Environment, Resource and Ecology Journal (2022)
Clausius Scientific Press, Canada

DOI: 10.23977/erej.2022.060110
ISSN 2616-3756 Vol. 6 Num. 1

Comparison of Lingshan Island Formation in Qingdao, Shandong Province and Shuinan Formation in Laiyang Sag

Jiahao Zhang[1], Shoujun Li[1, *], Zhenyu Zhang[1], Xiangyu Zhang[2]

[1]*School of Earth Science & engineering, Shandong University of science and technology, Qingdao, Shandong 266590, China*

[2]*Key Laboratory of stratigraphy and palaeontology, Ministry of natural resources, Institute of geology, Chinese Academy of Geological Sciences, Beijing 100037, China*

*Corresponding author: lishoujun@126.com

Keywords: Laiyang Sag, Laiyang Group, Shuinan Formation, Lingshan Island Formation, sedimentary age

Abstract: Constrained by geochronological and paleontological data, this paper conducts a comparative study on the Shuinan Formation and the Qingdao Lingshan Island Formation in the Laiyang Sag from the aspects of paleoenvironment, paleoclimate characteristics, and soft sediment deformation structures. The research results are as follows: (1) The minimum detrital zircon age values of the lower and upper strata of the Lingshan Island Formation are consistent with the minimum detrital zircon age values of the lower and upper strata of the Shuinan Formation within the error range, both belonging to the Early Cretaceous Aptian period; (2) The paleo-salinity of the Shuinan Formation and the Lingshandao Formation gradually decreased as the strata changed from old to new, while the paleo-salinity of the Wawukuang Formation and Zhifengzhuang Formation changed from old to new as the strata changed. (3) Both sets of strata were affected by seismic activity in the early stage of deposition, resulting in the development of soft sediment deformation structures; (4) The types of paleontology in the two sets of strata are the same. Therefore, the authors believe that the layers of the Lingshandao Formation and the Shuinan Formation are comparable, and the special structure, paleoenvironment and paleoclimate characteristics can be used as the basis for stratigraphic comparison and division.

1. Introduction

Irregular deposition of strata, complex tectonic movement and strong denudation and other factors will lead to incomplete preservation of strata, thus hindering the division and comparison of strata, and affecting the understanding of the original depositional pattern. Exploring an effective method for lateral stratigraphic correlation is helpful to accurately restore the original depositional pattern, and has important guiding significance for the comprehensive evaluation of petroleum geological conditions. At present, most of the methods commonly used in stratigraphic correlation research start from the aspects of paleontology, lithology, seismic reflection characteristics and logging response, etc., and few studies take the special structure in the stratigraphy, the climate and environmental evolution characteristics in the sedimentary record as the horizontal stratigraphic characteristics. content of comparison. Sedimentary strata will record the tectonic movement process and the characteristics of climate and environmental evolution during the deposition period. Therefore, under the constraints of geological background and geochronology, the special structures in the strata and the characteristics of climate and environmental evolution in the sedimentary record may be the lateral direction of the stratum. Comparative studies provide important information.

The depositional age of the Lower Cretaceous Laiyang Group developed on Lingshan Island in Shandong Province was initially thought to correspond to the depositional age of the top of the Lower Cretaceous Laiyang Group in the Jiaolai Basin. Lin Formation[1]. In recent years, some scholars believe that the Lower Cretaceous Laiyang Group of Lingshan Island is actually a set of Early Cretaceous marine turbidite, which was deposited in the residual ocean basin formed by the collision of the Yangtze plate and the North China plate[2, 3]. On this basis, Zhang Haichun et al. realized that the depositional age of the Lower Cretaceous Laiyang Group in Lingshan Island was the early and middle Early Cretaceous, and this set of Early Cretaceous marine turbidite was only found in Lingshan Island, which was the same as the surrounding sedimentary period of the same period[4]. None of the strata can be compared, so it is recommended to establish a new lithostratigraphic unit, the Lingshan Island Formation (K_1lsd). Subsequently, many experts and scholars participated in related researches on the age attribution, tectonic background, and paleoenvironmental evolution of the Lingshan Island Formation, which further promoted the geological research of this set of strata [5-11]. The geochronological data of the rhyolite on Lingshan Island provide a formation age of 119.2±2.2 Ma, which effectively constrains the maximum depositional age of the Lingshan Island Formation[12]. The detrital zircon of the coarse sandstone at the bottom of the Lingshan Island Formation shows that the maximum depositional age of this set of strata is 138-121 Ma[13], and many scholars have given research results similar to the above age[14,15], however, the current research on the geochronology of this set of strata mostly focuses on the bottom coarse sandstone section and the upper rhyolite, and there is no sandstone based on fossil horizons. The related research on the chronological analysis of zircon detritus has led to the lack of constraints on the deposition time of the fossil-bearing strata. In addition, the stratigraphic relationship between the Lingshan Island Formation and the strata of the same period is still unclear, and relevant research has not yet been carried out. Therefore, under the constraints of geochronology, it is necessary to carry out the comparative study of the Lingshan Island Formation and the strata of the same period from various perspectives. Based on this, in this paper, detrital zircon LA-ICP-MS U-Pb chronology test was carried out on the sandstone of the Lower Cretaceous Laiyang Group in Lingshan Island. A comparative study of geochronology, sedimentology and paleontology was carried out in the Dao Formation to determine the stratigraphic relationship between the Lingshan Dao Formation and the Shuinan Formation, and to explore the evolution of special structures, paleoenvironments and paleoclimate characteristics in the sedimentary records in the stratigraphic layers. Significance in a cross-sectional study. This paper not only provides a new idea for the lateral correlation study of strata, but also provides a reference for the correlation and division of the Early Cretaceous sedimentary strata in eastern China.

2. Regional geological background

Lingshan Island is located in the Sulu orogenic belt (Fig. 1a) in the collisional suture zone of the North China Craton and the Yangtze Craton, and its east and south are cut by the Qianliyan fault, and its north is adjacent to the Jiaolai Basin (Fig. 1b). Geographically, Lingshan Island is located in the coastal waters of the Yellow Sea in the southeast of Huangdao District, Qingdao City, Shandong Province(Figure 1b)[2]. The island as a whole runs from north to south, with a width of about 3 kilometers and a length of about 5 kilometers[16]. Two sets of Early Cretaceous strata developed on the island, from bottom to top, they are the Lower Cretaceous Laiyang Group (K_1L) and the Lower Cretaceous Qingshan Group (K_1Q), both of which are in unconformity contact (Fig. 1c)[17]. Institute of Geology and Mineral Exploration, 2003). The Lower Cretaceous Qingshan Group of Lingshan Island was divided into the Bamudi Formation (K_1Qb), and this set of division scheme is not controversial, while the Lower Cretaceous Laiyang Group of Lingshan Island was originally divided into the Fajialing Formation (K_1Lf), which was later proposed to be revised It is the Lingshan Island Formation (K_1Llsd).

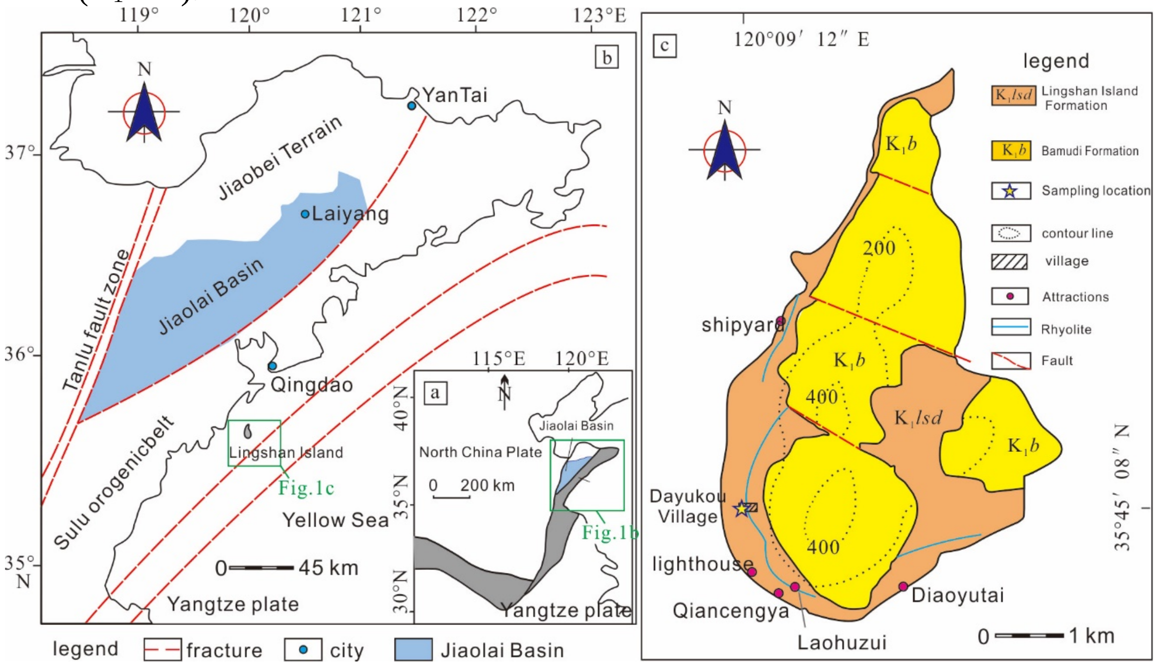

Figure 1: Regional geological map of Lingshan Island and Jiaolai Basin: (a) Geotectonic position of Shandong Peninsula; (b) Geotectonic position of Lingshan Island and Jiaolai Basin; (c) Early Cretaceous stratigraphic framework in Lingshan Island (from Ao Wenhao et al., 2018)

3. Test Methods

In this paper, two coarse sandstone samples were collected from the strata containing terrestrial fossils in the Lingshan Island Formation (Dayukouzicun section) for the detrital zircon LA-ICP-MS U-Pb age test. The numbers of the two sandstone samples are: LSD20-01 and LSD20-02.

The sorting of zircon, cathodoluminescence photography and zircon U-Pb dating were all completed in the micro-analysis laboratory of Nanjing Hongchuang Geological Exploration Technology Service Co., Ltd. Zircon LA-ICP-MS U-Pb dating was done in the micro-analysis laboratory of Nanjing Hongchuang Geological Exploration Technology Service Co., Ltd. using laser ablation-inductively coupled plasma mass spectrometer (LA-ICPMS). The laser ablation platform adopts Resolution SE type 193 nm deep ultraviolet laser ablation sample introduction system (Applied Spectra, USA), equipped with S155 type dual-volume sample cell. The mass spectrometer was an Agilent 7900 Inductively Coupled Plasma Mass Spectrometer (Agilent, USA). For detailed tuning parameters, see Thompson et al.[18]. The zircon samples were fixed on epoxy resin targets, ultrasonically cleaned in ultrapure water after polishing, and the surface of the samples was wiped with analytical grade methanol before analysis. Each ablation area was pre-ablated (ablation depth ~0.3 μm) with 5 laser pulses to remove possible contamination of the sample surface. The samples were analyzed under laser conditions with a beam spot diameter of 30 μm, ablation frequency of 5

Hz, and energy density of 2 J/cm2. The data was processed using the Iolite program[19], zircon 91500 was used as the calibration standard, GJ-1 was used as the monitoring standard, and two 91500 standards and one GJ-1 standard were analyzed every 10-12 sample points. Sample. Typically a 20-second gas blank is collected, a signal interval of 35-40 seconds is used for data processing, and depth fractionation correction is performed according to an exponential equation[19]. The ages of 91500 (1061.5 ± 3.2 Ma, 2σ) and GJ-1 (604 ± 6 Ma, 2σ) determined during this experiment are consistent with the recommended values within the uncertainty range. The U-Pb age harmony diagrams, histograms and probability distribution diagrams of zircon samples were drawn using Isoplot software.

4. Analysis results

4.1 The shape of zircon

The purpose of this detrital zircon U-Pb age test is to find the age distribution of the youngest detrital zircon grains in the sandstone of the Lingshandao Formation containing continental fossil strata to constrain the maximum depositional age of this set of strata. Therefore, in this study, zircon with complete zircon grain morphology and crystal form and obvious magmatic zircon oscillation rhythm was selected for the LA-ICP-MS U-Pb age test. A total of 173 zircons were tested on the two sandstone samples, and a total of 173 test points were obtained, including 81 points for the sample LSD20-01 and 92 points for the sample LSD20-02.

Most of the zircon particles in the LSD20-01 and LSD0-2 samples were between 40 and 80 μm in size, with individual zircon particles larger than 100 μm (Fig. 2). Most zircon is columnar in shape, and some zircon is round and granular. Although the morphology and internal structure of zircon are not identical, most of these zircon grains have euhedral morphology and obvious oscillatory rhythm rings and high Th/U ratio (>0.4), indicating igneous origin (Fig. 2).

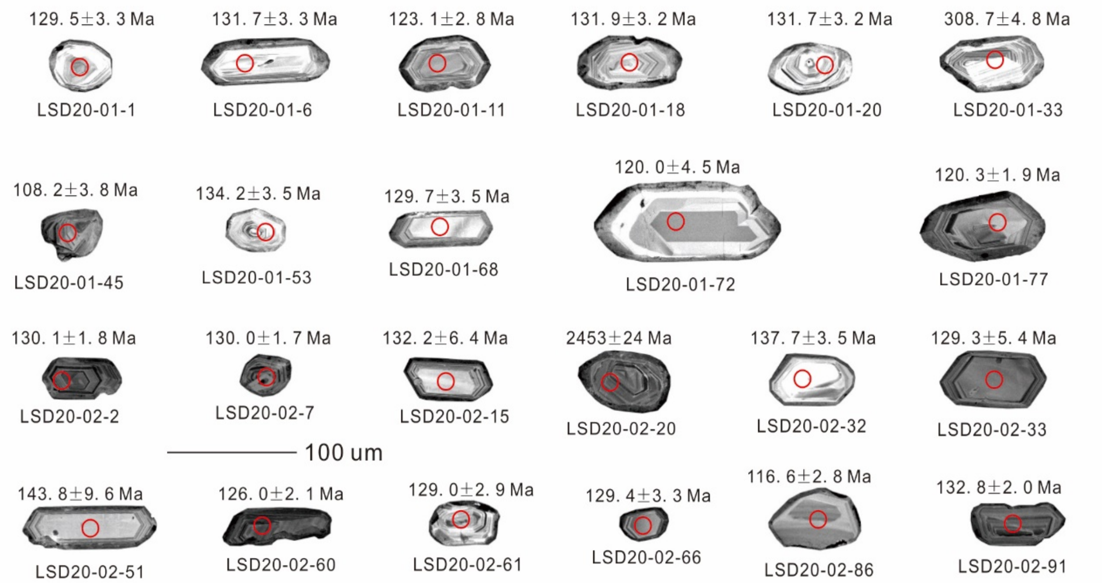

Figure 2: Representative CL images for Detrital zircons from the Laiyang Group in Lingshan Island

4.2 Zircon U-Pb Dating Results

The LA-ICP-MS U-Pb age analysis of 81 detrital zircon in the LSD20-01 sample was carried out, and 76 valid ages were obtained, which were mainly concentrated in 120.0~134.2 Ma, 202.2~469.9 Ma, 1.8~2.1 Ga and 2.3–2.5 Ga in the four age combinations, but the age distribution also includes several sporadic age values that are not statistically significant (Fig. 3). The Th/U ratios of detrital zircon of different age combinations in this sample ranged from 0.03 to 3.69. Notably, the minimum age of the detrital zircon from the LSD20-01 sample is only 108.2 Ma.

Statistical analysis of the age distribution of 92 detrital zircon U-Pb in the LSD20-02 sample obtained 65 valid ages, which are mainly concentrated in 126.0~137.7 Ma, 743.0~815.0 Ma, 2.0 Ga and 2.3~2.5 Ga Across the four age groups, the age distribution also included several sporadic age values that were not statistically significant (Fig. 3). The Th/U ratios of detrital zircon in different age groups in this sample ranged from 0.06 to 2.0 (Table 2). The minimum age of the detrital zircon in this sample is 116.6 Ma.

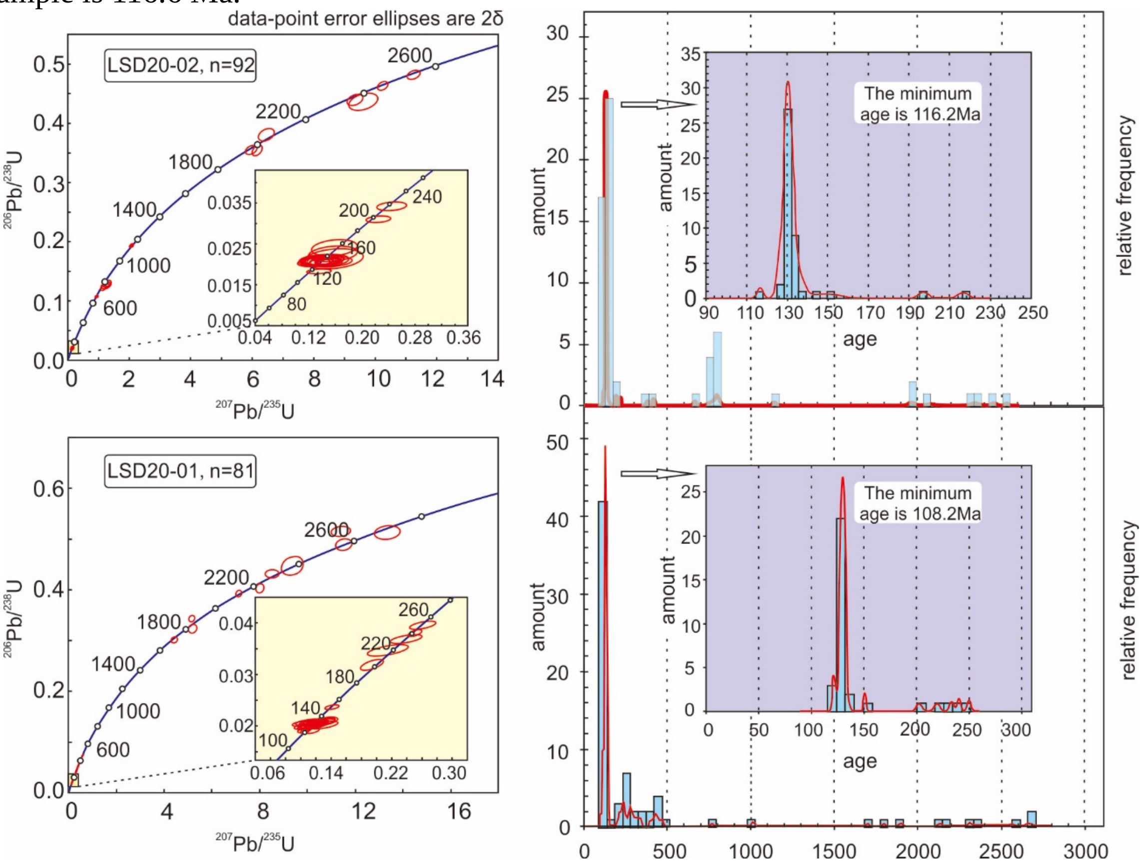

Figure 3: Concordant curve and histogram of U-Pb ages of detrital zircons from the Laiyang Group in Lingshan Island

5. Discuss

5.1 The maximum depositional age of the terrestrial fossil-bearing strata in the Lingshandao Formation

The minimum U-Pb age of detrital zircon can effectively limit the maximum depositional age of the sedimentary strata. In this study, the minimum U-Pb age of a single detrital zircon in the LSD20-01 sample is 108.2 Ma (2δ), harmonically The degree of harmony is 98%; the minimum U-Pb age of a single detrital zircon in the LSD20-02 sample is 116.6 Ma (2δ), and the degree of harmony is 90%. Although the high harmonicity of zircon can indicate that Pb is not lost in zircon and can be used to define the maximum depositional age of the formation, caution should be used when using the age of a single detrital zircon to define the maximum depositional age of the formation[20], so it is necessary to perform statistical analysis on the minimum age combination of detrital zircon in LSD20-01 and

LSD20-02 samples, and further analyze the morphology and size of the single detrital zircon that yields the smallest zircon age. Th/U ratio.

In this paper, Origion software was used to analyze the probability distribution of the minimum age combination of detrital zircon in the two samples. The probability distribution diagram showed that the minimum age of the detrital zircon in the LSD20-01 sample ranged between 108.2 Ma and 134.2 Ma (Fig. 4a). It is worth noting that although the detrital zircon producing the smallest age value has a clear ring outside, there are black metamorphic nodules inside this zircon (Fig. 4c), suggesting that this zircon has undergone metamorphism, so its Th The /U ratio was less than 0.4 (Fig. 4c). Therefore, the age value of 108.2 Ma is an invalid composite age value. The minimum age of detrital zircon in the LSD20-02 sample ranges between 116.6 Ma and 137.7 Ma (Fig. 4b), its Th/U ratio is 1.47 (Fig. 4d), and the zircon grains have weak rings, Indicates that this zircon is a magmatic zircon. Therefore, the minimum age value of detrital zircon in the LSD20-02 sample is valid, and the maximum depositional age of the terrestrial fossil-bearing strata in the Lingshan Island Formation is limited to 116.6 Ma.

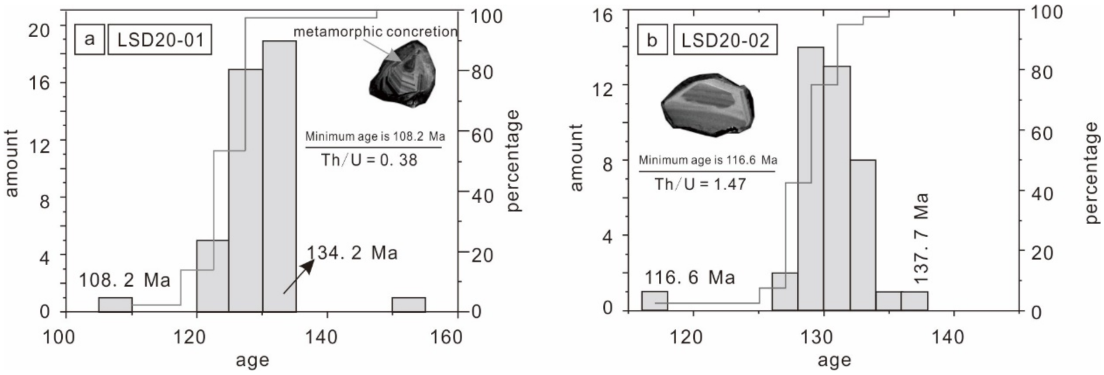

Figure 4: Probability distribution image of the minimal age group among detrital zircons: (a) histogram of the minimal age group among detrital zircons from the sample LSD20-01 and morphology of a detrital zircon with the minimum age value; (b) histogram of the minimal age group among detrital zircons from the sample LSD20-02 and morphology of a detrital zircon with the minimum age value

5.2 Comparison of sedimentary ages between Lingshandao Formation and Shuinan Formation in Laiyang Sag

With the gradual deepening of the geochronological study of the Early Cretaceous sedimentary strata, the depositional age of the Lower Cretaceous Laiyang Group in Lingshan Island and the Laiyang Sag of the Jiaolai Basin has been fully studied, providing time for the comprehensive comparative study of the two sets of strata. constraint.

The formation age of the rhyolite at the bottom of the Bamudi Formation in Lingshan Island is about 119.2±2.2 Ma[12], and later studies have given similar formation ages (118±2 Ma and 121.4±1.4 Ma)[8,14]; the formation age of the diabase porphyrite at the bottom of the Bamudi Formation is 109±3Ma[14]. The maximum depositional age of the bottom of the Lingshandao Formation has been limited to 121 Ma[13]. In this paper, the maximum depositional age of the terrestrial fossil-bearing strata of the Lingshandao Formation is limited to 116.6 Ma.

Based on the detrital zircon U-Pb chronology analysis of the coarse sandstone, the depositional age of the upper part of the Lower Cretaceous Laiyang Group in the Laiyang Sag, Jiaolai Basin is limited to 121–120 Ma[13,21]. The maximum depositional age of the Formation is about 121 Ma [13], the maximum depositional age of the Wawukuang Formation is about 123 Ma, and the maximum depositional age of the Zhifengzhuang Formation and Qugezhuang Formation are 121 Ma and 121

Ma, respectively. 114 Ma[22]. On this basis, Zhang Xiangyu and Li Shoujun further constrained the depositional ages of the Zhifengzhuang Formation and the Shuinan Formation by the minimum age of the detrital zircon of the coarse sandstone [9]. The maximum depositional age of the Zhifengzhuang Formation is At 120.9 Ma, the maximum depositional ages of the bottom and middle and upper strata of the Shuinan Formation are 119.8 Ma and 117.5 Ma, respectively. Obviously, the minimum detrital zircon age values of the lower and upper layers of the Lingshandao Formation are consistent with the minimum detrital zircon age values of the Zhifengzhuang Formation and the Shuinan Formation, respectively (Fig. 5). Therefore, the Lingshandao Formation, the Zhifengzhuang Formation and the Shuinan Formation have similar depositional times, all belonging to the Early Cretaceous Aptian. The depositional time constraints of these strata can be obtained from the detrital zircon age, but the stratigraphic relationship between the Lingshandao Formation and other strata cannot be determined.

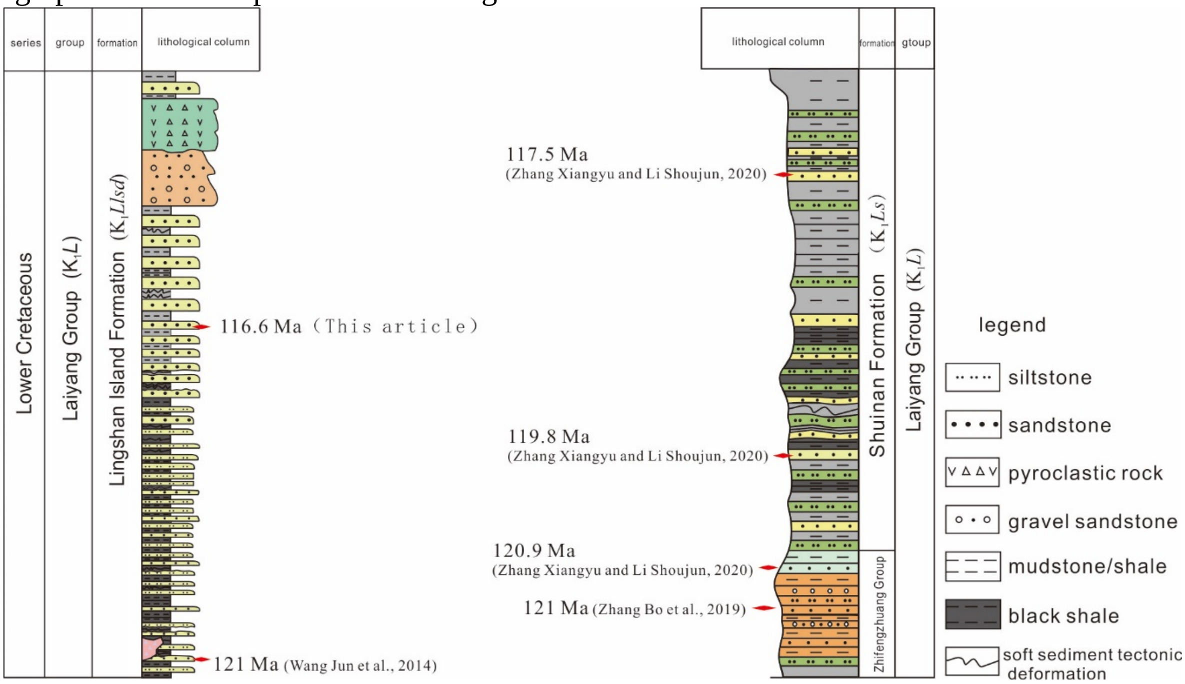

Figure 5: Minimum detrital zircon ages of the sandstones from the Lingshandao Formation, Zhifengzhuang and Shuinan Formations

5.3 Paleontological fossils in the Laiyang Group

The Laiyang Group of the Lower Cretaceous in the Laiyang Sag develops Wawukuang Formation, Zhifengzhuang Formation, Shuinan Formation, Longwangzhuang Formation and Qugezhuang Formation in sequence from bottom to top. The complete process from development to decline [23, 24]. The paleontology in the Laiyang Group is a typical Jehol biota. Due to the difference in the paleo-salinity of the water body, the paleontological features in each group are quite different[7, 9]. According to reports, the paleontological fossils discovered in the Wawukuang Formation include Yanjiestheria sinensis, Y. kyongsangensis, Diestheria sp. and Lycoptera sinensis Woodward, which are abundant in quantity, but monotonous[23]. In addition, non-marine trace fossils and theropod dinosaur footprint fossils are also preserved in this set of strata[25]. The fossils contained in the Zhifengzhuang Formation are bivalves (Sphaerium tani, S. altiformis, S. laiyangense) and gastropods (Probaicalia cf. prinadae, Valata zhuchengensis), and less solid fossils are preserved[24], trace fossils are also rare, only a small amount of Skolithos linearis and Planolites montanus [25], and no fossils such as phylloxtra and wolf-finned fish were found. The fossil assemblage of the Shuinan Formation is similar to the fossil assemblage of the Wawukuang Formation, both of which are assemblages of Yezhijie and Wolf-fin fish from Yanji. Yanji leaf limbs include Yanjiestheria yumensis, Y. kyongsangensis, Y. qudratoides, Y. chekiangensis and Y. longa; wolf-finned fish are Lycoptera sinensis Woodward and L. laiyangensis sp. nov., Sinamia sp. Low degree [23]. A small amount of trace fossils [25], vertebrate fossils and a large number of plant fossils are also preserved in this set of strata. Only a large number of trace fossils have been found in the Longwangzhuang Formation and the Qugezhuang Formation[25]. The paleontological fossils in the Lower Cretaceous Laiyang Group in the Laiyang Sag are shown in Figure 6.

The paleontological features of the Lower Cretaceous Laiyang Group on Lingshan Island are the Yanji Yelijie and Chinese wolffin assemblages[6], which are very similar to the paleontological assemblages in the Wawukuang Formation and the Shuinan Formation. The genus and species are characterized by monotonicity and low differentiation [8, 9]. From the evolution system of fish, it can be seen that Lycoptera is closely related to Paralycoptera and Pleciolycoptera that appeared in the mid-Cretaceous[23]. Wolffin is a primitive bony fish, while Chinese wolffin is a more primitive species of wolffin. The appearance of Chinese wolffin indicates that the Lingshandao Formation was deposited in the mid-Cretaceous, which is consistent with detrital zircon. consistent with the depositional age.

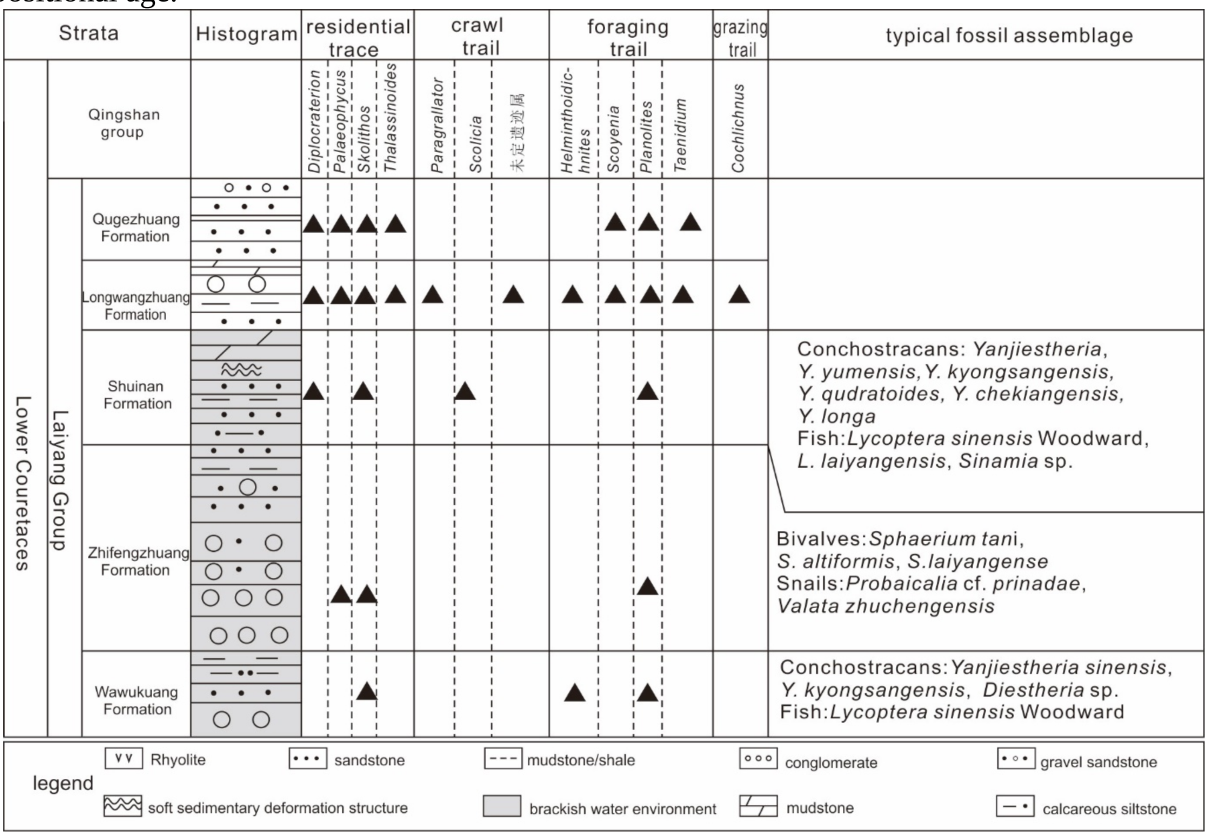

Figure 6: Paleontological fossils from the Lower Cretaceous Laiyang Group in the Laiyang Sag (from Li Rihui and Zhang Guangwei, 2001; Regional Geological Survey Team of Bureau of Geology and Mineral Resources of Shandong Province, 1990)

Judging from the Chinese wolf-finned fish and Yanji leaf limb fossils alone, the layers of the Lingshandao Formation seem to correspond to the Shuinan Formation or the Wawukuang Formation in the Laiyang Sag (Fig. 6). Therefore, under the constraints of geochronology and paleontological fossils, this paper further compares and analyzes the seismic activity, paleoclimate and paleoenvironmental background during the deposition of Lingshandao Formation, Wawukuang Formation, Zhifengzhuang Formation and Shuinan Formation, in order to find Lingshan The stratigraphic relationship between the island group and these strata.

5.4 Soft sediment deformation structure

Sedimentary strata will record the tectonic movement process during the deposition period, so some special geological structures may provide important information on the horizontal correlation of strata. The most striking thing in the Lingshan Island Formation is the soft sediment deformation structure. Many scholars have discussed the origin of the soft sediment deformation structure. Among them, seismic activity is considered to be one of the main triggering mechanisms of soft sediment deformation structures. In fact, seismites (soft sediment deformation structures) developed in the Lower Cretaceous Yangjiazhuang Formation in the Jiaozhou-Laiyang Basin, indicating that the Laiyang Group deposited early in the basin was characterized by widespread seismites due to strong seismic activity. In the Cretaceous stratigraphic division plan of the Jiaolai Basin, the Yangjiazhuang Formation of the Lower Cretaceous Laiyang Group in the Jiaozhou area corresponds to the Shuinan Formation and Zhifengzhuang Formation of the Lower Cretaceous Laiyang Group in the Laiyang Sag. During the deposition of the Shuinan Formation, the Shandong Peninsula had frequent seismic activities, and the strong seismic action led to the development of a large number of soft sediment deformation structures in the Shuinan Formation in the Jiaolai Basin and the Yangjiazhuang Formation in the Jiaozhou area.

Considering that seismic activity does not only lead to soft sediment deformation structures in the strata at a certain location, the strata at the same time will also produce similar deformation structures. Under the constraints of geochronology, sedimentology and paleontology, seismically derived soft sediment deformation structures can provide a reference for the division and comparison of strata. Geochronological data show that the maximum deposition time of the Lingshandao Formation is 116.6 Ma, which is consistent with the maximum deposition time (117.5 Ma) of the Shuinan Formation in the Laiyang Sag. The paleontological assemblages in the two sets of strata are similar, and both develop soft sediment deformation structures. Therefore, it can be speculated that the seismic action that led to the development of soft-sediment deformation structures in the Shuinan Formation also triggered soft-sediment deformation structures in the Lingshandao Formation.

6. Conclusions

Under the constraints of geochronology and paleontological data, special structures, paleoclimate and paleoenvironmental evolution characteristics can be used as a method for horizontal correlation of strata, and can be used as evidence to determine the horizon relationship of contemporaneous strata. The minimum detrital zircon ages of the Lingshandao Formation in Qingdao, Shandong Province and the upper and lower layers of the Shuinan Formation in the Laiyang Sag are consistent within the error range. The paleobiological assemblages of the two are similar, and the changes in paleo-salinity and paleoclimate are consistent. Activity-related soft sediment deformation structures. Therefore, the authors believe that the layers of the Lingshandao Formation and the Shuinan Formation are comparable.

Acknowledgments

This Work was financially supported by Key Laboratory of stratigraphy and paleontology, Ministry of natural resources, Institute of geology, Chinese Academy of Geological Sciences fund.

Funding: Key Laboratory of stratigraphy and palaeontology, Ministry of natural resources,

Institute of geology, Chinese Academy of Geological Sciences, Beijing 100037, China (KLSP 201902)
First author: jiahao Zhang, E-mail: 985553173@qq.com
*Corresponding author: shoujun Li, E-mail: lishoujun@126.com

References

[1] Shandong Provincial NO. 4 Institute of Geological and Mineral Survey. Regional Geology in Shandong Province. Jinnan: Shandong Cartographic Publishing House, 2003, p. 1–970.
[2] Lv Hongbo, Wang Jun, Zhang Haichun. Discovery of the Late Mesozoic Slump Beds in Lingshan Island, Shandong, and a Pilot Research on the regional Tectonics. Acta Geologica Sinica. (2011) No. 85(6), p. 938–946.
[3] Lv Hongbo, Zhang Haichun, Wang Jun, et al. Discovery of the Late Mesozoic giant slump rocks of turbidite in Lingshan Island. Geological Review. (2012) No. 58(1), p. 80–81.
[4] Zhang Haichun, Lu Hongbo, Li Jianguo, et al. The Lingshandao Formation: A new lithostratigraphic unit of The Early Cretaceous in Qingdao, Shandong, China. Journal of Stratigraphy (2013) No. 37(2), p. 216–222.
[5] Zhong Jianhua. Deep water source turbidity or continental delta of the Mesozoic sedimentary rocks in Lingshan Island? Geological Review. (2012) No. 58(6), p. 1180–1182.
[6] Li Shoujun, Zhang Xiangyu, Zhao Xiuli, et al. Discovery of fish and Conchostracan Fossils in Lower Cretaceous in Lingshan Island, Qingdao, Shandong. Geological Review. (2017) No. 63(1), p. 1–6.
[7] Zhang Xiangyu, Li Shoujun, Zhao Xiuli, et al. The sedimentary environment of Early Cretaceous rift basin in eastern China and its response to the Faraoni event. Geosciences Journal. (2019) No. 24(4), p. 359–377.
[8] Meng Yuanku, Li Rihui. Early Cretaceous tectonic evolution on Lingshan Island, Qingdao, and adjacent regions. Geological Review. (2019) No. 65(2), p. 385–388.
[9] Zhang Xiangyu, Li Shoujun, Zhao Xiuli, et al. 2020a. A New Understanding of the Sedimentary Environment of the Laiyang Group in the Lower Cretaceous of Lingshan Island, Shandong Province, East China. Acta Geologica Sinica - English Edition. (2020a) No. 94(5), p. 1325–1338.
[10] Zhang Xiangyu, Li Shoujun, Yan Mingming, et al. 2020b. Early Cretaceous black shale in the Fajiaying Formation (Lingshan Island, East China): Terrestrial record of hothouse climate. Journal of Asian Earth Sciences. (2020b) p.191, 104200.
[11] Du Shengxian, Zhang Yuanyuan, Li Yue, et al. Ichnofossils and Wrinkle Structures as Facies Indicators from The Lower Cretaceous in Qingdao, Shandong, Eastern China. Journal of Stratigraphy. (2020) No.44(2), p. 174–180.
[12] Zhou Yaoqi, Zhang Zhenkai, Liang Wendong, et al. Late Mesozoic tectono-magmatic activities and prototype basin restoration in Eastern Shandong Province, China. Earth Science Frontiers. (2015) No. 22(1), p. 137–156.
[13] Wang Jun, Chang Su-chin, Lv Hongbo, et al. Detrital zircon U–Pb age constraints on Cretaceous sedimentary rocks of Lingshan Island and implications for tectonic evolution of Eastern Shandong, North China. Journal of Asian Earth Sciences. (2014) No. 96, p. 27–45.
[14] Ao Wenhao, Feng Tao, Zhao Yan, et al. Early Cretaceous magmatic activities in the Lingshan Island and its geological significance. Acta Petrologica Sinica. (2018) No. 34, p. 1612–1640.
[15] Meng Yuanku, Li Rihui, Xu Yang, et al. U-Pb-Hf isotopes and Tectonic Significance of Early Cretaceous Detrital Zircons on Lingshan Island, Qingdao of Shandong Province. Earth Science. (2018) No. 43(9), p. 3302–3323.
[16] Luan Guangzhong, Wang Hongxia, Yin Mingquan, et al. Characteristics of Main Faulted Structures in Qingdao City and Their Influence on Urban Geological Environment. Acta Geoscientica Sinica. (2010) No. 31(1), p. 102–108.
[17] Shandong Provincial NO. 4 Institute of Geological and Mineral Survey. Regional Geology in Shandong Province. Jinnan: Shandong Cartographic Publishing House, 2003, p. 1–970.
[18] Thompson, J., Meffre, S., Danyushevsky, L. Impact of air, laser pulse width and fluence on U-Pb dating of zircons by LA-ICPMS. J. Anal. At. Spectrom. (2018) No. 33, p. 221–230.
[19]. Paton, C., Woodhead, J.D., Hellstrom, J.C., et al. 2010. Improved laser ablation U-Pb zircon geochronology through robust downhole fractionation correction. Geochem. Geophys. Geosyst. (2010) No. 11, Q0AA06.
[20] Dickinson W R, Gehrels G E. Use of U–Pb ages of detrital zircons to infer maximum depositional ages of strata: A test against a Colorado Plateau Mesozoic database. Earth and Planetary Science Letters. (2009) No. 288(1), p. 115–125.
[21] Wang J, Chang S, Lv H, et al. Detrital zircon provenance of the Wangshi and Laiyang groups of the Jiaolai basin: evidence for Early Cretaceous uplift of the Sulu orogen, Eastern China. International Geology Review. (2016) No. 58(6), p. 719–736.
[22] Zhang Bo, Liu Shaofeng, Lin Chengfa, et al. Source-to-sink system reconstruction in the northern Jiaolai Basin, eastern China, by multiproxy provenance methods and implications for exhumation of the Sulu orogen. Tectonophysics. (2019) No. 754, p. 18–32.
[23] Regional Geological Survey Team of Bureau of Geology and Mineral Resources of Shandong Province. The Stratigraphy and Palaeontology of Laiyang Basin, Shandong Provence. Beijing: Geological Pulishing House, 1990.p.1–255.

[24] Bureau of Geology and Mineral Resources of Shandong Provincial. Regional Geology of Shandong Province. Beijing: Geological Pulishing House, 1991. p. 1–595.
[25] Li Rihui, Zhang Guangwei. A preliminary study of nonmarine trace fossils from the Laiyang group (Early Cretaceous), Laiyang basin eastern China. Acta Palaeontologica Sinica. (2001) No. 40(2), p. 252–261.