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DISCUSSION ON THE STRUCTURAL-VOLCANIC ACTIVITIES AND BIOLOGICAL EVENTS DURING THE EARLY CRETACEOUS IN THE SIHETUN AREA, LIAONING PROVINCE, CHINA

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The Sihetun area is situated in a Mesozoic volcanic-sedimentary basin. The main structures of the Early Cretaceous in the area are NE and NW faults, which control not only the major boundaries of the basins, but also some volcanic edifices. Based on the field mapping, the Yixian Formation, which is the only strata of the Early Cretaceous in the area, may be subdivided into three members: The first member is basic and intermediate-basic volcanic rocks with intercalations of tuffite beds. The second member is mainly sedimentary beds of lacustrine facies with intercalations of crystal tuff, tuffite and some pillow lavas. And the third member is mainly basalt. The Jehol Biota (including gastropods, bivalves, conchostracans, ostracods, insects, fishes, amphibians, reptiles, birds, mammals, as well as fossil plants) occurs mainly in tuffite beds of the first member; and muddy shale beds are related to the second member of the Yixian Formation. Excavation and trace element analysis indicates: Jehol biota experienced mass mortality and rapid burial; toxic gases of volcanic activities are the main factors of the biological catastrophic event. According to isotopic dating, the Yixian Formation is Early Cretaceous in age. By comprehensive studies, six evolutionary stages (from A to F) of the structural-volcanic activities and biological events during the Early Cretaceous in the Sihetun area are also discussed. Stage A is “the formation of the embryonic basin and the early members of Jehol biota”; Stage B is “the first volcanic activity and biological hazard”; Stage C is “the dormant volcanic activity and the development of Jehol biota”; Stage D is “the volcanic exhalation and the catastrophe of Jehol biota”; Stage E is “tuff sediment”; and Stage F is “the end”, respectively.

Key words: **structural-volcanic activities, biological events, Early Cretaceous, Sihetun.**

INTRODUCTION

The Sihetun area, located in the west of Liaoning Province, Northeast China, is famous for its abundant fossils of Jehol biota [1,11,12,13,24]. About thousands of precious fossils have been excavated from the area since the end of the last century. The precious fossils, which are generally well preserved, include fishes, amphibians, reptiles, birds, mammals and fossil plants. The fossil-bearing beds are mainly of volcanic-sedimentary rocks of the Yixian Formation. The Yixian Formation, which is the only strata of Early Cretaceous in the Sihetun area, was formed by violent volcanic activities in a fault basin. There are also many obvious volcanic edifices developed in the fault basin [5,6,7,25,26].

To some extent, the Sihetun area is an Early Cretaceous museum of fossils, volcanoes, and structure. The area has been attracting many geologists since the middle ages of the last century. They have made a lot of important progress [2,6,7,10,12, 13,17,21,22,28,30], and on the other hand, also left some interesting questions for us. What is the age of the fossil-bearing beds? Why so many fossils occur in this area? What kind of geological activity caused biological mass mortality and rapid burial? Is there any relation between the biological event and geological activity?

By the support of China Geological Survey (CGS), the authors completed a large-scale (1:50,000) geological survey program in the area last year. We wish that it would be helpful to the research of Early Cretaceous geology.

1. BASIC FEATURES OF REGIONAL STRUCTURE

Tectonically, the Sihetun area is part of the Mesozoic circum-Pacific continental marginal active belt. The belt, which abounds with Mesozoic basins,

experienced violent tectonic-volcanic activity during the Early Cretaceous (6, 14,15). The Sihetun area is situated in one of the Mesozoic volcanic-sedimentary basins. The exposed strata of the area are mainly of the Early Cretaceous Yixian Formation and pre-Cretaceous (mainly of Late Jurassic) Tuchengzi Formation. During the Early Cretaceous, the main structures of the area are NE and NW faults, which control not only the major boundaries of the Early Cretaceous basins, but also the space distribution of the volcanic-sedimentary rock series of the Yixian Formation and some volcanic edifices (Fig.1, 2).

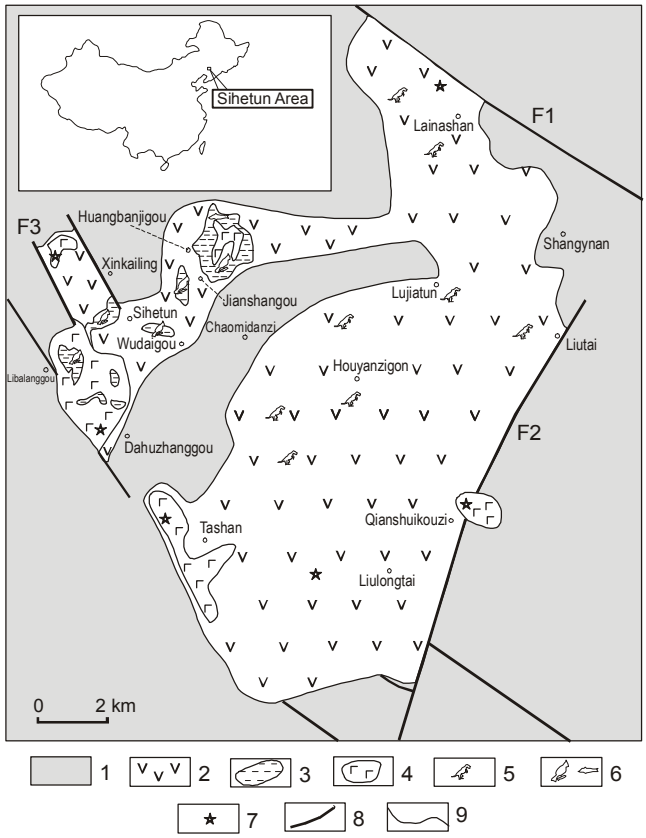


Fig. 1. Geological sketch map of the Sihetun area.

1 – Pre-Cretaceous; 2 – The first member of the Yixian Formation; 3 – The second member of the Yixian Formation; 4 – The third member of the Yixian Formation; 5 – Locality of *Psittacosaurus*; 6 – Locality of precious birds and fish; 7 – Volcanic edifice; 8 – Fault; 9 – Geological boundary.

The beginning of the Early Cretaceous is characterized by the unconformity between the Lower Cretaceous (Yixian Formation) and Late Jurassic (Tuchengzi Formation) strata (Fig. 2). The main boundary faults of the basin in the Sihetun area are described below.

1.1 Beipiao-Yixian fault (F1)

It is located at the northeastern margin of the Early Cretaceous basin with an exposure of more than 25 km long. There are fault scarp, terminal facet, schistosity zone, fractured zone, structural lenticular bodies, and basaltic porphyrite dike and quartz veins, added by linearly arranged volcanic edifices of the Yixian cycle. Generally, the fault is NW in strike with occurrence of 220°∠70° or 50°∠70°, and is characterized by a normal fault in the early stage while a left-lateral fault in the late Lamashan volcanic edifice occurred along this fault belt.

1.2 Shangyuan-Longqiantai fault (F2)

It is part of the southeastern marginal fault of the Early Cretaceous basin and shows clear multiperiodic activities. The fault, which is characterized by the NE trend, is more than 20 km long and 0.5–3 km wide, generally striking in NE direction with occurrence of 280°∠50° or 320°∠70°. It is mainly a downthrown normal fault, showing a compressed fracture zone, a fault plane, scratches, fault clay and a series of NE-trending volcanic edifices of the Yixian Formation (e.g. the Qianshuikouzi explosive breccia pipe, Zhalanyingzi volcanic edifice) along the fault belt.

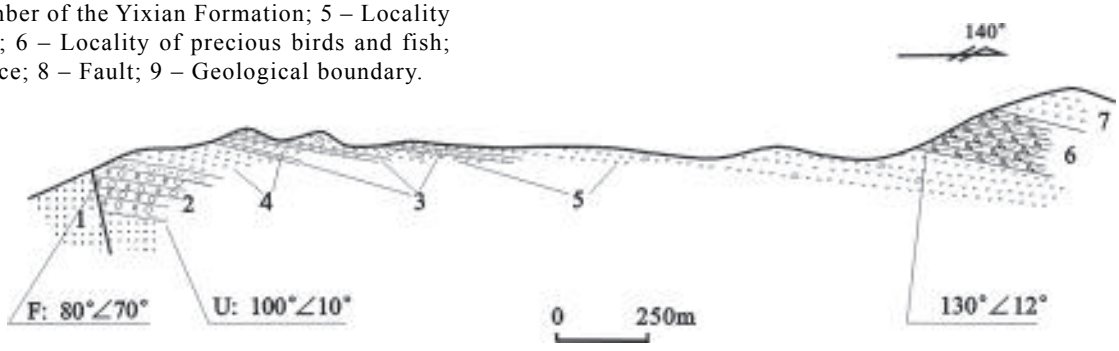


Fig. 2. Stratigraphic Section of the Yixian Formation in the Sihetun area.

1 – Pre-Cretaceous, Late Jurassic Tuchengzi Formation; 2 – Polymictic basal conglomerate of the Yixian Formation; 3, 4, 5 – Tuffite, basalt and basaltic agglomerate, the first member of the Yixian Formation; 6 – Calcareous shale and tuffaceous siltstone, the second member of the Yixian Formation; 7 – Basalt, the third member of the Yixian Formation; **F**: fault; **U**: unconformity surface.

1.3 Daheishan-Dahuzhanggou fault cluster (F3)

It is about 22 km long and 3km wide, is exposed at the southwestern margin of the Early Cretaceous basin and is composed of 3 parallel NW extended faults. Geomorphically, it appears as the parallel linear ravines and shows a compressed zone, a fracture zone, structural lenticular bodies and a drag fault along the fault cluster. It is also marked by multiperiodic activities, of which the early stage is of normal fault and the late stage is of downthrown fault generally striking in the NW and dipping in the NE direction (Fig. 2). The basaltic rocks of the third member of the Yixian Formation are extended NW along the fault cluster. The Heishangou, Dahuzhanggou and Tashan volcanic edifice occurred along this fault belt.

2. VOLCANIC-SEDIMENTARY ROCKS OF EARLY CRETACEOUS

The Yixian Formation, which is characterized by volcano-sedimentary rocks, is the only strata of Early Cretaceous developed in the Sihetun area (Fig.1, 2). Based on the field mapping, the Yixian Formation in Sihetun area may be subdivided into three members [3,5,7].

2.1 The first member

Its lower part is basal conglomerate that contacts with the underlying Tuchengzi Formation by unconformity (Fig. 2). The main parts are basic and intermediate-basic volcanic lavas, pyroclastic and explosive-sedimentary rocks, such as blackish gray olivine basalt, purplish gray vesiculate basanite, grayish yellow vesiculate-amygdaloidal basaltic andesite, andesite and their agglomerate. There are 3 intercalations of sandy tuff or tuffite (usually containing fossil bones) in the first member of the Yixian Formation [4].

The typical volcanic structure related to this member is the Houyanzigou volcanic edifice. It is a huge composite volcanic edifice with small ring-like craters surrounding the volcanism center, covering an area of about 30 km^2. The volcanic bombs are often found in the craters accumulated together with basaltic agglomerate, welded agglomerate, crystal lithic tuff and basic lava.

2.2 The second member

It is represented mainly by a series of lacustrine facies volcanic-sedimentary rocks with abundant precious fossils in it.

Its basal part is thin-bedded greywacke, sandy conglomerate and gray laminated calcic muddy siltstone. Its main part is marked by lamellar-laminar calcic muddy shale with (more than 10 beds) intercalations of yellowish brown crystal tuff, and tuffite. Some basaltic andesite pillow lavas are also found in the second member of the Yixian Formation.

The typical pillow lavas of lacustrine facies are found in the second member of the Yixian Formation. Three layers of rotating beddings are also found in the calcic shale. This may be caused by a volcanic earthquake [4,25]. The seismic deformed rocks are mainly found in the second member of the Yixian Formation and occur typically near Sihetun Village. It is marked by an asymmetric microfold in the tuff, tuffaceous shale and calcic shale layers. The seismic deformed rocks may be seen in three layers of the section, indicating at least three earthquakes caused by volcanism.

The typical volcanic structure of this member is the Qianshuikouzi explosive breccia pipe, which is located in the east of Qianshuikouzi Village exposed in the area of 2 km^2. This explosive breccia pipe is composed of subvolcanic rock bodies and polygenetic explosive agglomerate. On the wall of the breccia pipe, there are the rotary fault and scratch. The compression and friction between blocks and rubbles, as well as cementation of rock powder may be found in the pipe.

2.3 The third member

It is mainly gray-grayish black olivine basalt and plagioclase olivine basalt overlying various beds of the first and second members.

The typical volcanic structure related to this member is the Dahuzhanggou-Libalanggou volcanic edifices. The volcanism center is located in the southwest of Sihetun Village; the exposed area is 9 km^2. The craters are filled with grayish black olivine basaltic porphyrite of subvolcanic facies, and surrounded by amygdaloidal olivine basalt and basaltic andesite of effusive facies in the outer side. The volcanic rocks of this edifice overlie the volcanic rocks or precious fossil-bearing strata of the second member.

3. JEHOL BIOTA

Jehol biota, which is well developed in the Yixian Formation [2,6,21,28,30], is famous for its Early Cretaceous fossil assemblage with very abundant fossils, e.g. gastropods, bivalves, conchostracans, ostracods, insects, fishes, amphibians, reptiles, birds, mammals, and fossil plants.

3.1 The fossil assemblage of Jehol biota

The fossil assemblage of Jehol biota with gastropods, bivalves, conchostracnas, ostracods, insects, fishes, amphibians, reptiles, birds, mammals and fossil plants from bryophytes to angiosperms, belonging to 3 phyla and 20 classes of fossil animals, and 4 phyla and 7 classes of fossil plants, is a biota different from any

previous one. In the assemblage, the angiosperm *Archaefructus,* ostracod *Cypridea,* gastropod *Probaicalia* and dinosaur *Psittacosaurus* started to develop, and *Eosestheria-Ephemeropsis-Lycoptera* with the birds *Confuciusornis, Liaoningornis* entered a flourishing period to show a new stage of biotic development. Among them, the *Psittacosaurus* is a small ornithischia dinosaur widespread in Northern China, Mongolia, Siberia, Korea, Japan and Thailand in the Early Cretaceous strata.

3.2 The fossil distribution of Jehol biota

The fossils of Jehol biota in the Sihetun area occur mainly in the first and second members of the Yixian Formation (Fig.1). The distribution of Jehol biota fossils corresponds to that of volcanic-sedimentary rocks quite well [5, 7, 21] occurring mainly in tuffite beds of the first member.

3.2.1 Fossils of the first member of the Yixian Formation occur in the sandy tuff and tuffite beds, marked by *Psittacosaurus* and some fossil plants. The fossil bones of *Psittacosaurus* are mostly preserved after short-distance transportation. These small dinosaurs probably died from the volcanic hazard. The *Psittacosaurus*-bearing beds are distributed in Lujiatun, Liutai, Shuiquangou, Paodagou and Madaigou villages in the study area. These fossils are distributed mainly near or around edifices of the second member of the Yixian Formation.

3.2.2 Fossils of the second member of the Yixian Formation occur in the muddy shale beds of lacustrine facies, containing abundant fossils of "Jehol biota", e.g. fossil invertebrates (insects etc.), vertebrates (*Peipiaosteus, Manchurochelys, Sinosauropteryx, Confuciusornis,* and small mammals) and plants. It is confirmed that the fossils in the Libalanggou, Sihetun, Jianshangou and Huangbanjigou areas all belong to the equivalent beds. The fossils are distributed mainly in the northwest boundary of the basin.

3.3 The relationship between biological catastrophe and volcanic activities

According to the fossil excavation, there was a disaster caused to Jehol biota at that time [4,10,21,25]. There are abundant fossil animals and plants (about 2 fossil birds and, or 5 fossil fishes in less than 2 m^2) found in the volcanic-sedimentary strata of lacustrine facies of the second member of the Yixian Formation. There are also fossil baby animals (bird, fish etc.) excavated in the area. Most of the vertebrate fossils (*Confuciusornis, Zhanghetherium quinquespidens* Hu et al. and *Psittacosaurus* etc.) are preserved very well (dissected position). All evidence indicates that Jehol biota experienced mass mortality and rapid burial [21].

The fossil-bearing beds are generally muddy shale with intercalations of tuff, tuffite (more than 10 beds). The analysis of trace elements (Fig. 3) for samples from the fossils bearing-beds (Syp1G24, 36, 39 are main vertebrate fossils bearing beds) shows that the harmful constituents (S, As, Hg) are significantly higher than in the normal sedimentary beds (Syp8G2, 2, 10, 12 are pre-Cretaceous sedimentary beds in the study area).

The researches of a modern volcano tell us the following [9,17]: volcanic gases that pose the greatest potential hazard to people, animals, agriculture, and property are sulfur dioxide, carbon dioxide, and hydrogen fluoride. E.g. sulfur dioxide chiefly affects upper respiratory tract and bronchi. A concentration of 6-12 ppm of sulfur dioxide can cause immediate irritation of the nose and throat; 20 ppm can cause eye irritation; 10,000 ppm will irritate moist skin within minutes.

We can infer the following from the abovesaid: it may be air pollution from the volcanic exhalation and resulted in the mass mortality of Jehol biota. In other words, toxic gases of the volcanic activities are the main factors of the biological catastrophic event.

4. THE ISOTOPIC AGES OF THE YIXIAN FORMATION

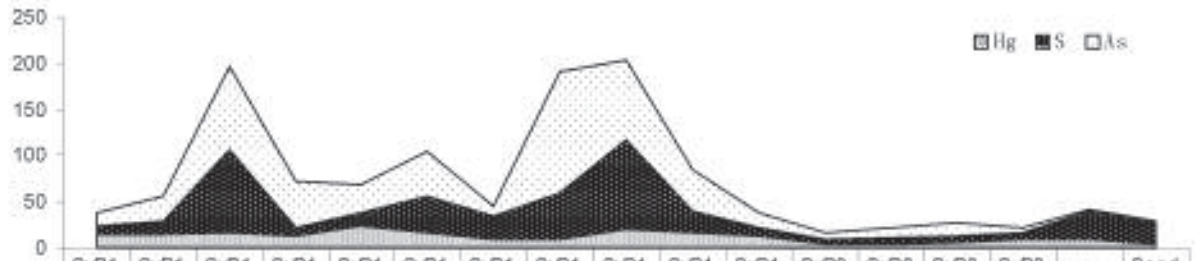
According to the subdivision of the Yixian Formation, we studied the isotopic ages of the Yixian Formation, especially of the precious fossil-bearing beds in detail by collecting samples systematically. A clear understanding of the geological features of the volcano-sedimentary rock series and the precious fossil-bearing beds, and their time-space distributions have obtained [18].

4.1 The first member of the Yixian Formation

We co-operated with Zhu Rixiang (Chinese Academy) to collect 2 samples from the basalt of the first member of the Yixian Formation near Xinkailing Village. We applied the whole rock K-Ar dating method and got the statistical weight mean ages of 133.20±0.11 Ma and 133.46±0.18 Ma, respectively.

Also, we collected samples from the basalt of the first member of the Yixian Formation near Sihetun Village, and applied the laser $^{40}Ar/^{39}Ar$ dating method to get the $^{40}Ar/^{36}Ar$-$^{39}Ar/^{36}Ar$ isochron age of 132.9±1.5 Ma from 5 laser points in the whole rock sample.

According to the IUGS 1989 Global Stratigraphic Chart by J.W Cowie and M.G. Bassett, the boundary between the Jurassic and the Cretaceous is 140–135 Ma in age. The earliest volcanic rock overlies directly the basal conglomerate of the Yixian Formation, and its age (133.46±0.18Ma) may represent the start age of the Yixian Formation that should be Early Cretaceous in age.



	SyP1 G4	SyP1 G18	SyP1 G24	SyP1 G27	SyP1 G29	SyP1 G33	SyP1 G34	SyP1 G36	SyP1 G39	SyP1 G41	SyP1 G45	SyP8 G1	SyP8 G2	SyP8 G10	SyP8 G12	Basalt	Sand stone
As	13.3	28.1	90.8	50.2	31.3	49.2	10.9	131	86.8	45.2	16.4	6.32	10.9	14.6	5.28	2	1
S	8.8	14	90	8.4	14	40	26	50	98	23	8.9	5.6	6.6	7	7.8	30	24
Hg	15	14	16	13	23	16	8.1	9.3	19	16	13	3.6	3.4	5.4	9	9	3

Fig. 3. Diagram showing the toxic composition of the fossil-bearing beds in the second member of the Yixian Formation compared with other normal beds.

Notice: 1 – The unite of S, As, Hg is 10^{-5}, 10^{-6}, and 10^{-8} respectively, the analyzing precision is 10^{-9}.

4.2 The second member of the Yixian Formation

There are some pillow lavas found in the precious fossil-bearing beds of lacustrine facies of the second member of the Yixian Formation near Sihetun Village. We collected samples from pillow lava (olivine basalt) and applied the laser $^{40}Ar/^{39}Ar$ dating method to get the isochron age of 126.1±1.7Ma from 5 laser points in the whole rock sample.

Wang Songshan et al. (20) also collected volcanic ash samples from the lacustrine sedimentary strata near Sihetun Village, and selected zircon crystals to take the U-Pb dating method, then got the age of 125.2±0.9 Ma.

All these ages are very close. We can confirm that the forming ages of the precious fossil-bearing beds are 125Ma~127Ma.

4.3 The third member of the Yixian Formation

Zhu Rixiang (29) collected 3 samples (olivine basalt) from the third member of the Yixian Formation near Sihetun Village and applied the whole rock K-Ar dating method to get the surface ages of 124.16±2.4 Ma, 124.42±2.4 Ma, and 124.91±2.4 Ma, respectively.

To sum up, the Yixian Formation is Early Cretaceous in age.

5. EVOLUTION OF STRUCTURAL-VOLCANIC ACTIVITIES AND BIOLOGICAL EVENTS DURING THE EARLY CRETACEOUS

By the end of the Late Jurassic, the study area experienced uplift and erosion, which is marked by unconformity [3,5,7,21] between the Lower Cretaceous (Yixian Formation) and the pre-Cretaceous (Upper Jurassic Tuchengzi Formation). At the early stage of the Early Cretaceous, the tectonic movement greatly changed that is marked by the structural stress field transformed from NW-SE directed compression to pull-apart to form a fault basin [6,17]. As a result, the volcanism of the Early Cretaceous began, and continuously strengthened. During the dormant period of volcanic activity, the paleoclimate enforced fast development of "Jehol biota". The alternative volcanism and sedimentation constructed the strata of the Yixian Formation. Five evolution stages are discussed below:

5.1 Formation of the embryonic basin and the early members of Jehol Biota (Fig. 4 A)

At the beginning of the Early Cretaceous, the structural stress field was dominated by NW-SE stretching stress which resulted in the formation of a NE-trending fault-F2 (the fault didn't reach the magma chamber at that time) and the embryo of an Early Cretaceous fault basin. The basin provided possible space for the basal conglomerate, water and the early members of Jehol biota, e.g. *Psittacosaurus* and some plants [26].

5.2 The first volcanic activity and biological hazard (Fig. 4 B)

With the development of NW-SE stretching stress, the NE-trending normal fault (F2) reached the magma chamber to cause the first volcanic activity of the Early Cretaceous. Most of the basal conglomerate and the early members of Jehol biota were covered by basic-intermediate volcanic lava, pyroclastic rocks and eruptive-sedimentary rocks of the first member of the Yixian Formation. The volcanism was continuously strengthened to form the Houyanzigou, Lamashan and Liulongtai volcanic edifices. There were more than 3 times of short volcanic periods during that time represented by three intercalated beds of explosive-sedimentary rocks with some fossil *Psittacosaurus* in it [3,5,7].

5.3 The dormant of volcanic activity and the development of Jehol biota (Fig. 4 C)

With the disappearance of NW-SE stretching stress, magma eruption exhausted and the first volcanic activity of the Early Cretaceous stopped temporarily on the earth's surface (though volcanic gas accumulated below in the magma chamber). The Sihetun paleolake was gradually formed in this volcanic dormant period. The sedimentary environment was mainly represented by a volcanic basin with paleocurrent coming from all margins of the lake basin and gathering to the center. The paleoclimate was warm and humid (7,8) to enforce the fast development of "Jehol biota", including spore, Pollens, gastropods, bivalves, conchostracans, ostracods, fishes, mammals, amphibians, reptiles, insects, plants and birds (*Confuciusornis*).

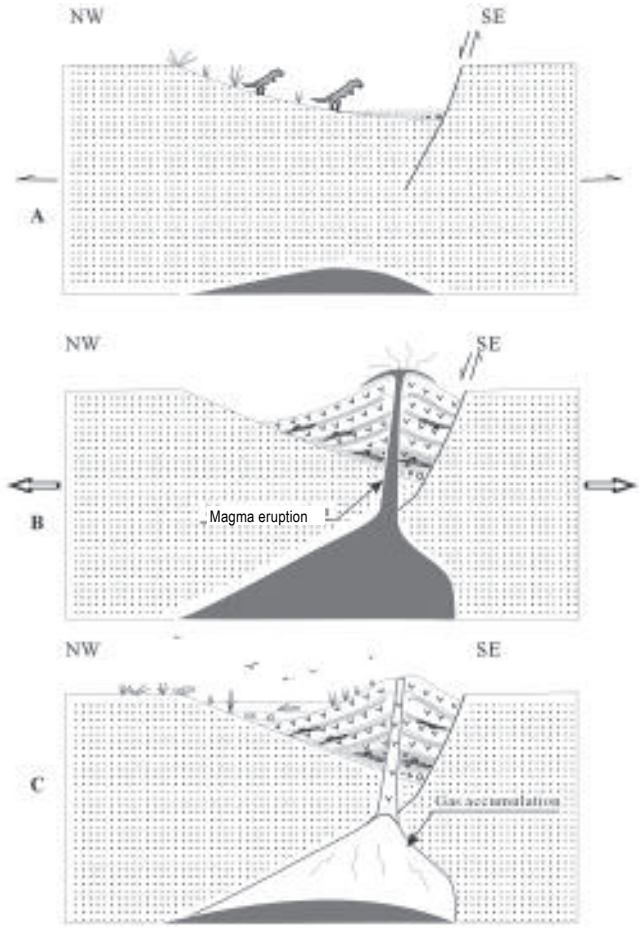


Fig. 4. The possible evolution of structural- volcanic activities and biological events during the Early Cretaceous.

A: The embryo of the basin and early member of Jehol biota
B: The first volcanic activity and biological hazard; C: The dormant period of volcano and development of Jehol biota.

With abundant water and fertilized volcanic soil around it, the Sihetun area was an ideal haven to Jehol biota at that time.

5.4 The volcanic exhalation and the catastrophe of Jehol biota (Fig. 5 D)

Affected by the multi-activity of the regional stress field (NW-SE stretching stress), the F2 fault revived. The temporary balance of the paleolake was upset by volcanic exhalation as soon as the magma chamber couldn't bear the high pressure of accumulated gas in it. The accumulated gas burst into the air from the structural-weak belt accompanied by volcanic rumbling and earthquake.

The air pollution from the volcanic exhalation resulted in the terrestrial lives (birds, mammals etc.) dying. Hundreds of dinosaurs, birds, and mammals, which lived near or around the paleolake, couldn't escape from the violent volcanic disaster. Many of them were killed by the heavily polluted air. Some bodies near or around the lake were carried by paleocurrent from all margins and gathered in the paleolake. Some birds dropped into the water directly when they flew over the paleolake.

To the aquatic lives (gastropods, bivalves, conchostracans, ostracods, fishes etc.), water pollution might be the dying reason. The volcanic earthquake conducted the volcano-associated geothermal system to the Sihetun paleolake, transporting magma and toxic elements (to form pillow lava) into the water (25) resulting in water pollution.

5.5 Tuff sediment (Fig. 5 E)

After (or along with) volcanic exhalation, continuous tuff sediments were deposited in the paleolake to "fulfil" the fossil burial and preservation of "Jehol biota" in the Sihetun area.

More than 10 beds of fossil-bearing muddy shale with intercalated tuffite occurred in the second member of the Yixian Formation in the Sihetun area. The alternative volcanic exhalation and tuff sedimentation constructed the fossil-bearing strata of the Yixian Formation. The Qianshuikouzi explosive breccia pipe of the second member of the Yixian Formation formed at that time.

5.6 The end (Fig. 5 F)

When the volcano lost its energy, gas and tuff exhausted in the magma chamber. The remained magma with high viscosity flowed up to the surface to form gray-grayish black olivine basalt and plagioclase olivine

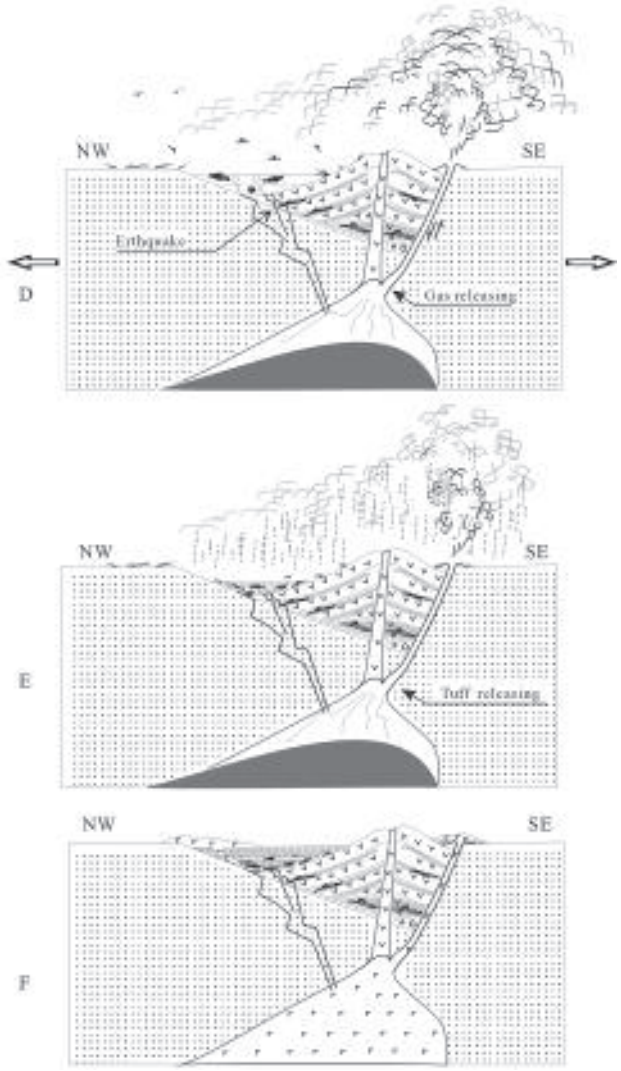


Fig. 5. The possible evolution of structural, volcanic and catastrophic events during the Early Cretaceous.

D: The volcanic exhalation and the catastrophe of Jehol biota; E: Tuff sediment; F: The end.

basalt. It is the symbol of the terminated product of the Yixian Formation in the Sihetun area. The Dahuzhanggou-Libalanggou volcanic edifices (the third member of the Yixian Formation) formed at that time. Some of them covered the sedimentary strata of lacustrine facies of the second member of the Yixian Formation.

To some extent, it helped the preservation of "Jehol biota" in the Sihetun area.

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Обсуждение структурно-вулканической активности и биологических событий в раннем мелу в районе Сыхэтунь (провинция Ляонин, Китай)

Район Сыхэтунь расположен в мезозойском вулкано-осадочном бассейне. Основными раннемеловыми структурами в этом районе являются разломы северо-восточного и северо-западного простирания, которые контролируют не только главные границы бассейнов, но также и некоторые вулканические постройки. По данным полевого картирования, формацию Исянь, представляющую собой единственные слои раннего мела в данном районе, можно подразделить на три пачки. Первая пачка представлена вулканическими породами основного и промежуточно-основного состава, переслоенными туфовыми слоями. Вторая пачка – это в основном слои осадочные пород озерной фации с прослоями кристаллического туфа, туфита и подушечных лав. Третья пачка представлена в основном базальтами. Биота Цзэхол (включая брюхоногих, двухстворчатых, ракушковых, насекомых, рыб, амфибий, рептилий, птиц, млекопитающих, а также ископаемых растений) встречается в туффитовых слоях первой пачки, а слои иловатого сланца связаны со второй пачкой формации Исянь. Экскавация и анализ микроэлементов указывает на то, что биота Цзэхол претерпела массовую смертность и быстрое захоронение; токсичные газы, выделяемые в ходе вулканической деятельности, являются основным фактором этого биологического катастрофического явления. Согласно изотопным датировкам, формация Исянь имеет раннемеловой возраст. В ходе всестороннего изучения также обсуждаются шесть эволюционных стадий (от А до Ж) структурно-вулканической деятельности и биологических явлений в раннем мелу, имевших место в районе Сыхэтунь. Стадия А – это "образование эмбрионного бассейна и ранних пачек биоты Цзэхол". Стадия Б – это "проявление первой вулканической активности и биологической опасности". Стадия В – это "стадия неактивной вулканической деятельности и развитие биоты Цзэхол". Стадия Г – это новая струя вулканической активности и катастрофа биоты Цзэхол". Стадия Д – это "туфовые осадки", и стадия Ж – это соответственно "конец".