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Depositional Systems of Nanpu Depression and its Petroleum Potential

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Abstract: The facies analysis is key to understand the evolution of a depositional system. Lacustrine depositional systems were considered in this study. In this study we used core samples and well log analysis to identify different lithofacies in variety of depositional systems. Tree chronostratigraphic units have been identified: The first is composed of Cretaceous, Jurassic, Carbo-Permian and Ordovician rocks, the second is composed by Paleogene System, which is consists of Shahejie Formation (Es_3, Es_2 and Es_1) and the Dongying Formation (Ed_3, Ed_2 and Ed_1) and the third is Neogene System, which comprised of Guantao (Ng) and Minghuazheng (Nm) Formations. The thickness of these tree stratigraphic units was estimated to being in the range of 7500 ~ 8000 m. Nanpu Depression as part of Bohaiwan Basin, underwent an extensional faulting in the early Cenozoic time. This dynamic process led to the development of faulted lacustrine basin, which controlled the sedimentary infilling. Depositional systems and facies types were influenced by paleogeography and the geology setting. The sedimentary facies and structural background of Nanpu Sag are favorable for finding more stratigraphic and structural oil traps.

Key words: Depositional system, nanpu depression, seismic stratigraphy, facies analysis, stratigraphic and structural oil traps

INTRODUCTION

Lakes are amongst the most varied of depositional environments, even though they occupy a relatively small percentage of the earth's (about 1%, according to Collison[1] and there no universal facies models for lacustrine environment[2].

The subduction of Pacific plate towards North China continent with strong rigidity of China Platform, brought about the violent fault block movement, which led to the formation of many dustpan-shaped depressions[3] (like Nanpu sag) in Bohaiwan Basin.

Nanpu depression covers an area of 1932 km^2 and it is based on the Huabei mobile faulted block. In middle of Cenozoic era the depression developed and took a dust-pan shape along NS direction. This depression is limited in North by Xinanzhuang fault and the Laowangzhuang protuberance, in East by Baigezhuang and the Matouying uplift, in South by Shaleitian Mountain which is adjacent to the Laomiao tectonic zone, in West the Beitang faulted ravine (Fig. 1).

Understanding and recognition of sedimentary facies is all based on its sedimentological, lithological, paleontological and structural characteristics[4] and the difference between facies analysis and depositional systems analysis is essentially one of scale[2]. The architectecture of sedimentary bodies and their spatial relationship in the depositional environment are dictated by the paleogeography and paleoclimate, which in turn influenced the transport agents as water and wind flows. The characteristics of sedimentary systems and the pattern spatial distribution are the results of basin substratum subsidence, which is in turn accompanied by water sea level changes or accommodation space. Basin architecture depends upon a complex interaction between the three dimensional evolution of a basin linkage trough fault propagation, the evolution of drainage and drainage catchments and the effects of changes in climate and sea/lake level. In particular, the processes of fault propagation, growth, linkage and death are the major tectonic controls on basin architecture, whereas non-tectonic effects arising from climate, sea or lake level changes are responsible for major changes in basin scale sedimentation patterns. The Nanpu depression is about a small size comparatively to continental faulted basins and is very sensible to the influence of each environmental factor. The Nanpu depression is a lacustrine basin (sub-basin or sag) with strong tectonics activities, which influence directly the basin evolution providing continental silico-bioclastic sediments. The detailed study of the characteristic of each depositional system, allowed understanding the evolution and the

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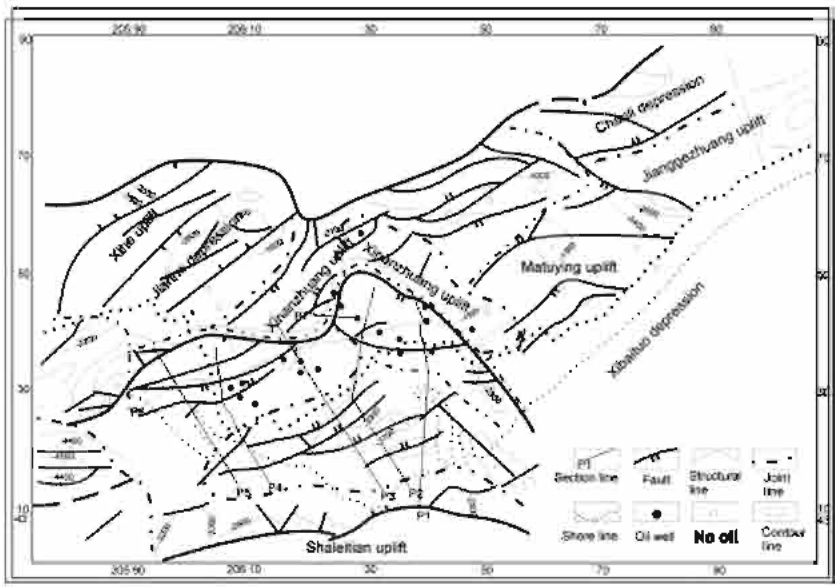

Fig. 1: Depositional environment and paleo-tectonic map of Nanpu Depression

development of any depositional environment. The facies analysis permits to know the variation of the tectonic activities along the faulted basin borders and at its basement. The internal sedimentary basin evolution allows establishing the relationships between sources rocks, reservoirs rocks and seal rocks.

MATERIALS AND METHODS

The main methods used in facies analysis in Nanpu depression were geophysical and geological surveys. This study adopts the spontaneous potential (SP) and apparent resistivity (AR) to reflect the composition and the size of sediments, which are crossed by electric power. These methods allow us to draw the pattern distribution of the sedimentary bodies, the maturity of their components, the contact relationships between them and their relative dimensions. The physical characteristics of sedimentary rocks are important keys for the definition of different sedimentary facies, which led people to define the depositional environment.

Deltaic systems in Nanpu sag: A classification of deltas which is now widely accepted is that by Galloway[5] in wave, tide- and river-dominated types, according to this classification deltaic environment in Nanpu is pertaining to the river-dominated.

Fan deltaic system: This sedimentary system was formed during the period of runoff carrying an important amount of alluvial detrital sediments in Lake of Nanpu sag[6]. The slowing down of current flow loaded and piled a variety of sediments at the lake embouchure (mouth). The fan deltaic system was quite developed in many sub-faulted basins in Bohaiwan and particularly in Nanpu sag. According to its lithostratigraphic composition, this system was developed during the intensive tectonic activities in Gaoshanbao, Liuzan and Laomiao fractured zones. The deltaic system in Napu sag was mainly composed of tree parts: deltaic plain, delta front and prodelta in the distal zone (Fig. 2)

The fan delta was mainly consisted of mudstone rocks, stream braided sediments consisting of main subfacies. The debris flows in mudstones were immature and varied in color from red brownish to gray and contained some gravel into a clay matrix. The particles debris and sand grains were mainly angular with irregular forms that indicated the proximity of sediments source and the intensive tectonic activities in Nanpu depression. The stratification in this system was not well developed and that can be seen through stepped and irregular curves of SP and AR. Core log observation combined with seismic stratigraphy show that the stream sediments of deltaic system consist of sandstone, conglomeratic sandstone and conglomeratic gravel in mudstone. Scoured surface is observed at the bottom of each sedimentary cycle. Most of the sedimentary cycles consist of a coarsened structure at its bottom and fine elements at their upper part showing a fining-up structure which resembled A Bouma turbidite sequence[2]. Each sedimentary cycle contained rounded gravel elements at its base, showing a hummocky cross-bedding and cross

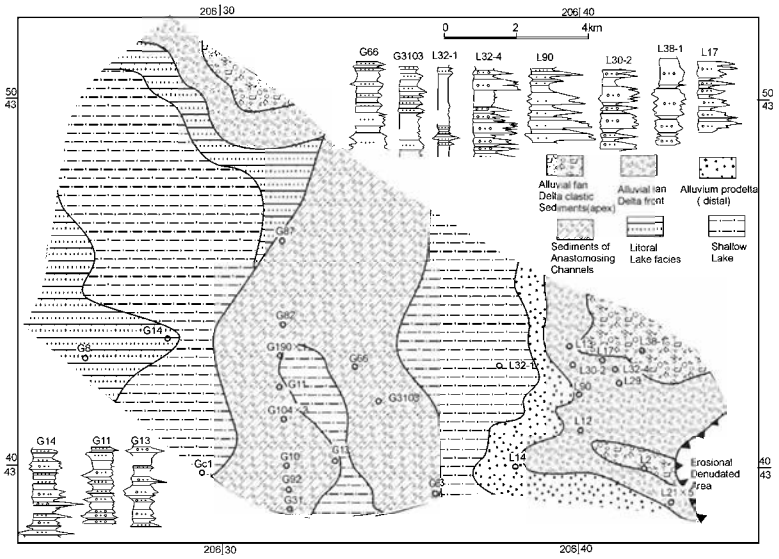

Fig. 2: Facies map and depositional systems of Sahejie Formation in Gaoliu area

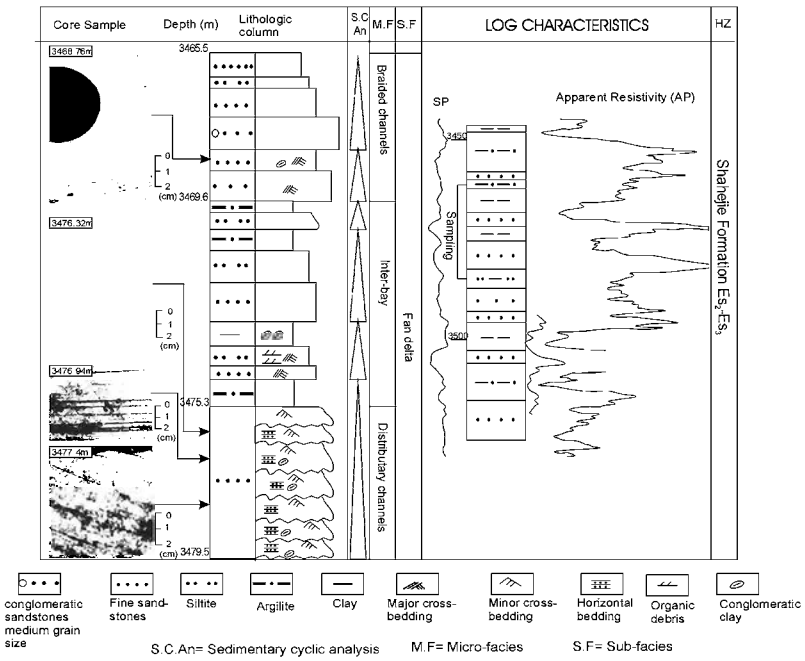

Fig. 3: Plain delta sediments of Es_3^5 sub-member of Shahejie and its log characteristics in Liuzan area L90

stratification that overlying some horizontal laminar beds, reflecting the characteristics of flooding episodic periods[6]. This can be seen on the log curve (Fig. 3) which changes soundly at the limit of different sequences of different lithologies.

Deltaic front system: This depositional system consists of grayish clay, argillaceous siltstone and fine sandstone. Globally, the delta front system is composed of turbidites accumulation during the flooding period, slumping sediments or gravity debris flow which was accumulated

down slope. The seismic reflection reveals three structural seismic configurations of sand bodies, which composed the fan delta: delta plain (that can be seen like a broom shape on seismic reflection), deltaic front showing a tilted surface (forest beds) towards the basin and prodelta, reflected into horizontal bedding in the centre of basin (Fig. 3).

Lacustrine system in Nanpu sag: The lake delta is in general built at the entry of a river into a standing water body of a lake, where a great amount of sediments were deposited by the slowdown current of transporting agent (water or wind) in contact with standing water body. Because the source of the sediments was relatively farther from the depositional environment, the sediments undergone the effects of long distance transport and abrasion that gave them a relatively high maturity[7]. The lacustrine system was well developed in the Beibao area, where an assemblage of sand bodies is accumulated during the relatively calm tectonic period along the faulted borders zones. One part of the lake delta is also well developed in Gaoshanbao area in the same tectonic still period. In this area the plain deltaic facies included: distributary channels, crevasse splay and some microfacies of flooding plain. The sediments of channels were mainly fine and mead sand grains, with muddy gravel and rock debris which were oriented in the sense of current flow. At the upper part of this sequence, the tabular horizontal beds overlay some folded and cross-bedding layers. The sequence shows a graded bed in which the sedimentary cycle began with coarse elements at the bottom and finishing with fine sediments in the upper part. Depending on the depositional system, the sequence thickness varies notably from meter to tenth of meters. In Gaoshangbao, the sediments of flooding delta plain were grayish, gray-greenish, purples and were composed of siltites and claystone beds taken in sandwich inside sandy clay. Often some coarsened sandstones were encountered in channel through. Most of horizontal beds consist of clay minerals with some rare salt crystals, coal fibers and fossils roots plant. The sediments of flooding delta plain consist of sandstone alternated with sandy clay[8]; the SP curve log shows small amplitude fluctuations. The deltaic front was comprised of the embouchure sand bar and the distal sand bar. Its architecture was well developed in Gashanbao and Gaoliu areas where the seismic reflection depicted very well its frontiers. The delta front in that area consists of a succession of deep-grayish clay stones and sandy beds overlying a sand cross-bedding. The slumping materials and some deep-water turbidites were observed in many core samples. Although the development of this depositional system was of a small size, it can be a target for oil drilling as a potential reservoir of hydrocarbon because of the great thickness of deposited sand bodies wherein.

The slumping system: The slumping gravity flow sediment is well developed in many parts of study area, particularly in Liuzan district of Nanpu sag.

The slumping system is mainly caused by a rapid accumulation of sediments on the slope, fallowed by sliding due to the effect of gravity. The regression of water sea/lake during the fault movements and the flooding period were often caused scoured surfaces onto their bottom. There's a tight relationship between the turbidite formations and the relative development of the basin faulted borders. The occurrence of coarse and fine grained sandstones in the slumping sedimentary bodies in Gaoshangbao, Beibao, Liuzan and Laoyemiao districts were related to the development of faults along the basin border. The slumping sediments are not sorted, material from grain size to pebbles and gravels are accumulated at the bottom of that sequence. Mud and sandy deformed beds are observed in upper part of slumping system. Owing to the intercalation of small mudstone layers and sandy beds, the log curves show some concentrated and high tongues discrimination between these two differentiable lithological features (Fig. 4). The seismic section shows them as lenses bodies' without internal reflections.

Gravity flow model in Nanpu Depression

Coastal fan: The coastal fan is generally formed along coastal plain area except in small basin as Nanpu depression where it's occurs on the surface of tilted normal fault. This system is present in Gaoliu and Laoyemiao districts. It formed during the deepening of the basin due to the intensive tectonic activities that involved changes in basin geometry. The main cause of its formation is the important sediment accumulation on the upper faulted slope and their sliding down-slope by gravity forces. The main components of coastal fan are alluvial sand deposits owing to different litho-biological features. In Nanpu depression, the coastal fan consists of Es_2, Es_3, Ed_2 (Shahejie and Dongying formations) sub-members which were formed during extension[9]. The main sedimentary bodies in this part were sandy bodies intercalated with dark grayish mudstones. In addition, some scoured surfaces occurred at the basis of these sandy bodies, filled with gravel mass in sandy matrix, the beds formed are not regular, reflecting the turbidity characteristics in origin during flooding period. The log curve shows some concentrated dendrites and irregular lines reflecting the heterogeneity in lithology.

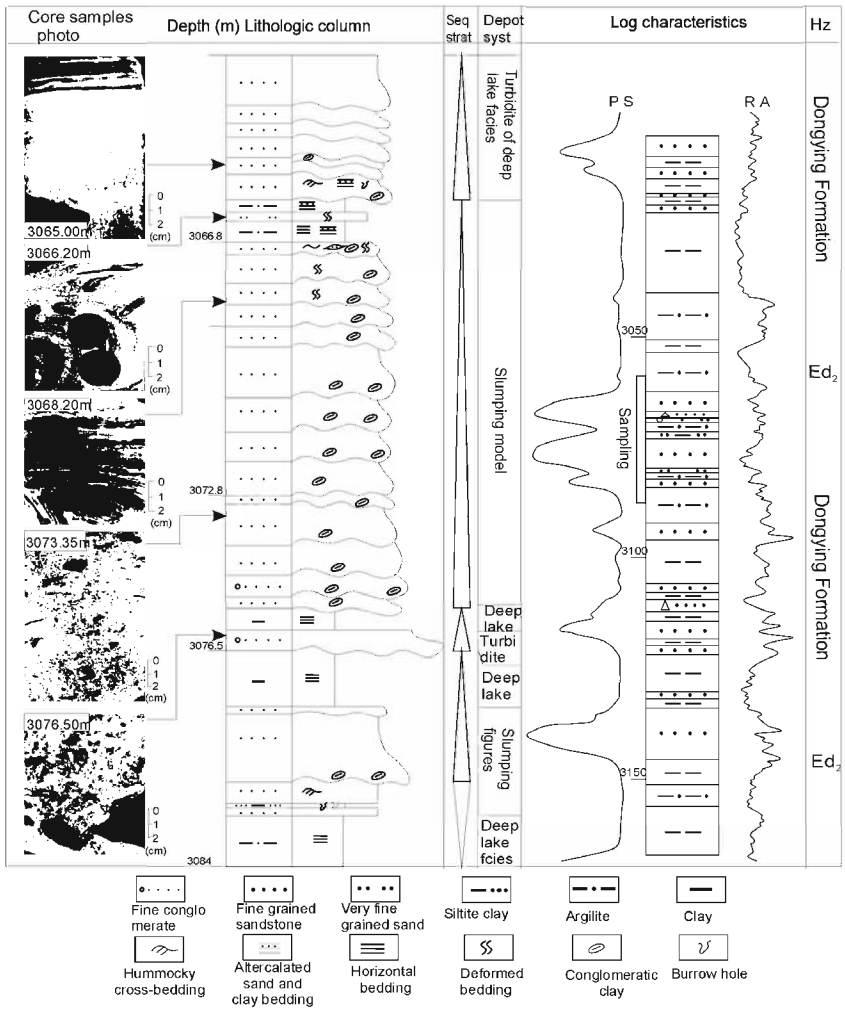

Fig. 4: Slumping and gravity flow and turbidites sediments and their log characteristics in Beibao district The lacustrine system

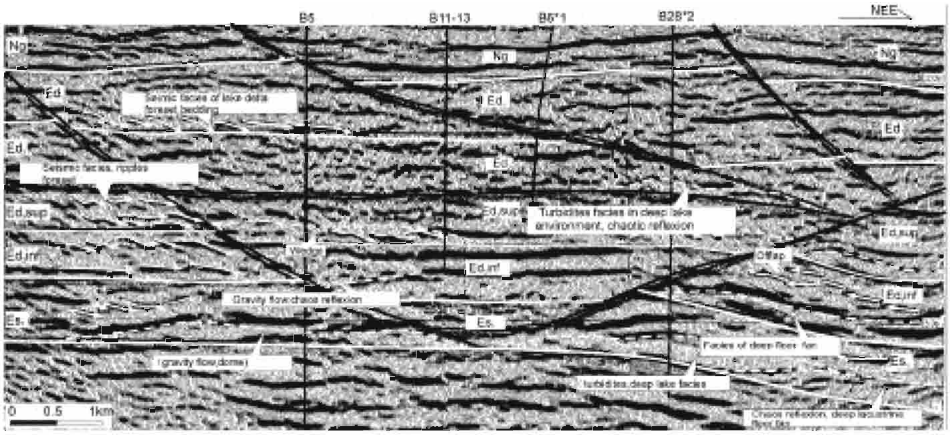

Fig. 5: Interpreted seismic section along profile no1 in Beibao area

Deep turbidites: It particularly developed in Beibao area, on the deltaic front. The lithology of this part is consisting of slight grayish siltstone, coarse and fine grained sandstones, sandy tabular beds, graded sandy beds, the turbidites of Bouma series[10].

The base of the sequence is generally coarser and graded, on which overlying horizontal sandstone beds and hummocky cross bedding. The spontaneous curve shows large and long amplitude altering with narrow and shorted ones. The seismic reflexions show some lenses forms with blank interior (Fig. 5).

The lacustrine system: The lacustrine system is comprised of shore line facies, the shallow lake facies and the deep lake facies. The lake coastal facies sediments are developed in the frontiers of basin borders where the water currents are slowing down at the embouchure bar sand body[11]. The waves deposited some fine to mean grained sandy bodies at the lake entry, where the cross-bedding stratifications were well developed[2].

These sediments are heterogeneous because of the alluvial plain influences. The seismic facies show the characteristics of sandy and argillaceous beds successions. The deep lake facies in Nanpu sag is comprise of grayish mudstone with slumping figures. The deep argillaceous facies is consisting of black clay in which have been observed the bivalves, brachiopods and astrocods fossils in rich organic matter[11]. This area can be a possible zone of sources rocks formation or a potential oil barrier.

CONCLUSIONS

Facies analysis in Nanpu shows the predominance of alluvial environment rather than marine, including fluvial, deltaic and prodeltaic facies. Climatic fluctuations and tectonic activities were the main factors, which led accumulation of thick lacustrine sediments. Many vast petroleum reserves were found in this type of environment in China continent, we suggest that more detailed stratigraphic and sedimentogical studies in Nanpu depression are highly desirable for further finding oil in this area. The advantage of lacustrine depositional environment for petroleum prospect is the combination of tectonic subsidence and the rapid deposition process that can led to the formation of good structural and stratigraphic oil traps. The variability of depositional systems and facies types in Nanpu Depression is a potential petroleum system.

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