Analysis of High-Resolution Sequence Stratigraphy in Sanzhao Depression of Putaohua oil-bearing layer, Songliao Basin

Jiajun Jiang

Daqing Toutai Oilfield Company Ltd, PetroChina, Daqing, 163113, Heilongjiang, China

jiangjiajun@petrochina.com.cn

Abstract. Based on the high resolution sequence stratigraphy theory, and core, logging, modern sedimentary and ancient outcrop data, and with the analyses of the sedimentary dynamics and spatial overlay style for all levels of base level cycle, to make the lake flooding surfaces as sequence boundaries, Putaohua oil-bearing layer ,eventually, is divided into one long-term base level cycle, two middle-term base level cycles and twelve short-term base level cycles. Researches show that: Putaohua oil-bearing layer has the sequence stratigraphic framework which controlled by uplift of syndepositional structure along the source layer thinning in the distal parts of delta, and its top and bottom gradually varied from northern sandstone to southern mudstone ,called "sand mud docking" model; Putaohua oil-bearing layer has five kinds of short-term cycle structures, and base level rising semi cycle which has high accommodation primarily; shallow water deltaic depositional system,controlled by fluvial, is developed in Putaohua oil-bearing layer, the main microfacies sand bodies are flaser distributary channel and extensive sheet sand, other microfacies sand bodies less developed; Putaohua oil-bearing layer has the characteristics that water system is divided into Eastern and Western ,and type of sand bodies is divided into North and South in plane, and has the sedimentary sequence evolution that quickly regressive in early stage,shock type lifting in medium-term, slowly transgression in late in vertical direction. Depended on the shallow water delta sequence stratigraphic framework which controlled by uplift of syndepositional structure, sedimentary characteristics of oil-bearing layer and the distribution of sand body and the pattern of oil and gas migration and accumulation control action, Putaohua oil-bearing layer ,eventually, has been set up a model of oil-bearing layer sedimentary with different sedimentary evolution stages.

Keywords: high resolution sequence stratigraphy; shallow water delta; model of oil-bearing layer sedimentary; Putaohua oil-bearing layer; Sanzhao Depression; Songliao Basin.

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1 Introduction

After nearly 40 years exploration and development, Putaohua oil-bearing layer in Sanzhao depression ,Songliao Basin ,successively found structural oil-bearing layer, fault-lithologic oil-bearing layer, lithologic oil-bearing layer in nose-like structure subject area which near the source in the depression, slope area which outside the source,and the inclined section which inside the source, oil and gas distribution has characteristic that full of oil in the depression in overall, but the rest of the unused evaluation area and blank area mainly locate in slope area and syncline area which have complex oil-bearing layer types and oil-water distribution[1].Guided by the theory of high resolution sequence stratigraphy, the high resolution sequence stratigraphic division and correlation by means of the anatomy of the outcrop area, modern sedimentation observation, coring wells core description, well logging curve comparison, seismic horizon tracking, and then establish Putaohua oil-bearing layer single sand body isochronous stratigraphic framework which take many classes lake flooding surfaces as sequence interface, and then summed up the shallow water delta short-term cycle structure and oil-bearing layer sedimentary model which under the influence of frequent lake level fluctuation in Putaohua oil-bearing layer and the different A/S, and it is significance to understand the development features of oil-bearing layer, the types of oil-bearing layer, and oil-bearing layer formation mechanism, and has a certain reference value for guide the continental basin complex oil-bearing layer exploration and development.

2 Regional geological survey

Songliao Basin, located in the northeast of China, is a large Cenozoic continental basin. Researches show that basin tectonic evolution mainly experienced three stages: early fault depression, medium-term depression and late inversion, the vertical overall performance has the characteristics of a "fault depression of long flat top" in the structure. The thickness of basin sedimentary cover has ten thousands meters. The Cenozoic strata sedimentary from bottom to top is Huoshiling Formation, Shahezi Formation, Yingcheng Formation, Denglouku Formation, Quantou Formation, Qingshankou Formation, Yaojia Formation, Nenjiang Formation, Sifangtai Formation, Mingshui Formation,Yian Formation, Daan Formation, Taikang Formation, and the Quaternary Strata[2]. Sanzhao depression as a second negative structure unit in the central depression of Songliao basin, its west is Daqing Changyuan, the east is Chaoyanggou terrace, and the north is Anda depression, 5575km^2, Putaohua oil-bearing layer in Yaojia Formation is the main oil-bearing formation in this area; Putaohua oil-bearing layer developed from the northern sedimentary system of Songliao Basin,it is a delta complex formation,including Sa Ertu station which located in Daqing Changyuan, Xingshugang water system,and Songfangtun area[3]; Controled by the basement fault with multi period difference settlement, top surface of Putaohua oil-bearing layer formed 8 thirdly tectonic units ,such as the Shangjia nose structure, Shengping nose structure, Songfangtun nose structure, Zhaozhou nose structure, Shengpingxi syn-

cline, Xujiaweizi syncline, Yongle syncline and Taidong slope, performaned have " four nose structures and three syncline with a slope" in general;Under the effection of non-positive tectonic background, many segmentation faults, thin sand-shale interlayer oil-bearing layer, and many oil-water systems in vertical, Putaohua oil-bearing layer in study area is a zone which enrich many types of important complex oil oil-bearing layer in northern Songliao Basin[4].

3 The high resolution sequence stratigraphic characteristics in Putaohua oil-bearing

3.1 The types of sequence boundary and response characteristics

The short-term base level cycle is the basic unit to establish and analysis the high resolution sequence stratigraphic framework, short-term cycle boundary always comprehensive defined by the core, logging and outcrop data; the short-term cyclic sequence structure mainly depends on the change of phase or phase sequence to determine, the datum development position and A/S value change can influence the development of symmetric composite cycle or non-symmetric half cycle, such as horizontal bedding mudstone, the top boundary of PuI 2_2 in Fang 122 well,-1482.2m, is the short term cycle sequence boundary. The medium-term base level cycle is composed of a series of short cycle superimposed; the types of mid-term cycle are controlled by short-term cycle's structural types and tectonic styles, which has the performance of the conversion of surface or mutation surface of sedimentary facies sequence which formed by similar or adjacent sequence progradational- retrogradation in the same sedimentary system in the deposition profile[5], such as mudstone in the top boundary of PuI 5_1 in Fang 136-150M well, -1526.8m,is the mid cycle interface; each medium-term cycles has a complete oil-bearing layer caprock assemblage relationship, which means they have an independent oil-water system and single oil and gas transporting layer. The interface analysis of long term base level cycles means the recognition of maximum flooding surface; in the delta sedimentary system, when the base level rise to the highest point, accommodation is maximum, the relative lake level is the highest, sediment supply is the least, the value of A/S is the largest, and lake has the owed compensation deposition state in the overall and deposited dark fine-grained mud deposition[6],such as the dark mudstone in the top boundary of PuI 1, -1514.1m,and the dark mudstone in the bottom boundary of PuI 9, -1540.28m,in the Fang 136-150M well, is the long-term cycle's top and bottom interface. Generally, all flooding surface levels have obvious features in the cores and well logging curve, such as natural gamma has high value, sonic has high anomaly amplitude positive, density has low value, resistivity has low value, but the oil shale shows high value in the resistivity (Fig 1).

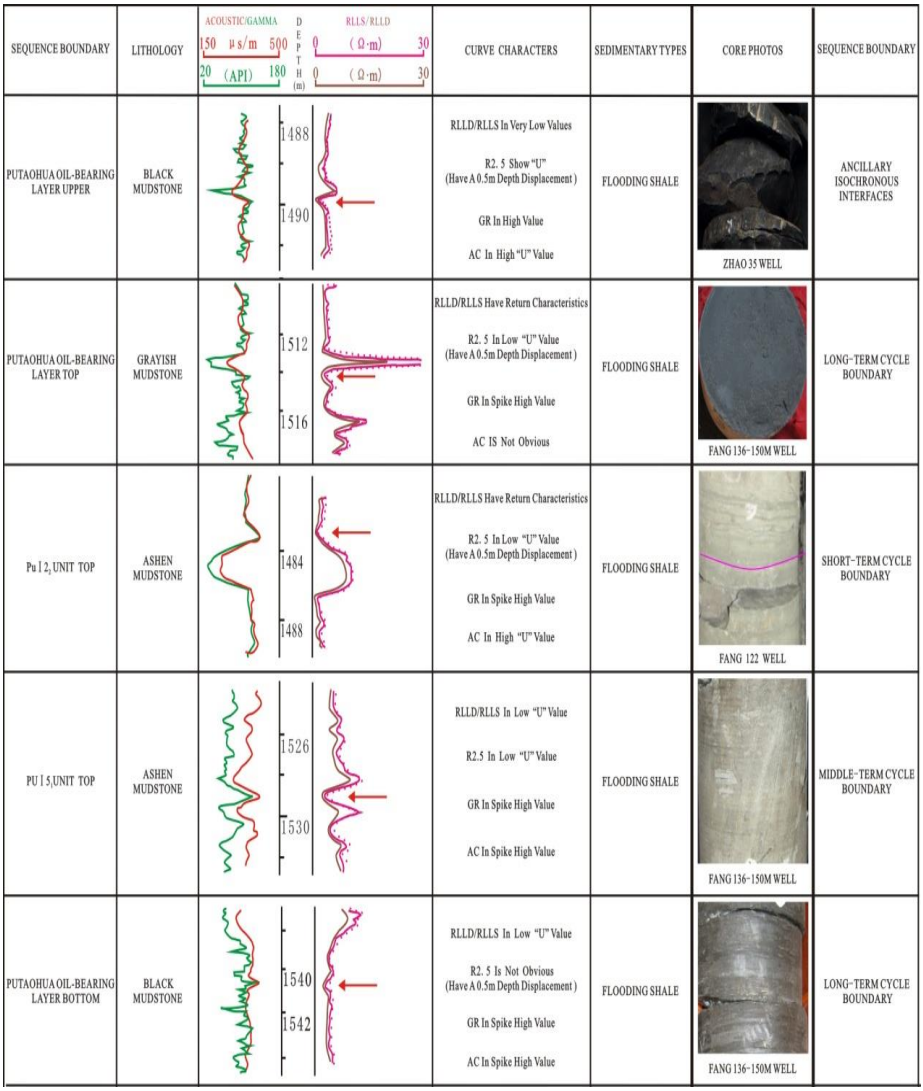


Fig. 1. Sequence interface features of Putaohua oil-bearing layer in Sanzhao depression

3.2 The development characteristics of Sequence stratigraphic

The analysis of high resolution sequence stratigraphy shows that the formation thickness changes quickly from North to South in Putaohua oil-bearing, and the formation thickness stability from East to West, then the sequence stratigraphic framework have these development characteristics: (1) Putaohua oil-bearing layer which effected by delta synsedimentary tectonic uplift becomes thinning from north to south through source direction, the evidences as follows: a. mudstone thickness which is the base of Putaohua oil-bearing layer gradually thickening from North to South, which reflected

that the strong source filling before deposition and the broad and flat and shallow lake sedimentary environment under the background of lake shrinking; b. mudstone thickness which is the top of Putaohua oil-bearing layer gradually thickening from North to South; c. dense well pattern sequence boundary contrast shows that Putaohua oil-bearing layer reduction deposition process through source, and the oil-bearing layer physical properties and scale of sand bodies from North to South gradually become worse; d. the analysis of water back sedimentary evolution sequence which developed in Putaohua oil-bearing layer bottom, tectonic evolution, and stress field in the earths crust shows that the southeast of Songliao basin has a regional tectonic uplift in early Yaojia deposition[7]; e. Putaohua oil-bearing layer developed a large red layer mudstone deposition in southern, which consistent with the regressive sedimentary filling structure which founded from Yaojia formation outcrop in southeast; (2) under the influnce of the position of base level is height, accommodation is enough, terrain slope is slow, the material source is strong, top and bottom of Putaohua oil-bearing layer developed the sandstone gradually phase into mudstone "sand mud docking" model from North to South, which means interface of sand and mud mutation in the top and bottom surface of Putaohua oil-bearing layer is not isochronous interface, evidences as follows: a. the P I 8 unit and P I 9 unit in the base of Putaohua oil-bearing layer mainly developed underwater distributary channel in the northern of Songfangtun nose structure, and front delta mud developed in the southern of Zhaozhou nose structure; b. the P I 1 unit and P I 2_1 unit in the top of Putaohua oil-bearing layer mainly developed mouth bar in the northern of Songfangtun nose structure ,and front delta mud developed in the southern of Zhaozhou nose structure; (3) Putaohua oil-bearing layer developed two stratigraphic thickness variation belt from North to South, which located in Xujiaweizi syncline and Zhaozhou nose structure, the thickness variation belt in the northern of Zhaozhou nose structure strata is very anastomosis with polygonal fault which non-tectonic origin, and Putaohua oil-bearing layer has the same characteristics in southern of Daqing Changyuan and the southern of Gulong depression[8]; (4) influenced by the strong material supply,slowly terrain slope, synsedimentary tectonic uplift and base level frequency lifting, Putaohua oil-bearing layer developed 5 kinds of short-term cycle structure: base level rising semi cycle which has high accommodation, base level rising semi cycle which has low accommodation, base level descending half cycle which has low accommodation, dominated by ascending half cycles which has high accommodation composite cycle, and dominated by falling half cycle which has low accommodation space composite cycle, the most developed cycle is base level rising semi half cycle which has low accommodation(Fig 2).

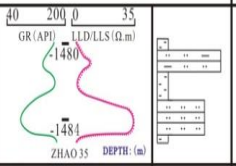
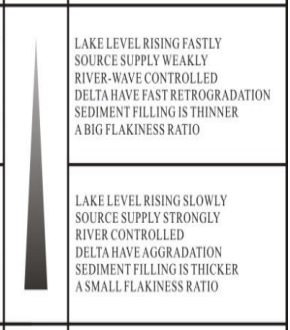
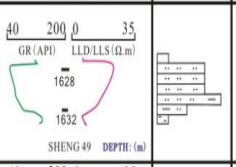
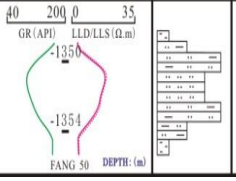
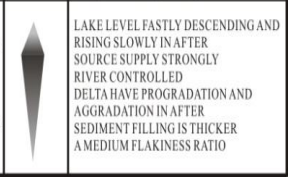
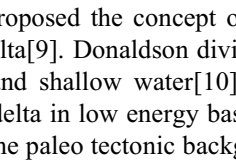
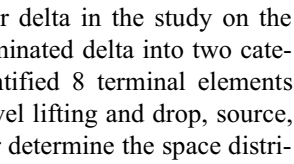
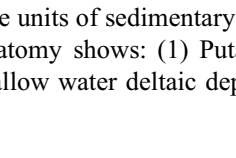
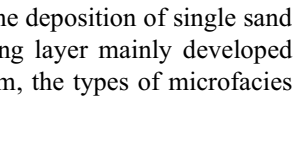
CYCLE	TYPE	SUBGROUP	LOGGING CURVES AND LITHOLOGIC	VERTICAL HORIZON	PLANE POSITION	BASE LEVEL	CONTROLLING FACTORS AND FILLING CHARACTERISTICS
SHORT TERM CYCLE	BASE LEVEL RISING SEMI CYCLE	BASE LEVEL RISING SEMI CYCLE WHICH HAS HIGH ACCOM--MODATION		P I 1 UNIT P I 2_1 UNIT	NORTH-CENTRAL SUBSIDENCE CE--NTRE SONG FANG TUN NOSE STRUCTURE SOUTH		LAKE LEVEL RISING FASTLY SOURCE SUPPLY WEAKLY RIVER-WAVE CONTROLLED DELTA HAVE FAST RETROGRADATION SEDIMENT FILLING IS THINNER A BIG FLAKINESS RATIO
		BASE LEVEL RISING SEMI CYCLE WHICH HAS LOW ACCOM--MODATION		P I 3 UNIT P I 4_1 UNIT P I 5_1 UNIT P I 5_2 UNIT P I 6 UNIT	NORTHEM PROVENANCE SONG FANG TUN NOSE STRUCTURE NORTH		LAKE LEVEL RISING SLOWLY SOURCE SUPPLY STRONGLY RIVER CONTROLLED DELTA HAVE AGGRADATION SEDIMENT FILLING IS THICKER A SMALL FLAKINESS RATIO
	BASE LEVEL DECEDING SEMI CYCLE	BASE LEVEL DESC--ENDING SEMI CY--CLE WHICH HAS LOW ACCOMMOD--TION		P I 2_1 UNIT P I 7UNIT P I 4_2 UNIT	SOUTHERN STRO--NG UPLIFT ZONE ZHAO ZHOU NOSE STRUCTURE SOUTH		LAKE LEVEL DESCENDING FASTLY SOURCE SUPPLY STRONGLY WAVE CONTROLLED DELTA HAVE AGGRADATION AND PROGRADATION IN AFTER SEDIMENT FILLING IS THICKER A MEDIUM FLAKINESS RATIO
	BASE LEVEL DECEDING AND THEN RISING CYCLE	HIGH ACCOMMODA--TION CYCLE WHICH DOMINATED BY AS--CENDING HALF CY--CLE		P I 8UNIT	CENTRAL SUBSIDENCE CE--NTRE XUJIAWEIZI SYNCLINE		LAKE LEVEL SLOWLY DESCENDING AND RISING FASTLY IN AFTER SOURCE SUPPLY WEAKLY RIVER CONTROLLED DELTA HAVE AGGRADATION(OR PROG--RADATION) AND RETROGRADATION IN AFTER SEDIMENT FILLING IS MEDIUM A BIG FLAKINESS RATIO
		HIGH ACCOMMODA--TION CYCLE WHICH DOMINATED BY FA--LLING HALF CYC--LE		P I 9UNIT	SOUTH-CENTRAL WEAK UPLIFT ZONE ZHAO ZHOU NOSE STRUCTURE NORTH		LAKE LEVEL FASTLY DESCENDING AND RISING SLOWLY IN AFTER SOURCE SUPPLY STRONGLY RIVER CONTROLLED DELTA HAVE PROGRADATION AND AGGRADATION IN AFTER SEDIMENT FILLING IS THICKER A MEDIUM FLAKINESS RATIO

Fig. 2. Short-term cycle structure feature of Putaohua oil-bearing layer in Sanzhao depression

3.3 The characteristics of sand body distribution and evolution

Fisk is the first to proposed the concept of shallow water delta in the study on the Mississippi River Delta[9]. Donaldson divided a river dominated delta into two categories, deep water and shallow water[10]. Postman identified 8 terminal elements from shallow water delta in low energy basin[11].Base level lifting and drop, source, climate change and the paleo tectonic background together determine the space distribution characteristics of oil-bearing layer sand body. On the base of short-term base level cycle, with analysis of Poyang Lake shallow water delta deposition, outcrops of Yaojia formation in YaoJia Zhan and the wells' rock electricity relationship, Putaohua oil-bearing layer ensured 1 facies,3 subfacies, 14 microfacies,and 19 sub micro energy unit, and with 4079 wells curve data and 10 wells cores, Putaohua oil-bearing layer can be plotted 12 time units of sedimentary micro facies, the deposition of single sand body microfacies anatomy shows: (1) Putaohua oil-bearing layer mainly developed fluvial controlled shallow water deltaic depositional system, the types of microfacies

are mainly banded distributary channel and sheet sand sheet, other types of microfacies sand body growth less, the distributary channel sand bodies are dense, continuous and stepwise bifurcation , sheet sand show that banded under river controlled along the source and lump under wave controlled in vertical source; (2) sedimentary microfacies distributed from East to West, and zoning in North and South, the performance in east-west is that Songfangtun water system and Shengping water system controled by the same northern source, the performance from north to south shows strip thick river channel developed in North which controlled by synsedimentary tectonic uplift and sheet of thin sheet sand developed in southern ; (3) sedimentary microfacies has multiple stages in vertical evolution, the lower of Putaohua oil-bearing layer has developed delta front subfacies ,such as subaqueous distributary channel, mouth bar, sheet sand and sand dam, flowing sand, the central of Putaohua oil-bearing layer has developed delta plain facies, such as distributary channel, crevasse channel, crevasse splay, overbank sand and natural levee, the upper of Putaohua oil-bearing layer has developed delta front subfacies, such as subaqueous distributary channel and sheet sand; (4) Putaohua oil-bearing layer in vertical developed the evolution deposition sequence which was the early forced rapid water back ,mid concussion type lifting ,advanced active slow water into , a. PuI 9 in bottom of Putaohua oil-bearing layer trans from delta facies mudstone to the underwater distributary channel and mouth bar thick layer, b. PI 4-6 in central of Putaohua oil-bearing layer developed purple red mudstone and gray green mudstone interbed, c. PI 1 in the top of Putaohua oil-bearing layer still developed distributary channel, d. the vertical sequence from Fang 136-150M system cored wells shows that Putaohua oil-bearing layer was the sedimentary evolution sequence which is that the first water back into the water.

3.4 Oil-bearing layer sedimentary model

When lower of Putaohua oil-bearing layer has deposition, the south of the study area has regional tectonic uplift, base level decreased rapidly, A/S >1, provenance supply slightly strong, sedimentary bedforms low, which mainly have sheet sand which developed from delta front subfacies subaqueous distributary channel and the end, river-controled mouth bar, river waves jointly controlled sand dam, river source, wave controlled vertical source sheet sand and overbank sand which developed from water; when the central of Putaohua oil-bearing layer have deposition, the tectonic uplift reaches the maximum in south of study area, base level reaches minimum, A/S < 1, provenance reaches strongest, sedimentary bedforms gentle, which developed delta plain subfacies such as broadband loop flow distributary channel, crevasse channel and crevasse splay, natural levee and overbank sand; when lower of Putaohua oil-bearing layer have deposition, the tectonic uplift in the southern study area, base level began to rise slowly, A/S > 1, the material supply is relatively weak, sedimentary bedforms is slowly, which developed delta front subfacies such as subaqueous distributary channel and river mouth bar end, controlling river along the source sheet sand. Eventually, Putaohua oil-bearing layer could establishe shallow water delta oil-bearing layer sedimentary model which controlled by synsedimentary tectonic uplift[12]: (1) the broadband loop flow distributary channel which belongs delta plain

subfacies; (2) the crevasse channel and crevasse splay which belongs delta plain subfacies; (3) the natural levee and overbank sand which belongs delta plain subfacies; (4) the narrow straight forked distributary channel which belongs delta front subfacies; (5) the river sand control flow which belongs delta front subfacies; (6) river mouth bar and sand dam controlled by river with waves which belongs delta front subfacies; (7) the sheet sand controlled by river which belongs delta front subfacies; (8) sheet sand controlled by wave which belongs delta front subfacies (Fig 3).

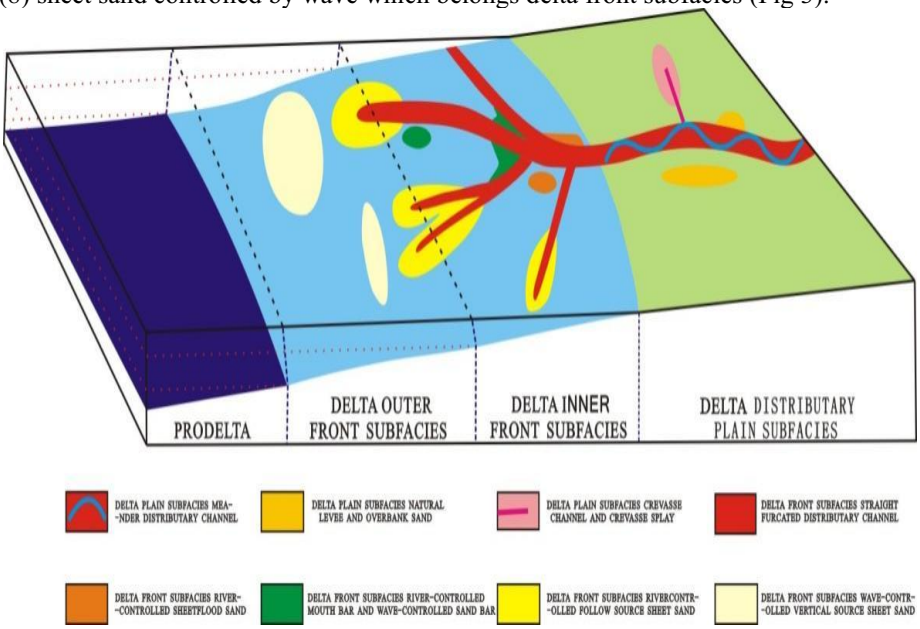


Fig. 3. Shallow deltas sedimentary models of Putaohua oil-bearing layer in Sanzhao depression

4 Conclusions

(1)With high resolution sequence stratigraphy theory, all levels of flooding surface sequence as the interfaces, Putaohua oil-bearing layer is divided into one long-term base level cycle, two middle-term base level cycles and twelve short-term base level cycles, eventually.

(2)Putaohua oil-bearing layer has the sequence stratigraphic framework which controlled by uplift of syndepositional structure along the source layer thinning in the distal parts of delta, and its top and bottom gradually varied from northern sandstone to southern mudstone ,called "sand mud docking" model.

(3)Putaohua oil-bearing layer has the characteristics that water system is divided into Eastern and Western ,and type of sand bodies is divided into North and South in plane, and has the sedimentary sequence evolution that quickly regressive in early stage, shock type lifting in medium-term, slowly transgression in late in vertical direction. Depended on the shallow water delta sequence stratigraphic framework which controlled by uplift of syndepositional structure, sedimentary characteristics of oil-

bearing layer and the distribution of sand body and the pattern of oil and gas migration and accumulation control action, Putaohua oil-bearing layer ,eventually, has been set up a model of oil-bearing layer sedimentary with different sedimentary evolution stages.

(4)Based on high resolution sequence stratigraphic framework, the syndepositional uplifting tectonic background and shallow water delta oil-bearing layer sedimentary characteristics, Putaohua oil-bearing layer in Sanzhao depression eventually established shallow water delta oil-bearing layer sedimentary model which controlled by synsedimentary tectonic uplift, which is important to guide the next exploration and development.

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