

Sedimentologic properties of the oil-producing Late Cretaceous fluvio-deltaic Fuyu reservoirs of the Quantou Formation, Songliao Basin, Anda Sag, NE China

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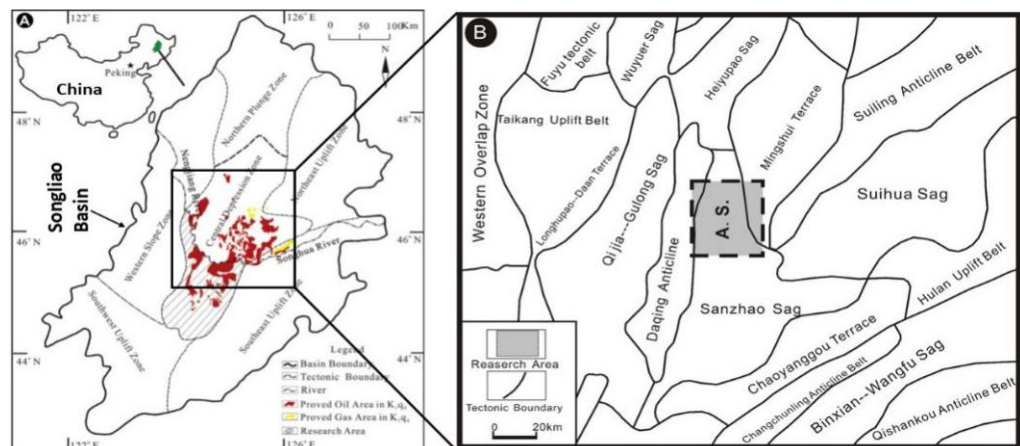
Summary

The Lower Cretaceous system of the Songliao Basin consists of several oil- and gas-producing sandstone intervals with muddy intervals that act as cap rocks. The reservoir units include, in an ascending order, Fuyu, Gaotaizi, Putahohua and Heidimioao. The Fuyu reservoir constitutes the upper part of the Quantou Formation, particularly the uppermost strata of K₁q₃ member and the overlying K₁q₄ member. The reservoir interval consists of fine-grained sandstone with claystone to siltstone interlayers. The sandstone reservoir units are characterized by moderately sorted, fine-grained, planar to low angle tabular cross beddings and cross-laminations. The sandstone commonly have sharp to erosional lower boundaries with the muddier facies and sharp to gradational upper boundary with the muddier facies. These sedimentary properties along with patterns of the wireline logs from wells in the study area suggest that the strata of the Fuyu reservoirs accumulated in a fluvial to deltaic depositional system that ended up in a lacustrine environment. The depositional system was most likely river-dominated where tidal influence and wave actions were apparently minimal. The sediments brought by the rivers were fine (clay to fine-sand size) in nature. It is interpreted that the sandy facies accumulated in both subaerial and subaqueous distributary channels of delta plane and proximal delta front settings. The muddy facies accumulated interchannel and distal delta front settings.

Introduction

Songliao Basin is one of the sedimentary basins that produce oil and gas in northeast China (Fig. 1A). The basin contains different tectonically-induced sags and uplifted zone which occurred during the early cretaceous (Li, 2002; Gao, 2017; Huang et al., 2017a, 2017b). One of these sags is the Sanzhao Sag and the study area is located in the northernmost part of the sag which is formed by a subsage called Anda (Fig. 1B). A number of wells have been drilled in the Anda subsag and the stratigraphic succession of the study area is shown in Fig.2. The Cretaceous succession of the study consists of siliciclastic units stratigraphic. The Fuyu reservoirs are Early Cretaceous stratigraphic unit which occur in subsurface of the Anda Sag of the Songliao Basin,

Fig. 1A Location map of the Songliao Basin and distribution of the oil and gas fields. The square shows location of Fig. 1B which shows different sags and highs. The shaded box depicts the study area located in the northern part of the Sanzhao Sag. A.S. stands for Anda Subsag.

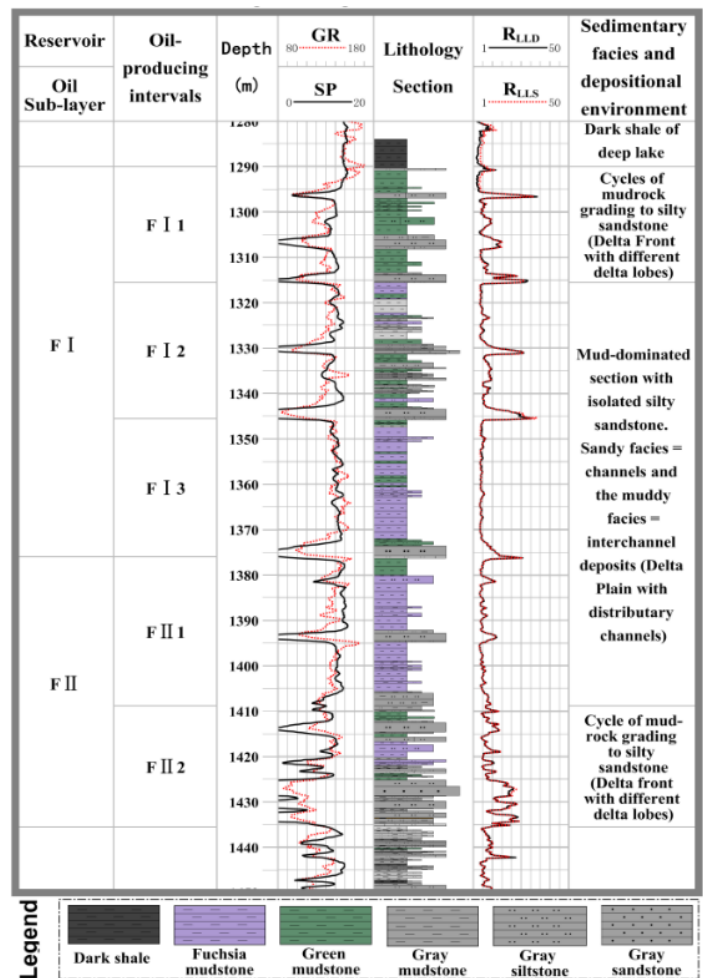


Northeast China (Fig. 1A). The reservoir unit represents the K₁Q₄ Member of the Quantou Formation which is characterized by mudrock and sandstone interbeds. The Fuyu reservoir is one of the most important sand-dominated units of the formation and consists of coarse- to fine-grained sandstone lithology. The latter is divided into two members, lower Fuyu I and upper Fuyu II with further subdivision of each of these two members (Fig. 3)

Period	Epoch	Formation	Member	Reservoir
Quaternary			Q	
Neogene	Pliocene	Taikang	N ₁ d	
	Miocene	Da'an	N ₁ d	
Paleogene	Oligocene	Yi'an	E ₁ y	
	Late Cretaceous	Mingshui (K ₁ m)	K ₁ m ₃	
Sifangtaizi		K ₁ s		
Cretaceous	Early Cretaceous	Nengjiang (K ₁ n)	K ₁ n ₅	
			K ₁ n ₄	Heidimiao (H)
			K ₁ n ₃	
			K ₁ n ₂	Sa'ertu (S)
			K ₁ n ₁	
		Yaojia (K ₁ y)	K ₁ y ₂₋₁	Putaohua(P)
		Qingshankou (K ₁ qn)	K ₁ qn ₃	Gaotaizi(G)
			K ₁ qn ₂	
			K ₁ qn ₁	
			K ₁ q ₃	Fuyu(F)
K ₁ q ₂				
Denglouku	K ₁ d			
Yingcheng	K ₁ yc			
Shahezi	K ₁ sh			
Jurassic	Late Jurassic	Huoshiling	J	
Triassic~Carboniferous			H-T	

Fig. 2 Carboniferous to Quaternary stratigraphic column of Songliao basin. Stratigraphic location of the Fuyu reservoirs is highlighted in yellow. The reservoirs represent the upper part of the K₁q₃ and K₁q₄ members of the Quantou Formation.

Fig.3 (right) Stratigraphic log from Well SONGV5 with wireline logs (Gamma, SP to the left and Resistivities to the right). The stratigraphic positions of the cleaner sandy facies of the Fuyu reservoirs (F_{I1}, F_{I2}, F_{I3}, F_{II1} and F_{II2}) are shown



Lithofacies properties and depositional enviro

The lithofacies properties of the K₁q₃-K₁q₄ members can be simplified to two major types: sandstone and mudrock lithofacies. Examples of these facies and their response to wireline logs are shown in Fig. 4A to Fig. 4H. The sandstone lithofacies is characterized by silty fine-grained sand (0.063~ 0.25mm) with planar to low angle cross-beddings (Fig. 4A & 4C). The SP and GR curves of the sandstone are characterized by a combination bell-shaped (e.g., Fig. 4B) to somewhat symmetrical (Fig. 4D) curves suggesting fining-upward, point bar deposits and amalgamation of distributary channel / crevasse splay deposits. These sediments accumulated in shallow, delta front setting where relatively higher energy channels were filled by the coarser sediments and interchannel areas were filled by finer muddy facies (Fig. 4E). The mudrock lithofacies includes two facies types: grey and green clay-rich siltstone deposited in interchannel areas within the delta front (Wang, 2006) and purple, red or yellow claystone to siltstone developed in between the interdistributary channels of the delta plain (Liu, 1998; The latter channels are filled by tabular cross-bedded fine- to medium-grained sandstone with mudchips derived from the interchannel deposits (Fig. 4G).

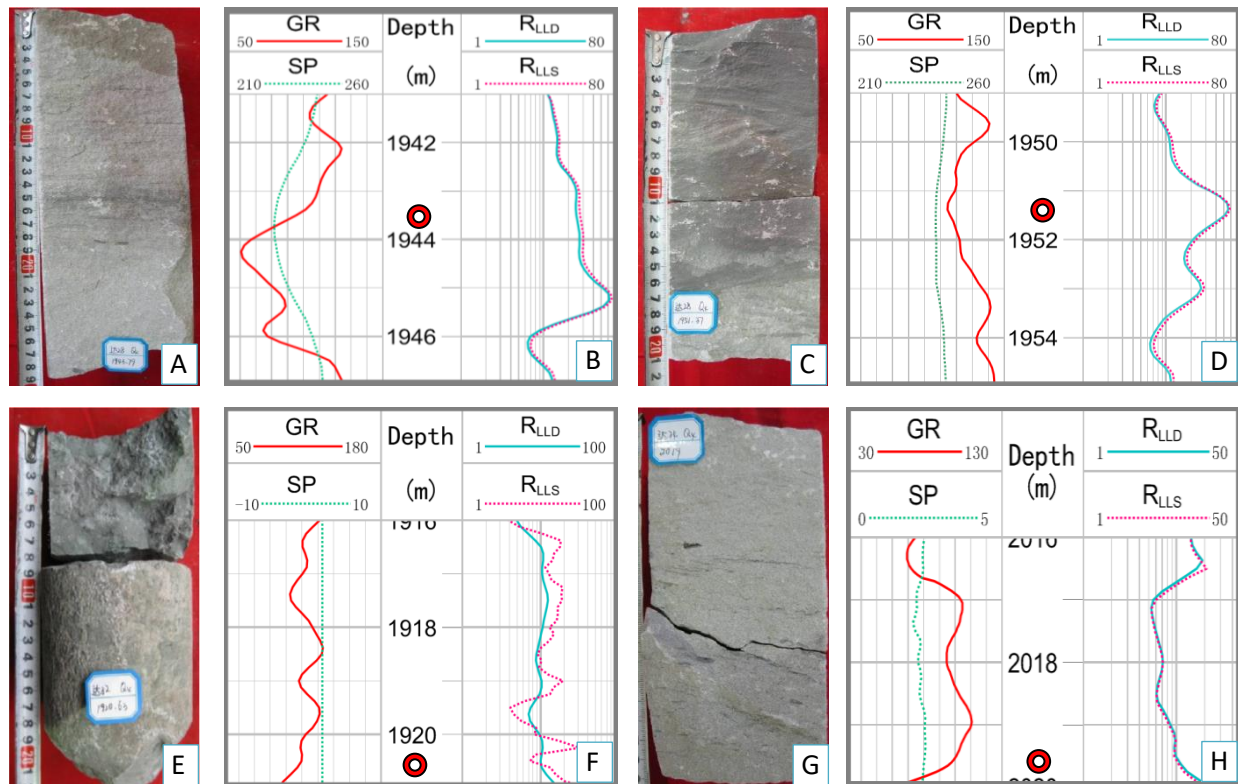
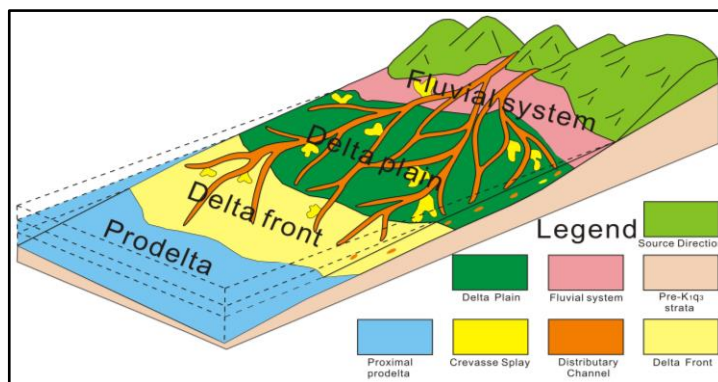


Fig.4 Selected core photos and wireline logs from the sediments of the Fuyu reservoirs. Circles in the wireline curves show locations of the cores. A) Subaqueous distributary channel deposits of gray sandstone with poorly-developed trough and tabular cross-beddings (Well: DAV28, 1943.79m). B) Bell-shaped SP and GR curves suggesting fining-upward, point bar channel deposits (Well DAV28). C) Subaqueous channel or crevasse splay deposits formed by cross-laminated, siltstone (Well: DAV28, 1951.37m). D) Symmetric GR curve (coarsening then fining upward) of possibly prograding delta lobe followed by waning of the depositional energy and gradual fining of the sediments within the delta front area (Well: DAV28). E) Subaqueous inter-distributary channel deposits of grayish green mudstone (Well: DAV32, 1920.63m). F) High value GR curve from the inter-distributary mudrocks of the delta front region (Well DAV32). G) Distributary channel deposits with purple mudrock chips of the delta plain channels. The mudrocks are reworked from the inter-channel zones (Well: DAV34, 2019m). H) High GR curve from the muddy facies of the delta plain inter-channel deposits (Well: DAV34).

Depositional model:

During the depositional period of Fuyu reservoir, Songliao Basin has been in a stable depression stage. The area of the lake basin was large with shallow lake water. The hinterland of the lake was not high, and the lake level fluctuated frequently. There were no tidal influence and the wave energy was weak. Under these depositional conditions, large, shallow, fluvio-delta sedimentary system was established and dominated by the fluvial action (Lou, 2004; Sun, 2012). The depositional system contained contiguous sub-environments of delta plain and delta front with interdistributary channels in both areas (Fig. 5). Besides the deposits of the delta plain and delta front, subordinate meandering river deposits also occurred beyond the delta plain (Fig. 5).

Fig. 5 Depositional model of the Quantou Formation (K_1q) in which the strata of the Fuyu reservoirs are included. The reservoir units mainly occur in the distributary channels in both delta plain and delta front areas, as well as crevasse splay deposits.



Conclusions

The Fuyu reservoirs occur in the upper part of the Early Cretaceous Quantou Formation (K_1q), particularly in the upper part of K_1q_3 member and K_1q_4 Member. Subsurface analysis of rocks and wireline logs from wells drilled through the two members demonstrates that the section consists of fine-grained sandstone lithofacies that commonly form the reservoirs that are filled by high resistivity fluids (oil and gas). The sandstone lithofacies are intervened by grey to green and purple to yellow mudrocks. The whole sequence accumulated in a fluvio-deltaic system in a lacustrine setting. The sandstone facies accumulated in distributary channels and possibly as crevasse splays at the delta plain and delta front whereas the mudrocks accumulated in inter-channel areas of the delta plain and delta front environments.

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