedimentary systems have been developed. The sedimentary system of shallow sea arenaceous (gravel) shoreland-shallow sea continental shelf-restricted platform was developed during Palaeozoic, and river- lacustrine sedimentary system was developed during Mesozoic.

(3) According to the reservoir-seal assemblages and trap type in the tectonic sequences, two Class I hydrocarbon plays (including proved Permian Class I and prospective Triassic Class I) and four Class II hydrocarbon plays (Triassic structure-unconformity, Triassic Stratigraphic-structure- unconformity, Permian structure-unconformity and Permian Stratigraphic-structure-unconformity) have been identified.

(4) For the further exploration of the basin, Permian Class I hydrocarbon play should be the exploration focus in vertical direction. Natural gas exploration should focus on Permian Class I hydrocarbon play and conventional oil exploration should focus on Triassic Class I hydrocarbon play. In horizontal direction, the most favorable oil and gas exploration area in Permian system is located at Phu Phan Uplift, south of Sakhon-Nakhon Subbasin and north of Loei-Phetchabun fold, and the most favorable oil and gas exploration area in Triassic system is located in the center and west of Phu Phan Uplift, north of Khorat Subbasin and west of Sakhon-Nakhon Subbasin.

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