Sedimentary structure characteristics and depositional facies of Paleogene Es4 in Dongying Sag, Jiyang Depression, Bohai Bay Basin, China

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Abstract. Through recognizing the characteristics of sedimentary structures in the cores, the sedimentary facies of Paleogene Es4 in southern slope of Dongying Sag were recognized. The sedimentary structures included bedding, bed plane structure, contemporaneous deformation structure, and biogenetic structure. Finally, the sedimentary facies, consisting of braided-river delta, alluvial fan, beach dam, and lacustrine, were recognized, which would not only contribute to the petroleum exploration and development in the initial period of Dongying Sag, but also help carry on the basin analysis of the rifted basins.

1. Introduction
Sedimentary facies is not only basic for the petroleum exploration and development in the oil-bearing basins, but also significance for basin-analysis, such as analyzing the paleo-environment, paleo-climate, etc[1,2]. The fourth member of Shahejie Formation (Es4) was deposited in the initial rift period of Dongying Sag, and was buried deep, the seismic profile quality was too poor to recognize the sedimentary facies, which has brought high risk to the petroleum exploration of Dongying Sag and large difficulty to carry on the basin-analysis. Therefore, how to recognize the sedimentary facies through other data or materials was significant and urgent.

It is known that the sedimentary characteristics in cores, such as the cross-bedding or parallel bedding, could reflect the sedimentary facies perfectly[3]. This paper aimed to use the cores and the sedimentary characteristics to recognize the sedimentary facies.

2. Geological background
Dongying Sag was surrounded by Luxi Uplift to the south, Chenjiazhuang Salient to the north, Bixian Salient to the west. The sag was formed during Paleogene by the extension stress, and extended with the trend of E-W. The study was located in the south of Dongying Sag[4].

During Paleogene, Kongdian Formation, Shahejie Formation and Dongying Formation were deposited in ascending order. The study strata was the fourth member of Shahejie Formation, which was located at the foot of Shahejie Formation, so was deeply buried.
3. The sedimentary structures

3.1. Bedding

Bedding was an important structure implying the sedimentary environment. In study area, the bedding included parallel bedding, cross bedding,

3.1.1. Parallel bedding

The parallel bedding was mainly produced in sandstone, and was very similar with horizontal bedding in appearance, but mainly formed in the strong hydrodynamic conditions, reflecting the rapid high-energy water in a shallow flow environment, such as river shore beach where the turbidity current deposits. Channel parallel bedding developed greatly in the study area, such as 2081.00 m in Well Wang 130 and 3053.00 m in Liang 120 (Fig.2), which implied the development of distributary channel and reflected the river delta deposition[5].

Fig.2 The parallel bedding. a: Well Wang 130, 2081.00m; b: Well Liang 120, 3053.00m

Fig.3 Wave-built cross-bedding. a: Well Wang 130, 1744.10m; b: Well Niu 5, 2753.95m; c: Well Liang 120, 3243.92m.
3.1.2. Wave-built cross-bedding
This cross-bedding is another important and special kind of cross bedding, which is characterized by the laminae being straight or slightly curved upward, and the laminae of adjacent oblique laminae incline in the opposite direction and intersect each other at an acute angle when extending to the laminae interface. Formed under the influence of waves, it is commonly found in deltas where rivers enter the lake or sea, or in coastal areas (Fig.3). It often reflect the deposition of beach dam[6].

3.1.3. Massive bedding
The material inside the block bedding is relatively uniform, and there is no differentiation in composition and structure. Block bedding can be formed by rapid deposition of suspended materials, such as flood deposition. It can also be formed by deposits of very dense, unsorted sediments, such as gravity flow deposits. Sometimes even strong biological perturbations can form block bedding. This area is rich in block bedding (Fig.4), which mainly occurs in the environment of alluvial fan[7].

3.2 Bed plane structure
Scour surface is an important bedding structure. The scour surface is an undulating scour surface due to the sudden increase of flow velocity and the fluid scour and erosion of the underlying sediments. The sediment on the scour surface is generally thicker than the underlying sediment. Sedimentary environments such as alluvial fan-shaped channels[6], river channels and distributary channels in deltas are prone to the formation of scour surfaces (Fig.5).

3.3 Contemporaneous deformation structure
Contemporaneous deformation structures refer to the structures formed by the deformation of sediments in the plastic state at the same time of sedimentation or before consolidation and diagenesis. Contemporaneous deformation structure is also called deformation structure or soft sediment deformation, is at the same time in the sedimentation of rock or sediment consolidation before the sediment in a plastic state under the soft sedimentary variant structure: such as weight, sand and sand cushion modular structure, globular structure, pillow, slump structure, lapped bedding, sandstone vein (dike) and rock bed, etc.

In Shahejie Formation of the study area, there are bulbous structure, heavy load and flame structure, slump deformation and other deformation structures (Fig.6). These structures implied the delta front deposit in Dongying Sag[8].
Fig. 6 Contemporaneous deformation structures. a: Well Liang 120, 3241.50m, bulbous structure; b: heavy load structure; c: bulbous structure; d: slump deformation.

4. Conclusions
The sedimentary structures in Paleogene Es4 in Dongying Sag included bedding, bed plane structure, contemporaneous deformation structure, and biogenetic structure.

The sedimentary facies in Paleogene Es4 consisted of braided-river delta, alluvial fan, beach dam, and lacustrine

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