Development mode and distribution characteristics of biolimestone of the Shahejie1 Formation in the Changdi Area of the Zhanhua Sag

chuanjin Xie *
Research Institute of Exploration and Development, Sinopec Shengli Oilfield company, Dongying, Shandong Province 257015, China

* Corresponding author e-mail: xiechuanjin.slyt@sinopec.com

Abstract. Using core, drilling, logging and seismic data, the development and sedimentary evolution of biolimestone of the first member of Shahejie Formation of Zhanhua Sag were researched. The first member of Shahejie Formation Changdi Area is defined as a third-order sequence, and the biolimestone developed in the first member of Shahejie Formation was divided into three fourth-order sequences. The lacustrine transgressive system tract and the lacustrine regressive system tract, where the biolimestone both developed were also identified. The development of biolimestone is influenced by paleoclimate, relative paleowater depth and paleogeomorphology. There are three types of paleo water depth variation in the Member of Shahejie Formation, namely the water withdrawal, the high position water and the low position water. Through paleogeomorphology restoration, it is clear that the biolimestone in the first member of Shahejie Formation is mainly distributed in the southeast and eastern slope trough, and then it is determined that there are two development modes in the study area, which are the biolimestone developed in gentle slope and the biolimestone developed in trough. Due to the periodic change of the lake level, the distribution of the biolimestone in the first member of Shahejie Formation also changed correspondingly. The biolimestone is thicker around the uplift and thinner along the gentle slope direction, and its belt-like distribution is parallel to the periphery of the buried hill.

1. Quote
Carbonate reef-beach facies is an ideal reservoir for oil and gas. It is a kind of special carbonate structure formed on the basis of reef building organism skeleton. The exploration practice of shengli oilfield proves that the biolimestone of the first member of Shahejie Formation in Changdi Area of Zhanhua Sag is an important target for oil and gas exploration in this area. Up to October 2019, 35 exploration Wells in this area have been drilled into biolimestone in the first member of Shahejie Formation and oil and gas shows have been seen, 13 industrial oil-flow Wells and 4 low-production oil-flow Wells have been obtained, indicating that biolimestone in the first member of Shahejie Formation has good exploration potential. However, previous studies on this issue are few and there are still the following problems: 1) The thickness of biolimestone in the area is relatively thin, ranging from 2-8m, and it is difficult to make vertical and horizontal comparison. Conventional seismic attributes cannot accurately predict the thickness distribution characteristics of biolimestone. 2) The controlling factors of
biolimestone development in the study area are not clear. 3) The development model of biolimestone in the study area has not been established, and the characteristics of planar distribution are not clear. Based on the research results of high-frequency sequence stratigraphic division and system domain, this paper studies the inner structure and development rules of biolimestone in the first member of Shahejie Formation of Changdi Area, identifies the controlling factors of biolimestone development, establishes its development model and implements its plane distribution characteristics.

2. Geological overview
Changdi Area is located in the central and southern part of Bohai Bay Basin, and its tectonic position is between Zhanhua Depression of Jiyang Depression and Huanghekou Depression. It is located in the south of Chengdao - Zhuangxi - Changdi - Gudong buried hill overburden belt. It is located in the south of Chengdao - Zhuangxi - Changdi - Gudong buried hill overburden belt. It is composed of buried hill overburden belt of Changdi and long embankment fault belt. It is composed of buried mountain overlying structure zone and long embankment fault zone, with a nearly north-south strip, covering an area of about 300 square kilometers[1]. The buried mountain mantle of Changdi was formed at the end of Yanshanian movement. It is a low sequence buried mountain mantle of Mesozoic Shanqiushan Basement[2]. The fault zone of Changdi Area is composed of a number of north-south and near-east-west faults cutting into each other in plane, and the whole buried mountain zone is divided into fault blocks or nose structures of different sizes. From west to east, it can be divided into three structural belts: low uplift belt, fault step belt and slope belt. The biolimestone in the first member of Shahejie Formation is mainly distributed in the slope belt, then in the low uplift belt and the fault step belt.

The sedimentary strata in Changdi Area include Paleozoic, Mesozoic and Cenozoic tertiary Shahejie Formation, Dongying Formation, Guantao Formation and Minghuazhen Formation. The bottom of the first member of Shahejie Formation is a regional unconformity interface, and the stratum of the second member of Shahejie Formation is mostly missing below it, which is in angular unconformity contact with the stratum of the third member of Shahejie Formation.

3. High frequency sequence stratigraphic division
Based on the core, logging and logging data, high frequency sequence stratigraphy was carried out for the biolimestone development section of Zhuang 1 well in Changdi Area[3, 4]. In the period of the first member of Shahejie Formation in the study area is a rising semi-cycle in the long-term base-level cycle, which is in the whole lacustrine transgression process with positive rhythm, and oil shale is developed at the top of the rising semi-cycle. Three medium-term base level cycles can be further identified from the bottom up of the ascending semi-cycle, which are PSQ1, PSQ2 and PSQ3. Each four-level sequence can be further divided into the lacustrine transgressive system tract and the lacustrine regressive system tract.

On the basis of high frequency sequence stratigraphy division of single well, Zhuang132, Zhuang181, Zhuang18 and Zhuanghai6 well in the study area were selected for well connection high frequency sequence stratigraphy correlation. The results show that the total thickness of three quaternary sequences developed in the first member of Shahejie Formation of the four exploration Wells is characterized by the two wings of the buried hill thicker than the top of the buried hill, the thickness and symmetry of the ascending and descending semi-cycles in each four-stage sequence are different. In the whole three-level sequence of the first member of Shahejie Formation, a set of oil shale as the boundary of system domain is the top marker layer of sequence stratigraphy division. This set of oil shale can represent the sedimentary environment with deep water body, weak hydrodynamic force and rich organic matter. The biolimestone of the first member of Shahejie Formation is mainly developed in the lacustrine retreat system domain of each four-level sequence, and relatively developed in the slope of the buried mountain in the north.

4. Biolimestone distribution control factors
The study area is relatively high in terrain and located in the uplift, with a small supply of terrestrial materials, which provides a stable tectonic background and relatively clear water environment for
biolimestone deposition. Based on the study of paleoclimate, relative paleo-water depth and paleogeomorphology, it is found that "three ancient" are the key factors controlling the distribution of biogenic limestone in the study area.

4.1. Paleoclimate
As a measure of temperature, precipitation, atmospheric humidity, and wind, climate determines the salinity and circulation of water. Previous studies believed that, in the period of the first member of Shahejie Formation, was relatively humid and the evaporation was relatively small. In terms of paleosalinity, the first sand section was a slightly salty lake and the water body was medium salt water, and the first member of Shahejie Formation was classified as a subtropical humid arid climate[5]. During the sedimentary period of the first member of Shahejie Formation subtropical humid arid climate and slightly salty lake environment were easy to develop biolimestone, which created conditions for the effective distribution of biolimestone in the study area.

4.2. Relative paleo-water depth
Previous studies have suggested that the limestone and dolomite in the carbonate beach dam are most suitable for the water depth of 20m and 25m respectively[6]. Due to the obvious cyclicality of stratigraphic deposition in the study area, the lake water expands and contracts alternately and the lake plane rises and falls periodically under the overall lacustrine transgressive background. Therefore, based on the high-frequency sequence division of a single well, this paper restated the change of relative lake level to analyze the relative paleo-water depth by bathymetry. Zhuang203, Zhuang317 and Zhuang4, for example, as a whole, the paleobybathymetry showed a trend of deepening, reflecting the large lacustrine transgressive background in the early period of the first member of Shahejie Formation. There were three cycles in the development of biolimestone relative to the paleobathymetry. In each cycle, ESP corresponded to a relatively large slope of the paleobathymetry curve, indicating a process of rapid lacuvial invasion and slow lacuvial retreat in one cycle. Biolimestone in Zhang 317 well was developed in the first quaternary sequence lacustrine regression system domain; Biolimestone in Zhang 4 well was developed in the second quaternary sequence lacustrine regression system domain; Biolimestone in Zhang 203 well was developed in the third quaternary sequence lacustrine regression system domain. Through the analysis of the relationship between the biogenic limestone and the relative paleobathymetric water, it is shown that the biogenic limestone in the study area is mainly in the water environment where the lake water is slowly decreasing and stable, and the absolute paleobathymetric range is 20m-35m.

4.3. Paleogeomorphology
The paleogeomorphology created by tectonic movement plays an important role in controlling the formation and development of sequence in continental basins especially rift basins; When the terrigenous detrital replenishment is lacking, the bioclastic beach system is developed in the partially uplifted underwater platform area[7].After restoration of the paleogeomorphology in the first member of Shahejie Formation of the study area, it was found that the paleogeomorphology controlled the horizontal distribution of biolimestone. Before the restoration of paleogeomorphology, the bottom boundary of the first member of Shahejie Formation was high in the south and low in the north. After the restoration of paleogeomorphology, the bottom boundary of the first member of Shahejie Formation was low in the southwest and east, and high in the northwest and southeast. Sedimentary period of the first member of Shahejie Formation around buried mountain of Changdi, the corresponding terrain gradient changes less. By comparing the paleogeomorphology map with the thickness prediction plan of biogenic limestone, it is found that the biogenic limestone with thicker prediction is developed in the gentle slope of the southern paleogeomorphology and the steep depression of the eastern paleogeomorphology.
5. Biolimestone development model

According to the change and distribution characteristics of biolimestone composition, the development model of biolimestone in the study area was determined by combining the classification results of high frequency sequence stratigraphy in the sedimentary period of the first member of Shahejie Formation as well as the characteristics of paleo-water depth change and paleogeomorphology [8]. According to the special geomorphic environment in Changdi Area, the development pattern of biolimestone can be further divided into two types: gentle slope biolimestone and depression biolimestone.

5.1. Growth model of biolimestone in gentle slope

Gentle slope biolimestone is distributed around the uplift in the study area. Controlled by the change of the relative lake plane and the gentle slope landform, the gentle slope biological beach was formed on the wave base surface, and the water was relatively calm and in a low energy state. The sedimentary period was a slow rising process of the water body, and the paleogeomorphology showed a gentle slope with a dip Angle of about 10° ~ 15°. The biolimestone of gentle slope is formed on the side of the wave face, and the seismic profile is mostly characterized by the reflection of upper and middle - strong amplitude (Fig.1).

5.2. Depression biolimestone development model

The biolimestone is distributed in the lower depression of the gentle slope in the east of Changdi Area under the control of paleobathymetric changes and depression geomorphology, depression biolimestone was formed on the wave base surface, and the water body was in a low-energy state. During the sedimentary period, the water body was in a slow rising process, and the paleogeomorphology was characterized by depression.

There may be two kinds of genesis of biogenic limestone deposited in situ and in other places. Biolimestone deposited in situ was formed on the side of the wave-facing surface, and the seismic profile was mostly characterized by bidirectional superreflection, corresponding to the

![A: Development section B: Seismic section](image)

**Fig. 1** The lower part of Es1 Section slope biolimestone development mode in Changdi Area wave crest with good continuity and strong amplitude, and extending to the bottom of the trough. The drilling of Zhuang310 well near the depression in the eastern part of the study area has been confirmed. The biolimestone deposited in other places was formed in the process of high water retreat. Due to the lack of material supply in the study area, the water was relatively clear. The sediments in the depression may be formed by the accumulation of nearby biogenic beach at the bottom of the depression after being broken up by lake waves, and 2 to 3 sets of biolimestone can be developed(Fig.2).
6. Distribution characteristics of biolimestone

During the development of biolimestone in the early sedimentary stage of the first member of Shahejie Formation, there were at least three smaller lacustrine variation cycles in Changdi Area [9]. Biolimestone deposits developed in 3 stages. According to the analysis of the section of the continuous well of Zhuang181 - Zhuang12 - Zhuang209, three sets of biolimestone developed in well Zhuang181, two sets of biolimestone developed in well Zhuang12 in PSQ1 and PSQ2, and one set of biolimestone developed in well Zhuang209 in PSQ1. The distribution of biolimestone has a certain regularity, which indicates that during the early lacustrine invasion in the first section of the sediment, the lake plane in the study area was oscillated with high frequency, and the sediments were deposited in the form of deaccumulation and superposition. When the lake plane changed in the first stage, the Wells of Zhuang181, Zhuang12 and Zhuang209 were located between the wave base plane and the lake plane, in the gentle slope break zone of the shallow-shore lake, where biolimestone deposits developed and were distributed in a band on the plane. When the lake level changed in the second stage, Wells Zhuang181 and Zhuang12 were located between the wave base and the lake level and developed biolimestone deposition, while well Zhuang209 were located below the wave base and mainly developed mudstone. When the lake level changed in the third stage, well Zhuang181 was located between the wave base and the lake level, and biolimestone deposits were developed, while wells Zhuang12 and Zhuang209 were located below the wave base, and mudstone was mainly developed. Due to the periodic changes in the lake plane, the distribution of biolimestone in the study area also changed accordingly. Biolimestone developed thick around the uplift and was relatively thin along the gentle slope, and distributed in a strip parallel to the buried mountain on the plane (Fig.3) [10].
7. Conclusion
The Changdi Area of Zhanhua Depression is located in the high tectonic position and the source of matter is lacking. Therefore, the lake water is relatively clear in the sedimentary period of the first member of Shahejie Formation, which created favorable conditions for the deposition of biogenic limestone. Based on the high-frequency sequence stratigraphy of single well, this paper established the high-frequency sequence of Wells in Changdike Area, classified the first member of Shahejie Formation as a three-level sequence into three four-level sequences, and further divided the lacustrine transgressive system domain and lacustrine regressive system domain. Biolimestone was developed in the four-level lacustrine regressive system domain. Paleoclimate, paleo-water depth and paleogeomorphology controlled the distribution of biolimestone in the study area. The biolimestone in the first member of Shahejie Formation was mainly developed during the slow decline of the lake water, but less developed during the rise of the lake water. The biolimestone on the plane is mainly distributed in the gentle slope in the southwest and the depression in the east. There are two types of biolimestone development models: gentle slope biolimestone development model and depression biolimestone development model.

Acknowledgments
This work was financially supported by National Natural Science Foundation of China (Grant number 41672129).

References
[1] ZHANG Jie. Reservoir forming condition of stratigraphic oil pool in palaeogene in Jiyang Depression [D]. Guiyang: Guizhou university, 2016.
[2] TIAN Bo. High resolution sequence stratigraphy analysis and subtle reservoir prediction of Lower Tertiary in Changdi Area, Shengli oilfield [D]. Chengdu: Chengdu university of Technology, 2004.
[3] CHARLES R. Williamson and M. dane picard. Petrology of carbonate rocks of the green river formation (eocene) Jounal of Sedimentary Petrology [J]. 1974, 44(3): 738-759.
[4] MURPHY D H, WILKINSON B H. Carbonate deposition and facies distribution in a central Michigan marl lake[J]. Sedimentology, 1980, 27(3): 123-135.
[5] DU Yunhua. Eogene lacustrine carbonaterocks and sedimentary model in Bohai Bay region [J]. Oil & Gas Geology, 1990, 11(4): 376-392.
[6] WANG Yanzhang. Controlling action of palaeo-water depth on the development of carbonate beach and bar [J] Petroleum Geology & Oilfield development in Daqing, 2011, 30(6): 27-31.
[7] DENG Hongwen, Wang Hongliang, Wang Dunze. Control of Paleo-Morphology to stratigraphic sequence in continental rift basins: Take Lower Tertiary of western slope in Bozhong depression as an example [J]. Oil & Geology, 2001, 22(4): 293-296.
[8] JIANG Xiufang. The distribution pattern and sedimentary mode of the carbonate rock in Sha4 member in Jiyang Depression[J]. Petroleum Geology and Recovery Efficiency, 2010, 17(6): 12-15.
[9] WAN Lin, WANG Qingbin, ZHAO Guoxiang, et al. Quantitative characterization of the diagenesis of Ed3 fan-delta sandbodies in the steep slope belt of Shijiu tuo Uplift[J]. Petroleum Geology &Oilfield Development in Daqing, 2017, 36(6): 31-39.
[10] CAO Jianwen, XIA Riyuan, ZHANG Qingyu, et al. Typical fillingmodels of a fractured - vuggy system in carbonate rocks under a moist environment[J]. Petroleum Geology & Experiment, 2016, 38(1): 56-62.