Journal of Energy and Natural Resources
2020; 9(1): 44-50
http://www.sciencepublishinggroup.com/j/jenr
doi: 10.11648/j.jenr.20200901.18
ISSN: 2330-7366 (Print); ISSN: 2330-7404 (Online)

Coarse-grained Lacustrine Slope Apron Deposits in Shaobo Area, Gaoyou Sag, Southern China

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To cite this article:
Zhou Yigang, Li Cunlei, Yan Yunbiao, Chen Panpan. Coarse-grained Lacustrine Slope Apron Deposits in Shaobo Area, Gaoyou Sag, Southern China. *Journal of Energy and Natural Resources*. Vol. 9, No. 1, 2020, pp. 44-50. doi: 10.11648/j.jenr.20200901.18

Received: February 18, 2020; **Accepted**: March 16, 2020; **Published**: April 1, 2020

Abstract: The Dainan formation reservoirs in Shaobo area, Gaoyou sag, Southern China, sedimented mass conglomerates dominated by lacustrine slope apron system which fended by multiple flood channels with massive terrigenous clasts. In the early days, offshore fan-shaped sediments in the Shaobo area of the Gaoyou Sag were considered to be the main sedimentary system. However, a new lacustrine sedimentary model is presented in this paper. By careful core description and interpretation, four facies unions are recognized: (1) Facies union 1: Downslope clastic pathways that composed of massive conglomerates up to 6-25m thick, alternating with brown-dark gray mudstone and the etching structures can be often observed; (2) Facies union 2: Debris-flow Lobe is composed of massive conglomarates, matrix-supported to clast-supported polymictic conglomerates up to 10-50m thick; (3) Facies union 3: Underwater distributary channel is composed of trough cross-stratified sandstone, horizontally stratified sandstone and ripple cross-stratified fine to medium-grained sandstone, up to 5-20m thick; (4) Facies union 4: mudstone is dominates by thick grey black mudstone interbeding thin sandstone, the etching features are rare and bedding is typically parallel. In our study area, the traction current deposits constitute the producing petroleum reservoirs, and the conglomerates deposits are poor reservoirs. The sedimentary model may be applicable to other fault depression for predicting reservoir distribution.

Keywords: Slope Apron, Gaoyou Sag, Lithofacies, Facies Union, Depositional Model

1. Introduction

Slope apron was first proposed as a gravity apron sedimentary accumulation body with multiple supply channels while Cooks studied the allochthonous carbonate blocks [1]. Dorrik reposed overlapping-fan slope-apron system which represents a series of small overlapping fans that forms a thick (300m) slope-arpon accumulation of sediments deposited in a narrow belt along an active fault zone [2]. Russell et al. deemed the Northwest African continental magrin to a typical fine-grained calstic slope apron, with pelagic & hemipelagic 'background' sedimentation overprinted by downslope gravity flows and modified by alongslope bottom currents [3].

Gaoyou sag has been the focus of intensive research in the last thirty years. Early sedimentary facies maps show the nearshore subaquous fan is the main depositional system of Shaobo area in Gaoyou sag [4, 5], but the exploration and development practices show the main oil reservoirs are the sandy layers (caused by traction flow) which distribute between or the front of the conglomerate layers. It is different to explain this phenomenon by the nearshore subaqueous fan model which deposits are dominated by turbidity currents. The significance of our study is that we propose a new lacustrine sedimentary model (lacustrine slope apron) to explain this phenomenon and guide the oil exploration and development. The establishment of this model is benefit by the vast core data which make it possible to do the distribution research of lithofacies.

2. Geological Setting

Gaoyou sag which faults in the south and overlaps in the north is a grabenlike fault depression in the abdomen of Dongtai depression, Subei Basin. It is about 100km in the east-west direction, and about 25-30km in the south-north direction. The area is about 2670km^2. It had deposited about 7 kilometer continental strata at the last stage of the Eocene. Shaobo area locates between Huangjue area and Zhenwu area on the southern abrupt slope of Gaoyou sag [6, 7]. To the north, it is the Shaobo sub-sag, which is an important hydrocarbon generation sub-sag of Gaoyou sag and offers favorable oil source [8, 9] (Figure 1). The thickness of Dainan formation in Shaobo area is about 100-900m.

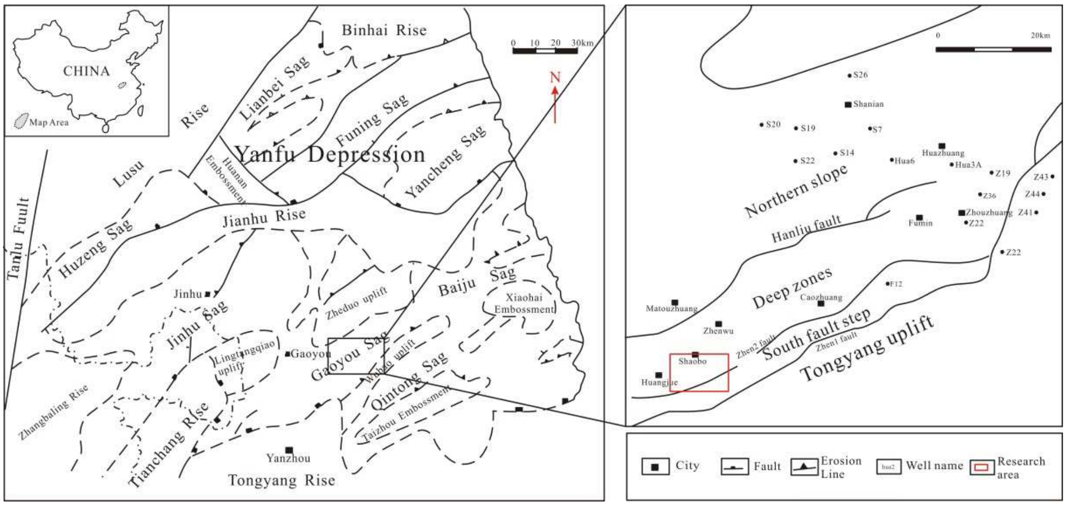

Figure 1. The structural map of Gaoyou sag.

3. Methods

The shengtuo area possesses abundant data (including drilling, log, test and seismic data, etc.), so it is conducive to detailed lithological and sedimentological recognition.

6 well cores were taken from locations in the study area, and all these cores were situated and sampled with the application of grain size analysis. Sedimentary descriptions were made from all cores with a particular focus on sediment color, and visual grain size. Sediment slabs were collected from the spilt core section and examined by red epoxy using a SCOPIX digtal X-ray imaging system and the obtained digital images were used to provide a precise identification of the sedimentary structures. Five main sedimentary structures were identified in the study area.

All samples from the 6 wells were examined with a Hitachi S−530 scanning electron microscope (SEM) equipped with a Hpilips 9100 energy dispersive X-ray spectrometer (EDS). All collected cores were sampled for grain-size analyses using a Coulter laser micro-granulometer (LS130). Two main types of sediments were distinguished: lithic arkose and arkose.

4. Results and Discussions

4.1. Facies Unions and Sedimentary Environments

A total of 80m of conventional cores are described and sampled of grading analysis. We have recognized 12 lithofacies. The description and interpretation of lithofacies are summarized in table 1. The 12 lithofacies described above occur in four discrete lithofacies associations recognized through analysis of core data which revealing the distribution of lithofacies in vertical and plane.

Table 1. Lithofacies distinguished in study area.

Lithofacies	Description	Interpretation
Gmd	Matrix-supported (matrix content 25% - 40%), disorganized glutenite with boulder and pebbles	Debris flow depositions which form from underwater viscous debris flows [10]
Gm	Matrix-supported to clast-supported massive glutenite with cobble and pebbles	Debris flow depositions form from underwater mudstone debris flows [11]
St	Very fine to coarse-grain size trough cross-stratified sandstone	The typical traction flow depositions form from traction flow
Sh	Very fine to coarse-grain size horizontally stratified sandstone	Traction flow planar bed flow, high flow regime of traction flow [12]
Sr	Ripple cross-stratified fine to medium-grained sandstone	Form from high flow regime of traction current [12]
Swl	Fine to medium-grain size wavy -Lenticular bedding sandstone	Form from suspension settling to low flow regime [12]
Sd	Light grey fine-grained deformed bedding sandstone with exhibiting slum folding	Form from sedimentary sandy slumping [12]
Sm	Fine-grained light to gray massive sandstone with floating mudstone and shale clasts of various seize	Form from High density turbidity current by Lowe [13], or form from sandy debris flow by Shanmugam [14]
Sg	Normal graded bedding coarse fine sandstone and silt	Form from turbidity current
Sdi	Normal bedding light grey fine-grained sandstone interbedded dark grey mudstone	Form from turbidity currents from suspension settling [15]
Lm1	slum folding structure brown-dark gray mudstone	Form from fairly deep lake
Lm2	lenticular bedding massive black mudstone to siltstone.	Form from suspension deposits in deep lake zone

4.1.1. Facies Union 1: Downslope Clastic Pathway

This union forms disorganized, matrix-supported conglomerate (Gmd) up to 6-25m thick, alternating with brown-dark gray mudstone (Lm1). The conglomerates assigned to the union show scoured bed, and the etching structures can be often observed (Figure 2).

The conglomerates of this union represent deposition on a dowmslope clastic pathway which controlled by the alluvial rivers in the steep slope zone (proximal zone). The high matrix ratio, internally chaotic nature, and contorted rip-up chaotic of the underlying beds indicate deposition from viscous debris flow channels that may have originated form mud-rock flow resources [16, 17, 18].

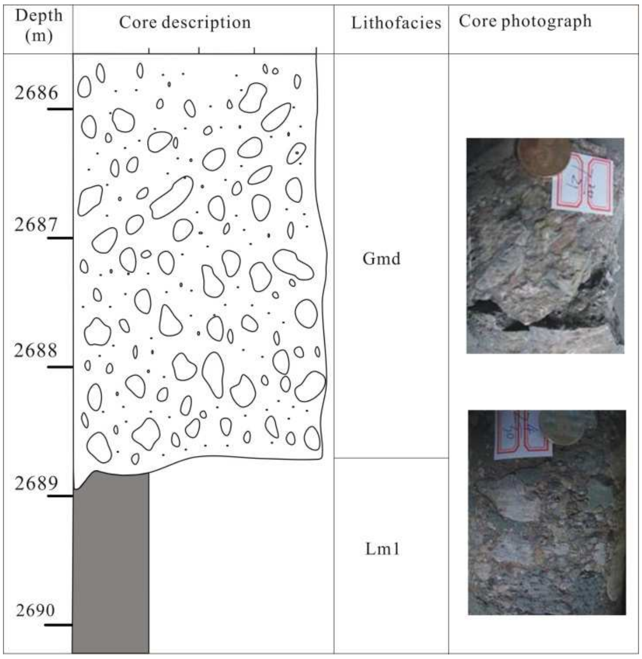

Figure 2. Sedimentological log of well shao9 showing the characteristics of facies union 1. Core photograph showing disorganized conglomerates.

4.1.2. Facies Union 2: Debris-Flow Lobes

This union composed of disorganized matrix-supported conglomerate and normally graded conglomerate-sandstone couplets with intercalation of mudstone and thin-bedded sandstone beds. The common bedding in this area includes deformation bedding, massive bedding, and inverse graded bedding, but the traction flow beddings are not very obviously. This union can from a 20-50m thick succession. The vertical sequence appears positive rhythm. The sediments have the characteristics such as large change of grain-size, complicate composition, high shale content and poor sorting property (Figure 3).

Disorganized, clast-supported conglomerates are probably deposits of debris flows, or density-modified grain flows [13] Due to its low mud content, dispersive pressure produced by clast collision would have played an important role in supporting clasts within the flow. The sandstone capping probably represent deposits of sediment-laden turbulent flows entrained above and deposited after the moving debris mass flow. Debris-flow is a kind of non-Newtonian fluid formed by the flow of sediment of high concentration, and the fluid type is laminar flow [19, 20]. The relative density of matrix is as high as 2.5. The debris-flow will stop when the tension along the slope (the middle zone) caused by gravity is no more than the shearing force of the debris-flow block, and then will form debris-flow lobe.

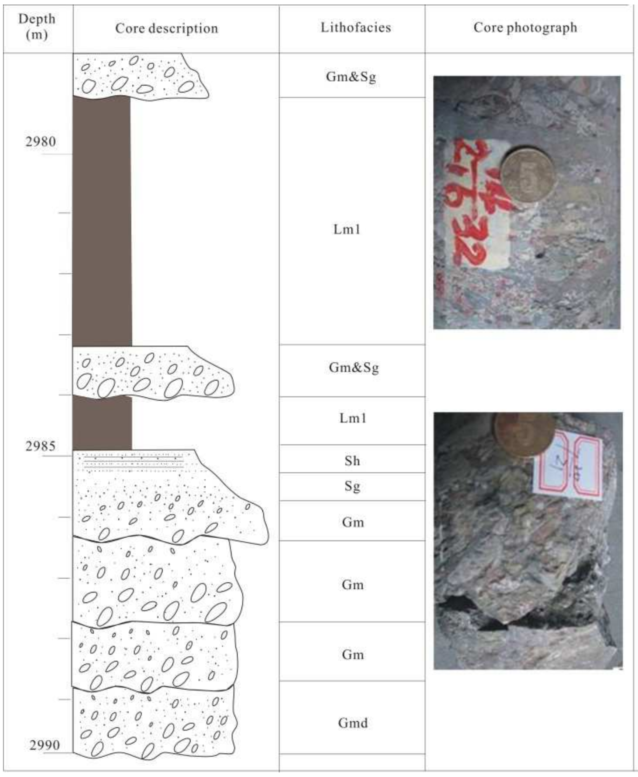

Figure 3. Sedimentological log of well shao9 showing the characteristics of facies union 2. Core photograph showing disorganized conglomerates and conglomerates with orientational gravels.

4.1.3. Facies Union 3: Underwater Distributary Channels

This union is composed of Gm, Sm, St, Sh and Lm1, forming positive rhythm sequence. The bottom of sequence mainly abrupt contact with the subjacent mudstone, and some other are gradually contact. the lower sequence is composed of massive, matrix-supported to clast-supported conglomerates and rough cross-stratified sandstone. In the upper of the sequence, the conglomerates are poor, mainly composed of low angle cross-bedding and ripple sandstone (Figure 4). This single depositional union is thick (some can even reach to 7 meters). This union always distributes above or front of the unin 2.

Underwater distributary channels are not only the extension of downslope clastic pathway in semi-deep water zone, but also are controlled by the source systems which transform form mudstone flow (debris flow) to slack current. The lower of this union occasionally appears the characteristics of debris flow, but the main body of this sequence mainly is dominated by traction current. Because of the slope-grade elimination, fine-grained pelagic sediments are widespread which controlled by multiple underwater distributary channels and the clastic deposits form an apron shape in the middle zone.

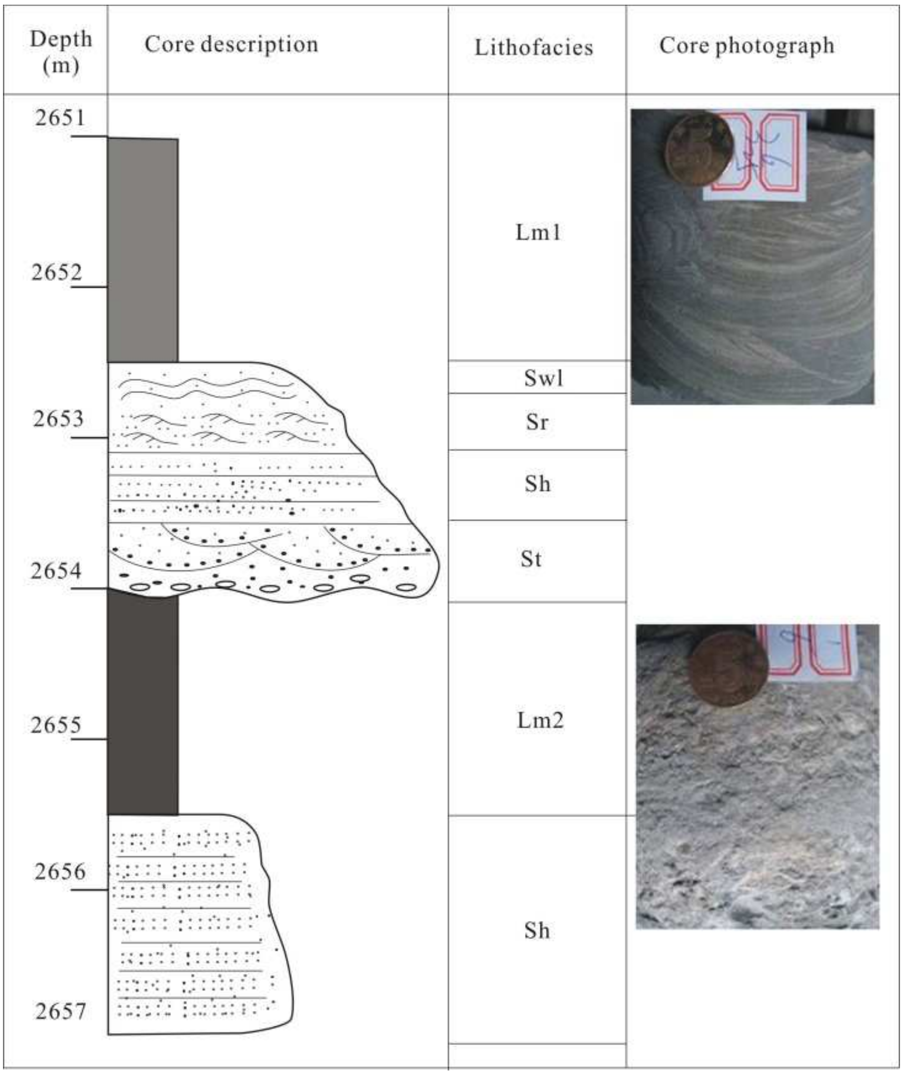

Figure 4. Sedimentological log of well shao9 showing the characteristics of facies union 3. Core photograph shows positive rhythm sequence. With Sh, Lm2, St, Sh, Sr, Swl and Lm1.

4.1.4. Facies Union 4: Mudstone

This union is located in front of slope apron, and have fell into the deep lakebed. It is dominated by thick black mudstone interbeding thin sandstone, the etching features are rare and bedding is typically parallel. at the same time, the massive sandstone or normal graded bedding sandstone can be observed.

This union represents a low-energy, subwave base setting (the distal zone), characterized by sedimentation from sandy debris flow and turbidity currents which are intermittently interrupted deposit in the deep lake environment. The deformed bedding sandstones (Sd) indicate the depositional setting is unstable. Slumping and sliding can be attribute to the origins of sandy debris flow.

Previous studies consider that the sedimentary facies of Shaobo area, Gaoyou sag is nearshore subaqueous fan, but we hold the views that slope apron system is the dominated sedimentary system in study area. In this paper we distinguish them by source supply styles, causes of formation, Lithology and lithofacies, sedimentary tectonics and depositional sequence.

4.2. Slope Apron Model

Depositional models indicate and describe the relationship among the sedimentary environment, sedimentation and sedimentary resultant (sedimentary facies). It is the explanation of the cause and the theoretical generalization of sedimentary facies. The depositional model is not only displays the most typical characteristic but also shows the connection between the sedimentary facies and environment in nature [21]. The dark mudstone exposes that the study area is deep environment. The high changes of mudstone color grads, from south to north, exposes the high grade of abrupt slope of the research area.

In our study area that deals with default depression deep lacustrine environments, available data suggest the new sedimentary model: lacustrine slope apron model which has as Line source (multiple sources) and multiple etching supply channels, as shown in the Figure 5.

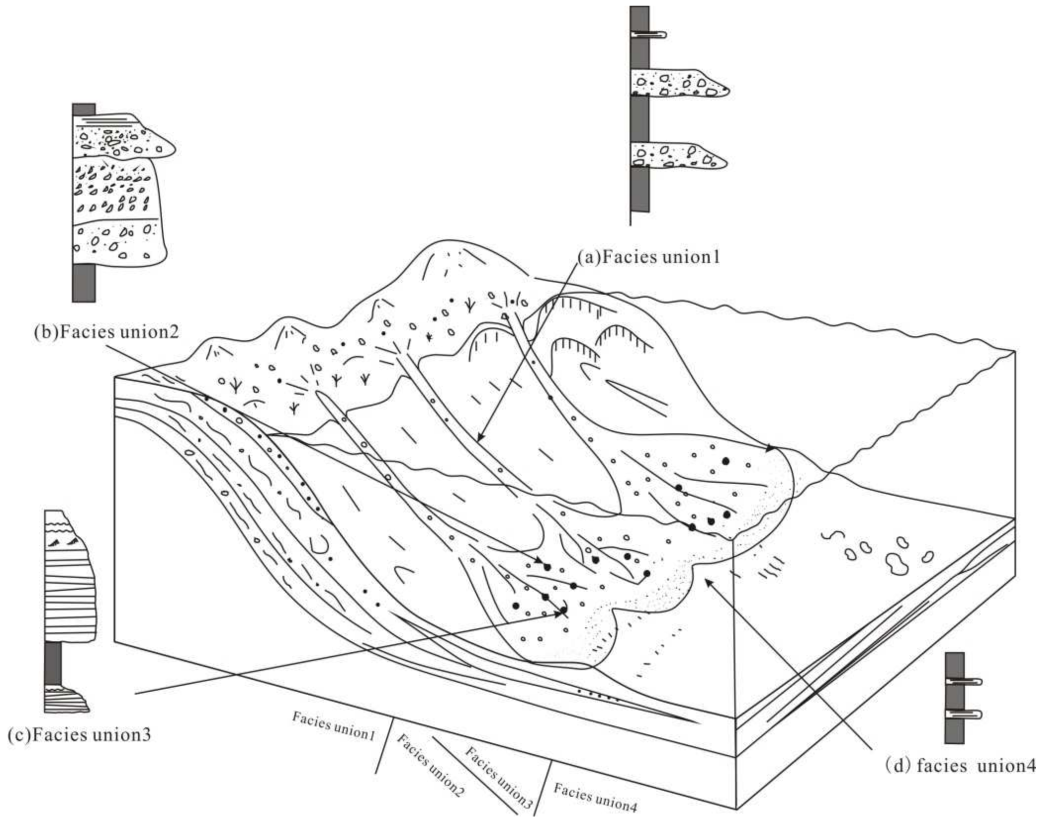

Figure 5. *Depositional model of slope apron, E2D, Shaobo area, Gaoyou sag.*

4.3. Facies Union Distribution

At the stage of E2D, the research area presents the feature of water rising and sand receding. The source mainly comes from south Tongyang rise. The sources enter lake by several channels and form several apronlike fan sand bodies at the deep water area. The sand mainly distributes along the shao6-shao7-shao11 well and extends to the basin direction. Several channels extend to the basin direction and form the channels system which link together and form large depositional lobes. The four facie unions of slope apron of this area develop well. The distributary channels develop on a large scale, and develop thinner granularity's apron bar sand bodies at the front of that. In general, the distributary channels are strong trend and the sand granularity minish form south to north (Figure 6).

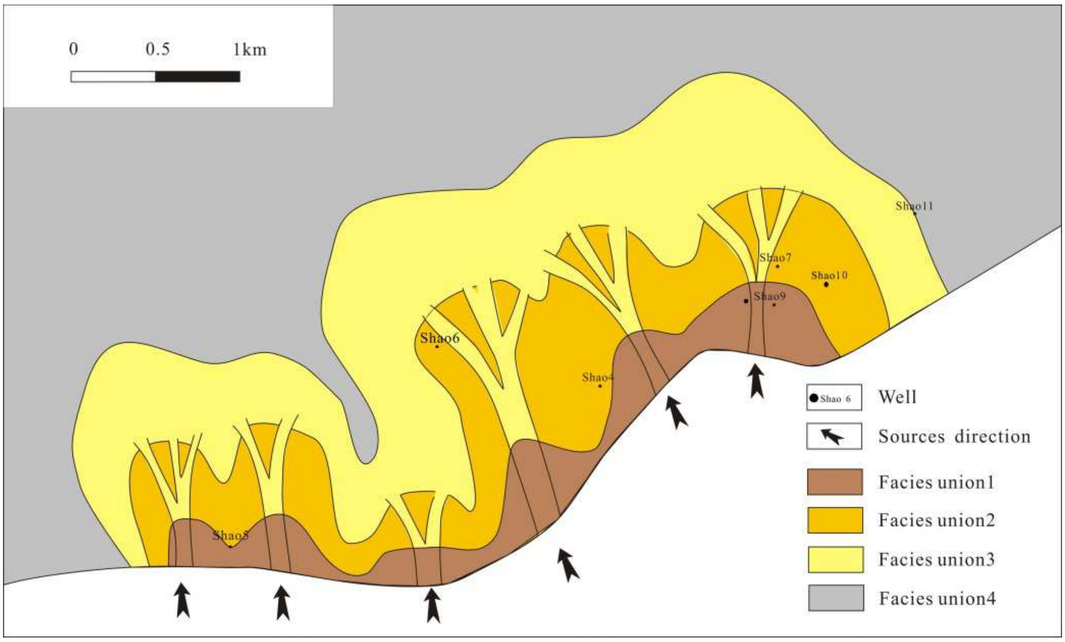

Figure 6. *Distribution map of facies unions in Shaobo area, E2D.*

5. Conclusion

The sedimentary system is a typical clastic slope apron with multi-sources in Shaobo area. It can be identified four facies unions: downslope clastic pathways, debris-flow Lobe, underwater distributary channel and mudstone. The slope apron is made up of various architectural elements, and consist both constructional and etching sections. The pattern of sedimentation in this area is controlled by topography. The facies-control on the sand distribution is obvious: the fine-grained pelagic sediments mainly distribute in the above and front of debris-flow lobes of the middle zone, which could be good oil and gas reservoir.

There are some various different between slope apron and nearshore subaqueous fan. The slope apron is debris flow system with line-source, and the main sequence is positive rhythm sandy conglomerate with blocky bedding, but there is not high density turbidity current sequence. The nearshore subaqueous fan is turbidity system with point-source, and the high density turbidity current sequence and the Bouma sequence is the distinguished features.

Slope apron sand-body always superpose with deep-lake mudstone, which can became good lithologic trap and source-reservoir-cap assemblages, and appear to gather oil and gas.

Acknowledgements

This paper is supported by Natural Science Foundation of China (41502100), Liaoning provincial research foundation of China (201601328), Basic research projects of Liaoning province (L2017LQN017), Talent scientific research fund of LSHU (XJJ2016-026). The authors thank Sinopec, Jiangsu oilfield Corporation for supplying researching data and offering convenience for observing the cores.

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