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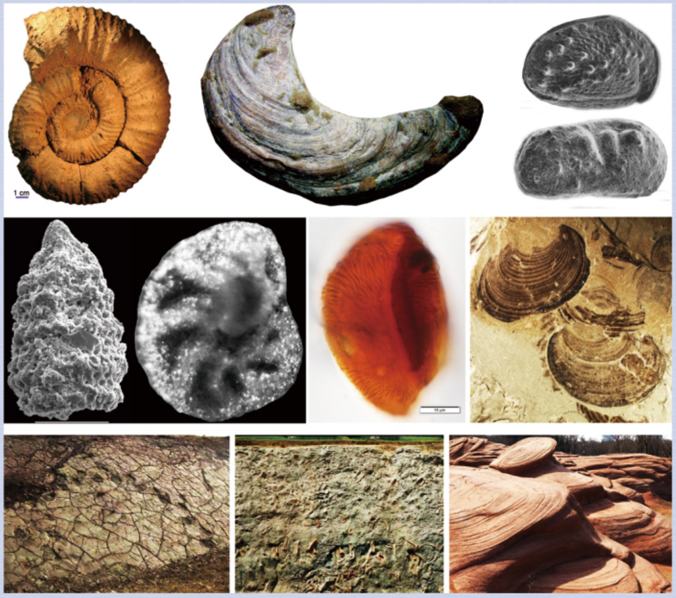
Cretaceous Earth Dynamics and Climate in Asia



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Preface

Cretaceous Earth Dynamics and Climate in Asia

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Since the industrial revolution, the increasing usage of fossil energy by humans has led to a continuous increase in atmospheric CO_2 emissions, thereby disrupting and unbalancing the global carbon cycle [1]. The direct result is a very rapid global warming. We are now experiencing its likely effects, such as the waning of pole ice caps, rising sea levels, regional changes in precipitation, acidification of the ocean, more frequently extreme weather events (such as heat waves), and expansion of deserts. The development of human civilization urgently requires us to acquire a deeper understanding of the development trend of this rapid climate change and its environmental effects, a topic that in recent years has become a hot issue of common concern from the general public to the scientific community [2] [3].

The Asian continent offers unique opportunities for studying the Cretaceous greenhouse climate and ecosystems. A variety of environments resulted in diverse ecosystems on land and in the oceans. Cretaceous marine strata of the eastern Tethys (India and Tibet of China) and the western Pacific (Japan, South Korea, China and Russia) open an indispensable window for the study of the oceanic anoxic events, oceanic oxygen-rich events and rapid climate changes [4] [5] [6]. Cretaceous continental deposits in Asia [7] [8] [9] [10] contain abundant terrestrial organisms that witness the ecosystem evolution and significant rapid climate changes [11] [12] [13].

Various Cretaceous terrestrial lithologic records and large igneous provinces in Asia bear witness to the environmental changes and ecosystem evolution [14] [15]. Cretaceous pedogenic carbonates of paleosols and fossil leaf stomatal index quantitatively depicted the fluctuation and evolutionary trends of the atmospheric CO_2 levels [16]. Desert deposits in the interior regions of the continent (Mongolia, China, and Thailand) reveal the shift of subtropical high-pressure belt and dramatic changes in climatic zonation pattern in Asia [17].

In this special issue, there are 50 short research papers covering a broad spectrum of fields reflecting many facets of biodiversity, palaeoenvironment, palaeogeography and palaeoclimate from the marine and non-marine Cretaceous sequences in Asia. The special issue is divided into four sections: 1) new research results on fossil records in the marine Cretaceous deposits in Asia provide important taphonomic [18], palaeogeographic and palaeoecological information which are useful for inter-continental, marine and non-marine biostratigraphic correlation [19] [20], and palaeoceanographic and palaeoenvironmental reconstruction; 2) new research results on Cretaceous non-marine fossil records provide the information of the palaeogeography, palaeoecology and palaeoclimate on land in Asia and South America, including a discussion on the origin of angiosperm [21], the turnover of fossil flora and faunas, and the description of new dinosaur taxa; 3) the overview of progress in the Cretaceous stratigraphy in China, Malaysia, Pakistan, the Far East of Russia, Thailand and Vietnam, especially including a discussion on the new stratigraphic framework in Shandong province [22], and the new progress on the Jurassic/Cretaceous and Cretaceous/Paleogene boundaries in China; 4) Cretaceous palaeoclimate reconstruction based on evidence from fossil records, special lithology and palaeo-weathering index. The Late Cretaceous floral turn-over in the Indian subcontinent indicates a latitudinal shifting of the Indian plate from sub-tropical to tropical zone during the Maastrichtian [23]. A palaeoweathering analysis of claystone samples intercalated within the mid-Cretaceous aeolian sandstone indicates that an alternate pluvious/arid paleoclimate controls the Sichuan basin during the mid-Cretaceous [24]. Aeolian deposits documented in the Santai Formation in the Mengyin Basin may indicate a change in palaeowind regime during the Late Jurassic to Early Cretaceous time interval [25]. The four sections of the special issue are topically overlapping and closely linked. They demonstrate a new exciting start of the UNESCO-IUGS IGCP Project 679.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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The Key Role of Aptian-Albian Marine Fossils from Eastern Heilongjiang in Marine-Nonmarine Stratigraphic Correlation

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Abstract

The alternating marine and nonmarine coal-bearing Lower Cretaceous successions are well developed in eastern Heilongjiang, northeastern China, including the Jixi Group in the west and the Longzhaogou Group in the east. The correlation of these two lithostratigraphic groups with the nonmarine Jehol Group is important for dating the exceptionally well-preserved Jehol Biota. The Early Cretaceous marine fossils recovered from eastern Heilongjiang include ammonites, bivalves, radiolarians, foraminifers and dinocysts. During the early Aptian transgression the ammonite fauna entered the Hulin and Mishan areas and the bivalve *Aucellina* fauna in the Jixi area. This enables correlation of the marine lower part of the Chengzihe Formation of the Jixi Group with the Qihulin Formation of the Longzhaogou Group.

Keywords

Lower Cretaceous, Aptian, Albian, Marine-Nonmarine Correlation, Marine Fossils, Eastern Heilongjiang, Northeastern China

1. Introduction

The upper Mesozoic deposits in China are mainly of nonmarine origin [1] [2]. The lack of index fossils makes it difficult to correlate precisely the nonmarine Cretaceous successions with the standard geological time scale. In particular, it is problematic to identify the nonmarine Jurassic-Cretaceous boundary [3], and to date the well-known Jehol Biota [4] [5]. In eastern Heilongjiang in northeastern China, an upper Lower Cretaceous succession of alternately marine and nonmarine coal-bearing rocks is well-developed, comprising the Jixi Group in the west (in which component taxa of the Jehol Biota were recovered) and the Longzhaogou Group in the east [6]. Since the discovery of the first ammonite specimen in 1958 [7], the coal-bearing beds in eastern Heilongjiang have attracted the attention of the Chinese geologists, not only because of the economic value of the coal, but also owing to the difficulties of stratigraphic correlation of the nonmarine and marine beds.

2. Marine Transgressions in Eastern Heilongjiang

The Early Cretaceous transgressions introduced marine faunas into eastern Heilongjiang, thus providing opportunities to correlate the Jixi and Longzhaogou groups. During the early Aptian transgression, the seawater advanced from the eastern continental margin through a narrow bay across the Hulin and Mishan areas to the Jixi area. The lower Aptian marine beds of the lower part of the Chengzihe Formation (Jixi Group) have yielded an *Aucellina* (*A.*) *caucasica*-*Filosina subovalis*-*Thracia rotundata* assemblage [8]. The contemporaneous marine Qihulin Formation (Longzhaogou Group) has yielded the following macro- and micro-faunas: 1) a low-diversity ammonite fauna dominated by *Pseudohaploceras*? cf. *nipponicum* and *Pseudohaploceras peideense*, with subordinate *Eogaudryceras* (*E.*) cf. *yunshanense* [9]; 2) an abundant bivalve fauna containing *Nuculana* (*Praesaccella*) cf. *yatsushiroensis*, *Filosina subovalis* and *Thracia rotundata* [8]; 3) a low-diversity, poorly preserved radiolarian fauna containing *Archaeodictyomitra* sp., *Novixitus* sp. and *Xitus* sp. [10]; 4) a low-diversity agglutinated foraminifer fauna with *Cribrostomoides nonioninoides, Haplophragmoides concavus* and *H. gigas minor* [11].

The upper Aptian marine deposits of the upper part of the Yunshan Formation (Longzhaogou Group) are characterized by an *Aucellina* (*Aucellina*) *caucasica*-*A.* (*A.*) *aptiensis*-*Filosina subovalis*-*Thracia rotundata* bivalve assemblage, overlain by beds containg an *Aucellina* (*A.*) cf. *caucasica*-*A.* (*A.*) cf. *aptiensis* bivalve assemblage and an *Odontochitina operculata*-*esperopsis didaoensis* dinocyst assemblage. The upper part of the Chengzihe Formation (Jixi Group) contains a marine *Sinopsamobia ovalis*-*Filosina subovalis* bivalve assemblage [8].

The Albian marine transgression introduced dinocysts to the Muling Formation (Jixi Group), which include the endemic taxa *Circulodinium cingulatum* and *Sentusidinium* sp., and the cosmopolitan species *C. attadalicum*, *Palaeoperidinium cretaceum* and *Oligosphaeridium totum* [8]. A contemporaneous marine *Sinopsamobia ovalis* bivalve fauna has been identified in the Zhushan Formation (Longzhaogou Group).

3. Marine-Nonmarine Correlation

The marine lower part of the Chengzihe Formation can be correlated with the Qihulin Formation through the early Aptian marine transgression that brought the ammonite fauna to the Hulin and Mishan areas and the bivalve *Aucellina* to the Jixi area [9]. The brackish-water bivalve *Sphaerioides yixianensis* (= *Tetoria yixianensis*) and the freshwater bivalves *Arguniella* cf. *quadrata* and *Arguniella* cf. *ventricosa* from the upper Chengzihe Formation provide direct correlation with the Shahai Formation of the Jehol Group in western Liaoning [9]. The overlying Fuxin Formation of the upper part of the Jehol Group can be correlated with the Muling Formation of the upper part of the Jixi Group, through a *Sphaerium* bivalve fauna contained in both formations.

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Conflicts of Interest

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Taphonomy and Sedimentological Significance of Oyster Shell Beds within Cretaceous Transgressive Sediments in Japan

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Abstract

Through taphonomical analyses of *Crassostrea* shell beds included in several Japanese Cretaceous strata, paleoecological and sedimentological significance of intertidal muddy and sandy bottom dwelling oysters are examined. The Upper Cretaceous *Crassostrea* shell beds show a variety of modes of occurrence, lithological changes and sedimentary structure, suggesting composite formative, paleoecological and sedimentary processes. *Crassostrea* seems to have adapted from muddy substratum during early Cretaceous to coarser sandier substratum often influenced by physical turbulence such as tidal currents and waves during the mid-Cretaceous time, associated with increasing in shell size and thickness, and colony dimension.

Keywords

Taphonomy, Oyster, *Crassostrea*, Cretaceous, Japan

1. Introduction

Oysters are sessile and suspension filter-feeding bivalves living on rocky/shelly ground as epifauna and sand/mud bottom as epi-/semi-infauna [1]. Among several genera of oysters, *Crassostrea* has adapted to muddy tidal flat in brackish-water inner bay areas since Late Jurassic, often forming large-scale colonies/reefs [2]. Because *Crassostrea* shell beds are often recognized in Japanese Cretaceous strata, they provide useful information on sedimentary processes of the estuary deposits as well as paleoecology of *Crassostrea* and its reefs.

2. Paleoecological and Sedimentological Significance

Physically unstable, brackish and tide-influenced muddy tidal flat is not suitable for filter feeding benthos because of high sedimentation rate and soupy substrate easily subject to burial and smothering of gill by suspended mud. However, *Crassostrea* could overcome these problems by the lightweight shell microstructure and a relay-type ecological strategy that new generations of individuals grow upward attached to other shells of the previous generations as a response to the rising sediment surface and succeeded in occupying a large niche. As it has flourished since early Cretaceous, many large-scale *Crassostrea* shell beds are found in several strata of various ages and areas, also in Japan.

Sedimentologically, *Crassostrea* shell beds are a good index for inner bay brackish environments as a facies fossil. In general, estuary and inner bay systems tend to be formed during transgressive stages. Their sediments and *Crassostrea* shell beds are mostly restricted to incised valley fills within transgressive systems tracts (TST). *Crassostrea* shell beds are one of keys for evaluating formation processes of TST.

Because of active bioturbation in estuary and inner bay environments, strata are usually massive and lack of physical sedimentary structures. But autochthonous oyster shell beds preserve the original features of colonies/reefs such as growth patterns of individuals and colonies as well as burial processes. Semi-autochthonous and even allochthonous shell beds also record event stratifications and accumulations such as storm/tidal/tsunami erosion and reworking.

Crassostrea shells and their fragments are often reworked and transported into shallow open-marine environments by waves and tidal and storm currents. *Crassostrea* reefs may have been eroded through shoreface erosion during transgression and provide a large amount of reworked shells into shoreface. *Crassostrea* reefs are one of large carbonate factories/sources providing shell materials in siliciclastic shallow shelf setting in the Northwest Pacific region.

3. *Crassostrea* Shell Bed Distribution in Cretaceous Strata of Japan

Japanese Cretaceous strata are distributed reflecting the tectonic setting of Cretaceous arc-trench system composed of backarc, intra-arc, forearc and trench-fill basins [3]. In the intra-arc side *Crassostrea* shell beds are found in the Lower Cretaceous strata such as the Yoshino Formation (Fm) (Berriasian-Valanginian), Toyonishi Group (Gr) in west Honshu, and the Ushimaru Fm (Hauterivian-Barremian), Tetori Gr in central Honshu, represented by *Crassostrea ryosekhiensis* and *C. tetoriensis*, respectively.

On the other hand, along the forearc side from SW to NE, 1) Goshoura (Albian-Cenomanian) and Mifune Grs (Cenomanian) represented by *C. kawauchidensis*, 2) Himenoura Gr (Campanian) in Kyushu, 3) Shiroyama Fm (Upper Campanian), Izumi Gr in Shikoku, 4) Tamagawa Fm (Upper Turonian–Lower Coniacian), Kuji Gr in north Honshu, 5) Mikasa Fm (Upper Cenomanian-Lower Turonian), Yezo Gr and 6) Hakobuchi Fm (Upper Campanian), Yezo Gr in Hokkaido, include characteristic shell beds in mode of fossil occurrence respectively. Except 1) for *C. kawauchidensis*, *Crassostrea* species in 2) to

6) are still not taxonomically identified. However, their stratigraphic ranges generally cover the whole Cretaceous: Lower Cretaceous by the intra-arc strata, and mid and Upper Cretaceous by the forearc strata.

4. Paleoecological Trends on *Crassostrea* and Shell Beds

Early Cretaceous *Crassostrea* species tend to be smaller less than 15 cm in size (shell height) and thinner in shell thickness, though they form bouquet-like small patchy shell concentrations. They generally occur from muddy lithofacies suggesting sporadic small patchy reefs on muddy tidal flat substratum.

Mid- and Late Cretaceous species are generally thicker than a few cm and longer than several tens cm at maximum, and form thick shell beds over several tens' cm long, occasionally over 1 m. They often constitute composite/multiple-event shell beds formed by intermittent colonization and physical reworking units within each bed. Several shell beds are intercalated with fine sandy layers without fossil shells in a thick intertidal sandstone section as exemplified in the Tamagawa Fm, Kuji Gr. The mid- and Upper Cretaceous shell beds tend to be silty very fine to fine sandstone in lithology, and coarser than the Lower Cretaceous ones.

This suggests that *Crassostrea* adapted from muddy substratum to coarser sandier substratum influenced by tidal currents and waves with increasing in shell size and thickness, and colony dimension during the mid-Cretaceous time.

5. Conclusion

Crassostrea shell beds often included in the Cretaceous transgressive deposits in intra-arc and forearc basins in Japan, provide important information on their taphonomical and sedimentological formative processes. *Crassostrea* and its related species have adapted from muddy tidal flat in brackish-water inner bay areas during early Cretaceous also to sandier tidal flat often influenced by tidal currents and waves during the mid-Cretaceous time, with general trends of increasing in shell size and thickness, and colony dimension.

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Conflicts of Interest

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Land-Ocean Linkage: Pelagic Cherts in Mesozoic Neritic-Terrestrial Sequences in East Asia

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Abstract

Chert clast-bearing epi-continental neritic-terrestrial Jurassic and Cretaceous sequences are sporadically distributed in southwestern Japan. Typical and geological entities are the Torinosu Group and Tetori Group. Radiolarian dating of chert clasts enables us to discuss denudation stages of mid Mesozoic accretionary complexes. Chert clast-dominated conglomerate can be used for identifying marine beds within terrestrial sequences.

Keywords

Pelagic Radiolarian Chert, Conglomerate, Accretionary Complex, Neritic-Terrigenous Sediments

1. Introduction

Mesozoic sedimentary sequences in East Asia are categorized into two types; marine accretionary complexes and epi-continental neritic-terrestrial sequences. The accretionary complexes are distributed in the eastern margin of Asia including Russian Far East, the Japanese Islands, and the Philippines [1] [2]. The epi-continental neritic-terrestrial sequences are distributed mainly in Russian Far East, China, the Korean Peninsula, and the Japanese Islands. Oceanic rocks such as pelagic chert are typical components of accretionary complexes. They are also included in neritic-terrestrial sequences as recycled clasts. They are important not only in recognizing the provenance of sedimentary basins but also in tracing the denudation history of accretionary complexes. The pelagic materials are tools for linking lands and oceans. We introduce two examples of chert-bearing conglomerate in neritic-terrestrial sequences in Japan: the Torinosu Group in the Southern Chichibu Terrane, Outer Zone of southwest Japan and the Tetori Group in the Hida and Hida-Gaien terranes, Inner Zone of southwest Japan. Significance of the pelagic cherts within neritic-terrestrial sequences is discussed.

2. Epi-Continental Neritic-Terrestrial Jurassic and Cretaceous Sequences in Southwest Japan

2.1. Torinosu Group

The Torinosu Group and its equivalents are late Jurassic to early Cretaceous neritic sequences distributed disconnectedly in the Chichibu Belt in southwest Japan. Three terranes are recognized in the Chichibu Belt based on characteristic features of their components and geologic structures: the Northern Chichibu, Kurosegawa (Middle Chichibu), and Southern Chichibu terranes from north to south. The Torinosu Group occupies the Southern Chichibu and Kurosegawa terranes. In the type locality of the Torinosu Group (Sakawa area in central Shikoku), this group unconformably covers the Togano Group [3] [4] of Jurassic accretionary complex or the Naradani Formation of trench slope sediments. The basal part of the Torinosu Group is the Tsukadani Formation composed mainly of chert clasts. They are regarded to have been derived from the Togano Group because the group is the basement of the Torinosu Group and contains a large amount of chert sequences. No microfossils, however, have been obtained from the chert clasts due to recrystallization.

2.2. Tetori Group

The Tetori Group ranging in age from the Middle Jurassic to Cretaceous is distributed over the Hokuriku District in central Japan. Most parts of the Tetori Group overly unconformably constituent geologic units of the Hida and Hida-Gaien terranes. These units do not include mid-Mesozoic accretionary complexes. This group is divided into the Kuzuryu, Itoshiro, and Akaiwa subgroups in ascending order and interbeds conglomerate layers. Permian, Triassic, and Jurassic microfossils were obtained from siliceous and muddy rock clasts in the conglomerates. Based on fossil dating and lithological characteristics, most of these clasts were presumably derived from the mid-Mesozoic accretionary complexes in East Asia [5] [6].

3. Discussion and Conclusion

As mentioned above, the Torinosu Group and Tetori Group are good examples for chert clast-bearing epi-continental neritic-terrestrial Jurassic and Cretaceous sequences in southwest Japan. These chert clasts must be derived from mid Mesozoic accretionary complexes formed in the eastern margin of Asia. Ito *et al.* [7] discussed denudation stages of mid Mesozoic accretionary complexes based on the dating of chert clasts by means of radiolarian fossils not only from the

Japanese Islands but also the Korean Peninsula.

Highly resistant nature of chert clast suggests certain sedimentary environments. Chert clast-dominated conglomerate could be a good marker indicative of high energy sedimentary environment such as marine beach. The Tsukadani Formation in the Torinosu Group is considered to be beach sediment resting on mid Mesozoic accretinary complex or slope sediments directly covering the accretionary complex. Chert clast-dominated conglomerate within the upper part of the Itoshiro Subgroup in the Tetori Group is possibly marine beach origin. Chert clast-dominated conglomerate can be used for identifying marine beds within terrestrial sequences.

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New Data on the Litho- and Biostratigraphy of the J/K Boundary Interval of the Lower Reaches of the Lena River (Eastern Siberia)

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Abstract

New data on the litho- and biostratigraphy of the Jurassic/Cretaceous (J/K) boundary interval of the lower reaches of the Lena river, at the Cape Chekurovka and Cape Chucha, are presented. Volgian-Valanginian interval of the Chekurovka section is represented by Buolkalakh and Kigilyakh formations and corresponds to beds with *Buchia fisheriana*, beds with *B. unschensis*, beds with *B. okensis* and *B. volgensis*, beds with *B. volgensis*, beds with *B. volgensis* and *B. tolmatschowi* and beds with *B. keyserlingi*. Volgian-Valanginian interval of the Chucha section is represented by Chonoko, Khairgass and Kigilyakh formations and corresponds to beds with *B. unschensis*, beds with *B. volgensis* and *B. okensis*, beds with *B. volgensis* and *B. tolmatschowi* and beds with *B. keyserlingi*.

Keywords

Stratigraphy, Jurassic, Cretaceous, Siberia, Lena River

In the summer 2018 expedition group of IPGG SB RAS has studied the J/K boundary interval in the sections of Chekurovka and Chucha located in the lower reaches of the Lena river (Figure 1). As a result, bio- and lithostratigraphy have been clarified.

On the Cape Chekurovka Volgian-Valanginian deposits with stratigraphic unconformity overlie condensated Oxfordian sandstones (Figure 1). Volgian-Ryazanian part of the section belongs to the Buolkalakh Formation and consists of alternated greenish-grey and grey siltstones and light-grey sandstones

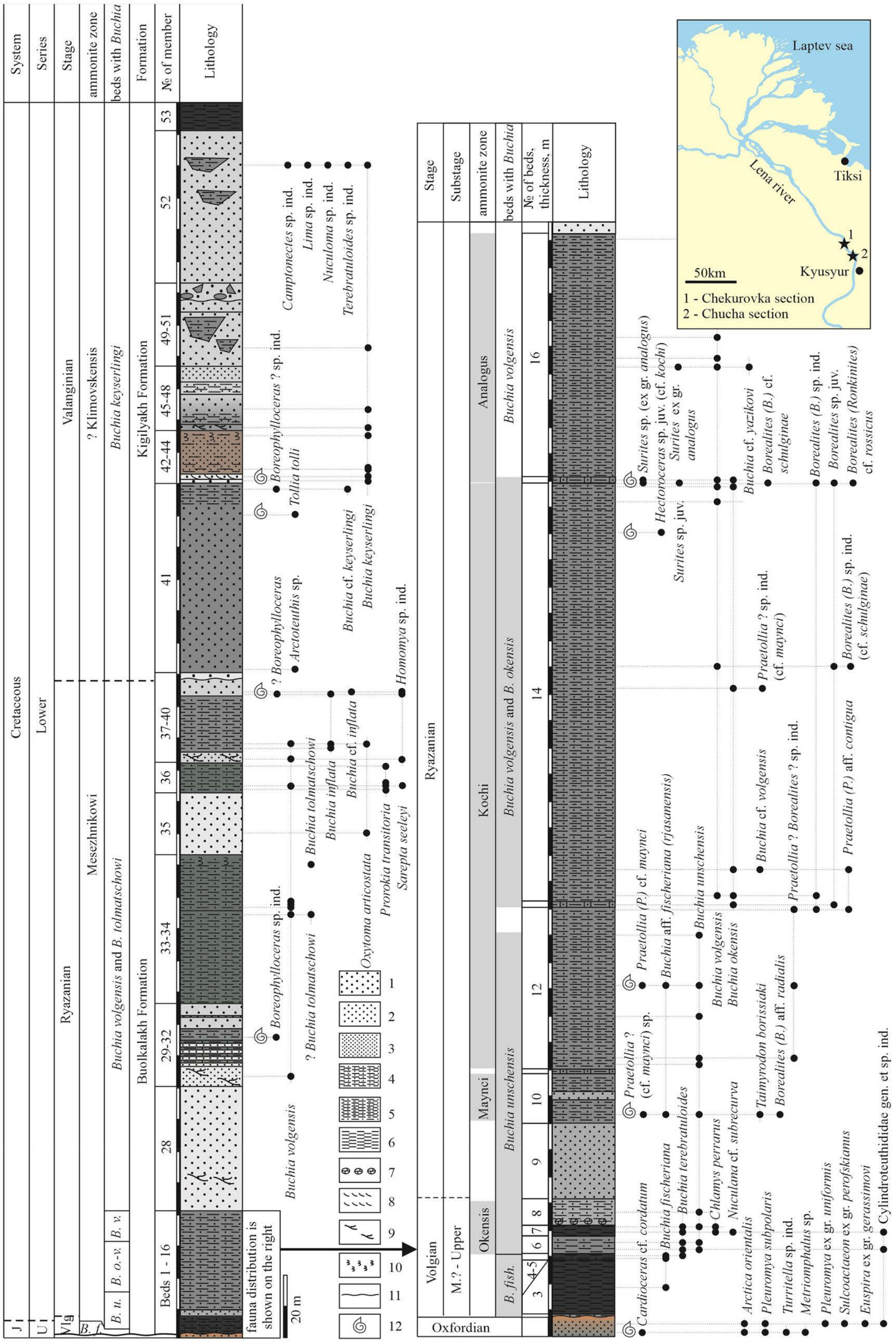

Figure 1. Litho- and biostratigraphy of the Chekurovka section and map with locations of the Chekurovka and the Chucha sections. Numeration of beds and members is given after [1]. Legend: 1: coarse sandstone, 2: medium-grained sandstone, 3: fine-grained sandstone, 4: siltstone, 5: clayey siltstone, 6: silty argillite and argillite, 7: carbonate nodules, 8: oblique lamination, 9: carbonized plant detritus, 10: bioturbation, 11: erosional surface, 12: finding of ammonites.

with black and dark-grey argillites and siltstones in the lower part. The total thickness of the formation is more than 220 m. The Valanginian Kigilyakh Formation which overlies the Buolkalakh Formation consists of sandstones with breccias and silty argillites in the upper part. The boundary between Buolkalakh and Kigilyakh formations is marked by an erosional surface. The total thickness of the Kigilyakh Formation is more than 180 m.

Succession of *Buchia*, typical for the Boreal Scale, has been identified in the Chekurovka section: beds with *B. fisheriana*, beds with *B. unschensis*, beds with *B. okensis* and *B. volgensis*, beds with *B. volgensis*, beds with *B. volgensis* and *B. tolmatschowi*, and beds with *B. keyserlingi* (**Figure 1**). Beds with *B. fisheriana* comprise also *B. terebratuloides* in the upper part. Based on ammonite *Praechetaites* sp. nov. this interval previously has been correlated with uppermost Middle Volgian [1]. Beds with *B. unschensis* comprise *B. terebratuloides* in the lower part. Beds with *B. okensis* contain single *B.* cf. *yazikovi*. Beds with *B. volgensis* and *B. tolmatschowi* also contain *B. inflata* in the upper part. The Ryazanian/Valanginian boundary is conventionally marked on the erosional surface between members 39 and 40 [1]. The Valanginian part of the section corresponds to beds with *B. keyserlingi*.

Section on the Cape Chucha is located approximately 20 km south of the Chekurovka section. It differs from the Chekurovka section by its lithostratigraphic construction. This is linked with its position near the boundary of Olenek and Lower Lena facial regions where sedimentation occurred in shallower part of sea compared to Chekurovka [2]. Volgian part of the Chucha section with stratigraphic unconformity overlies Oxfordian sediments and consists of sandstones and siltstones of the Chonoko Formation. The Ryazanian Khairgass Formation mainly consists of whitish-grey sandstones alternated with greenish-grey and grey siltstones. It is conformable overlaid by the Kigilyakh Formation represented here by rhythmic alternating of fine-grained sandstones and siltstones with beds of sandstones and silty argillites. The total thickness of Volgian-Valanginian deposits is more than 300 m. The following succession of beds with *Buchia* is identified in the Chucha section: beds with *B. unschensis*, beds with *B. volgensis* and *B. okensis*, beds with *B. volgensis* and *B. tolmatschowi*, and beds with *B. keyserlingi*.

Acknowledgements

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Macrofossil Assemblages in the Ryazanian Stage (Lower Cretaceous) of the Stratotype Region

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Abstract

The stratotype region of the Ryazanian stage is located in the Oka River Basin near Ryazan, Central Russia. Since ammonites are very well studied here, we investigated other groups of macrofossils. We report a large number of bivalve genera: *Arctica*, *Astarte*, *Buchia*, *Camptonectes*, *Chlamys*, *Ctenostreon*, *Entolium*, *Gomomya*, *Gresslya*, *Hartwellia*, *Lima*, *Meleagrinella*, *Modiolus*, *Oxytoma*, and *Pleuromya*. The belemnites are represented by two cylindroteuthidid genera, *Acroteuthis* and *Liobelus*. In addition, brachiopods (Rhynchonellidae and Terebratulidae) and unidentifiable gastropod fragments have been revealed. The highest taxonomic diversity of macrofauna is observed in the *Surites spasskensis* ammonite Zone.

Keywords

Fossil Mollusks, Brachiopods, Ryazanian, Central Russia

1. Introduction

The problem of correlation of the Volgian and Ryazanian stages with the standard Tithonian and Berriasian stages has not yet been unambiguously solved, but it has been proven that the upper part of the Upper Volgian substage belongs to the Cretaceous System. Nevertheless, it is still justified to recognize the Volgian and Ryazanian in the vast Boreal palaeobasins, because these regional stages reflect two different periods of geologic history, primarily that of palaeobasin in the East European Platform [1]. To some extent, this is also a tribute to the traditions, according to which most of the geological documents for Boreal regions were compiled in the XX-early XXI centuries. And the Volgian-Ryazanian boundary is characterized by reliable bioevent markers in Boreal sections. However, it is hardly correct to treat the Volgian-Ryazanian boundary as the Jurassic-Cretaceous (J-K) boundary. The definition of the Ryazanian stage and its base largely depends on the detailed study of the stratotype region located in the Oka River Basin near Ryazan, Central Russia.

2. A Review of New Data

The precise stratigraphic position of fossil finds in the Ryazanian of the stratotype region is usually difficult to determine due to the highly condensed J-K boundary sections in Central Russia, their small thicknesses and numerous sedimentation interruptions. Therefore, the stratigraphic position of the lower horizons of the Ryazanian in Central Russia is still under discussion.

The Ryazanian deposits in the Oka River Basin contain numerous shells of mollusks, especially those of bivalves, but ammonites are the best studied group in the stratotype region [2] [3]. Following Mitta [3], we recognize three ammonite zones within the Ryazanian in the Oka River Basin, namely the *Riasanites rjasanensis*, *Surites spasskensis* and *Surites tzikwinianus* zones. Bivalves, belemnites, gastropods as well as brachiopods are the main objects of our research.

Representatives of the genus *Buchia* are most abundant among bivalves. It is noteworthy that Boreal zonal scales based on Buchiidae are successfully used for the subdivision and correlation of the J-K boundary beds in Boreal regions [4]. In addition to the beds with *Buchia fischeriana*, a sequence of mixed assemblages from different *Buchia* zones is observed in the Ryazanian stage for the Oka River sections [5]. These are beds with *Buchia volgensis* + *Buchia okensis* + *Buchia jasikovi*, and beds with *B. volgensis* + *B. jasikovi* + *Buchia tolmatschowi*. In the standard Boreal biostratigraphic scale, the *B. okensis* Zone, the *B. jasikovi* Zone and the *B. tolmatschowi* Zone have been distinguished as a series of zones parallel to the *B. volgensis* Zone [4] [6] [7]. Other bivalve taxa identified from the Ryazanian on the Oka River are members of the genera *Hartwellia*, *Lima*, *Pleuromya* (in the *Riasanites rjasanensis* Zone), *Arctica*, *Astarte*, *Camptonectes*, *Chlamys*, *Ctenostreon*, *Entolium*, *Gomomya*, *Gresslya*, *Hartwellia*, *Meleagrinella*, *Modiolus*, *Oxytoma*, and *Pleuromya* (in the *Surites spasskensis* Zone).

In all studied sections, belemnites are represented by two genera, *Acroteuthis* and *Liobelus* (Cylindroteuthididae). Cylindroteuthidid belemnites are a relatively new tool for pan-Boreal correlation of the J-K boundary beds [8] [9]. Two belemnite beds can be recognized in the Ryazanian on the Oka River: an upper part of the regional beds with *Liobelus russiensis* and *Acroteuthis mosquensis*, and the beds with *Acroteuthis explanatoides* [5]. Belemnites are rather frequent here, especially *Acroteuthis*. A certain sequence in the appearance of species from the genus *Acroteuthis* is observed upward in the section: *A. mosquensis* - *A. arctica* - *A. subquadratoides* - *A. explanatoides*.

In addition to cephalopods and bivalves, we found brachiopods (Rhynchonellidae and Terebratulidae) and unidentifiable gastropod fragments, all in the

Surites spasskensis ammonite Zone. This zone is characterized by the highest taxonomic diversity of macrofauna.

3. Conclusion

In the Ryazanian stage of the stratotype region, the richest assemblage of macrofossils is recorded from the Subboreal *Surites spasskensis* ammonite Zone, which corresponds to the middle part of the *Hectoroceras kochi* Zone - *Surites analogus* Zone in the Boreal ammonite scale.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Biradiolites from the Yigeziya Formation of the Southwestern Tarim Basin

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Abstract

Two *Biradiolites* species described from the Yigeziya Formation of the southwestern Tarim Basin are revised. The Maastrichtian *Biradiolites boldjuanensis* is small and pipe-like species that is usually preserved as clusters or bouquets. Although it was considered to be endemic to Central Asia, similar specimens are abundant in Maastrichtian of other Tethyan regions. *Biradiolites minor* specimens have no relationship with the genus *Biradiolites* because their ventral and posterior bands are protruding ridges and interband is depressed broad groove. This species is comparable with the Campanian-Maastrichtian eastern Arabian species *Glabrobournonia arabica*, by the character of smooth outer shell layer in right valve, and simple radial bands and ridges on margin of each shell flank, but it differs from the latter species in size and the shape of left valve. This study will be a supportive tool for the establishment and reconstruction of the palaeogeographic connection between Central Asia and other Tethyan regions.

Keywords

Tarim Basin, Cretaceous, Rudist, *Biradiolites*

1. Introduction

Biradiolites d'Orbigny 1850 is radiolitid which is characterized by the protruding interband and relatively depressed ventral and posterior bands, as well as the absence of the ligament infolding and central tooth in right valve. It has a cosmopolitan distribution with the age ranging from Turonian to Maastrichtian. Two *Biradiolites* species, *Biradiolites boldjuanensis* Bobkova 1960 and *Biradiolites minor* Pojarkova 1955, had been described by Lan and Wei (1995) from the Yigeziya Formation of the southwestern Tarim Basin. Both of them were considered as endemic species that are restricted to the southeast Central Asia including Tajik, Fergana and Tarim Basin. As similar specimens have been recorded from other Tethyan regions like eastern Arabia [1], the taxonomic position and distribution of these two species need to be revised.

2. Geological Setting

The SW Tarim Basin in Xinjiang Ugur Autonomous Region is one of the main areas in China where the marine Cretaceous is well developed [2]. The Upper Cretaceous deposits crop out as a narrow belt along the southwest border of this basin and are represented mainly by sediments of littoral, near-shore neritic and estuarine facies divided in ascending order into the Kukebai, Wuyitake, Yigeziya and Tuyiluoke formations [3]. Ygeziya Formation distributed as a narrow NNW belt encompassing Kashgar, Wuqia, Aketo, Yengisar, Kargant and Yecheng counties, with its thickness thins gradually from west to east, changing from 125 m to 10 m [4].

3. Revision of *Biradiolites* Species from the Yigeziya Formation

Biradiolites boldjuanensis was recorded in the upper part of the Yigeziya Formation. Lan and Wei' specimens are small in size, with the commissural diameter ranging from 3 mm to 7 mm, and mostly preserved as clusters or bouquets. The right valve is elongate cylindrical, has about 6 to 10 radial ribs. As the dental and myophoral structures are not preserved, it is difficult to identify the position of the radial bands. Lan and Wei [4] defined the most protruding rib as the interband. The outer shell layer develops coarse cellular structure. This species is abundant in the Maastrichtian of Southeast Central Asia including SW Tarim Basin, east Tajik Basin and SW Darwasi [5]. Although it was considered as an endemic species that restricted to Central Asia, similar specimens that usually preserved as clusters are abundant in Maastrichtian of other Tethyan regions [6], detailed study on the relationship of *B. boldjuanensis* with other contemporaneous *Biradiolites* species like *B. mooretownensis* need to be carried out in the future.

Biradiolites minor was described from the middle part of the Yigeziya Formation. Most Tarim specimens were preserved as small individuals, the height of right valve ranging from 20 mm to 35 mm. Left valve is operculiform, right valve is conical, with four acute ridges on the margin of dorsal, posterior, ventral and anterior flanks. The ridge located on the anterior margin of the ventral flank is ventral band, and the adjacent one on the posterior margin is posterior band. The outer shell layer of right valve is thin and smooth, without longitudinal ornamentations on the surface. Except for Tarim Basin, it has also been reported from the Campanian-Maastrichtian of Fergana Basin and Alai. This species has no relationship with the genus *Biradiolites* because their ventral and posterior bands are protruding ridges and the interband is depressed broad groove. They show typical characteristics of the genus *Glabrobournonia* Morris and Skelton, 1995, including the smooth outer shell layer of right valve, simple radial bands and ridges on the margin of each flank, but differ from the eastern Arabian type species *G. arabica* in size and the shape of the left valve.

4. Conclusion

Biradiolites boldjuanensis is small radiolitid which is usually preserved as clusters or bouquets. Although it was considered to be endemic to Central Asia, similar specimens are abundant in Maastrichtian of other Tethyan regions. *Biradiolites minor* specimens from the SW Tarim Basin have no relationship with the genus *Biradiolites* because their ventral and posterior bands are protruding ridges and interband is depressed broad groove. This species is comparable with the Campanian-Maastrichtian eastern Arabian species *G. arabica*, but differs from the latter in size and the shape of left valve. The rudist taxa discussed herein, probably have a relatively cosmopolitan Tethyan distribution; this finding could be a supportive tool for the reconstruction of the palaeogeographic connection between Central Asia and other Tethyan regions.

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Conflicts of Interest

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First Report of Redeposited Cretaceous Radiolarians in the Eocene Sand-Shale Member of Zhepure Formation, Tüna, Yadong, Tibet

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Abstract

Cretaceous radiolarians were firstly reported from the Eocene Sand-Shale Member of Zhepure Formation in the Gulupu section, Tüna, Yadong, Tibet. In spite of poor preservation, 24 species of 14 radiolarian genera have still been identified, clearly indicating an age, ranging from early Aptian–Maastrichtian, and therefore should have occurred in the Eocene as a result of redeposition. The study of the stratigraphic origin of these radiolarians will shed light on the paleoenvironment and late evolutionary history of the Tibet-Tethys.

Keywords

Cretaceous, Redeposited Radiolarians, Eocene, Zhepure Formation, Paleoenvironment, Yadong

Radiolarian Biostratigraphy

A certain number of radiolarians were obtained in the Eocene strata of Gulupu section, based on the previous studies on Cretaceous radiolarians in Tibet [1] [2] [3] [4], and other areas [5] [6], 24 species of 14 genera were identified, which provides an age of middle to late Cretaceous. The important elements (**Figure 1**) include *Turbocapsula fugitive* O'Dogherty, early Aptian to early Albian; *Cryptamphorella conara* (Foreman), Albian to late Maastrichtian; *Pessagnobrachia irregularis* (Squinabol), middle Albian to middle Cenomanian; *Acaeniotyle umbilicate* (Rust), late Campanian; *Holocryptocanium tuberculatum* Dumitrica, late Cenomanian; *Xitus spicularius* (Aliev), middle Albian; *Stichomitra compsa* Foreman, Maastrichtian; *Pseudodictyomitra carpatica* (Lozyniak),

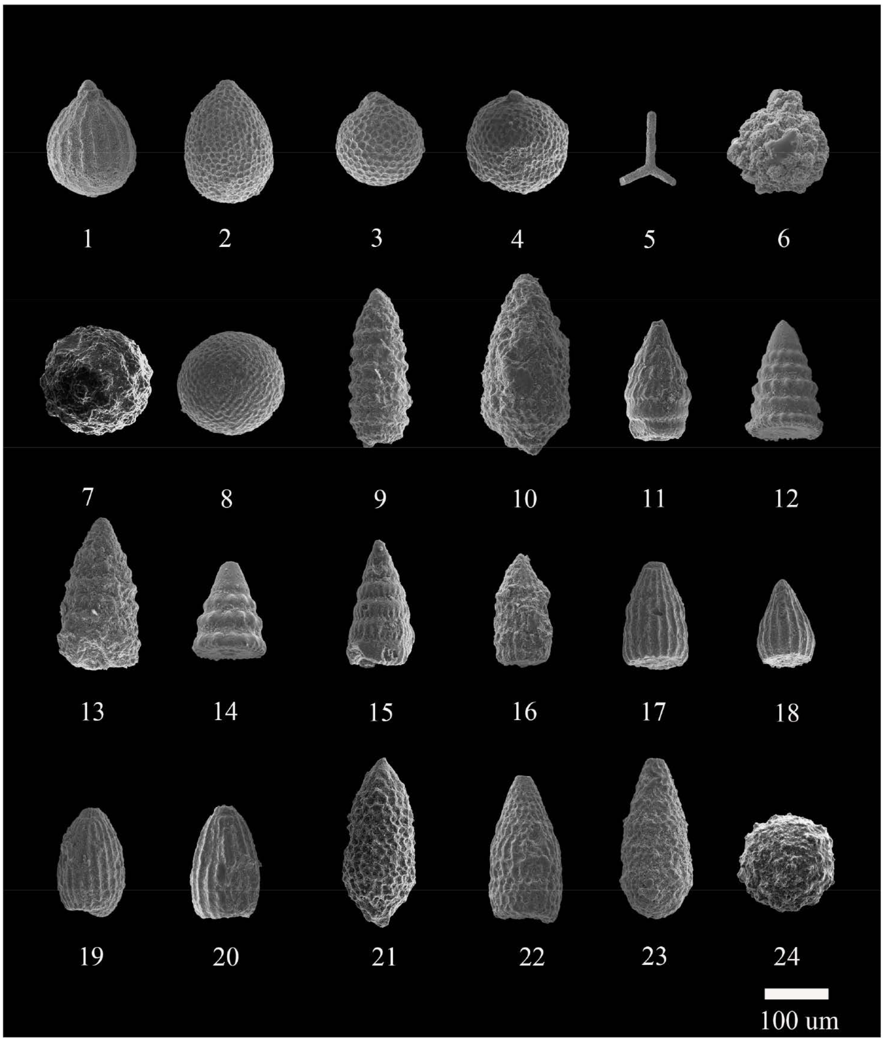

Figure 1. Scanning electron micrographs of reworked radiolarians in the Gulupu section. 1. *Turbocapsula costata* (Wu); 2. *T. fugitive* O'Dogherty; 3. *Cryptamphorella conara* (Foreman); 4. *C. sphaerica* (White); 5. *Pessagnobrachia irregularis* (Squinabol); 6. *Acaeniotyle umbilicate* (Rust); 7. *Holocryptocanium tuberculatum* Dumitrica; 8. *H.* sp.; 9. *Xitus spicularius* (Aliev); 10. *Stichomitra compsa* Foreman; 11. *Pseudodictyomitra carpatica* (Lozyniak); 12. *P. hornatissima* (Squinabol); 13. *P. nuda* (Schaaf); 14. *P. pachicostata* (Wu and Li); 15. *Dictyomitra communis* (Squinabol); 16. *D. montisserei* (Squinabol); 17. *D. multicostata* Zittel; 8. *Thanarla brouweri* (Tan); 19. *T. conica* (Squinabol); 20. *T. veneta* (Squinabol); 21. *Distylocapsa veneta* (Squinabol); 22. *Lithostrobus litus* Forman; 23. *Amphipyndax stockii* (Campbell and Clark); 24. *Praeconocaryomma californiaensis* Pessagno.

early Aptian; *P. nuda* (Schaaf), early Aptian; *P. pachicostata* (Wu and Li), Turonian; *Dictyomitra communis* (Squinabol), late Aptian; middle Albian; *D. multicostata* Zittel, early Turonian; *Lithostrobus litus* Forman, late Cretaceous; *Thanarla conica* (Squinabol), Middle Albian; *T. veneta* (Squinabol), late Albian to Turonian; *Amphipyndax stockii* (Campbell and Clark), Campanian; *Distylocapsa veneta* (Squinabol), late Albian to middle Cenomanian and *Praeconocaryomma californiaensis* Pessagno, Coniacian-Santonian.

During Eocene, there was a residual basin in Yadong area [7]. According to the plate tectonic background and stratigraphic characteristics of Yadong and adjacent areas, it is inferred that the redeposited radiolarian should come from the underlying Cretaceous strata in the study area and adjacent areas, which redeposited in Eocene residual sea basin after weathering, erosion and transportation.

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Conflicts of Interest

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Hauterivian-Barremian Bivalves from the Boulouha Formation of the Dahar Escarpment, Southern Tunisia: Stratigraphy and Regional Correlation

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Abstract

The Lower Cretaceous mixed siliciclastic-carbonate successions of the Boulouha Formation at the type locality in the Dahar escarpment of southern Tunisia have yielded a new discovered assemblage of bivalves which contains *Anomia laevigata* (Sowerby); *Modiolus* sp. cf. *M. dahuashuensis* (Yu et Li); *Astarte* sp.; and ?*Mytilus* sp.. The temporal distribution of the *Anomia laevigata* (Sowerby) and *Modiolus* sp. cf. *M. dahuashuensis* (Yu et Li) is limited to the Aptian formations of northeastern China, Japan and Korea, thus we suggest a Hauterivian-Barremian age for the Boulouha Formation. Henceforth, the new biostratigraphic data are used to improve a regional chronostratigraphic correlation between the lower Cretaceous strata of the Saharan Platform domain and those coeval from the Chotts domain.

Keywords

Bivalves, Hauterivian-Barremian, Boulouha Fm., Dahar Escarpment, Tunisia

1. Introduction

The Saharan Platform domain of southern Tunisia has recorded very thick Mesozoic successions that developed during the syn- and post-rifting stages in the Tataouine basin. These strata hosted a huge number of faunal and floral fossils that widely contribute to providing the necessary chronostratigraphic data for the establishment of the southern Tunisian stratigraphic chart. However, the lower Cretaceous deposits cropping out along the Dahar escarpment are worldwide known from the numerous biota sites discovered over the past twenty years which yield macro- and microfossil vertebrate remains [1] [2] as well as very well preserved fossil plants [2]. The present work provides new biostratigraphic data based on fossil bivalves and aims to: 1) refine the age of the Lower Cretaceous succession of the Tataouine basin and 2) correlate these lower Cretaceous strata with those of the Chotts basin.

2. Study Area

The Lower Cretaceous deposits are widely exposed in the Saharan Platform domain along the Dahar escarpment which runs for about 300 km in a roughly N-S direction along the northeastern margin of the Tataouine basin (**Figure 1(a)**). At the type locality, the Late Jurassic (Oxfordian-Kimmeridgian)-Early Cretaceous (Aptian) Merbah el Asfer Group, siliciclastic dominated succession, is divided into three formations which are from the base to top: Bir Miteur, Boulouha, and Douiret [2] (**Figure 1(b)**). The deposits of Bir Miteur and Douiret formations encompassed several fossiliferous beds which have yielded faunal and floral assemblages characterizing the Kimmeridgian and the Early Aptian respectively. However, the Boulouha Formation is attributed to different ages including the Barremian-Aptian [1] [2] and the Hauterivian (**Figure 1(b)**). Each Formation is bounded by erosional surfaces of regional extent called D1-D4 [2]. The Fossil bivalves assemblage recently discovered from the Boulouha Fm. allowed giving new insights on its age.

3. Results

The Boulouha Formation consists of approximately 80 meters of interbedded sandstones and greenish clays with frequent intercalation of dolomitic beds characterizing a siliciclastic/carbonate tidal flat setting [2] (**Figure 1(b)**). The greenish clay horizons have previously yielded fossil plants [2] and for the first time well preserved bivalve specimens were collected from a claystone bearing horizon situated at about 10 m above the Kimmeridgian carbonate marker bed (**Figure 1(b)**). This horizon contains the following bivalve species, *Anomia laevigata (*Sowerby); *Modiolus* sp. cf. *M. dahuashuensis (*Yu et Li); *Astarte* sp.; and ?*Mytilus* sp.. This bivalve association indicates a Hauterivian-Barremian age. The temporal distribution of the *Anomia laevigata (*Sowerby) and *Modiolus* sp. cf. *M. dahuashuensis (*Yu et Li) is limited to the Aptian formations of England, northeastern China, Japan and Korea [3].

Henceforth, the Hauterivian-Barremian Boulouha Formation of the Saharan domain constitutes coeval strata of the Hauterivian-Barremian Bouhedma Formation of the Chotts domain.

4. Conclusion

The Hauterivian-Barremian age is for the first time attributed to the Boulouha Formation of the Dahar escarpment, Saharan Platform domain, based on well

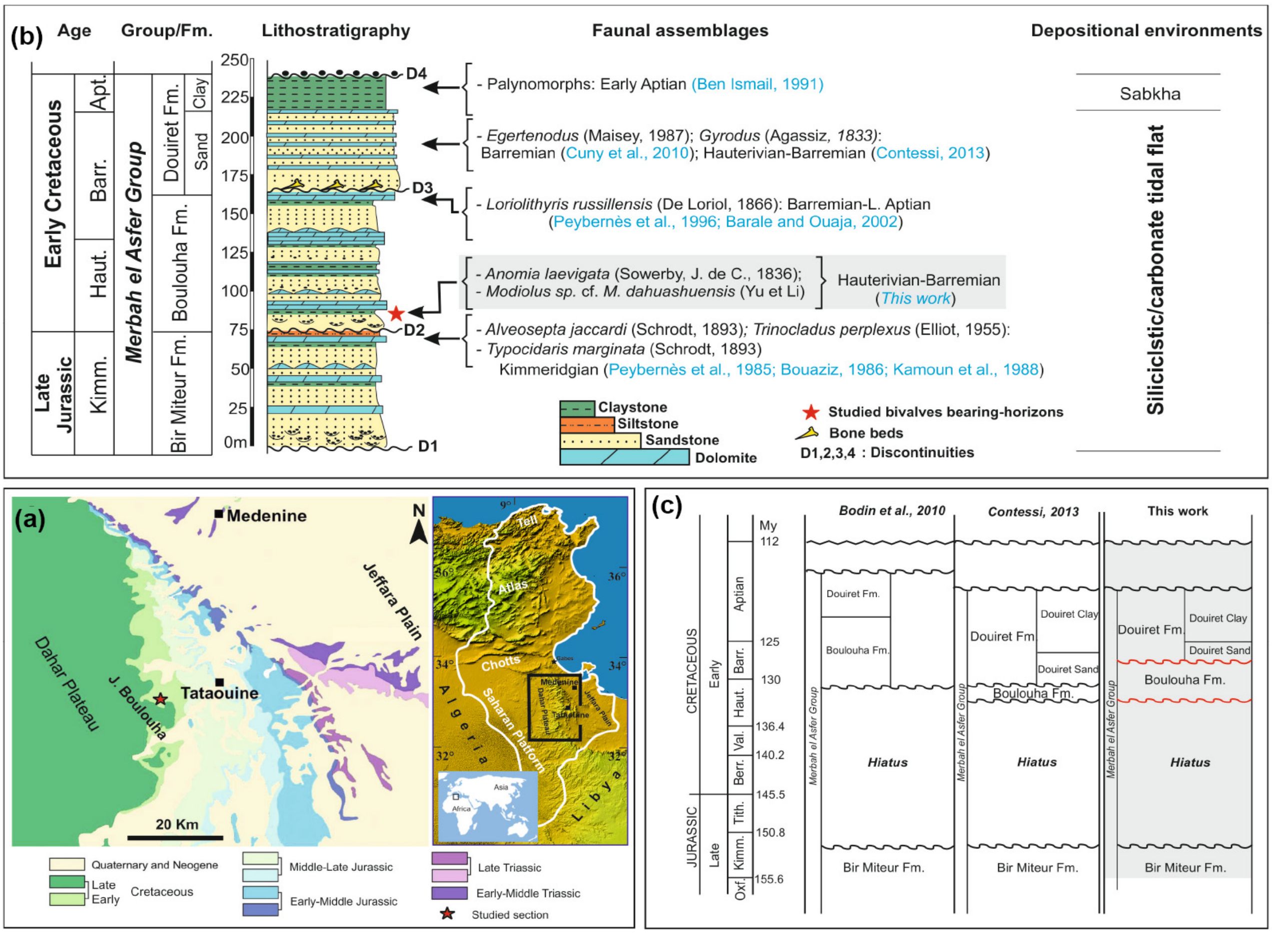

Figure 1. (a) Location of the study area; (b) Lithostratigraphy and key fossiliferous beds; (c) Stratigraphic ranges updates of the studied area at the prominent Jeffara Escarpment.

preserved bivalve assemblages. This new direct dating of the lowermost strata of the Boulouha Formation (=Bouhedma Formation of the Chotts basin), just few meters above the D2 which in turn is capping the widespread Kimmeridgian carbonate marker bed, corroborates the hypothesis [2] suggesting the presence of a major gap (20 Ma) between the Jurassic and the Early Cretaceous in the Sahara Platform domain.

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Conflicts of Interest

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Kimmeridgian Foraminiferal Faunas of Northern Eurasia: Significance for Interregional Correlations and Palaeobiogeography

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Abstract

Foraminifer is a very useful microorganism to perform biostratigraphical zonation of the Upper Jurassic. Foraminiferal biozones are calibrated by the ammonite standard zones and can be used for intra- and interregional correlations. Furthermore, the fossil record of foraminiferal faunas is well known among basins of the Northern Eurasia and is also used for accurate palaeoenvironmental, palaeobiogeographical, or biofacial reconstructions. It allows identifying a complex set of biotic and abiotic events which may be used to propose a more general palaeoecoloecological and palaeoceanographical reconstruction of the Subboreal, Boreal, and Arctic seas. Then, the late Kimmeridgian Northern Eurasian seas formed a network of well-connected palaeobasins during the sea-level rise and resulted in rather similar palaeoenvironmental conditions.

Keywords

Late Jurassic, Foraminifers, Palaeoceanography, Northern Eurasia

The study of the Upper Jurassic of the western part of Northern Asia and Europe dates back to the end of the 19th century. The biostratigraphical analyses were performed near the end of the 20th century. At that time, most of the micropalaeontological investigations across different regions of Europe and Western Siberia were performed separately. Various interpretations on the observed taxa by different authors resulted in problematic interregional correlations. The first generalized micropalaeontological investigation was performed by Kuznetsova [1], based on foraminiferal assemblages from different regions of western, eastern and northern Europe, as well as Siberia and Arctic Canada. This work introduces the occurrence of widely spread marker-species of the Kimmeridgian foraminiferal zone, which may be used for interregional correlations. In this way, recent studies based on foraminiferal assemblages from different regions of Northern Eurasia (**Figure 1(a)**) have shown that many of the previously described foraminifer species could be assigned to several single species, characterized by wide intraspecific variabilities [2] [3].

Then, the Kimmeridgian representatives of the genus *Pseudolamarckina* have shown that the East-European index-species *Pseudolamarckina pseudorjasanensis* was characterized by wide intraspecific variabilities and may encompass various previously described Kimmeridgian species of pseudolamarckiniids. The first appearance of *P. pseudorjasanensis* is recorded from the latest early Kimmeridgian of sub-Mediterranean and peri-Tethyan to Arctic regions [4] [5] (**Figure 1(b)**). Furthermore, it is recorded during the late Kimmeridgian together with a high number of widely distributed species. The Kimmeridgian foraminiferal *P. pseudorjasanensis* Zone appears to be an important interregional marker, which is used for the correlation of various widespread sections across Subboreal, Boreal and Arctic basins.

The composition of the upper Kimmeridgian foraminiferal associations of Northern Eurasia underlines the occurrence of two rather different assemblages

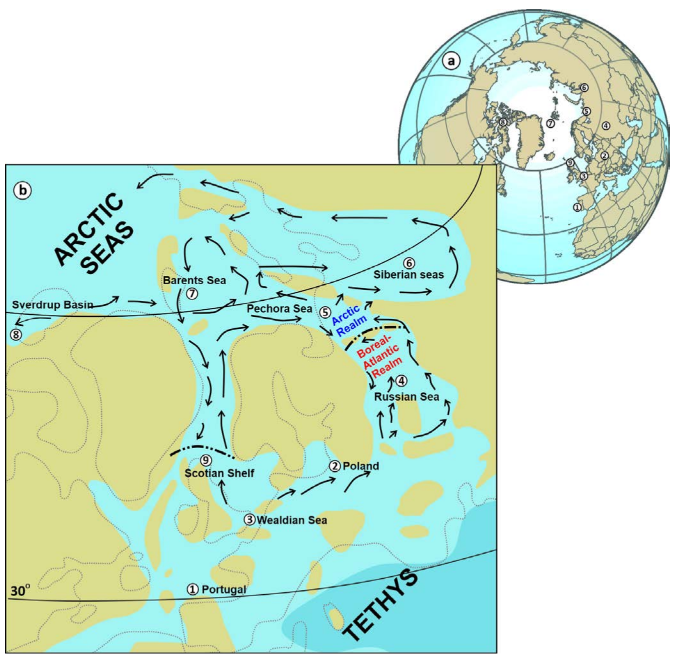

Figure 1. a. Geographical location of the studied regions of interest; b. Palaeobiogeographical and palaeoceanographical reconstructions of the Late Kimmeridgian North Eurasian seas.

that respectively belong to the Boreal-Atlantic and the Arctic realms [6] (**Figure 1(b)**). Furthermore, some rare species of nodosariids, ceratobuliminiids and lituoliids are significant for biostratigraphical correlations, and are recorded from the Arctic to peri-Tethyan regions. This indicates good connections between the Kimmeridgian palaeobasins. During the Late Jurassic, the Subboreal to Boreal and southern Arctic regions were covered by shallow epeiric surface water, influenced by terrestrial inputs and restricted in seawater circulation [6]. The occurrence of common foraminiferal associations between regions of Western Europe and Western Siberia, as well as across the Greenland-Norwegian seaway indicates the periodic connections probably associated with changes of sea-level and palaeoceanographical conditions (**Figure 1(b)**). The Subboreal Western European Sea was probably affected during the Late Jurassic by northern cold-water inputs, interpreted to have flowed southward through the western side of the Greenland-Norwegian Seaway along the coast of the Greenland and Canada territories. On the other hand, a warm water current was characterized by southwest to northeast orientation and probably favored the migration of typical taxa of the Boreal-Atlantic Realm [3] [4] [5] [6] [7].

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Conflicts of Interest

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Origin of Angiosperms and Their Diversification in the Cretaceous

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Abstract

The dominating hypothesis stated that angiosperms originated in the Early Cretaceous, there were no pre-Cretaceous angiosperms, and carpels (the basic units of gynoecium) were derived from former megasporophylls bearing ovules/seeds along their margins through longitudinally folding and enrolling. However, there are increasing evidences of pre-Cretaceous angiosperms, the assumed megasporophyll actually does not exist, and the Cretaceous-only history of angiosperms appears much shorter than suggested by molecular clocks. Here I will integrate new knowledge of living and fossil plants to give a plausible explanation for the origin and early evolution of angiosperms. Several lines of evidence indicate that the ancestor of angiosperms may well have been present in the Triassic. The former gap between angiosperms and gymnosperms is artificial. Some Triassic fossils playing a role intermediate between angiosperms and gymnosperms seem to favor the Unifying Theory.

Keywords

Jurassic, Triassic, Angiosperms, Origin, Evolution, Fossils, Unifying Theory

1. Introduction

Under the light of the newly discovered Bennettitalean fossils with bisexual organs [1], the Traditional Theory advanced by Arber and Parkin [2] thought that Magnoliaceae was the basalmost group in angiosperms, and their conduplicate carpels were derived from former megasporophylls bearing ovules along their margins. Surprisingly and embarrassingly, today many botanists have to admit that they have no idea on the homology of carpels. The history of angiosperms was thought no earlier than the Cretaceous [3], although molecular clocks suggested that the origin of angiosperms must be much older [4]. Therefore, this mainstream thought becomes shaky in front of recent progress made in palaeobotany as well as botany.

2. Fossil Record of Early Angiosperms

Needless to say, there are abundant angiosperms in the Early Cretaceous, including *Chaoyangia*, *Archaefructus*, *Sinocarpus*, *Callianthus*, *Baicarpus*, *Liaoningfructus*, *Nothodichocarpum* from the Yixian Formation [5]. Slightly younger macrofossils from South America [6] demonstrate notable diversity of angiosperms. Mesofossils from Europe and North America embody the diversification of angiosperms in the early-middle Cretaceous [3]. At the beginning of the Late Cretaceous, Eudicots (accounting for 70% species diversity in living angiosperms) started playing a major and increasingly important role in the ecosystem [7]. This rapid diversification was erroneously called an "abominable mystery" by Darwin.

So far angiosperms in the Jurassic include *Schmeissneira*, *Xingxueanthus*, *Solaranthus*, *Euanthus*, *Yuhania*, *Juraherba*, and *Nanjinganthus* [5] [8]. *Nanjinganthus* with more than two hundred specimens convincingly suggest 1) flowers have occurred in the Early Jurassic, 2) some angiosperms may have flourished in certain niches although still rare and ecologically minor in the vegetation.

Currently there are little traces of bona fide angiosperms in the Triassic. However, Nubilora from the Upper Triassic of Yunnan [5], although not a bona fide angiosperm, demonstrate a great resemblance to angiosperms, in term of ovule-enclosing. Pollen grains from the Middle Triassic [9] are hard to be distinguished from those of angiosperms.

3. Bridging the Gap between Angiosperms and Gymnosperms

More than two decades ago, studies on functions genes have suggested that the ovules are parts independent from others [10]. Studies on the assumed ancestral Magnoliaceae revealed that each of their carpels comprises an ovuliferous branch and a subtending leaf [11] [12]. Given this Bau-plan of carpels, it is easy to see that lateral appendages in some former controversial Mesozoic "conifers" (such as *Palissya, Metridiostrobus, Stachyotaxus* [13] [14] [15]) and some living conifers (e.g. *Juniperus*) seem to stand between typical conifers and Magnoliaceae: all are characterized by subtending bract/leaf with an axillary branch bearing ovules. Given the new knowledge of magnoliaceous carpels [11] [12] and their resemblance to these Mesozoic fossil taxa, it requires little imagination that carpels characteristic of angiosperms may come into existence when the subtending leaf fully encloses the ovules in its axil.

4. Conclusion

Increasing fossil evidence suggests that angiosperms originated earlier than assumed, mostly likely in the Triassic (>200 Ma), a conclusion in line with molecular clocks. Angiosperms have undergone a long time of little-understood development and extinction in the Jurassic. They underwent two episodes of diversification in the Cretaceous.

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Conflicts of Interest

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Preliminary Study of Flora from the Upper Lower Cretaceous Dalazi Formation in Luozigou Basin, Wangqing, Jilin Province, Northeast China

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Abstract

In the middle Cretaceous vegetation changed rapidly for the diversification of angiosperms, there are few extensive analyses of the plant fossils (including leaves, fruits, seeds and woods) from this period in China. New abundant fossil plants collected from the upper Lower Cretaceous Dalazi Formation in the Luozigou Basin, Wangqing, Jilin Province were studied and 25 species belonging to 17 genera were recognized. Up to date totally 39 species belonging to 25 genera were discovered in the Luozigou Basin. The assemblage is composed mainly of conifers (47.5%) and early angiosperms (30%) and indicates that the vegetation was a transitional flora between the Early Cretaceous fern-gymnosperm flora and the Late Cretaceous angiosperm flora. The flora was a *Pseudofrenelopsis*-angiosperm assemblage in succession of Early Cretaceous flora and the late Early Cretaceous, probable Albian in age. During the late Early Cretaceous, the Luozigou Basin was dominated by hot and arid climate and sometimes probably interrupted by wet climate.

Keywords

Dalazi Formation, Early Cretaceous, Flora, Jilin

1. Introduction

Analyses of the plant fossil record have provided clear evidence for the rapid diversification of angiosperms from the Early Cretaceous onwards [1] [2]. The Cretaceous represents an intriguing interval to examine how changes in vegetation and environment. The plant-bearing strata in the Luozigou Basin of

Wangqing, Jilin Province, have been considered to belong to the Lower Cretaceous Dalazi Formation which is well developed in Dalazi, Zhixin Town, Longjing County in Yanji Basin, Jilin Province [3] [4] [5]. Fossil plants from the Luozigou Basin were firstly recognized by Japanese palaeobotanist Oishi [6] and the following collections of fossil plants yet no detailed study except for some additions to the plant list [2] [5]. In recent years some studies have been carried on cheirolepidiaceous conifers [7] [8] and abundant plant fossils are collected from the Luozigou Basin. The new collection provides more detailed morphological and taxonomic information of this flora. The characteristics of this flora give a new interpretation of palaeovegetation and ecological environment in this area during the late Early Cretaceous.

2. Materials and Methods

The fossil plant specimens with well-preserved cuticle were collected from the Dalazi Formation in the Luozigou Basin. All specimens are deposited in the Nanjing Institute of Geology and Palaeotology, Chinese Academy of Sciences.

3. Results and Discussion

Based on the new collection 25 species belong to 17 genera of fossil plants were identified. There are a number of fossil plants listed and reported previously from the Dalazi Formation in the Luozigou Basin of Wangqing. Combined with previous studies totally 39 species belonging to 25 genera were discovered in the Luozigou Basin. The plant assemblage from the Dalazi Formation consists of *Selaginellites* cf. *fausta*, *Ruffordia goepperti*, *Gleichenites nipponensis*, *Coniopteris saportana*, *Onychiopsis elongate*, *Cladophlebis exiliformis*, *C.* sp., *Otozamites anglica*, *O.* sp., *Pityocladus iwaiana*, *P.* sp., *Pityocladus*? sp, *Pityolepis* sp., *Elatides curvifolia*, *Cupressinocladus elegans*, *C. gracilis*, *C.* sp., *Pseudofrenelopsis gansuensis*, *Frenelopsis*? sp., *Suturovagina intermedia*, *Brachyphyllum crassum*, *B. ningshiaense*, *B.* sp.1, *B.*? sp.1, *Elatocladus* cf. *manchuria*, *Pagiophyllum* sp., *Conites* spp., *Sassafras*? sp., *Paliurus*? sp., cf. "*Andromeda*" *parlatorii*, *Eucalyptophyllum oligonerve*, *Rogersia longifolia*, "*Sassafras*" *bilobatum*, *Sterculaephyllum eleganum*, *Ulmiphyllum brookense*, *Dicotylophyllum* spp and *Monocotylophyllum*? sp. (detailed description and discussion will be in another paper). There is only one species of *Selaginellales* in the assemblage; six species of five genera belong to ferns; Bennettitales are rare with only two species of one genera; *Ginkgoales* is absent; conifers are composed of 19 species of 10 genera which accounting 47.5% in the assemblage and early angiosperms are composed of 12 species of 8 genera accounting about 30% in the assemblage. It is noted that *Selaginellites fausta* was firstly reported from the Dalazi Formation in the Luozigou Basin which represents the latest fossil record of *Selaginellites* in China so far. Moreover, conifers are mainly represented by scale leafy shoots including *Cupressinocladus Brachyphyllum* and *Pseudofrenelopsis*, cuticles of them are preserved well, and angiosperms in this assemblage are all dicotyledons and their venations show a certain extent development. The abundant conifers and the considerable diversity of angiosperms show that this flora was a *Pseudofrenelopsis*-angiosperm assemblage in succession of Early Cretaceous flora.

4. Conclusion

Based on preliminary analysis totally 39 species belonging to 25 genera were recognized from the Lower Cretaceous Dalazi Formation in the Luozigou Basin. The result shows that the assemblage is composed mainly of conifers (47.5%) and early angiosperms (30%), accounting 77% totally. *Bennettitales* and *Ginkgoales* are few or absent. The characters of this assemblage from the Dalazi Formation indicate a late Early Cretaceous age, probable Albian. The vegetation was a transitional flora between the Early Cretaceous fern-gymnosperm flora and the Late Cretaceous angiosperm flora. The features of the assemblage indicate that the Louzigou region of Wangqing in the late Early Cretaceous was dominated by hot and arid climate and sometimes probably interrupted by wet climate.

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Conflicts of Interest

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Phototropism of Petrified Wood and Its Relation with the Rotation of Different Blocks in China and the Possibility of Application in the World

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Abstract

Normally, trees on the side directly exposed to sunlight will grow faster than the opposing side. This phenomenon is termed plant phototropism. Moreover, palaeomagnetists have revealed that the Junnar Block has never rotated since the Mesozoic. The petrified woods in the Jiangjunmiao area of Qitai County show the positive phototropism direction of SSW220. By compared with the modern normal growth stumps in plain area, which have positive phototropism direction of SSW 219 ± 5, this observation supports the conclusion of palaeomagnetic researchers: the Junggar basin has never rotated since the Late Jurassic.

Keywords

Jurassic Petrified Wood, Phototropism, Plate Rotation, Palaeogeography

1. Introduction

It is common knowledge that phototropism refers to the direction of plant growth in relation to a light source. Positive phototropism relates to plant growth towards a light source and includes most plant parts, such as leaves and stems. In general, phototropism is easy to observe in crown and the trunk near roots. The definition intensity of plant phototropism varies regularly along with latitudinal change as "strong to weak to disappeared" ranges from high to low. This phototropism phenomenon exists also in the well-protected *in situ* petrified wood formed in geological ages. Therefore, we can obtain important first-hand information of important geological significance through the investigation into the shape and rings of the *in situ* fossil tree trunks [1].

2. Relationship between Tree Ring Eccentricity and the Latitude

The link between the tree ring eccentricity and the latitude can be proved in the arbors in the Northern Hemisphere. It seems that the lowest latitude of identifiable phototropism phenomenon of trees is possibly at least to the Tropic of Cancer (N23˚26'), but the further south line still needs more data of the extant trees to further confirmation.

What should be pointed out is that according to the practical experience of some present-day foresters, gravitropism plays a more important role during the growth of trees [2]. In contrast, other foresters believe that the comprehensive factors of sunshine, gravity, wind direction and other disturbing elements influence the growth of trees [3]. However, the *in situ* silicified wood was usually preserved in relatively open and flat environments, and sunshine should be the major element influencing the growth of trees.

The shape of rings of silicified wood preserved in strata can also reflect the ancient latitudes. The Middle Jurassic silicified wood from the Chaoyang District, western Liaoning Province, had an obvious phototropism feature; but the Early Cretaceous silicified wood from the Huolinhe basin, eastern Inner Mongolia, showed a little eccentricity according to the sketches by Deng [4] (**Figure 1**). If there were more definite materials to confirm the above comparison, it possibly implicated that the ancient latitude of the North China Plate and the east part of Inner Mongolia moved slightly toward the direction of south from the Jurassic to Cretaceous, and therefore the previous conclusion that the North China Plate largely moved northwards is incorrect.

3. Orientation of the *in Situ* Preserved Silicified Trunk and Rotation of the Junggar Block

The Upper Jurassic Shishugou Group of the Jiangjunmiao area, Qitai County, North Xinjiang (Junggar basin) is rich in petrified wood [5]. The first author of this paper found that the tree rings of the *in situ* preserved silicified trunks are clear and characterized by the obvious asymmetry in the SW 220 sides. Compared with the living trees phototropism [6], the result is almost the same. This means that the positive phototropism the trees are in accordance with the present ones, and possibly indicating that the Junggar basin has never rotated since the Late Jurassic.

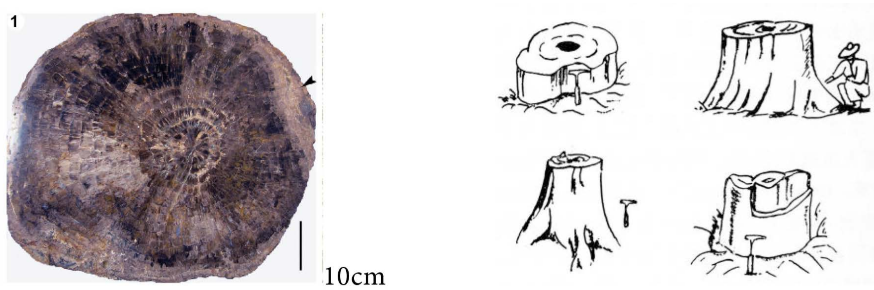

Figure 1. Comparison between the Middle Jurassic silicified wood in Chaoyang, western Liaoning Province and the Early Cretaceous silicified wood from the Huolinhe Basin, eastern Inner Mongolia.

4. Significances of Palaeogeography

How to release the relationship and interaction among the different spheres of the Earth system during the Jurassic to Cretaceous transition in a reasonable way on the base of new results of comprehensive and multidisciplinary studies has become a new challenge to scientists all over the world.

Hence, a deep and multiple-dimension investigation of the silicified wood in terms of systematic earth science has a priority and is promising in the world.

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Conflicts of Interest

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Pollen and Spores from the Lower Cretaceous of Central Mongolia and Their Paleoclimatic Significance

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Abstract

The present study focuses on the Lower Cretaceous Khukhteeg Formation (Central Mongolia), which yields palynological assemblage that is used to understand the paleoclimate. Palynology samples from the Khovil opencast mine Choir-Nyalga Basin in the Central Mongolia have been analyzed for palynomorphs with SEM. The assemblage is dominated by pollen to conifers, such as Pinaceae, Podocarpaceae and Taxodiaceae, indicating the vegetation of conifer forests. The assemblage contains abundant spores Schizaeaceae, Cyatheaceae, which are generally associated with wet habitats. According to the detailed analyses, the plant community indicates that warm and humid subtropical paleoclimate controlled the study area during the Early Cretaceous.

Keywords

Khovil Opencast Mine, Lower Cretaceous, Khukhteeg Formation, Spore, Pollen, Mongolia

1. Introduction

Coal-bearing strata from Central Mongolia (Khukhteeg Formation) of Aptian to Albian age contain next to dominating Pinaceae, Cupressaceae pollen [1]-[5]. The Khovil opencast mine is located in Central Mongolia southeast of Ulaanbaatar in the Choir-Nyalga Basin. The Choir-Nyalga Basin is the result of extensional tectonics that was prevalent during the Lower Cretaceous north-south trending fold and thrust belt in the central of Mongolia [6] [7]. The sediments of the Khovil opencast mine belong to the lithostratigraphic unit of the coal-bearing Khukhteeg Formation which is, part of the Zuunbayan Group. The Khukhteeg Formation includes conglomerates, gravels, sandstones, and thick lignite coal [7].

2. Material and Methods

A total of 25 samples collected from Khovil opencast mine. The samples were treated with HCl and HF using standard palynological procedures then fossil pollen grains were investigated by scanning electron microscope (SEM). In Figure 1, SEM photos are presented.

3. Results and Conclusion

Palynological assemblage is characterized by the abundant of fern spores Cyathaceae and Schizaeaceae, Selaginellaceae, Lycopodiaceae and pollen Pinaceae, Podocarpaceae (Figure 1). In this assemblage, not observed spores *Appendicisporites*, very rare pollen *Cedripites*, contain chlorantahaceous angiosperms *Clavatipollenites* and unknown angiosperm pollen *Retimonocolpites*, *Liliacidites-like*, *Platanus-like.*

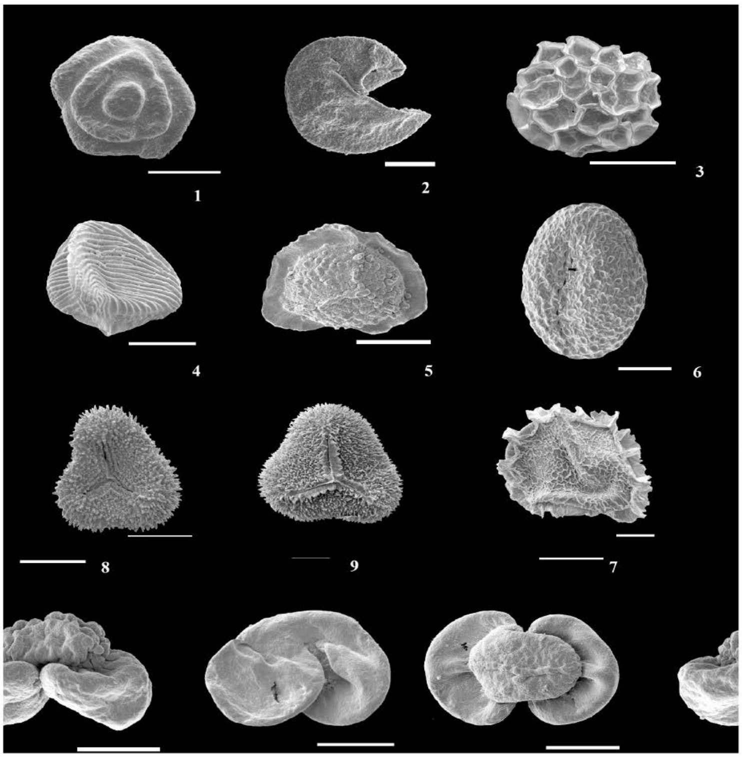

Figure 1. Spores and pollen from Khukhteeg Formation: (1) *Taurocusporites reduncus*, 5453×, *2* μm (2) *Taxodiaceaepollenites sp.*, 8830×, 10 μm (3) *Lycopodiumsporites marginatus*, 6829×, 10 μm (4) *Cicatricosisporites dorogensis*, 5907×, 20 μm (5) *Aequitriradites spinulosus*, 4293×, 30 μm (6) *Schizosporis sp.*, 5907×, 50 μm (7) *Pilosisporites notensis*, 5907×, 30 μm (8) *Pilosisporites sp.*, 5907×, 30 μm (10) *Lycopodium sp.*, 6829×, 10 μm (10) *Podocarpites luteus* 3566×, 10 μm (11) *Podocarpites multisinus* 3701×, 10 μm (12) *Piceapollenites sp.*, 2313×, 50 μm.

This palynological assemblage is important for inferring paleoecological and paleoclimatic conditions of the region during the Early Cretaceous. The assemblage is dominated by pollen of conifers, such as Pinaceae, Taxodiaceae, indicating the vegetation of conifer forests. The assemblage contains abundant above mentioned pollen taxa, which are generally associated with wet habitats. The conifer plants grew on foothills at different distances from the lake, but Filicopsida dominated the lake shore. *Clavatipollenites* is also khown from lower latitudinal fossil localities (Spain, Portugal, Brazil, USA) and their presence in Mongolia might be evidence for the admixture of temperate and subtropical floras [8]. The Choir-Nyalga basin, which was a periodically ever-wet (presence of algal cysts, *Botryococcus* and liverworts *Aequitriradites*), low diverse peat producing environment situated in a more northern position at higher latitudes, where newcomers arrived later than at the lower latitudes.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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The Origin and Diversification of Plant Family Dipterocarpaceae

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Abstract

The Dipterocarpaceae plant family, that shows a disjunct distribution in Gondwanan continents and Southeast Asia, is a dominant constituent of the tropical rain forests of Southeast Asia. The high species diversity of Dipterocarpaceae in SE Asian rain forests suggests its origin from SE Asia. However, its fossil history is much younger, from Oligocene, from the region. Based on the pollen fossil records from the late Cretaceous-early Paleogene sedimentary sequences of Indian subcontinent and the contemporaneous distribution of its extant taxa, evolutionary history of Dipterocarpaceae has been traced. The study suggests a West Gondwanan origin for this family. Present study also provides first evidence of Dipterocarpaceae genus *Vateriopsis* (endemic in Seychelles) type fossil pollen record from the late Cretaceous and early Palaeogene sedimentary sequences of western Indian margin.

Keywords

Fossil, *Vateriospis*, Pollen, Cretaceous, Dipterocarpaceae

1. Introduction

Dipterocarpaceae, an economically important arborescent family distributed in SE Asian tropical regions, is important for the production of timber, camphor and resins. There exist a lot of opinions about its systematic classification [1]. The family is subdivided into three subfamilies: 1) Monotoideae, restricted to Africa, Madagascar and South America; 2) Pakaraimoideae, endemic to South America; 3) Dipterocarpoideae, distributed in SE Asia [2]. Except the two genera, *Pseudomonotes* and *Marquesia,* the representatives of Monotoideae distributed across Africa and Madagascar cultivate in seasonally dry forests. Whereas members of Pakaraimoideae and Dipterocarpoideae subfamilies prefer lowland rain forest. It has been found that various species of Dipterocarpoideae have the adaptability to seasonally wet and aseasonal perhumid tropical regions of SE Asia [1]. Due to more plasticity in the climatic adaptive nature, members of Dipterocarpoideae exhibit greater species diversity compared to the other two subfamilies. The family is disseminated across continents following a strict disjunct distribution pattern which raises a question of its place and time of origin. Dipterocarpoideae clade dominates in SE Asia and almost 80% of its diversity has been found to occur in wet forest of SE Asia particularly in Western Malaysia (Borneo), and hence SE Asia was considered to be its centre of origin [3]. There are two plausible hypotheses proposed for the evolutionary history and biogeography of the family Dipterocarpaceae. One hypothesis supports a SE Asian origin (Into India hypothesis). The other suggests a Gondwanan origin (Out of India hypothesis) [3]. In the present study, we are trying to assess both biogeographic hypotheses based on fossil data.

2. Material and Method

Studied samples were collected from three sites: 1) Late Cretaceous infratrappean bore core samples from Yeotmal region, Maharashtra; 2) Late Cretaceous intertrappean samples from Gowmukh area, Madhya Pradesh; 3) Early Palaeogene (Danian) samples from Gurha lignite mine, Bikaner region, Rajasthan. For comparison purposes, extant flower buds of *Vateriopsis* collected from Seychelles were acetolysed for pollen study and the extant pollen were compared with the fossil palynomorphs.

3. Results

The current study finds the presence of *Vateriopsis* type pollen fossil from the Upper Cretaceaous and Lower Palaeogene deposits of intertrappeans of central India and Bikaner Basin, Rajasthan, India, respectively. This study also documents the variety of *Dipterocarpus* type pollen fossils from the Upper Cretaceous of infratrappeans and intertrappeans of Maharashtra and Madhya Pradesh, central India, and the Lower Paleogene of Bikaner Basin, Rajasthan, western India.

4. Discussion and Conclusion

The Late Cretaceous *Vateriopsis* and *Dipterocarpus* type fossil pollen records suggest the Out of India hypothesis. *Dipterocarpus* type fossil pollen is recovered from the Indian Upper Cretaceous, the time when Indo-Seychelles plate was in surficial contact with Africa [4]. The distance between Asia and India during the Late Cretaceous was too large and could not facilitate the dispersal of the family. The presence of *Vateriopsis* type fossil pollen in Indian Lower Paleogene is the time just before the separation of Indo-Greater Somalaria from Seychelles [4]. The present distribution of *Vateriopsis* in Seychelles suggests its migration from

India. Moreover, the presence of possible *Dipterocarpus* fossils from Africa [1] [5], a continent where only Monotes is found in the present day, also strongly indicates the diversification of the family on Gondwanan landmass. Our consent of Out of India hypothesis for Dipterocarpaceae dispersal in SE Asia is much more strengthened by the presence of polycadinene resin in the Upper Eocene of Mayanmar which was a part of Indian plate before its collision to Asia [6]. This suggests that the family might have migrated to Asia after the contact between India and Asia was established.

Furthermore the sharing of ectomycorrhizal symbiotic relation between Dipterocarpaceae and Sarcolaenaceae, a family endemic to Madagascar in present time, signifies that both families share a common ancestor [7]. The previously stated fact and the only Miocene fossil record of Sarcolaenaceae from Africa [8] imply that the diversification of the families should have occurred on the Gondwana landmass before the separation of Madagascar from India-Seychelles block.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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The Stratigraphic, Palaeobiogeographic and Phylogenetic Significance of *Aquilapollenites*

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Abstract

Angiosperm evolved and diversified during Cretaceous. During this course of evolution and radiation, various pollen of uncertain origin had evolved. *Aquilapollenites* represents the early stock of angiosperms attaining its acme with respect to diversity and dominance during Campanian and Maastrichtian age. It was globally present (except Antarctica) however more dominant in northern hemisphere (Canada, North America, Sakhlain Oblast and China). In India, the *Aquilapollenites* sp. is present in Maastrichtian aged deposits. The pollen affinity has been associated with Loranthaceae and Santalaceae plant families. Here, a comparative description of all the *Aquilapollenites* sp. comprising a wide range of morphological diversity has been discussed. The wider morphological diversity and ecological adaptability of *Aquilapollenites* sp. infer that it is globally significant and warrants a more detailed study.

Keywords

Triprojectate Pollens, Late Cretaceous, Maastrichtian, Paleocene

1. Introduction

Aquilapollenites sp. [1] was amended with the advancement in the field of microscopy [2] [3]. *Aquilapollenites* sp. belongs to a group of Triprojectacites [4]. This group includes angiosperm pollen with three equatorial projections and a polar projection on each side. *Aquilapollenites* sp. attained its maximum abundance and diversity during Campanian and Maastrichtian [5]. It is believed to evolve during the Turonian [6]; there are several pre-Turonian records from northern and southern hemisphere. Records of this pollen extend up to Eocene but most are reworked [7].

There is a total of 180 species of *Aquilapollenites* sp. out of which only twelve occur in Indian sub-continent, restricted to Maastrichtian aged deposits [8]. The pollen is morphologically very diverse and consists of a wide variety of features. The pollen affinity has been discussed in detail by Jarzen [9] and assigned to Loranthaceae and Santalaceae plant family with uncertainty. Here we present the comparative description of morphological variation in the *Aquilapollenites* sp. along with its stratigraphic, palaeobiogeographic and phylogenetic significance.

2. Comparative Morphological Description of *Aquilapollenites* sp.

Aquilapollenites sp. bears a unique morphology with three equatorial protrusion and one polar protrusion on each side. It constitutes heteropolar, subisopolar to isopolar pollen forms. The size of the polar protrusion varies considerably. Pollen which either have one very small polar projection (less than half of the developed polar projections) or bear only one polar projection have been transferred to the genus *Mancicorpus* [3]. The number of equatorial projections is 3 - 4, oriented either equatorially or meridional. The shape of equatorial protrusion ranges from cylindrical, auriculate to conical. There is a wide difference between the ratio of polar and equatorial protrusion. In few species both protrusions are well developed while in others either of the two is well-developed. In Indian *Aquilapollenites* sp. forms, polar protrusion is well developed while equatorial protrusions are very small peg like structure [8]. The apertures are 3 to 4 in number and situated either equatorially or meridionally. The most common aperture type of *Aquilapollenites* sp. is colpi, rarely demicolpi (common in Indian species) and only one species of tricolporate pollen (*A. amicus*).

There is a wide variety of morphological diversity in the exine ornamentation, supratectal elements and their distribution. Pollen mostly bear reticulate and striatoreticulate ornamentation. However, psilate, punctate, foveolate, retipilate, infrareticulate and granulate also occur in some species. The supratetcal elements mostly consist of acuminate spines with few species having pila, scale or crystal shaped spines. Most of the Indian *Aquilapollenites* sp. bear striatoreticulate ornamentation and are devoid of supratectal elements. In few species, dimorphism is very common in *Aquilapollenites* sp. showing different ornamentation on equatorial, polar and central region of the pollen. Sometimes spines only occur at the borders of the colpi extending from one end to the other forming a "Dragon Comb" like structure [10].

3. Stratigraphic, Palaeobiogeographic and Phylogenetic Significance of *Aquilapollenites* sp.

Aquilapollenites sp. represents the early stock of angiosperm. It originated during the Early Cretaceous when the world was represented by one phytogeographical province [11]. The increased tectonic activity during the late Cretaceous resulted in the formation of new continental assembly and changing global precipitation pattern and climate [12]. The angiosperms diversified during this time gave rise to nine phytogeographical provinces [13]. The *Aquilapollenites* phytogeographical province was majorly restricted to northern hemisphere due to its higher abundance and diversity in this region. However, *Aquilapollenites* sp. was globally present in the late Cretaceous palynoassemblages except Antarctica. Its affinity has been related to parasitic plants of Loranthaceae and Santalaceae families with uncertainty [9]. Thus, *Aquilapollenites* sp. holds an interesting history of angiosperm diversification and adaptation which warrants more detailed study. The vast array of data regarding *Aquilapollenites* sp. needs to be compiled and analyzed using phylogenetic approach to identify its affinity, contribution in angiosperm evolution and palaeobiogeographic distribution.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Advances in the Study of the Non-Marine Ostracods in Luanping Basin, Northern Hebei (North China): A Preliminary Result

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Abstract

The Luanping Basin of northern Hebei, North China, is well known for its continuous nonmarine Lower Cretaceous deposits and the preservation of the Jehol Biota. However, there are still some controversies about the stratigraphic correlation in these regions. Here we report some advances on the study of the nonmarine ostracods of Luanping, focusing on its biostratigraphical utility. Preliminary results indicate that the nonmarine ostracods from Luanping Basin consist of 17 genera and around 44 species. The ostracod assemblages of the Dabeigou, Dadianzi and Xiguayuan formations of this Basin can be assigned to the *Luanpingella-Ocrocypris-Eoparacypris* (Late Valanginian-Early Hauterivian age), *Cypridea-Timiriasevia-Daurina* (Late Huaterivian-Barremian age) and *Cypridea-Limnocypridea-Lycopterocypris* (Aptian stage) zones, respectively. This temporary framework can be served as a stratigraphic correlation tool in northern Hebei, as well as contributed to a better understanding of the evolution of the Jehol Biota.

Keywords

Ostracoda, Biostratigraphy, Luanping Basin, Early Cretaceous, Jehol Biota

1. Introduction

The Jehol Biota represented a diverse ecosystem in the Cretaceous world, particularly with respect to the high diversity and abundance of fossil species [1]. The study of the Jehol Biota has mainly focused on the Yixian and Jiufotang formations of Western Liaoning, China, which represent the middle and late stage of this biota [2]. The early Jehol Biota and its relevant strata, however, remain to be studied further [3]. The Luanping Basin and other basins in the northern Hebei Province, China, preserve abundant fossils of the early Jehol Biota, including non-marine ostracods [2]. Detailed fieldwork on representative sections of the Lower Cretaceous Dabeigou, Dadianzi and Xiguayuan formations of the Luanping Basin have revealed a diverse ostracod fauna with ostracods occurring frequently in the sections and in high abundance [4] [5] [6] [7]. Previous taxonomical and biostratigraphical analyses of the ostracods contribute to the improved age assignment and correlation of respective formations, the correlation with the relevant stage of the Jehol Biota, and on the controversy on the position of the J-K boundary in the Luanping basin and adjacent basins [8]. These studies demonstrated the need for more detailed work and thorough taxonomical revision of the ostracod fauna and its biostratigraphical and paleoenvironmental utility.

2. Materials and Methods

In an ongoing PhD project, detailed studies on relevant sections of the Dabeigou (Yushuxia section), Dadianzi (Shangying-Xiaying section), and Dadianzi or Xiguayuan (Liying section) formations of the Luanping Basin are carried out, including high-resolution measuring and sampling for microfossils as well as detailed sedimentological descriptions to establish the lithostratigraphic framework.

3. Results and Discussion

Preliminary taxonomic analysis of non-marine ostracods from the Lower Cretaceous interval of Luanping Basin revealed (depending on sections and formations) 7 - 17 genera, including *Cypridea*, *Yumenia*, *Luanpingella*, *Pseudoparacypridopsis*, *Daurina*, *Yanshanina*, *Ocrocypris*, *Eoparacypris*, *Limnocypridea*, *Djungarica*, *Darwinula*, *Alicenula*, *Rhinocypris*, *Timiriasevia*, *Damonella*, *Lycopterocypris* and *Mongolianella*, and around 44 species (Detailed discussion will be on another paper). Fieldwork on the Lower Cretaceous interval of the Liying section, the stratigraphical assignment of which either to the Dadianzi or the Xiguayuan Formation is still debated, revealed abundant fossils of gastropods, bivalves, ostracods, spinicaudatans, fishes, shrimps and plants. The ostracod biostratigraphy of the Dabeigou, Dadianzi and Xiguayuan formations can be recognized as the *Luanpingella-Ocrocypris-Eoparacypris* (Late Valanginian-Early Hauterivian age), *Cypridea-Timiriasevia-Daurina* (Late Huaterivian-Barremian age) and *Cypridea-Limnocypridea-Lycopterocypris* (Aptian stage) assemblage zones, respectively. In addition, the ostracod assemblage zone of the Dadianzi Formation can be subdivided into the *Cypridea stenolonga*, *C. luanpingensis*, *C. sulcata*, and *C. pangi* subzones, which mainly distributed at members 1 - 4 of this formation, respectively. Based on biostratigraphic correlations of the Dadianzi Formation to stratigraphically equivalent formations of adjacent basins, it is concluded that the earliest occurrence of *Cypridea*-species in the northern Hebei-western Liaoning area, North China, is ~130 Ma (lowermost Barremian).

4. Conclusions

Based on preliminary analysis, 17 genera and around 44 species of the nonmarine ostracods from the Lower Cretaceous interval of Luanping Basin have been recognized.

The ostracod assemblages of the Dabeigou, Dadianzi and Xiguayuan formations of Luanping Basin have been temporarily proposed as the *Luanpingella-Ocrocypris-Eoparacypris* (Late Valanginian-Early Hauterivian age), *Cypridea-Timiriasevia-Daurina* (Late Huaterivian-Barremian age) and *Cypridea-Limnocypridea-Lycopterocypris* (Aptian stage) zones, respectively.

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Conflicts of Interest

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Late Turonian Microfossils and Paleoclimate in the Songliao Basin, NE China

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Abstract

Although the paleoclimate of the marine Cretaceous has been well studied, the paleoclimate of the non-marine is still not well understood. The Songliao Basin was one of the largest non-marine rift basins during Cretaceous. The Well-preserved Cretaceous lacustrine deposits in this basin provide a unique opportunity to study terrestrial paleoenvironments and paleoclimate during the Late Cretaceous. Here, the microfossils from the Late Turonian Qingshankou Formation of the Songliao Basin were used to investigate the paleoenvironments and paleoclimate of east Asia. There are two spore and pollen assemblages recognized: a *Cedripites-Cyathidites-Classopollis* assemblage from Upper Member 1, and a *Cedripites-Cyathidites-Classopollis* assemblage from Lower Member 2 of the Qingshankou Formation, respectively. Besides, relatively abundant ostracods have been identified. In the Songliao Basin, the climate was relatively warm and wet during Late Turonian, with good source rock deposited in the Songliao lake.

Keywords

Cretaceous, Songliao Basin, Spore and Pollen, Paleoclimate

1. Introduction

The Songliao Basin was one of the largest non-marine rift basins during Cretaceous [1]. Widespread deposits in the basin are mainly composed of clastic sediments which contain abundant fossils, such as spore and pollen, clam shrimps, ostracods, gastropod, bivalves and vertebrates. These spore and pollen fossils provide us valuable information about Cretaceous climate changes and biotic responses in a greenhouse environment. Although the paleoclimate of the marine Cretaceous has been well studied [2] [3], the paleoclimate of the non-marine is still not well understood. The Well-preserved Cretaceous lacustrine deposits in this basin provide a unique opportunity to study terrestrial paleoenvironments and paleoclimate during the Late Cretaceous [4] [5]. Here, the microfossils from the Late Turonian Qingshankou Formation of the Songliao Basin were used to study the paleoenvironments and paleoclimate of East Asia.

2. Materials and Methods

The samples were collected from Upper Member 1 to Lower Member 2 of the Qingshankou Formation of the Lijiatuozi section in the Songliao Basin. Analyses of spore and pollen and ostracod samples were carried out in the microfossil laboratory. The organic residues recovered were sieved through a 10 μm mesh screen, after which they were boiled in potassium hydroxide solution (KOH, 10%) for 10 min to remove soluble humic substances. The sieved residues were strewn mounted on glass slides using epoxy. The slide numbers were prefixed 'mg' for Well Mao-206 which is another name of SK1(S). In case of less productive samples, we prepared another four slides to scan and count.

3. Results and Discussion

Preliminary analysis of spore and pollens, as well as ostracods from the Upper Member 1 to Lower Member 2 of the Qingshankou Formation has been taken. Two spore and pollen assemblages have been recognized. *Cedripites-Cyathidites-Classopollis* assemblage is belong to Upper Member 1 of the Qingshankou Formation, including *Cyathidites*, *Schizaeoisporites*, *Cicatricososporites*, *Lygodioisporites*, *Balmeisporites*, *Cedripites*, *Podocarpidites*, *Classopollis*, *Pinuspollenites*, *Abiespollenites*, *Piceaepollenites*, *Quercoidites*, *Chenopodipollis* and a few other taxa. *Cedripites-Cyathidites-Classopollis* assemblage is belong to Lower Member 2 of the Qingshankou Formation, including *Schizaeoisporites*, *Foraminisporis*, *Cedripites*, *Classopollis*, *Taxodiaceaepollenites*, *Rugubivesiculites*, *Psophosphaera*, *Cycadopites*, *Quercoidites*, *Callistopollenites*, *Salixipollenites*, *Beaupreaidites*, *Tricolporopollenites*, and a few other taxa. The spore and pollen fossils suggest that the climate was relatively warm and wet during this period (Late Turonian), but a little dry during sedimentation of the Lower Member 2 of the Qingshankou Formation. Beside the spore and pollens, the ostracods fossils have been identified, including *Cypridea dekhoinensis*, *C. gibbosa*, *C. bistyloformis, C. tuberculata*, *C. adumbrata*, *C.* aff. *adumbrata*, *C. nota*, *C. fuyuensis*, *Triangulicypris tosuosus* var. *nota*, *T. virgate*, *T. torsuosus*, *T. fertilis*, *T. similis* and *Limnocypridea*, suggesting a fresh to slightly brackish water environment.

The Upper Member 1 to Lower Member 2 of the Qingshankou Formation has been dating as Late Turonian [6] [7] [8] [9]. The global paleoclimate was suggested to hot during this period [2]. Based on the core of SK1(s) from the Songliao Basin, a detailed study of spore and pollen suggested a relatively warm and wet climate during Late Turonian [5], which is consistent with our results. During Late Turonian (Upper Member 1 to Lower Member 2 of the Qingshankou Formation), the Songliao lake was deep in central part, but relatively shallow in marginal part, with good source rock deposited in the central part of this large lake. The spore and pollens suggested that a relatively warm and wet paleoclimate in East Asia during Late Cretaceous.

4. Conclusion

Relatively abundant spore and pollen, as well as ostracods have been discovered in the Lijiatuozi section of the Upper Member 1 to Lower Member 2 of the Qingshankou Formation, including two spore and pollen assemblages and one ostracod assemblage. In the Songliao Basin, the climate was relatively warm and wet during Late Turonian, with good source rock deposited in the central part of the Songliao lake.

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Conflicts of Interest

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A Hope for an Integrated Taxonomy of Fossil and Extant Clam Shrimps

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Abstract

Clam shrimps are large bivalved branchiopod crustacean. They first occurred in the Devonian, and flourished during the Mesozoic in Asia. Fossil clam shrimps play an important role in the subdivision and correlation of non-marine fossil-bearing strata. The phosphatized carapaces or carapace external/internal moulds are the main objects for taxonomical studies. The delicate ornament and the ontogenetically developing morphological patterns on the growth bands of carapaces are the main fossil taxonomic criteria. While modern clam shrimp taxonomy is based on soft body morphological features and molecular data, which could not be found in the fossil records. This makes it difficult to discuss the fossil and modern clam shrimp phylogenetic relationship. Nowadays scanning electron microscopes are widely available, and can play an important role in investigating clam shrimp carapace morphology which could be common language to integrate fossil and modern taxonomy.

Keywords

Clam Shrimps, Fossil, Extant, Taxonomy

1. Introduction

Clam shrimps are large branchiopod crustaceans. They have laterally compressed shrimp-like bodies which are enclosed in chitinous bivalved carapace. This is the reason why they are called clam shrimps. Extant clam shrimps are widely distributed on all continents except for Antarctica, but fossil clam shrimps are widely distributed, and they were also found in Antarctica. According to the fossil records, clam shrimps extend back to the Devonian Period. The evolution of clam shrimps was initially centred on Europe, but in Mesozoic they diversified more rapidly in Asia [1]. During the Cenozoic they gradually declined with very scarce fossil records [2], and resulted in both low abundance and diversity. Nowadays only fourteen genera in five families remain [1].

2. Living Environment of Clam Shrimps

Clam shrimps inhabit seasonally astatic wetlands such as playas, vernal (rain and snow-melt) pools, rice field or fishless lakes [3]. This living environment is consistent with their relatively short life cycles. Their resting eggs are able to survive dormant for several years under dry conditions. All these special features make clam shrimps the very successful colonizers of ephemeral freshwater ecosystems [4] under a wet and dry alternating climate setting in the earth history [5]. This results in very abundant fossil records worldwide in the Mesozoic fine lacustrine deposits [6]-[11].

3. Taxonomy of Fossil and Extant Clam Shrimps

Clam shrimp fossil records demonstrate that their fossilized soft parts are very rare. Most common cases are that they are preserved as phosphatized carapaces [12], or the external or internal moulds of carapaces. Thus, the classification and taxonomy of fossil clam shrimps are mainly based on the morphological characters of their carapaces, such as the carapace outline, structure and the fine ornamentation patterns on growth bands [5]. While extant clam shrimps are classified based on the soft body morphological characters and molecular data. In order to solve this dilemma, a common language should be found for an integrated classification for fossil and extant clam shrimps [13]. During The Crustacean Society Mid-Year Meeting (May 2019 Hong Kong), fossil and extant clam shrimp specialists have carried out detailed discussion about the future research on clam shrimp taxonomy. Most participants agreed that clam shrimp carapaces could be the main object for searching for morphological features to discuss the relationship between fossil and modern clam shrimps.

Nowadays scanning electron microscopes (SEMs) are widely available and play a more important role in taxonomy of fossil clam shrimps [14]. The previous studies of fossil clam shrimps, mainly based on the observation under a light microscope, made un-precise descriptions of carapace ornamentation features, and thus taxonomic relationships cannot be determined clearly. A new SEM imaging of the type material of *Neodiestheria dalaziensis* from the Albian Dalazi Formation in northern China has revealed ontogenetically developing morphological patterns on growth bands of the juvenile stage of the carapace, which indicate that *Neodiestheria* is closely related phylogenetically to *Triglypta* [15]. This shows us that further investigation on the fossil and extant clam shrimp carapaces by the help of SEM could get more fruitful results to discuss their phylogenetic relationship.

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Conflicts of Interest

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SEM Morphological Study of the Paratype of the Spinicaudatan *Feiyunella zhedongensis* (Chen and Shen, 1977) from Cretaceous of Linhai, Zhejiang, South-East China

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Abstract

Spinicaudatans, a suborder of the abandoned taxonomic group "Conchostraca", are very useful for biostratigraphic subdivision and correlation of the non-marine successions, remarkably in otherwise fossil-scarce red beds. *Feiyunella*, a monospecies spinicaudatan genus, was established based on specimens from sediments of Upper Cretaceous red beds in different localities of Zhejiang Province. The morphological examination under a scanning electron microscope of the type specimens of *Feiyunella zhedongensis* (Chen and Shen, 1977) has found that the paratype from the Fangyan Formation at Xiaoling of Linhai City, Zhejiang Province, is not *Feiyunella*, but a younger individual of *Linhaiella*.

Keywords

Spinicaudatan, *Feiyunella*, *Linhaiella*, Taxonomy, Cretaceous, South-East China

1. Introduction

Debate continues about the stratigraphic correlation of the widely distributed non-marine red beds in south-east China. The spinicaudatans are one of the important groups for biostratigraphic correlation of the fossil-poor red beds [1] [2]. The *Linhaiella* fauna was established from the Cretaceous strata which pertain to the Fangyan Formation at the Xiaoling Section in Linhai, Zhejiang

Province [3]. The fauna was subsequently discovered in Anxi of Fujian, Gaohe of Guangdong, China, and Kiwado of Yamaguchi, Japan. The diversity of this fauna is extremely low, only several species in two genera, *Linhaiella* and *Feiyunella* are contained [4]. A recent morphological restudy of the type specimens of *Feiyunella* has revealed that the *Feiyunella* paratype from the Xiaoling Section is *Linhaiella*, totally different from the holotype which was collected from the Cretaceous strata at the Konglong Section in the Zhengwan village, Wencheng, Zhejiang Province.

2. Material and Method

The examined specimen is a paratype (NIGPCAS 42283) of *Feiyunella zhedongensis* [5], which is deposited in the collection of the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPCAS). The current study examined the specimens by a HITACHI SU3500 scanning electron microscope (SEM).

3. Results and Conclusion

The examination indicates that the paratype of *Feiyunella zhedongensis* (NIGPCAS 42283) is a younger individual of *Linhaiella longiformis* [6]: most of its growth bands are ornamented by relatively widely spaced and slender radial lirae, lirae branch to form reticulations, on external mould appearing as lender, branched grooves with intercalated fine nodules (**Figure 1(b)**, **Figure 1(c)**); mesh walls are thin, mesh cell diameter ca. 5 - 10 μm; radial lirae on the distal

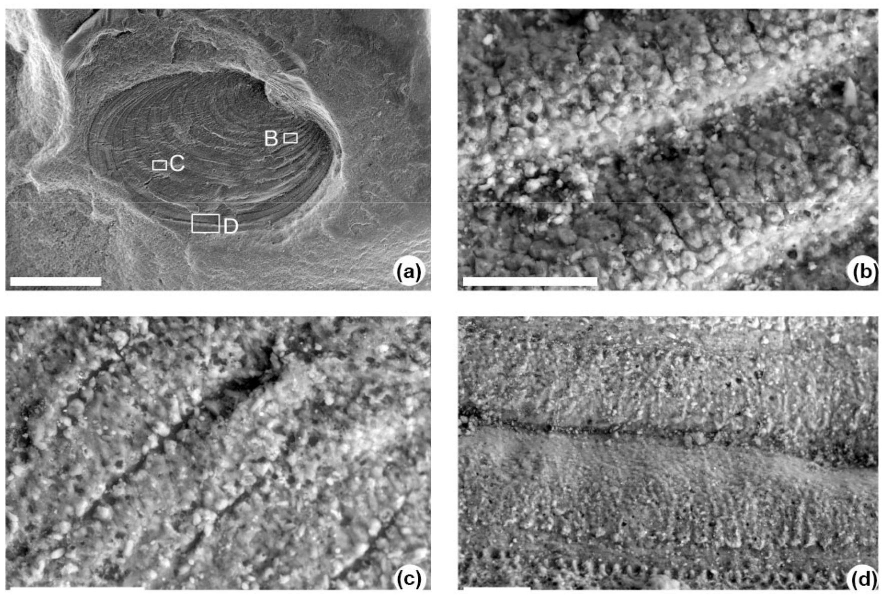

Figure 1. *Linhaiella longiformis* Chen and Shen, 1982, the paratype of '*Feiyunella*' (NIGPCAS 42283) from the Fangyan Formation at the Xiaoling Section of Linhai, eastern Zhejiang Province. (a) External mould of a left valve; (b) (c) External mould of branched slender radial lirae on growth bands, appearing as lender, branched grooves with intercalated fine nodules; (d) External mould of ornamentation on the marginal area of the carapace. Scale bar = 1 mm in A, 50 μm in (b)-(d).

most three growth bands are almost disappeared, especially on the upper part of each growth band; meshes change to evenly distributed puncta; and near the margin of each growth band, 2 - 3 rows of puncta are relatively deeper than others on the same growth band; on external mould, puncta appear as linearly arranged nodules on the lower part of each growth bands (**Figure 1(d)**). In contrast, growth bands in the lower part of the true *Feiyunella* carapace are ornamented by long and straight lirae, the lirae is stouter than that in *Linhaiella*. It was usually reported that *Feiyunella* co-occurred with *Linhaiella*; however, type specimens of the referred species are poorly preserved to identify. A further study with more focus on more taxonomic features of the true *Feiyunella* is therefore suggested; it would be helpful for biostratigraphic correlation of the Cretaceous non-marine red beds in south-east China.

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Conflicts of Interest

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"Conchostracan" Records from Western Gondwana Related to Cretaceous Palaeoclimatic Features

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Abstract

Cretaceous System is widely represented in South America. "Conchostracans" are best represented with 47 early Cretaceous species and only 5 Late Cretaceous ones. Its warm climate with rainfall and marked seasonality allowed the development of the "conchostracan" populations. This information shows that more detailed analysis between climate and "conchostracan" records is needed to reconstruct environments in the Cretaceous times.

Keywords

"Conchostraca", Cretaceous, Climate, Fossil Record, South America

1. Introduction

The Cretaceous System is widely represented in South America, but its geographical outcrop spread is not related to "conchostracan" records, the best represented group among the continental invertebrates [1]. "Conchostracan" first report came from northeast Brazil [2], where the highest diversity record (42 spp. described) was reported, followed by Argentina (6 spp.) and Uruguay (4 spp.) [3] [4]. In Brazil, 37 species came from the early Cretaceous and only 5 to the Late Cretaceous. Ten species from Argentina and Uruguay were found in Lower Cretaceous sequences [3] [4] [5]. The integration of geological and paleontological data will allow inferring the Cretaceous paleoclimate for the southwest Gondwana.

2. Cretaceous Climate

The arid climate, with heavy rainfall, generated favorable seasonal conditions for the development of a diverse "conchostracan" fauna [3] [4] [5]. The diversity of the northeastern Brazil faunas [4] was influenced by the weather. However, it is inferred that, the scarce record in southern South America (e.g. Argentina and Uruguay) is mainly related to collection biases [3] [5]. However, during the Jurassic-Cretaceous periods, marine transgressions and other events (such as magmatism of Serra Geral and Botucatú erg-desert) conditioned the dispersion (marked endemism) and the establishment of continental microfossils (ostracods and charophytes) in Patagonia Argentina and the rest of South America [6]. Subsequently, in [6] analyzed the [4] postulates and applied them to the "conchostracan" faunas found in other sequences, incorporating into this analysis the large South American river drainage networks (Paraná-Uruguay and Orinoco-Amazonas). The climate defined for mid-Cretaceous, maintained favorable characteristics (seasonality) for the development of "conchostracan" faunas. During the late Cretaceous warm weather prevailed with greenhouse periods, globally average temperatures higher than today are recorded. Scarce "conchostracan" records in Brazil, where only 5 species were found, restricts the possibilities of making considerations about the characteristics of the climate and its relationship with the "conchostracan" populations.

3. Cretaceous Geological Units Bearing "Conchostracan" Faunas

The main Cretaceous units with "conchostracan" of Argentina are the La Amarga, Lagarcito and Cañadon Calcáreo formations, while of Uruguay only the Tacuarembó and Castellanos formations have been reported, and numerous Brazilian ones [3] [4] [5]. The Cañadón Calcáreo Formation (Upper Jurassic - Lower Cretaceous) with subtropical seasonal dry and warm climatic conditions allowed the establishment of a rich and diverse conchostracan fauna [7]. The Botucatú Formation (paleoerg, Late Jurassic - Early Cretaceous, Brazil) and its equivalent shares 12 species, 3 of them, were referred to another 6 equivalent geological units from the northeast Brazil. The Santana Formation (Lower Cretaceous, Northeast Brazil) with a tropical climate with strong seasonal periods represents favourable conditions to stablish "conchostracan" populations [3]. The Bauru Basin (Upper Cretaceous, Southeast Brasil) was characterized by hot, arid and desert conditions. The scarce "conchostracan" records from the Upper Cretaceous are insufficient to assess to the influence of climate on the "conchostracan" faunas.

4. Conclusion

Finally, the still biased and not very diverse record of the South American Cretaceous "conchostracan" faunas prevents us from providing definitive conclusions about the impact of the Cretaceous climate on them. Also, considering that

South American has a large number of geological units and different environmental conditions and also the paleogeographical context of the southwest Gondwana. However, the climatic characterization for the Cretaceous of South America summarized as a warm climate with rainfall and marked seasonality is characteristics that allowed the development of the "conchostracan" populations. This information shows that we need a more detailed and in-depth analysis of the relationship between the climate and the "conchostracans".

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Conflicts of Interest

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New Vertebrate Fossil Site from the Early Cretaceous Sao Khua Formation, Sakon Nakhon Province, Northeastern Thailand

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Abstract

A new vertebrate fossil site, "Phu Sung" in Sakon Nakhon Province was discovered. Various vertebrate fossils belonging to fresh water shark, bony fish, turtle, crocodile and dinosaur were found in reddish silty mudstone of the Early Cretaceous Sao Khua Formation of the Khorat Group. Crocodilian remains including a complete skull and partial articulated skeleton are very well preserved associated with turtle remains. Moreover, well preserved 19 turtle shells were found accumulated together. These discoveries will certainly fulfill our knowledge about these aquatic taxa from the Early Cretaceous Sao Khua Formation. The exceptional preservation of Phu Sung fossils could probably relate to the paleoenvironment in the Early Cretaceous of Thailand.

Keywords

Vertebrate, Sao Khua Formation, Early Cretaceous, Northeastern Thailand

1. Introduction

The Lower Cretaceous Sao Khua Formation of the Khorat Group mainly distributed in northeastern Thailand (**Figure 1**), is well known for the rich fossils especially for dinosaurs. Some Sao Khua fossil sites in Sakon Nakon were previously mentioned about the discoveries of vertebrate remains including fresh

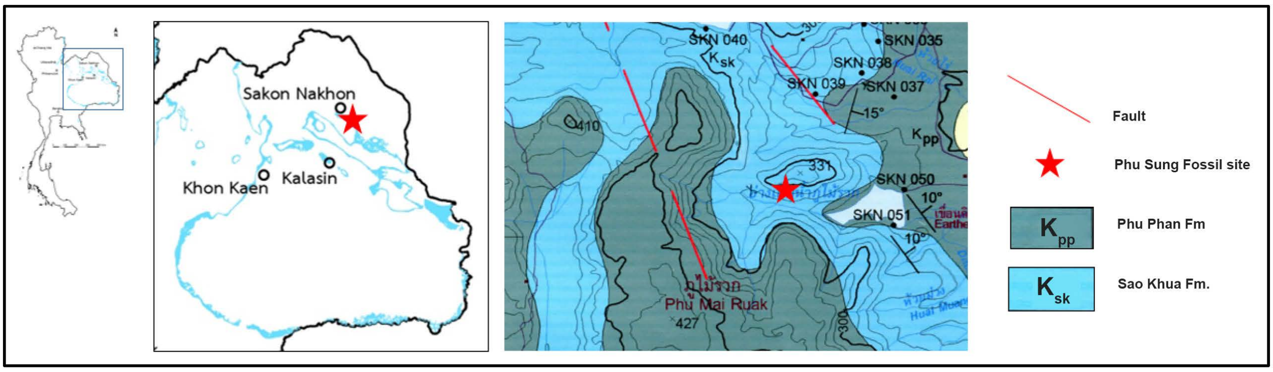

Figure 1. Distribution of Sao Khua Formation and Phu Sung locality showing in red star.

water shark, bony fish, turtles, crocodiles, pterosaurs, dinosaurs and lizard eggs, however, most of them are fragmentary and rarely articulated. One interesting site of Sakon Nakhon, Phu Din Daeng, found in 2012 has been reported with a new adocid turtle [1]. Most recently, a new vertebrate fossil site "Phu Sung" was firstly found by a forest ranger in the National Reserved Forest of Phu Lom Khao and Phu Peg area. Several vertebrate fragments, such as dinosaur, crocodile and turtle were found on the surface obviously in the intermittent rills. In December 2018, the excavation was proceeded and found the exceptionally preserved articulated crocodile and turtles remains which kind of preservation has rarely reported from the Lower Cretaceous of Thailand.

2. Geological Setting

Phu Sung is located at the eastern side of Phu Phan Range in Muang Sakon Nakhon District, Sakon Nakhon Province (**Figure 1**). Fossils found in situ from reddish silty mudstone which is underlain and overlain by sandstone beds. The site is mapped in the Barremian Sao Khua Formation of the Khorat Group [2].

3. Fossil Assemblage

Phu Sung fossil site yields various vertebrate taxa. Many remains were collected from the erosional surface including a tooth of Chondrichthyes possibly belonging to *Heteroptychodus* sp., a maxilla of a bony fish sinamiid possibly *Siamamia* and dinosaurs. The dinosaur material consists of a large isolated tooth with serration and manual claws of indeterminate theropods, a conical tooth fragment of a spinosaurid, a peg-like tooth of a sauropod similar to one of *Phuwiangosaurus sirindhornae* and large bone fragments of indeterminate taxon. Surprisingly in the mudstone layer, crocodilian remains including a complete skull and partial articulated skeleton are found associated with turtle shell and bones (**Figure 2**). This crocodile skull is the most complete skull ever found from the Sao Khua Formation. It is probably referred to a goniopholidid and interesting to compare with *Siamosuchus phuphokensis* which found from another Early Cretaceous site of Sakon Nakhon Province [3] and *Goniopholis phuwiangensis* from Phuwiang, Khon Kaen Province [4]. These two Thai goniopholidid

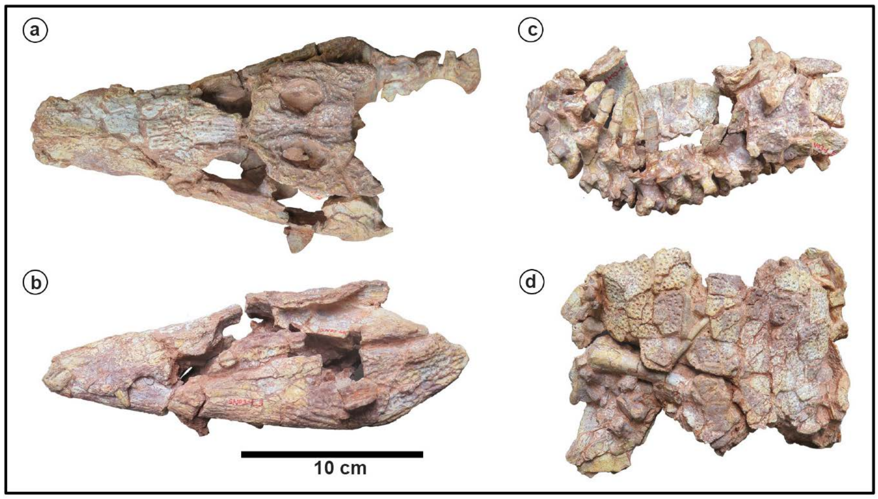

Figure 2. Crocodilian remains including a nearly complete skull (a) in dorsal and (b) in left lateral views, (c) partial articulated vertebrae and (d) articulated osteoderms.

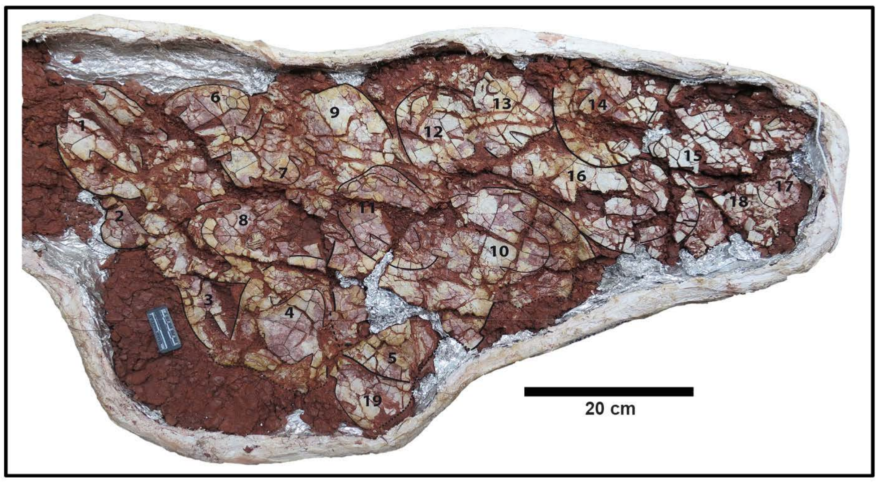

Figure 3. Nineteen adocid turtles accumulated together in reddish silty mudstone.

species lack of common specimens. Thus, this new Phu Sung goniopholidid can clarify the diversity of the Early Cretaceous crocodilian in Thailand. Moreover, few meters from where the crocodile remains were found, well preserved accumulated 19 turtle shells were discovered (**Figure 3**). These turtles belong to an adocid and are comparable to *Isanemys srisuki*. However, the turtles are still in the plaster jacket and need more preparation in another side for more information.

Although, the fossil assemblage from Phu Sung is quite similar to several sites from the Sao Khua Formation, the fossils from Phu Sung site such as crocodile and turtles are very complete with the exceptional preservation. These discoveries will certainly fulfill our knowledge about these aquatic taxa from the Lower Cretaceous Sao Khua Formation. The taphonomy and the extraordinary preservation of Phu Sung fossils could probably relate to the paleoenvironment and the paleoclimate changes in the Early Createaceous of Thailand. The further excavations and geological studies will help us to better understand the geology and paleontology of this site.

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Conflicts of Interest

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Induszalim bala Mesoeucrocodile from Pakistan

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Abstract

Induszalim bala is the first diagnostic mesoeucrocodile from Indo-Pakistan subcontinent having rostrum articulated with dentary symphysis and associated vertebrae and limb bones and provides facility for comparison with other mesoeucrocodiles. *Induszalim* is a medium to large sized mesoeucrocodile found in the latest Maastrichtian Vitakri Lameta Formation of Fort Munro Group just below Cretaceous-Paleogene boundary line. *Induszalim* has sufficient skeletal elements and can be used for phylogenetic studies. *Induszalim* shows Gondwanan paleobiogeographic affinity with some endemic elements.

Keywords

Mesoeucrocodile, *Induszalim bala*, Latest Maastrichtian, Indo-Pakistan Subcontinent

1. Introduction

Induszalim bala mesoeucrocodile as the new genus and new species was first reported by [1] and formally published by [2]. Here *Induszalim* is being described for evolutionary study.

2. *Induszalim bala* Mesoeucrocodile from Pakistan

Systematic paleontology of *Induszalim bala* is as follows: Crocodyliformes, Mesoeucrocodylia, Induszalimidae [1], *Induszalim* [1] [2], *Induszalim bala* [1] [2] (**Figure 1**). *Induszalim bala* holotypic rostrum and lectotypic caudal vertebrae, proximal humerus and distal femur (**Figure 1**) from Alam 19 type locality found in latest Maastrichtian Vitakri Lameta Formation of Fort Munro Group, Barkhan District, Balochistan, Pakistan. *Induszalim bala* referred

Figure 1. *Induszalim bala* fossils. Row 1, holotypic rostrum MSM-155-19c in poaterior and left lateral views. Row 2, holotypic rostrum MSM-155-19c in anterior view, lectotypic caudal vertebrae un-number and MSM-65-19 in one view. Row 3, lectotypic caudal vertebra MSM-65-19 in one view, proximal humerus in one view, and distal femur MSM-66-19 in 2 views. Row 4, referred dorsal vertebra MSM-64-15 in 2 views, dentary MSM-63-4 in 4 view and proximal humerus in one view. Scale, each black or white digit is 1 cm.

dorsal vertebra from the Mari Bohri 15, dentary andhumerus from the Kinwa 4 localities found also in the latest Maastrichtian (67-66 Million years ago) Vitakri Lameta Formation of Fort Munro Group, Barkhan District, Balochistan, central Pakistan. These fossils are housed in the museum of Geological Survey of Pakistan, Quetta. Genus Induszalim name is after Indus River of Pakistan and Zalim (Urdu and Saraiki word) meaning cruel, and species named Induszalim bala is after Saraiki word bala meaning big terrible animal.

2.1. Diagnosis of *Induszalim bala*

Induszalim bala secondary plate and age shared with mesoeucrocodiles. Induszalimidae is based on *Induszalim bala* genus and species. *Induszalim* bony secondary plate is formed by premaxilla, maxilla and palatine while *Pabwehshi* secondary plate is formed by premaxilla and maxilla only; external nare subterminal (while vertical in *Pabwehshi*); anterior rostrum moderately inclined (while vertical in *Pabwehshi*); narial fossa anteriorly has stepped premaxilla strip (while *Pabwehshi* has no step); *Induszalim* has twice deep palatal cavity than *Pabwehshi*; in *Induszalim* the suture of nasal with premaxilla and maxilla is generally straight line with fine zigzag butt suture; splenial and dentary are united as concavo-convexo style with axis in mid while its axis is shifted ventrally in *Pabwehshi*; in *Induszalim*, the diverticulum in wall of internal naris is negligible while diverticulum is well developed in *Pabwehshi*; tooth bearing maxillary ramus is twice away from internal naris cavity in *Induszalim* than *Pabwehshi*; dorsoventrally oriented elongated large pneumatopores in maxilla; Dentary is thick with large pneumatopores in *Induszalim* while small pneumatopores in *Pabwehshi* dentary; *Induszalim* has relatively small internal naris cavity than *Pabwehshi*; large and deep palatal cavity than *Pabwehshi*; partial roof over the external naris; in *Induszalim* the palatine ramus shows elongated contact with maxilla while not found in *Pabwehshi*; first and second tooth of Dentary are small in diameter than *Pabwehshi*, while third is more but fourth is maximum in diameter of *Induszalim* than *Pabwehshi*; Neurocentrally straight suture opens in dorsal centrum; Caudal centra are strongly waisted.

2.2. Description of Fossils of *Induszalim bala*

Induszalim bala shows anterodorsally directed external nares, high or deep and narrow rostrum, the ziphodont type laterally compressed teeth (symmetric to asymmetric oval to asymmetric D shaped, subcircular and heterodont in size), and thick rostral elements. Deep D-shaped rostrum is ornamented with pitted and sculptured lines or grooves and ridges. Height of the rostrum is ¾ to its width like *Pabwehshi*. In *Induszalim* the external nares are subterminal while it is terminal in *Pabwehshi*. External narial fossa face anterolaterally and laterodorsally. Rostrum has many small and large internal pneumatic cavities (**Figure 1**). Premaxilla is sub-quadrangular in lateral views. It contacts with nasal posterodorsally and the maxilla posteriorly. Premaxilla and nasal enclose the external nares. Laterally the suture of maxilla and premaxilla is a butt joint. Dorsally the premaxillae contact with each other to form the midline contact and form the lip. Premaxillary lip forms more than 3/5 of anteroposterior length of dorsal roof of external nares. Ventrally, the premaxillae may contact one another at the midline to form the anterior portion of the secondary palate. A diastema is found on the contact of maxilla and premaxilla (**Figure 1**).

Maxilla and premaxilla form side wall of rostrum, while palatines are separated bones. In *Induszalim* the palatine lateral torus has elongated contact with the maxilla while this contact is not found in *Pabwehshi*. It represents that secondary palate formed by separate bones. Dorsally the maxilla meets with nasal forming contact subparallel to midline (with fine zigzag fine tuning). Maxilla, nasal and palatine bones enclose the internal naris. Nasal forms the dorsal and some dorsolateral margin of internal naris. Upper half of internal naris is bounded by maxilla while lower half of internal naris is bounded by palatine. A prominent and exceptionally very large elongated internal coel (dorsoventrally elongated) is found in maxilla (**Figure 1**). Nasal forms the roof of rostrum. Lower portion of bilaminae internarial bar is clearly formed by palatine while dorsal portion is damaged (**Figure 1**).

Holotypic dentary symphysis is preserved in interlocking with maxilla and premaxilla (**Figure 1**). Further both rami of dentary also articulated with the relevant splenial. Pitted structures on dentary are aligned anteroposteriorly with some random rough contouring. Dentary is pneumatic. Splenial joined with relevant dentary is concave-convex which axis found in the dorsoventrally centre of bones, while shifted ventrally in *Pabwehshi*. Induszalim referred mandible is D-shaped. Two diverse mandibles are found fragmentary, one belongs to Pabwehshi and other assigned to Induszalim. First and second tooth of dentary are small in diameter than *Pabwehshi*, while third is relatively more but the fourth is maximum in diameter of *Induszalim* than *Pabwehshi*, the fourth dentary tooth is large and shows a marked heterodonty in size and is more transversely compressed of *Induszalim* than *Pabwehshi*. A diastema is also found in the dentary at the level of dentary tooth 4. Splenial at cross section is thick robust four limbs X shaped or four rayed star shaped. Palatine meets on midline formed secondary plate. Dorsal centrum is amphicoelous, big in size than caudal vertebrae. Dorsal centrum is long, slightly tall and slightly waisted. Neurocentral suture open in dorsal vertebra. Caudal vertebrae are amphicoelous, long, strongly waisted and formed arced. Proximal humerus is broad. Femur tibial condyle is greater than fibular condyle, elliptical shaft is curved.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Smallest Titanosaur from Indo-Pakistan Landmass

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Abstract

Almost complete skulls of most derived titanosaurs which provide complete teeth row are rare. *Saraikimasoom vitakri* is the smallest sized, the most derived titanosaurian sauropod based on very small sized 15 - 18 cm long and 7 - 9 cm high partial skull. Dorsal profile of skull inclined 40˚ anteriorly. It provides full teeth row with dental formula 4, 13/9-13. *Saraikimasoom* is the smallest titanosaur so far found from Indo-Pakistan subcontinent. Its height is about 2 meter, length 8 - 10 meter and weight about 5 tons. *Saraikimasoom vitakri* shows Gondwanan paleobiogeographic link with some endemic elements.

Keywords

Smallest Titanosaur, Latest Maastrichtian, Vitakri Lameta Formation, Indo-Pakistan

1. Introduction

Out of 15 taxa, only four titanosaur taxa like *Pakisaurus* and *Isisaurus* of pakisaurids and *Gspsaurus* and *Saraikimasoom* of gspsaurids were recognized on diverse teeth, skulls, braincases, vertebral (especially caudal vertebrae), appendicular (especially tibiae, femora, humerei and scapulae) skeletons collected from Indo-Pakistan especially from Pakistan. *Saraikimasoom vitakri* as a new genus and new species was reported by [1] and formally published by [2]. This is being described here which can be used for phylogeny.

2. *Saraikimasoom vitakri* Smallest Titanosaur from Indo-Pakistan

Systematic paleontology of *Saraikimasoom vitakri* is as follows: Dinosauria, Saurischia, Sauropoda, Titanosauria, Gspsauridae [2], Saraikimasoominae [2], *Saraikimasoom* [1] [2], *Gspsaurus pakistani* [1] [2] (**Figure 1**). *Saraikimasoom vitakri* as a new genus and new species was first described by [1] and later on formally published by [2]. *Saraikimasoom vitakri* holotypic had very small skull (**Figure 1**) from South Kinwa 4 holotypic locality, and referred associated cranial, vertebral and appendicular elements from North Kinwa 4n, and some fossils from Mari Bohri 15, Top Kinwa 16, South Kinwa 4, mid Kinwa 4 m, South Zubra 7, mid Bor 2 (to be examine key tibia), Grut Gambrak 8 and Shalghara 3 localities found in latest Maastrichtian Vitakri Lameta Formation of Fort Munro Group, Barkhan District, Balochistan, central Pakistan. These fossils are housed in the museum of Geological Survey of Pakistan, Quetta. Some fossils from Vitakri Lameta Formation of India are also referred. Genus *Saraikimasoom* honors Saraiki language of the area while masoom is Urdu and Saraiki word meaning innocent. Species name *S. vitakri* named after the host Vitakri area and Vitakri Lameta Formation, Barkhan District, Balochistan, Pakistan.

2.1. Diagnosis of *Saraikimasoom vitakri* Smallest Titanosaur

Saraikimasoom vitakri is a very small sized stocky sauropod sharing with Titanosauria as procoelous caudals (except first biconvex caudal); forward insertion of neural arches on caudals, prominent olecranon process on ulna and vertebrae lacking hyposphene-hypantrum articulations. *Saraikimasoom vitakri* autapomorphies are very small sized spongy skull dorsal profile inclined moderately or 40˚ from horizontal; skull without anterior step; low angle palatine; premaxillary canal is reversely triangular and high angled V shaped; conical teeth converge and taper gradually from base of crown to tip; teeth are small, circular and slightly recurved: upper and lower U shaped teeth rows; dentary ramus anterior depth is slightly more than dentary at mid length: dentary with narrow anteroposteriorly symphyses; anterior dentary rounded (no chin or very small chin); dentary symphysis, perpendicular to axis of jaw ramus; dental formula 4, 13/9-13?; small braincase with sub rectangle shaped basioccipital condyles angles 120˚ (from skull roof) toward posteroventrally; Braincase has a prominent supraoccipital wedge and proatlantal facets; ventrally reduced broad caudals; trispinous distal caudals; and subcircular proximal tibia with equal anteroposterior and transverse width.

2.2. Description of *Saraikimasoom vitakri* Smallest Titanosaur

Very small sized skull interlocked with dentary is highly spongy. Its upper profile inclination is 40˚ from horizontal. It preserved cross section which shows ventral and dorsal palatal processes. Lower and upper teeth row anteriorly formed U-shaped (unlike *Gspsaurus* which have lower teeth row V-shaped). Teeth are circular to subcircular, relatively small, slightly recurved and conical-taper gradually from base to tip and tooth slenderness indices vary from 3 - 5.

Figure 1. *Saraikimasoom vitakri* fossils. Row 1, Map of Pakistan (black circle show Kinwa type locality), holotypic skull MSM-142-4 in anterior and ventral views. Row 2, holotypic skull in left and right laterals and posterior views. Row 3, 4, Referred associated cranial and postcranial elements from north Kinwa. Row 5, Referred proximal and distal tibia, proximal and distal humerus, proximal ulna and astragalous. Row 6, Referred first bi-convex caudal, mid and posterior caudals, distalmost trispinous caudal in anterior and posterior views, sternal, large oval armour (or ungual) and jaw type with spine osteo-derm. Scale, each black digit is 1 cm.

Rostrum dorsal profile dorsoanteriorly inclined moderately 40˚. Skull is very small sized and highly spongy. Rostrum has no anterior step on premaxilla. Teeth are inserted on anterior and lateral rostrum (unlike diplodocoids). Low angle, broad reversed V-shaped palatal, and V-shaped dorsal palatal hook, each limb attached on the contact of maxilla and premaxilla. Palatal maxillary and premaxillary canals occurred. Dentary ramus anterior depth is slightly more than dentary at mid length. Dentary has short or narrow anteroposteriorly symphyses. Dentary symphysis angled 70˚ or more anteriorly to axis of jaw ramus. Anterior Dentary rounded (feeble chin or no chin). External nares retracted posteriorly. Eye situated posteroventrally to the external nares. Premaxillary mid line contact is prominent. Small braincase with sub rectangle shaped (unlike Indian braincases) basioccipital condyle. Cervical centra are broad. Cervical and dorsal centra are opisthocoelous. One dorsal centrum has bony septa in pleurocoel and pleurocoel is divided, while others have no bony septa (*Gspsaurus* have bony septa in axis centrum pleurocoel). Long dorsal centrum has deep pleurocoel with thick lip. Sacral centra are short, broad, pneumatic and have a ventral keel. All caudal centra are procoelous except first caudal. First caudal is biconvex, broad and long (while *Gspsaurus* has ball like). Anterior caudal centra are broad and have separated transverse process and did not extend to neural arch (except first caudal). Middle caudal centra ventrally reduced. Posterior ball of distal caudal centra is not restricted (unlike *Gspsaurus* restricted posterior ball). Trispinous distalmost caudal centrum, two oval shaped spines extend posteroventrally or posterodorsally and one spine upward or downward. Proximal humerus lateral limb is longer than medial limb. Distal Humerus has anteriorly expanded radial condyle. Pubis has small articular surface for ilium peduncle and large acetabular glenoid. Ischium has low and not expanded articular surface for ilium peduncle, followed by long glenoid and then area for pubis attachment. Ischium is thin and plate. Proximal femur is non-deflected. Distal condyles are strongly expanded with rugosities extended on medial and lateral sides. Subcircular proximal tibia has equal anteroposterior and transverse width. Astragalus, a synclinal fold type with both limbs and central depression. First mosaic type armour bone and second false jaw ramus type with embedded teeth type spikes as osteoderms and third large oval plate may be osteoderm or ungual.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Medium Sized Stocky Titanosaur from South Asia

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Abstract

Recently, four coexisted titanosaurs from latest Maastrichtian Vitakri Lameta Formation of Indo-Pakistan are recognized as *Isisaurus* and *Pakisaurus* of large-sized slender pakisaurids, *Saraikimasoom* and *Gspsaurus* of the smallest and medium sized transversely stocky gspsaurids. *Gspsaurus pakistani* based on associated skull (with conical teeth tapering gradually from base to tip), vertebral and appendicular elements found from Alam 19 locality of Vitakri area, Barkhan district, Balochistan, Pakistan, South Asia. *Gspsaurus* bears sufficient skeletal elements and can be used for evolutionary studies.

Keywords

Medium Sized Stocky Titanosaur, Associated Skeleton, Latest Maastrichtian, South Asia

1. Introduction

Gspsaurus pakistani medium sized stocky titanosaur as a new genus and new species was reported by [1] and formally published by [2]. For phylogeny, this is being described here.

2. *Gspsaurus pakistani* Medium Sized Titanosaur of Indo-Pakistan

Systematic paleontology of *Gspsaurus pakistani* is as follows. Dinosauria, Saurischia, Sauropoda, Titanosauria, Gspsauridae [2], Gspsaurinae [2], *Gspsaurus* [1] [2], *Gspsaurus pakistani* [1] [2] (**Figure 1**). *Gspsaurus pakistani* as a new genus and new species was first described by [1] and later on formally published by [2]. *Gspsaurus pakistani* holotypic skull and lectotypic braincase, vertebrae and

Figure 1. *Gspsaurus pakistani* fossils. Row 1, holotypic skull MSM-79-19 and MSM-80-19 from Alam locality in ventral and posterior views. Row 2, photo 1, Map of Pakistan (black circle represent Alam type locality); photo 2-7, lectotypic fossils from Alam. Row 3, lectotypic fossils from Alam locality. Row 4, referred fossils, proximal tibia in 2 views, proximal and distal femur. Row 5, distal expanded scapula, pubis, and atlas-axis in 2 views. Row 6, mid caudal, trispinous distal caudal in 2 views, armour mosaic plate, large oval two plates (armour or ungual). Scale each black digit is 1 cm. Last photo represents model of *Gspsaurus vitakri* (fossil based) or *Pashtosaurus zhobi* (track based model managed by Mr. Nicholas Allen British Journalist and prepared by Dr. Dmitry Bogdanov).

appendicular elements (**Figure 1**) from Alam 19 type locality, and referred post-cranial fossils from Top Kinwa 16, South Kinwa 4, Mari Bohri 15, Rahi Wali 10 and Darwaza 8 localities found in latest Maastrichtian Vitakri Lameta Formation of Fort Munro Group, Barkhan District, Balochistan, Pakistan. Some fossils from Vitakri Lameta Formation of India are also referred. These fossils are housed in the museum of Geological Survey of Pakistan, Quetta. Genus ***Gspsaurus*** honors the Geological Survey of Pakistan, and saurus means lizard. The species name *G. pakistani* honors the country of origin Pakistan. The pronunciation of *Gspsaurus* is G. S. P. saurus.

2.1. Diagnosis of *Gspsaurus pakistani* Medium Sized Stocky Titanosaur

Gspsaurus pakistani medium sized sauropod shares with the Titanosauria as vertebrae lacking hyposphene-hypantrum articulations; procoelous caudals (except the first caudal); forward insertion of neural arches on caudals; and prominent olecranon process. *Gspsaurus pakistani* autapomorphies are as small sized spongy skull; teeth circular to subcircular, slender, slightly recurved and conical. The thickness of diameter decreases gradually from base to tip; palatal shelf between the ventral palatal process and dorsal palatal process forms left and right maxillary canals; dorsal palatal shelf just below the left and right premaxillae and between the dorsal palatal processes forms reverse triangular premaxillary canal; some teeth cone blunted showing wear facet, broad U shaped upper teeth row and V shaped lower teeth row. Reversed V-shaped ventral palatal processes with oval shaped rod contacted week with maxilla; V-shaped small dorsal palatal processes attached on the contact of maxilla and premaxilla. Dentary ramus anterior depth is slightly less than mid length, dentary with long anteroposterior symphyses, angled 15˚ or more anteriorly to axis of jaw ramus, transversely thick and anteroposteriorly lense shaped proximal tibia and transversely oval shaped distal tibia.

2.2. Description of *Gspsaurus pakistani* Medium Sized Stocky Titanosaur

Skull is small sized and spongy. Teeth are circular to subcircular, slender, slightly recurved and conical-taper gradually from base to tip. Premaxilla is without anterior step. Ventral palatal shelf forms left and right maxillary canals. Dorsal palatal shelf forms one premaxillary canal. Premaxillary canal is enclosed dorsally by both fellow of premaxillae, ventrally and laterally by dorsal palatal processes. Premaxillary canal is high angled V shaped. Upper teeth row as broad U shaped and lower teeth row as V-shaped. Dentary ramus is thick, tall and pneumatic. Dentary ramus anterior depth is slightly less than dentary at mid length. Dentary has long anteroposteriorly symphyses. Dentary symphysis, angled 15˚ or more anteriorly to jaw axis. Reversed V-shaped palatal with long limb, and V-shaped dorsal palatal hook with short limbs attached on the contact of maxilla and premaxilla. Braincase is large size with quadrangle shaped basioccipital condyles with median cut on dorsal and ventral views. Basioccipital condyle is constricted dorsoventrally in the middle; Lateral side of basioccipital condyle is generally straight (unlike Indian braincases). Basal tubera have high angle unlike Indian titanosaur braincases (similar to *Rapetosaurus* braincase from Madagascar). Atlas-axis is very broad, pneumatic and have many pleurocoels on lateral and posterior views. Axis centrum is about twice broad than height. Axis parapophysis is rectangular located posteriorly on ventral aspect of centrum. Axis diapophysis is thick and located posteriorly on the lateral sides of centrum just posterior of the pleurocoel. Axis pleurocoel has inclined thin bony septa in mid. Anterior cervical is small and broad, and mid cervical is very broad and large. Parapophysis is changed from rectangular (in anterior cervical) to oval (in middle and posterior cervicals. Neural spine is not bifid. Cervical and dorsal centra are opisthocoelous. First caudal centrum is ball like and has anterior and posterior articular balls (biconvex). Full middle caudal series is heavy and slightly tall and at the end squarish with ventral view slightly compressed than dorsal view of centrum. Distal caudal is cylindrical with restricted ball. Distalmost caudal centrum forming caudal cap have anterior well developed concavity while posterior ball is trispinous, two spines directing downward and one spine directing upward or vice versa. Chevron is simple. Chevron arch and chevron spine anteroposteriorly compressed. Distal scapula is expanded well. Medial extrusion of proximal humerus prominent. Medially non-deflected proximal femur is like *Saraikimasoom* (and unlike *Pakisaurus* and *Isisaurus*). Distal femur has maximum expansion. Femur distal condyles have rugosities on ventral surfaces which extended on laterally and medially. Transversely thick and anteroposteriorly lense shaped proximal tibia. Proximal condyle of stocky tibia has broad groove or depression on dorsal view. Lateral fibular condyle of proximal tibia is symmetric (while tilted in *Pakisaurus*). Distal tibia transversely oval shaped. Tibia and fibula closely articulated. Dorsoventrally compressed large oval plate may be osteoderms (or ungual which provide the best support for stocky body (and also fit by footprints of basal and most advanced titanosaurs from Pakistan.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Large Titanosaur from Indo-Pakistan Peninsula

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Abstract

Indo-Pakistan subcontinent is lucky to host the smallest, medium and large sized titanosaurian sauropod dinosaurs. *Saraikimasoom* is the smallest sized, and *Gspsaurus* is the medium sized transversely stocky, *Pakisaurus* and *Isisaurus* are the large sized titanosaurs of South Asia. *Pakisaurus balochistani* is a slender type of pakisaurid titanosaurian based on associated vertebral and appendicular skeletons. *Pakisaurus balochistani* includes key elements like transversely thin or narrow tibia and ventrally not reduced tall caudal vertebrae, along with other elements which are significant for cladistic analysis.

Keywords

Large Titanosaur, Latest Maastrichtian, Vitakri Lameta Formation, Indo-Pakistan

1. Introduction

Pakisaurus is included among four recently recognised titanosaurian sauropods from South Asia. *Pakisaurus balochistani* is described here and significant for comparisons, Gondwanan paleobiogeography and evolutionary studies.

2. *Pakisaurus balochistani* Large Titanosaur from Indo-Pakistan

Systematic paleontology of *Pakisaurus balochistani* is as follows. Dinosauria, Saurischia, Sauropoda, Titanosauria, Pakisauridae [1], *Pakisaurus* [1], and *Pakisaurus balochistani* [1] (**Figure 1**). *Pakisaurus balochistani* as a new genus and new species was formally published by Malkani [1]. *Pakisaurus balochistani* holotypic caudal vertebrae [1] and lectotypic vertebral and appendicular elements from South Kinwa 4 holotypic and lectotypic locality (**Figure 1**), and referred fossils from West Bor 2, northern Top Kinwa 16, North Alam 19n, Shalghara 3, Mari Bohri 15, Darwaza 8 and Grut 9 localities are found in the latest Maastrichtian

Figure 1. *Pakisaurus balochistani* fossils. Row 1, Map of Pakistan (black circle) show Kinwa type locality, holotypic caudal vertebrae from Kinwa. Row 2, 3, 4, 5, lectotypic vertebral and appendicular elements from Kinwa. Row 6, referred associated tibia and humerus (photo 1/p 1) and femur (p 2) from west Bor or lower Bor; chevron 2 views (p 3 - p 4). Row 7, referred coracoid (p 1), proximal radius (p 2), ungual (p 3) and osteoderms jaw ramus with diastema type embedded spikes (p 4 - p 5) and dentary symphysis type with teeth like spikes (p 6). Scale, each black or white digit is 1 cm.

(67 - 66 Ma ago) Vitakri Lameta Formation of Fort Munro Group, Barkhan District, Balochistan, central Pakistan. These fossils are housed in the museum of Geological Survey of Pakistan, Quetta. Some fossils from Vitakri Lameta Formation of India are also referred. Genus *Pakisaurus* honour the host country Pakis-

tan, saurus mean lizard. Species named *P. balochistani* honour the host province Balochistan.

2.1. Diagnosis of *Pakisaurus balochistani* Large Titanosaur

Pakisaurus balochistani sharing with Titanosauria as procoelous caudals; forward insertion of neural arches on caudals; prominent olecranon process on ulna and vertebrae lacking hyposphene-hypantrum articulations Pakisauridae characters are same as genus and species. *Pakisaurus balochistani* is recognised as more derived lithostrotian titanosaur based on procoelous anterior and middle caudal vertebrae. *Pakisaurus balochistani* is recognised as most derived Poripuch lithostrotian titanosaur based on procoelous anterior, middle and posterior caudal vertebrae. *Pakisaurus balochistani* is characterised by long slender legs and tall tail; narrow, long and recurved teeth with constant thickness from base to tip (except tip); large sized braincase with D-shaped occipital condyle; basal tubera breadth narrower than occipital condyle; caudals are tall quadrangular shape except a few anteriormost caudals which are broad; distal most caudal centrum anterior articular face shape procoelous while posterior face ball is biconvex cone with a horizontal transverse groove in the middle; distal scapula relatively less expanded than *Gspsaurus*; distal scapula with relatively anteroposteriorly long glenoid; distal scapular articular length for coracoid is relatively small (unlike Isisaurus); acromian process is narrow; expanded radial condyle exposed on the anterior aspect of distal humerus (unlike *Isisaurus*); femoral shaft, lateral margin shape, proximal one-third deflected medially with wavy style (and not straight as in Isisaurus); transversely narrow proximal Tibia with arc shaped lateral fibular condylar ridge ended just below cnemial crest; and osteoderms spikes on ramus.

2.2. Description of *Pakisaurus balochistani* Large Titanosaur

Teeth are narrow, long and recurved with constant thickness from base to tip (except tip). Braincase is large sized. Occipital condyle is large and broad and greater part of its convexity faces downward. Thick occipital condyle has broad flat upper surface. Basal tubera breadth is narrower than occipital condyle. Occipital region of skull is flat and distally recurved. Paroccipital processes oriented transversely. Basal tubera are long process, diverging laterally with relatively lower angle than *Gspsaurus* who have high angle basal tubera. Basal tubera directed slightly backwards. Basipterygoid processes diverge somewhat anteriorly and much longer than the basal tubera. Caudals are tall quadrangular shape except a few anteriormost caudals which are broad. Anteriormost caudals neural spine is vertical. Distalmost caudal centrum anterior articular face shape procoelous while posterior ball face is biconvex cone with a horizontal transverse groove in mid. Distal scapula relatively less expanded than *Gspsaurus.* Distal scapula has relatively anteroposterior long glenoid. Articular length for coracoid is relatively small (unlike *Isisaurus*). Acromian process of scapula is narrow.

Proximal humerus has prominent lateral process than medial process. Expanded radial condyle exposed on the anterior aspect of distal humerus (unlike *Isisaurus*). Proximal ulna with tri-limbs has prominent olecranon process. Femoral shaft, proximal one-third deflected medially with wavy style (and not straight as in *Isisaurus*). Proximal Tibia is transversely thin bone or narrow (unlike thick lense shape of *Gspsaurus* and thick subcircular shape of *Saraikimasoom*) with arc shaped fibular condylar ridge ending just below the cnemial crest. Posterior process of proximal tibia is about half of total anteroposterior width in *Pakisaurus,* while posterior process is about three quarter 3/4 of the total anteroposterior proximal width of *Isisaurus* tibia. Ratio of anteroposterior width of distal end to anteroposterior width of proximal end is 0.80 in *Pakisaurus* while the ratio of anteroposterior width of distal end to anteroposterior width of proximal end is as low as 0.64 in *Isisaurus.* Osteoderms present, arced ramus with diastema having random false teeth like spikes on ramus and also on base skin which forms diastema on arced ramus and false dentary type symphysis with spikes/spines; and Pedal ungual sickle-shaped, much deeper dorsoventrally than broad transversely.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Cretaceous-Paleogene Transition of Reptilian Tetrapods across Deccan Volcanism in India

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Abstract

Eruptions of lava flows of Deccan large igneous province straddled the Cretaceous-Palaeogene boundary (K-Pg). Sediments associated at different stratigraphic levels within the lava piles of Deccan volcanic sequences (DVS) are mainly terrestrial. We studied the sediments of Eastern and Central Deccan Volcanic Province, and the Malwa Plateau for tracking changes in reptilian tetrapods across the volcanism. The reptiles are mainly represented by abelisaurid-titanosaurid dinosaurs, *Alethinophidia madtsoiia* snakes, *Notosuchian crocodylomorph Simosuchus*, bothremydid Kurmademydinae turtles and Anguimorph and Scincomorphs lizards. The evidences suggest that the non-avian dinosaurs were adversely affected by the arrival of the first volcanic flows locally in the province either within C30N or C29R Maastrichtian. The abelisaurid theropods became extinct whereas a single or two species of titanosauriforme dinosaurs survived but eventually became extinct at least 350 ky before the K-Pg boundary with increasing volcanism. The madtsooid snakes and crocodylimorphs were also adversely affected with decline in their diversity and abundance, whereas the Bothremydid turtles survived the initial onslaught of Deccan volcanism and continued across the K-Pg boundary.

Keywords

Deccan Volcanism, Maastrichtian-Paleocene, Reptiles, Extinction

1. Introduction

Deccan Large Igneous Province (DLIP) is designated [1] as Western Deccan Volcanic Province (WDVP), Central Deccan Volcanic Province (CDVP), Eastern Deccan Volcanic Province (EDVP), Malwa Plateau and undesignated sequences of Saurastra and Kutch (Figure 1). The different provinces have separate sites, source, timing and duration of eruptions [2]. Erupting in at least three

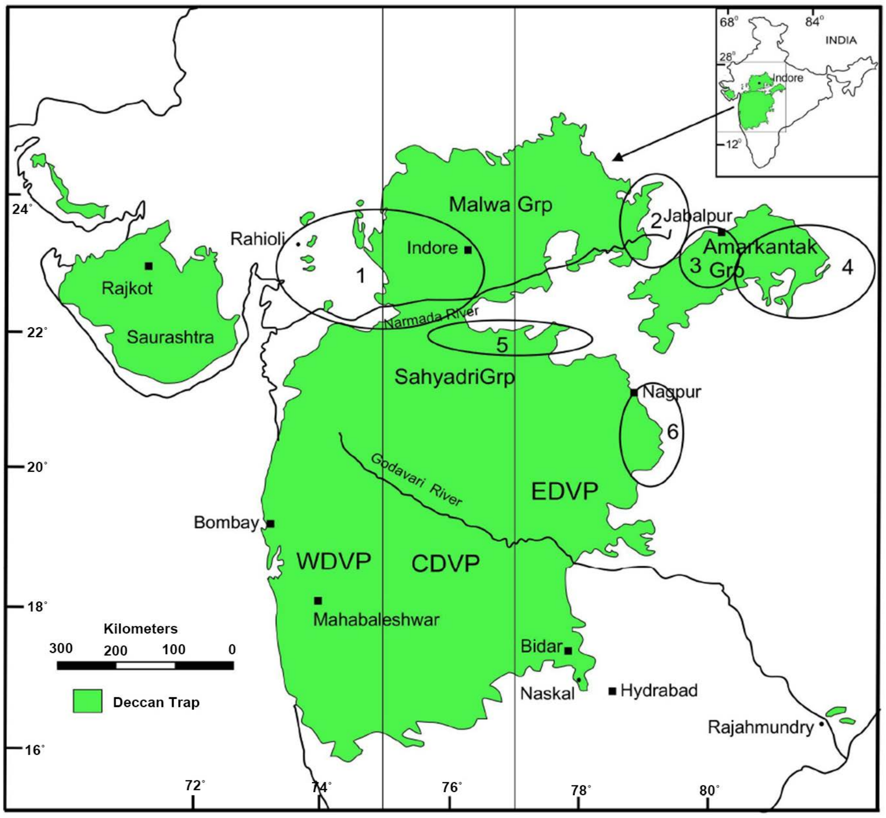

Figure 1. Map showing Deccan Volcanic Provinces in India [4]. 1-6, Lameta (Maastrichtian) inland basins. 1, Balasinor-Jhabua. 2, Sagar. 3, Jabalpur. 4, Ambikapur-Amarkantak. 5, Salburdi. 6, Nand-Dongargaon.

phases across the K-Pg boundary the total duration of Deccan volcanism is debatable [3] but currently considered to have spanned between 68 - 62.5 Ma ago. The study of lava piles associated with multiple sedimentary deposits is critical for tracking biotic and environmental changes across the volcanism.

2. Geological Setting

Deposits associated with Deccan volcanic sequences are designated as "Lameta Formation or infratrappean" deposited before the first lava flows and as "intertrappean" deposited between lava flows during the period of quiescence. Deposited in different inland basins [4] (**Figure 1**) under alluvial-limnic environments under semi-arid conditions the sediments are main fossiliferous horizons for the Maastrichtian reptiles. The Lameta Formation is of C30N-C29R Maastrichtian age. The intertrappean lake deposits are developed over the fresh lava surface at multiple stratigraphic levels under fluctuating climatic conditions from semi-arid to humid during Deccan transition. Relatively, reptilian fauna in intertrappean sediments is less commonly recorded.

3. Reptilian Fauna from Indian Maastrichtian-Paleocene

The reptilian fauna includes two sauropods (*Isisaurus colberti* and *Jainosaurus* *septentrionalis*), four medium to large bodied abelisaurid theropods (*Indosuchus raptorius*, *Indosaurus matleyi*, *Rajasaurus narmadensis*, *Rahiolisaurus gujaratensis*) and three small bodied theropods (*Laevisuchus indicus*, *Jubbulpuria tenius*, *Composuchus solus*). A large number of nest-sites of titanosuriforme dinosaurs with megaloolithid eggs and of abelisaurid theropods with elongatoolithid eggs are known from the Lameta sediments. The dinosaur eggshells are only recovered as small fragments on wet-screening of the sediments, excepting a latest sole find of a single Megaloolithus egg from Teegaon in Madhya Pradesh on Nagpur-Betul road.

The non-dinosaurian reptiles are mainly represented by associated bones of 1) turtles-Shweboemys/Bothremydid/Kurmademydinae (*Sankuchemys* and *Kuramademys*). 2) Notosuchian crocodylomorph *Simosuchus*. (3) Althenophidian madtsoiid snakes-*Sanajeh indicus*, *Madtsoiia pisdurensis* [5] [6] from Lameta sediments. The Scincomorph and Anguimorph lizards are recorded mainly from intertrappean sediments of both C30N and C29R Maastrichtian.

4. Conclusion

The impact of Deccan volcanism on terrestrial reptiles and plants preceded the K-Pg boundary. The titanosaurid and abelisaurid dinosaurs became extinct at least 350 ky before the global K-Pg mass extinction and the abelisaurids were the first to disappear from the Greater India. Titanosaurid and abelisaurid dinosaurs, turtles, *Alethinophidia madtsoiia* snakes and crocodylomorph Simosuchus were diversified and well established during C30N-C29R before the first Deccan flows. A change in dinosaur fauna from C30N was found in Kheda region in western India, N-D basin in Central India and Malwa Plateau to C29R in the Jabalpur region. The diversity and abundance rapidly declined with the arrival of the first volcanic flows in the region and only titanosaurids with decreased diversity and much reduced abundance could survive the initial onslaught of the volcanism. Anguimorph and Scincomorphs lizards are indicated to have better flourished after the initiation of Deccan eruptions during Maastrichtian (C30N-C29R). The record of reptiles from the Indian Paleocene sediments associated with DVA is almost absent but it could be owing to inadequate sampling.

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Vitakrisaurus saraiki Theropod from South Asia

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Abstract

Vitakrisaurus saraiki abelisauroid theropod dinosaurs reported from Pakistan and extended distribution into India. *Vitakrisaurus saraiki* is medium to large sized theropod which is represented by associated vertebral and limb elements and especially hand elements. Out of 14 small to large bodied theropods from Indo-Pakistan subcontinent, only less than half of these are restricted to some common elements. *Vitakrisaurus saraiki* theropod of Pakistan is based on associated vertebral and limb elements especially hand including articulated carpals, metacarpals, phalanges and claws which are significant for Gondwanan paleobiogeographic link, comparisons and systematic.

Keywords

Theropod, Maastrichtian, Vitakri Lameta Formation, Pakistan

1. Introduction

Two theropod dinosaurs were known from Pakistan. *Vitakrisaurus saraiki* is a medium sized theropod, which is significant for systematic and comparisons.

2. *Vitakrisaurus saraiki* Medium Sized Theropod of South Asia

Systematic paleontology of *Vitakrisaurus saraiki* is as follows: Dinosauria, Saurischia, Theropoda, Abelisauroidea, Vitakrisauridae [1], *Vitakrisaurus* [1], *Vitakrisaurus saraiki* [1] (**Figure 1**). Holotype and lectotype specimens were collected from the mid Bor 2 locality and referred specimens (**Figure 1**) were collected from the Shalghara 3 locality found in the uppermost Maastrichtian (67 - 66 Ma ago) Vitakri Lameta Formation of the Fort Munro Group, Barkhan district, Balochistan, Sulaiman or middle Indus basin, central Pakistan. Genus *Vitakrisaurus* honors the *Vitakri* host locality; saurus means lizard. Species name is in honor of the Saraiki language of locals of Sulaiman Range. These fossils are

Figure 1. *Vitakrisaurus saraiki* theropod fossils. Row 1, Map of Pakistan (black circle) show mid Bor 2 type locality, holotypic hand/manus. Row 2, lectotypic vertebral and limb fossils from mid Bor 2. Row 3, referred fossils from Pakistan (p 1 - 3) and India (p 4). Each black digit is 1 cm.

hosted in the Quetta museum of Geological Survey of Pakistan. Amphicoelous caudal vertebra with two chevrons from India [2] was referred to *Vitakrisaurus saraiki*.

2.1. Diagnosis of *Vitakrisaurus saraiki* Theropod from South Asia

Vitakrisaurus saraiki has circular elongated cylinder type dorsal centrum jointed on all dorsal length with neural arch (while dorsal centra of *Vitakridrinda* is rectangular and elongated while the dorsal centrum of *Rajasaurus* is tall); *Vitakrisaurus* has transverse process on upper part of caudal centrum and extends into neural arch like *Rajasaurus* while *Vitakridrinda* has oval shaped transverse process which did not contact with neural arch and located on upper part of posterior articular ring on anterior caudal centrum. Neural arch on anterior caudal is forwardly inserted while in *Rajasaurus* the neural arch covers all along the dorsal surface of centrum. *Vitakrisaurus* did not have ventral keel in dorsal and caudal centra while *Rajasaurus* and *Rahiolisaurus* had ventral keel. *Vitakrisaurus* neural canal is dorsoventrally compressed while *Rajasaurus* it is circular shaped; *Vitakrisaurus* has well developed chevron facets in anterior/mid caudals while *Rajasaurus* has no chevron facets. *Vitakrisaurus* anterior and midcaudal vertebrae have posterior yard on posterior uncover part of dorsal aspect of centrum surrounded by laterally and posteriorly thin boundary wall while this yard is not found in *Rajasaurus* thick bones of manus/hand; Metacarpal I is short and thick, metacarpal II and metacarpal III are thick, long and subequal; manual phalanges are thick; and manual ungual/claw I is thick and slightly recurved downward.

2.2. Description of *Vitakrisaurus saraiki* Theropod from South Asia

Vitakrisaurus saraiki has dorsal centrum which is circular, amphicoelous, slightly waisted with lateral feeble fossa. *Vitakridrinda* has rectangular and elongated dorsal centrum, while *Rajasaurus* has tall dorsal centrum. The dorsal centrum in *Vitakridrinda* and *Vitakrisaurus* has no ventral keel. In *Rajasaurus*, *Rahiolisaurus* and *Nhandumirim*, a longitudinal keel is present on ventral surface of centrum. The dorsal centrum in *Rajasaurus* is spool-shaped, with its articular faces deeper than broad. *Vitakrisaurus* has circular elongated cylinder type dorsal centrum jointed on all dorsal length with neural arch. *Vitakrisaurus* has transverse process on upper part of caudal centrum and extended into neural arch as *Rajasaurus*, while *Vitakridrinda* has oval shaped transverse process, not contacted with neural arch and located on upper part of posterior articular ring on anterior caudal centrum. Neural arch on anterior caudal is forwardly inserted while in *Rajasaurus* the neural arch cover all along the dorsal surface of centrum. *Vitakrisaurus* have well developed chevron facets in anterior/mid caudals. *Rajasaurus* has no chevron facets. In *Vitakrisaurus* neural canal is dorsoventrally compressed, transversely oval shaped in anterior and middle caudal vertebrae. In *Rajasaurus* neural canal is circular shaped. In *Vitakrisaurus* anterior and midcaudal vertebrae have posterior yard on the posterior vacant/uncover part of dorsal aspect of centrum. This yard is surrounded laterally and posteriorly by thin boundary wall. *Vitakrisaurus* have leg bones with thin peripheral bone on the central hollow cavity. *Vitakridrinda* has thick peripheral bones on central hollow cavity. The hand/manus has three preserved digits. The metacarpal I is the smallest while Metacarpal II is largest and metacarpal III is relatively intermediate. The metacarpal I is expanded at proximal and distal ends, while in the middle constricted. The metacarpal II is the longest and also thickest. The metacarpal III is intermediate in length, thicker than metacarpal I and metacarpal II. The metacarpal I (7 mm wide, 21 mm long) is short and thick, metacarpal II and metacarpal III are thick, long and subequal. Manual phalanx I is thick and long while reducing length and increasing count from digit I to digit II and then to digit III. Manual ungual/claw I is thick and slightly recurved downward.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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The Cretaceous of Shandong Province

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Abstract

A well preserved terrestrial Cretaceous succession outcrops in Shandong Province. Although previous studies have conducted much work on the geochronology, subdivision of stratigraphic units, regional correlation and paleontology, high controversies remain about geochronology, subdivision of stratigraphic units and sedimentology. Here, we report a synthesized study of the Cretaceous successions and stratigraphy in Shandong based on the new results. Accordingly, reconstruction of framework of the Cretaceous stratigraphy in Shandong is summarized as, in descending order, the Mengyin Group of the Jurassic/Cretaceous transition, the Lower Cretaceous Laiyang Group, Qingshan Group, Dasheng Group and the Upper Cretaceous Wangshi Group.

Keywords

Terrestrial, Cretaceous, Shandong Province, China

Terrestrial Cretaceous in Shandong Province is, in ascending order, the Mengyin Group of the Jurassic/Cretaceous transition, the Lower Cretaceous Laiyang, Qingshan, Dasheng groups and the Upper Cretaceous Wangshi Group. The Mengyin Group consists of the lower Santai Fm and the upper Fenshuiling Fm. The former is mainly eolian deposits of the purple red sandstone with giant inclined beddings and interbedded interdune fluvial conglomerates [1], which yields the youngest detrital zircons of 164 - 146 Ma [2], suggesting its age of the earliest Cretaceous. The Fenshuiling Fm is chiefly composed of calcareous siltstone with intercalations of tuffs or tuffaceous siltstones and sandstones. Sauropoda dinosaur tracks are present within the Santai Fm [3] and particularly both skeleton fossils and foot prints of *Euhelopus zdanski* [4] are well preserved in the Fenshuiling Fm. The Lower Cretaceous Laiyang Group, being estimated of an age interval of 132 - 124 Ma dated by interbedded tuffs and volcanics, is composed of the fluvial conglomerates on the bottom with an unconformity separating the underlying Precambrian basement, the middle lacustrine siltstone and shale, indicating vast lacustrine expanding and fluvial sandstones and conglomerates in the top, implying the evolution end of lacustrine basin of the Laiyang Group age. A spectacularly soft sediment deformation occurred within the middle Laiyang Group in Lingshan island, Qingdao. It is very important yet that vertebrate tracks including dinosaur, bird, turtle and pterosaur and invertebrate traces are very common in the middle-upper Laiyang Group [1] [5] [6] except for plenty of fish and insect fossils in lacustrine sediments of the Shuinan Fm in the middle Laiyang Group. One of the quarries of the middle-upper Laiyang Group displays spectacular dinosaur tracks, including tens of giant Sauropoda tracks and thousands of Theropoda foot prints and tracks [7] [8], indicating a favorable palaeoecology environment at that time. The Qingshan Group with an age interval of 124 - 118 Ma is located between the underlying Laiyang Group and the overlying Dasheng Group and a series of intermediate and acid volcanic interbedded fluvial sediments formed in rift basins. The Dasheng Group with the oldest age of 118 Ma and the youngest age estimated as 99.5 Ma is the terminal units of the Lower Cretaceous and dominantly calcareous mudstone and the fluvial sandstones and conglomerates in the bottom. There are a lot of sedimentary structures formed in arid, hot and shallow lacustrine environment as ripples, cracks, salt and gypsum pseudos casts in the Dasheng Group. In addition, a lot of vertebrate tracks of giant Sauropoda and Theropoda, particularly well-preserved bird footprints are widely and well preserved in lacustrine sediments of the Dasheng Group [3] [5] [9]. The Wangshi Group consists of the lower Hongtuya Fm of the Upper Cretaceous and the upper Jiaozhou Fm of a K/T transition age. The former consists mainly of purple red and cyclic deposits of fluvial sandstone and conglomerates, indicating a warmer and arid palaeoclimate environment. The Jiaozhou Fm consists chiefly of gray-green fluvial and shallow lacustrine deposits implying a reduced arid and hot setting. A diabase sill of (Ar-Ar) 73.2 Ma age [10] separates the lower and middle of the Hongtuya Fm. In addition the Jiaozhou Fm shows signs of the potential K/T boundary in term of positive gammar anomaly [11] and possible impact glass balls (Master dissertation, Ding Chong, 2016), there are at least three horizons of mass death of dinosaurs on the bottom of the Hongtuya Fm, e.g., one of the quarries of dinosaur fossils in Zhucheng displays ten thousands of dinosaur bone fossils in the bottom bonebed [1]. In the meantime, five horizons with mass burials of both dinosaur bones and egg fossils were present within the upper Hongtuya Fm [12], which records a co-evolution between dinosaur extinction and environmental change. In perspective of palaeoclimate, all palynological assemblages within the Cretaceous successions show that palaeoclimate changed periodically from hot and arid to subarid and semihumid in tropical to subtropical zones. But an extreme drought and hot palaeoclimate in the Late

Cretaceous supposed by palynological assemblages may be responsible for the extinction event on the K/T boundary [13].

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Cretaceous Stratigraphy, Paleoenvironment and Terrestrial Biota in Shandong Province

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Abstract

The terrestrial upper Jurassic-Cretaceous (upper and lower)-Cenozoic stratigraphic succession developed continuously in Shandong province. There are intact and continuous terrestrial paleoecosystems dominated by dinosaurs, including five vertebrate fauna (bone fossil assemblages) beds from the bottom to top in the Cretaceous successions of Shandong Province. There are multiple vertebrate footprints (group) bearing beds in the transition period between Jurassic-Cretaceous and Early Cretaceous, and multiple large-scale dinosaur burial bone beds in Late Cretaceous. In recent years, it has also been found that extraterrestrial impact geological event may occur in the K/Pg transition over a hundred meters (siliceous pellet and gamma element anomalies, etc.). Shandong has a well-developed terrestrial Cretaceous succession with perfect information on paleoenvironment and paleoecology, which is an ideal area to explore the co-evolutionary relationship between terrestrial biota and paleoenvironment.

Keywords

Cretaceous, Paleoenvironment, Terrestrial Biota, Shandong Province

1. Shandong Province Developed the Most Systematic and Complete Continental Cretaceous Stratigraphic Succession

In recent 10 years, on the basis of predecessors' researchers, our team not only systematically set and updated the Cretaceous succession of Shandong Province, but also further divided it into the J_3- K_1^1 (Mengyin Group between transitional Jurassic-Cretaceous), K_1^2 (Lower Cretaceous Laiyang Group), K13 (Lower Cretaceous Qingshan Group/Dasheng Group), K_2^1 (the lower part of Hongtuya

Formation of the Upper Cretaceous Wangshi Group) and K_2^2 (the upper part of Hongtuya Formation of the Upper Cretaceous Wangshi Group). Especially combined with a large number of measured chronological data, we established a comprehensive Cretaceous litho-chronostratigraphic framework with high-precision, and preliminarily summarized the paleogeographic evolution model of Cretaceous sedimentary basin [1] [2] [3] [4].

2. It Contains Cretaceous Paleogeographic Evolution Information

The Cretaceous basin is only developed in western Shandong, which is a fluvial-lacustrine environment with no strong volcanic activities in J/ K_1^1 transitional period (~145 - 132 Ma). The basin extends to eastern Shandong during K12 (~132 - 125 Ma) [3] [4], which was dominated by extensive lacustrine environment. Magma intrusion and volcanic eruption (Qingshan Group) occurred briefly but strongly, and intermittent alluvial-fluvial-lacustrine facies environment existed in the early K13 (~125 - 120 Ma). Rift basin was mainly developed along the Yishu Fault zone, dominated by wide-shallow lake environment in the late K13 period (~120 - 100 Ma) [2]. An extremely hot and arid climate prevailed during the K21 - K22 deposited. Braided rivers dominated in the northern Jiaolai Basin and western Shandong while alluvial fan-fluvial and lacustrine environments co-existed in the central and southern part of Jiaolai Basin [5].

3. It Develops Well-Preserved Terrestrial Ecosystem

Cretaceous in Shandong Province not only outcrops continuously, but also develops 5 sets of vertebrate fossil assemblages dominated by dinosaurs from Early to Late Cretaceous. They are:

1) The *Euhelopus zdanskyi*, the largest sauropod ever described in China developed in J/K11 in western Shandong Provinces. 2) Psittacosaurus of the Linjiazhuang Formation in Jiaolai Basin in K13. 3) Ornithopoda duck-billed dinosaur Shantungosaurus assemblage in K21, including *Shantungosaurus*, *Zhuchengosaurus maximus Zhao et al.* and *Giant cathaysian*, Accompanying ceratosaurs, such as *Sinoceratops zhuchengensis gen. et* sp. nov, theropod *Zhucheng tyrannosaurus rex*, *Zhuchengtyrannus magnus*, as well as a few ankylosaur, coelurosauria scattered bones. 4) Taniussinensis assemblage, accompanied by a number of other dinosaur bone fossils, and a large number of dinosaur egg fossils in K22 in Jiaolai basin. 5) The ornithopoda assemblage represented by *Tsintaosaurusspinorhinus* is also symbiosis with fossil dinosaur eggs in K22 in Jiaolai Basin [5].

The assemblage and buried situation of dinosaur fauna not only reveal the differences of living and buried environment among different dinosaur faunas, but also directly relate to the evolution of Cretaceous paleogeography and paleoclimate. At the same time, the Lower Cretaceous in Shandong Province also has abundant and diverse vertebrate relics dominated by dinosaurs and birds with a very high distribution density, which reflects the habitats of diverse vertebrate fauna and their systematic evolution characteristics [2]. The dinosaur footprints of theropods, sauropods, ornithopods and other different species [2], pterosaur footprints were developed in the Early Cretaceous and J/K transition period.

4. K/Pg Boundary Recorded Extraterrestrial Impact Event

Several vitreous spherulite layers more than 100 meters thick found on top of K2 [6] and abnormal combination of Ir and Pt elements at K/Pg transition site [7] may indicate the occurrence of extraterrestrial impact events.

Therefore, successions in Shandong Province not only developed complete terrestrial cretaceous stratigraphic sequence, but also bored abundant and diverse information of paleoenvironment (sedimentary basin, paleogeography, paleoclimate and geological events, etc.), evolution and replacement. Especially, it also preserved continuous and perfect ecological system information (flora and fauna and fossil assemblage), and together constituted a complete Cretaceous record of environment evolution, different biome initiation, radiation, replacement or dying or even extinction.

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Conflicts of Interest

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Comparison of the Palaeomagnetic Parameters of Non-Marine Jurassic-Cretaceous Boundary Sediments in Dorset (SW England), Hebei and Liaoning (NE China)—A Preliminary Study

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Abstract

The Purbeck beds in Dorset, the Tuchengzi Formation in western Liaoning Liaoning Province or the Houcheng Formation in northern Hebei Province are non-marine Jurassic/Cretaceous (J/K) boundary sequences. A Czech-China Inter-Governmental S&T Cooperation Project has been carried out to search for the non-marine J/K boundary in northern China and making international correlation with the Purbeck beds in southern England. The combination of palaeomagnetism and biostratigraphy in northern China and southern England localities proves that these distant places had similar climatic conditions and the same fauna during the Late Jurassic and Early Cretaceous. A preliminary joint research has shown a fruitful result in searching for the non-marine J/K boundary in northern China.

Keywords

Jurassic-Cretaceous Boundary, Dorset, Northern Hebe, Western Liaoning, Palaeomagnetism, Biostratigraphy

1. Introduction

A joint study of the Jurassic/Cretaceous (J/K) boundary sections in northern China [1] and Dorset, southwestern England [2] [3] began in the year 2017. In northern China the well-developed non-marine Upper Jurassic to Lower Cretaceous sequences are widely distributed, which straddle the J/K boundary, and suitable for the study of the J/K boundary magnetostratigraphy [4] [5].

In recent years, more and more precise radiometric dating data indicate that the Tuchengzi Formation in western Liaoning and the contemporaneous Hocheng Formation in northern Hebei straddle the J/K boundary [6] [7]. Palaeomagnetic and magnetostratigraphic research clarifies and constrains interpretations of the J/K boundary interval.

The studied Dorset sites are on the Isle of Portland and at Swanage. The first, the older, is Jurassic in age. It consists of six successive sequences. Layered marine cherty limestones are below and homogeneous Portland "freestone" carbonates being above, with the non-marine Purbeck beds overlying. The other section is the major cliff profile at Swanage, entirely in continental Purbeck sediments, of Tithonian to Berriasian age.

2. Methods

Palaeomagnetic methods used differ between the carbonate rocks and clastics. Thermal demagnetisation dominated for the Portland Stone limestone and the sediments in the upper part of the Swanage section. Alternate field demagnetization was performed on the more clastic sediments in the lower part of the Swanage Purbeck section and on all the Chinese samples. The main carriers of magnetization were investigated using analysis of the isothermal remanent magnetization curve following Kruiver *et al.* [8].

3. Results

We show that in Hebei and Liaoning the sedimentation rate was so rapid that individual studied profiles contain only one magnetozone, which is an advantage for magnetostratigraphy when it is used as an aid for the J/K boundary determination. Specifically, we have found that both measured profiles of the Houcheng Formation in northern Hebei have a normal polarity, whereas the measured profile of the Tuchengzi Formation displays a reverse polarity. The individual profiles are to be stratigraphically linked.

The preliminary results on the Portland sediments prove only one normal polarity zone with one subzone. The first result from pilot sampling in the Purbeck beds at Swanage shows at least three normal and two reverse polarity zones.

Additionally, we have identified fossils of the clam shrimps (Diplostraca) [9] [10] and ostracods (Ostracoda) and combined them with magnetostratigraphy. This allowed correlations of sites in northern China with southern England.

4. Discussion

More magnetozones might be still recognized in both areas. The sampling in northern China has to continue above and below the sampled profiles, and the section at Swanage has to be sampled more densely. Measurement of previously sampled specimens still continues. Bed-by-bed correlation of the results between the studied part of the Swanage section and the results of Ogg *et al.* [11] is a priority.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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A New Understanding of the Lower Cretaceous Jiufotang Formation in Western Liaoning

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Abstract

The Lower Cretaceous Jiufotang Formation in western Liaoning is the most important fossil production horizon of the Jehol Biota, which is widely distributed in the Mesozoic basins of western Liaoning. Due to the influence of historical data, previous scholars believed that there was no volcanic activity in the Jiufotang Formation in western Liaoning. In a field investigation in western Liaoning, the authors discovered basalt and andesite in the Hujiayingzi bed. In addition, a conformable boundary was found between the Yixian and the Jiufotang formations. It indicates that both the Jiufotang Formation and the Yixian Formation are strata containing volcanic-sedimentary rocks, only differing in strength of volcanic activity.

Keywords

Western Liaoning, Lower Cretaceous, Jiufotang Formation, Volcanic Rocks, New Discoveries

1. Introduction

Because the Jiufotang Formation is the most significant producer of fossils from the Jehol Biota, it is favored by paleontologists. It produces birds, dinosaurs, pterosaurs, turtles, mammals, fish and many other fossils like clam shrimps. The fossils from the Jiufotang Formation are complete and numerous, thus, they make them rare treasures in the world of paleontology. As a lithologic unit, the Jiufotang Formation is defined as a set of layers of ash, which is widely distributed in various Mesozoic basins in western Liaoning, above the Yixian Formation, under the Fuxin Formation, or under the Binggou Formation. It contains typical Jehol Biota fossils amongst yellow-green siltstone, shale, sandstone, and combinations of conglomerate and oil shale [1].

2. Discussion

Scholars often correlated the Jiufotang Formation in western Liaoning with the Longjiang Formation, the Guanghua Formation in the Daxinganling or the Xiaoling Formation and the Lishugou Formation in eastern Liaoning [2]. However, it was previously believed that there was no volcanic activity during the deposition period of the Jiufotang Formation in western Liaoning. According to the regional geological records of Liaoning Province, the Jiufotang Formation does not contain volcanic rocks, and is thus distinguishable from the Yixian Formation. However, the Jiufotang Formation has been found to contain a large amount of tuff components (tuff, siltstone, etc.). Previous reports have interpreted this volcanic ash as evidence of volcanic activity from the northern Hebei or Daxinganling area. Because they are adjacent to the south of the Pingzhuang Basin in western Liaoning, the Jiufotang Formation in the Kailu Basin and the Guanghua Formation in the Xing'anling area possess andesite, basalt, and volcaniclastic rocks. The authors have reported that gray-black basalt and gray andesite were found in the Hujiayingzi area in Dapingfang-Meileyingzi Basin, but due to the established viewpoint, the previous researchers put this volcanic rock combined in the Daxingzhuang Formation [3]. According to the authors' investigation, this set of volcanic rocks is integrated with the sedimentary rocks of the Jiufotang Formation and should belong to the Jiufotang Formation. At the same time, some people think that the rhyolite and basalt found in the Xintaimen area of Huludao belong to the Jiufotang Formation [4]. Therefore, it has been proven that there are lavates such as andesite, rhyolite, and basalt in the Jiufotang Formation in western Liaoning.

Since the andesite is also present in the Jiufotang Formation, the boundary between the Jiufotang Formation and the Yixian Formation is questionable. The authors find that the previous definition of the Jiufotang Formation was not accurate according to our aforementioned field investigation. Therefore, the authors speculate that the Jiufotang Formation and the Yixian Formation are combinations of volcanic and sedimentary rocks, and there is no obvious unconformity boundary between the two formations.

3. Conclusion

Based on the above data, the authors believe that the Jiufotang Formation and the Yixian Formation are lithologic formations of a set of volcanic-sedimentary rhythmic interbeds and affected by volcanic activities from different regions. And the boundary between the two should be a conformable interface.

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Conflicts of Interest

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A Research of the Cretaceous-Paleogene Boundary in the Pingyi Basin, Shandong Province

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Abstract

The Bianqiao Formation (in the Pingyi Basin, Shandong Province, China) is a typical set of continuous lacustrine carbonate deposits during the Cretaceous-Paleogene period, which is considered as an ideal stratigraphic unit for KPB research. This study is based on the borehole PYZK01, which is located at Tongjiazhuang village in Bianqiao Town of Pingyi country. According to biostratigraphy research, the Bianqiao Formtion establishes one charophyte assemblage: *Porocharaanluensis-Charayuntaishanensis var. acuta-Turbocharaspecialis*, and one sporopollen assemblage: *Deltoidosporaadriensis-Rugubivesiculites-Schizaeoisporites*. This result indicates that the stratigraphic age during 0 - 12.25 m is the Paleogene, 37.8 m - 60 m is the Late Cretaceous, and 12.25 - 37.8 m is a transition stage from the Late Cretaceous to the Paleocene. By geochemical study, it was established carbon and oxygen isotopic strata in the drill. Through the magnetostratigraphy research, we find eight positive polarity zones and seven reversed polarity zones, build the magnetic polarity sequences of the borehole, and propose a contrast scheme with the international standard magnetic polarity time column. After comprehensive discussion, it is preliminarily believed that the Cretaceous-Paleogene boundary is located at the depth of 31.98 m in PYZK01, namely, in the first section of the Bianqiao Fm.

Keywords

Cretaceous-Paleogene Boundary, Biostratigraphy, Isotopic Stratigraphy,

Magnetostratigraphy, Pingyi Basin

At the turn of the Cretaceous and the Paleogene, major events occurred all over the world, such as the mass extinction of dinosaur and the rise of mammals, and the research of the Cretaceous-Paleogene boundary has become a hotspot. Although the research of KPB has made important progress, many important problems still have not been solved in non-marine stratigraphy [1] [2] [3] [4]. So the establishment of the non-marine Cretaceous-Paleogene boundary stratigraphy is necessary. The Bianqiao Fm of the Guanzhuang Group in the Pingyi Basin of Shandong Province is a typical set of fluvial and lacustrine deposits, mainly consisted of carbonate rocks and gypsum ore beds, near the Mesozoic-Cenozoic boundary in China. Besides, it is also one of the strata units with the largest thickness of continuous sedimentary limestone in continental lacustrine basins in the same period in our country, which contains very important geological information, such as biological, sedimentary, and terrestrial carbonate lake basin evolution. Much great progress has been made in KPB [5] [6] [7] [8] [9]. Based on previous work, we conduct a comprehensive study on biostratigraphy, isotopic stratigraphy, and magnetic stratigraphy of PYZK01, which is the first time in the region.

In terms of petrostratigraphy, it is continuous that the whole lithology shows a set of sedimentary characteristics with alternating shore-shallow lacustrine facies and shallow lacustrine facies. From the perspective of sedimentary environment, the lithology mainly consists of gray, purple and flesh-red limestone and marl, indicating the dry and hot palaeoclimate environment. However, reductive environmental strata represented by dark sediments no longer appeared above 31.57 m, showing obvious rapid changes or abrupt events of sedimentary environment and paleocaterium, which may be related to geological events at the turn of the Cretaceous to the Paleogene.

In terms of biostratigraphy, we obtain abundant fossils of chardonophytes, palynophytes, metamorphoses and gastropods. Among them, *Sphaerochara cf. chinensis* (Huang et Xu) was found at 12.25 m, indicating that the strata shallower than 12.25 m are not earlier than the Paleogene. The charophyte assemblage of *Porocharaanluensis-Charayuntaishanensis* var. *acuta-Turbocharaspecialis* indicates that the stratigraphic age deeper than 40.03 m was determined as the late Late Cretaceous, and it is also further confirmed by the palynological assemblage of *Deltoidosporaadriensis-Rugubivesiculites-Schizaeoisporites* from 37.8 m to 40.3 m and the gastropod fossils from 37.8 m to 57.5 m. Thus, the KPB is limited of 12.25 m to 37.8 m by biostratigraphy.

In terms of magnetostratigraphy, we find eight positive polarity zones and seven reversed polarity zones, build the magnetic polarity sequences of the borehole, and propose a contrast scheme with the international standard magnetic polarity time column. The KPB was further restricted to the third reverse polarity zone which is from 25.7 m to 37.6 m, and a significant negative drift of the susceptibility curve occurred at the depth of 31.98 m.

In terms of isotopic strata, carbon and oxygen isotopic strata were established, and an obvious phenomenon of oxygen isotopic curve positive drift and carbon isotopic curve negative drift also appeared at 31.98 m.

Based on the above results, the Bianqiao Fm in the Pingyi Basin has the Cretaceous-Paleogene boundary, and its location is basically confirmed to 31.98 m deep in PYZK01, namely, in the first section of the Bianqiao Fm.

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Conflicts of Interest

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Magnetic Susceptibilities in the Cretaceous-Paleogene Section in Uzgruň, Czech Republic

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Abstract

A new multidisciplinary study is being carried out in several localities from Outer Carpathians of Central Europe. Outer Carpathians allow studying the Cretaceous-Paleogene (K-Pg) interval of the oceanic facies, including lower bathyal-abyssal sub-CCD turbidites. Preliminary results of field-measured magnetic susceptibilities from Uzgruň K-Pg section in the Czech Republic are presented.

Keywords

Cretaceous-Paleogene, Outer Carpathians, Magnetic Susceptibilities

1. Introduction

The Cretaceous-Paleogene (K-Pg) boundary marks the limit between the Cretaceous and Paleogene periods and coincides with one of the five large mass extinctions in Earth's history. A new research project "Cretaceous-Paleogene boundary in the Carpathians—multidisciplinary search for local variations in global cataclysm event" was launched at the beginning of 2019. The project comprises of magnetic, biostratigraphic, sedimentological and geochemical investigations of several Central European Carpathian sections in order to characterize the K-Pg transition sequence in deep-sea sub-CCD facies, to provide paleoenvironmental information and study its impact to magnetic and biotic changes. One of the key locations of this research is Uzgruň, Czech Republic (**Figure 1**).

2. Uzgruň Section

The Uzgruň section is situated near Velké Karlovice village and represents a

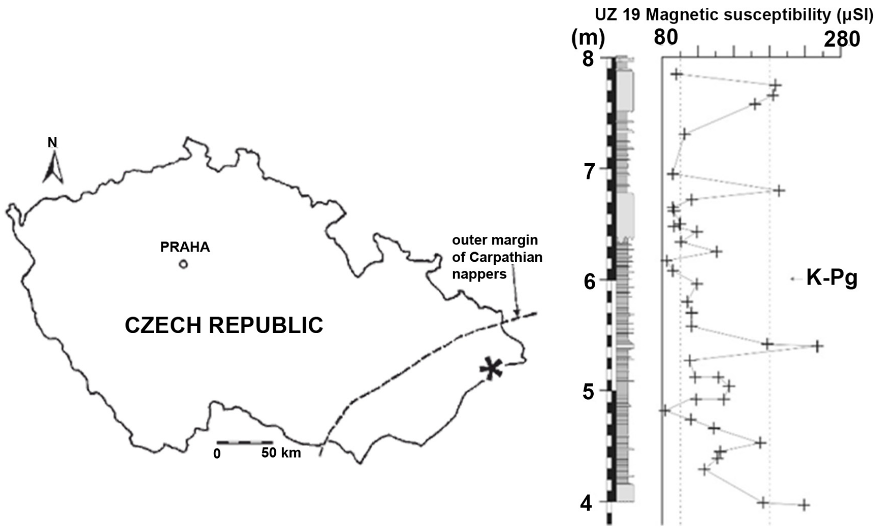

Figure 1. Left: Schematic map of the Uzgruň section location. Right: Magnetic susceptibility of UZ 19 subsection.

continuous composite section. The section belongs to the Soláň Formation of the Rača Unit and is predominantly built up by turbiditic sequences of calcareous and non-calcareous claystones with thin siltstone intercalations as well as occasional sandstones and marlstones [1]. The composite section comprises three subsections in different tectonic slices that are correlated using characteristic sequence of marker turbidite layers. Fossil record of Uzgruň includes benthic agglutinated foraminifers, nannofossils, radiolarians and organic-walled dinocysts. A biostratigraphic study was carried out at the end of 1990's-early 2000's and resulting integrated biostratigraphy is summarized by Bubík *et al.* [2]. The base of the Danian is indicated by the lowest occurrence of dinocyst *Carpatella cornuta* and supported by typical sequence of dinocysts, radiolarians and benthic foraminifers. More recently, the entire *Micula prinsii* zone of the topmost Maastrichtian was confirmed in the section.

3. Sampling and Results

A new sampling of the Uzgruň locality was carried out during summer 2019 to magnetically characterize the local K-Pg as well as revise and extend the fossil and geochemical record and, thus, gain insights to local variations of paleoenvironment. To assist with sample selection for rock- and paleomagnetic laboratory study, and provide the first outline of magnetic properties, the magnetic susceptibility of the composite section was measured in the field using portable susceptibility meter KT-10.

The preliminary results of field measurements of magnetic susceptibility indicate mostly paramagnetic behavior (Figure 1). Several slightly higher magnetic intervals were identified and, for the most part, seem to correspond to sandstone layers. The field measurements don't appear to display a higher magnetic susceptibility zone at suggested K-Pg boundary; however, more detailed laboratory measurements are needed to verify the presence or absence of any distinct magnetic signatures at the K-Pg boundary in Uzgruň.

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Conflicts of Interest

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Jurassic-Cretaceous Stratigraphy of Malaysia

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Abstract

In Peninsular Malaysia, the Jurassic-Cretaceous sequences are represented by continental deposits in several isolated basins. Generally, the sequences are characterised by the fining upward sequences, comprising reddish brown to red siltstone, sandstone and conglomerate often interpreted as molasse sequences. In Sabah and Sarawak, the Jurassic-Cretaceous sequences are represented by the marine deposits comprising argillaceous, some arenaceous and calcareous rocks and associated chert, lava, and pyroclastics.

Keywords

Jurassic-Cretaceous, Peninsular Malaysia, Continental Deposits, Sabah and Sarawak, Marine Deposits

1. Introduction

In Peninsular Malaysia, the Jurassic-Cretaceous sequences are represented by the continental deposits that were deposited in several isolated basins throughout the country. Generally, the sequences are characterised by the fining upward sequences comprising reddish brown to red siltstone, sandstone and conglomerate often interpreted as molasse sequences.

The Jurassic-Cretaceous continental sequences distributed in Peninsular Malaysia are Saiong Formation, Kayu Hitam Formation, Berapit Formation, Tan Hain Formaton, Panau Formation, Koh Formation, Tembeling Group, Gagau Group, Gerek Sandstone, Bertangga Sandstone, Ma'okil Formation, Paloh formation, Lesong Sandstone, Ulu Endau Beds, Tebak Formation and Panti Formation. The sequences are distributed in the Western, Central and Eastern Belts of Peninsular Malaysia. Most of the sequences are exposed in the Central Belt, whilst only the Saiong Formation is exposed in the Western Belt and extends northwardly into southern Thailand. In the Eastern Belts, the Jurassic-Cretaceous sequences are in the southeastern part of the Peninsular. Fossil gastropods, bivalves and plants as well as palynomorphs were discovered within those rock units. Dinosaur teeth and footprints were discovered in the Lotong Sandstone of the Gagau Group in Hulu Terengganu. The dinosaur teeth also were reported in the Cretaceous rocks in Pahang.

In Sabah and Sarawak, the Jurassic-Cretaceous sequence is represented by the marine deposits comprising argillaceous, some arenaceous and calcareous rocks, and associated chert, lava, and pyroclastics. Among the Jurassic-Cretaceous sequences in Sabah is the Madai-Baturong Formation, whilst in Sarawak it is represented by the Kedadom Formation, Sejingkat Formation, Pedawan Formation, Serabang Formation, Bau Limestone and Sebangan Hornstone. Most of them are shallow marine shelf deposits except for the chert dominant Sejingkat Formation and part of the Serabang Formation and the Sebangan Hornstone which might be deposited in a deeper marine condition.

2. Stratigraphy

The Jurassic-Cretaceous continental sequences distributed in Peninsular Malaysia are shown in Table 1.

In Sabah and Sarawak, the Jurassic-Cretaceous shallow to deep marine deposits are shown in Table 2.

3. Correlation

Based on lithological characteristics and fossil contents, the Jurassic-Cretaceous sequences in Peninsular Malaysia have the same relative stratigraphic position but are not necessarily contemporaneous. The Mangking Sandstone of the Tembeling Group is possible to be correlated with the Lotong Sandstone of the Gagau Group. Generally, the other predominantly arenaceous sequences namely the Ulu Endau Beds, Tebak Formation, Panti Formation, Bertangga Sandstone, Koh formation, Lesong Sandstone, Tebak Formation and Gerek Formation are also possible to be correlated with the Mangking Sandstone. The Paloh Formation is partly lateral equivalent of the Ma'Okil Formation [1].

In Sarawak, the upper part of the Kedadom Formation is interfingered with the lower part of the Bau Limestone. The Sejingkat Formation is interfingered with the Serabang Formation and the lower Kedadom Formation and the Bau Limestone. The Pedawan Formation is also laterally equivalent to the Bau Limestone [1].

Table 1. List of the Jurassic-Cretaceous sequences within the Western-Central-Eastern Belts in Peninsular Malaysia.

Age	Western Belt		Central Belt - Eastern Belt		
	Kedah-Perak		Kelantan	Pahang-Terengganu	Johor
Jurassic-Cretaceous	Saiong Formation Kayu Hitam Formation	Berapit Formation Tan Hain Formation	Panau Formation Koh Formation	Gagau Group Tembeling Group Gerek Sandstone Bertangga Sandstone	Ma'Okil Formation Paloh Formation Lesong Sandstone Ulu Endau Beds Tebak Formation Panti Formation

Table 2. List of the Jurassic-Cretaceous sequences in Sabah and Sarawak.

Age	Sabah	Sarawak
Jurassic-Cretaceous	Madai-Baturong Formation	Kedadom Formation Sejingkat Formation Pedawan Formation Serabang Formation Bau Limestone Sebangan Hornstone

4. Conclusion

In Peninsular Malaysia, the Jurassic-Cretaceous rocks are mostly of continental deposits, generally reddish in colour with grey varieties in parts. Only the Paloh Formation was deposited in the transition from shallow marine to continental environment. Dinosaur teeth and footprint had been discovered within the Lotong Sandstone of the Gagau Group in Hulu Terengganu. Dinosaur teeth had also been reported in Pahang. Detail study needs to be done on the continental deposits to determine another potential dinosaur site in Malaysia. In Sabah and Sarawak, the Jurassic-Cretaceous sequences were deposited in a shallow to deep marine environment.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Cretaceous Stratigraphy of Pakistan

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Abstract

Cretaceous strata of Pakistan yielded many significant fossils of terrestrial ecosystems like poripuch (all caudals are procoelous) lithostrotian titanosaurian sauropods, abelisauroids theropods, mesoeucrocodiles, pterosaurs and gymnosperm stem wood. Both marine and non-marine strata well exposed through the Cretaceous, Jurassic-Cretaceous and Cretaceous-Paleogene boundaries found in Pakistan especially in Indus Basin. Indus Basin represents strata from Precambrian to Recent. Here a glimpse of Cretaceous Stratigraphy of Pakistan is being presented.

Keywords

Terrestrial, Marine, Stratigraphy, Cretaceous, Pakistan

1. Introduction

Pakistan is lucky to host the Gondwanan, Eurasian and Tethyan heritage. Gondwanan heritage is represented by Indus Basin of Pakistan located in the centre, south and eastern Pakistan. The Eurasian heritage is represented by Hindukush-Karakoran basin located in northernmost Pakistan. The Tethyan heritage is represented by Balochistan magmatic arc and basin in western Pakistan, and Kohistan-Ladakh magmatic arc located in northern Pakistan. Cretaceous rocks are exposed in all these basins but only Indus basin yields Cretaceous fauna [1] so far. So here Cretaceous Stratigraphy of Indus basin is being presented.

2. Cretaceous Stratigraphy of Indus Basin of Pakistan

Cretaceous deposits (Figure 1) are more than 3000 meters thick in the Indus basin. The Cretaceous of upper Indus (Kohat-Potwar) Basin shows marine Chichali, (glauconitic muds), marginal marine Lumshiwal (quartzose sandstone with subordinate shale) and Kawagarh (limestone) and terrestrial to deltaic Indus (coal, laterite, carbonaceous shale = Vitakri Lameta sediments) formations

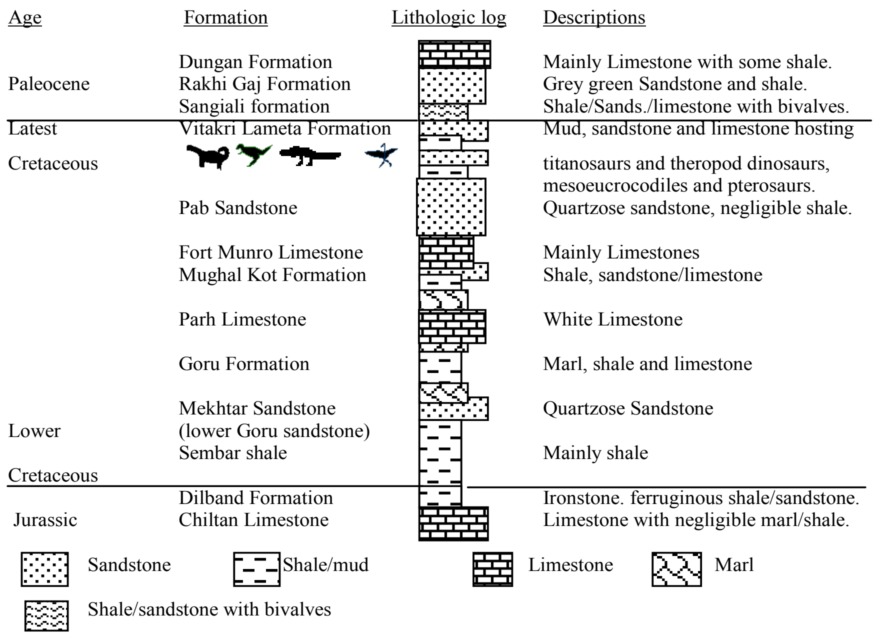

Figure 1. Cretaceous stratigraphic sequence of Indus basin of Pakistan.

followed by the Lower Paleocene deltaic Hangu Formation (coal, sandstone and shale). Middle Indus (Sulaiman) and lower Indus (Kirthar) basins represent the Lower Cretaceous fine pelagic, shallow marine and deltaic Parh Group (Sembar, Goru, Parh formations; belemnite bearing shale, marl and limestone), and the Upper Cretaceous was emerged by a regression of sea which shows the Mughal Kot (shale and sandstone with minor limestone), Fort Munro (limestone), Pab (mainly sandstone with negligible shale) and Vitakri Lameta (terrestrial alternating red muds and sandstone, at places limestone) formations of Fort Munro Group, deposited under muddy to sandy shelf, distal deltaic and fluviatile environments. At early Paleocene the transgression of sea emerged, which deposited the marine Sangiali (bivalves, nautiloids and gastropods bearing limestone and shale with some Deccan volcanic dust), Rakhi Gaj (sandstone and shale with Deccan volcanic dust observed in Rakhi Gaj section of Dera Ghazi Khan, central Pakistan) and Dungan Limestone of Sangiali Group. Eocene was mostly marine, deltaic and partly terrestrial. In the Oligocene and onward the mollase alluvial environments became dominant.

The contact of the Cretaceous Sembar shale and marl with the Jurassic Dilband Formation (disconformity) and or Chiltan limestone represents the Jurassic-Cretaceous J/K boundary which consists of light brown to grey shale and marl in the central and southern Kirthar basin, while the red iron stone beds (Dilband iron deposits) in the northern Kirthar basin. Further the poorly preserved and poorly recognized fossils of *Brohisaurus kirthari* were also found from the northern Kirthar basin. The contact of Cretaceous Sembar shale and marl with the Jurassic Loralai limestone in the Sulaiman basin, and the contact of Chichali glauconitic shale and sandstone with the Jurassic Samanasuk limestone and shale in the upper Indus (Kohat and Potwar) basin represent the Jurassic Cretaceous J/K boundary which consists of light brown to grey shale/marl.

The Cretaceous-Paleogene K-Pg boundary sharing formations in the Lower Indus (Kirthar) and Middle Indus (Sulaiman) basins are the latest Cretaceous Vitakri Lameta Formation (two red, maroon, grey green clay horizons alternated with two sandstone horizons, limestone at places) and Early Paleocene Khadro and Bara formations (Lower Indus) and Sangiali and Rakhi Gaj formations (Middle Indus). The Vitakri Lameta Formation belongs to only upper part (up to 35 m thick) of Previous Pab Formation (up to 800 m thick) in Indus Basin. In Western Sulaiman Basin, the K/T boundary is represented by Ziarat laterite of Vitakri Formation which is contacted by Cretaceous Parh limestone (porcelaneous belemnite bearing) and Paleocene Dungan limestone (autoclstic marine invertebrates bearing). The K/T boundary in Upper Indus are Cretaceous Chichali (ammonite bearing glauconitic shale and sandstone), or Lumshiwal (quartzose sanstone) or Kawagarh (NW of Upper Indus; limestones) and Latest Cretaceous Indus Formation (laterite, carbonaceous shale; = Vitakri Lameta Formation; lower Hangu). At places the K/T boundary is represented as infra tertiary boundary between the varying Tertiary rocks with also varying older rocks such as Precambrian, Paleozoic and Mesozoic units.

Until now the latest Cretaceous dinosaurs (and other archosaurs) from Sulaiman basin are reported from the Vitakri Lameta Formation [1], which represents fluvial meandering river and over bank system. The K/T boundary is marked on the top of fluvial sandstone (white, thin to thick bedded, slightly calcareous to non calcareous, poorly sorted and have ferruginous nodules and rusty brown weathering on bivalve fossils) unit of Vitakri Lameta Formation which is capped by the shallow marine bivalves bearing green shale, sandstone and yellow brown limestone of Early Paleocene Sangiali Formation. The Vitakri Lameta Formation thickness varying from 15 to 35 m is increasing toward WSW and decreasing ENE directions.

The J/K and K/T boundaries in Pakistan represent wide exposures of marine as well as continental condition. Indus Basin of Pakistan holds a large number of section sites for lateral and vertical rapid environmental/climate change in the Cretaceous greenhouse world.

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The Difference between Jurassic and Cretaceous Cherts in Central Europe and Its Heat Treatment before Stone Chip-Ping (Pilot Study)

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Abstract

Rock-magnetic methods prove that the cultures in Moravia (Europe) 15,000 - 11,500 years ago might know the technique how to enhance knapping properties of Jurassic chert and Cretaceous flint in order to make stone tools.

Keywords

Jurassic, Cretaceous, Magdalenian, Chert, Flint Artifacts, IRM Aquistion

1. Introduction

The Olomučany chert outcrops are located NNE of Brno in a relic of Jurassic sediments in the vicinity of Olomučany village. The layered chert intercalates in Callovian-Kimmeridgian limestones [1]. The chert has dark grey color and microscopically is formed by microfossils and opaque material partly by organic origin. The opaque material is colored rusty-brown due to the presence of iron oxides. Sponge spicules and bryozoans dominate the microfossils. The transparent material is formed by chalcedony and scarce crystals of macro quartz. The chalcedony forms the 0.2 mm spherulites and cryptocrystalline matrix. The spherulites are probably replaced microfossils [2]. The coarser grain size is typical for Olomučany chert that helps to macroscopically recognize from erratic flints encountered in Silesian and North-Moravian territory. A rare component of the *Olomučany chert* is glauconitic grains. A healed fissure acts as planes of weakness during flint-knapping of the chert. However, a heat-treatment of the rock improves the flaking properties.

The majority of flintstone sources at the North Moravia lies north of Nový Jičín towards the border of the Czech Republic and continues to Poland. The southernmost sediments that were probably used in Magdalenian era were transported during the Saale glaciation [3]. The flint is derived from Scandinavian chalk sediments of Maastrichtian to Danian age. The Campanian flints were not detected in the area. The macroscopic observation shows milky-white, yellow, brown, reddish-brown or grey colors with glossy luster. The microscopic investigation proves mostly pelagic origin with micritic primary texture. The Daanian flints are rich in Briozoas, while Mastrichtian flints are richer in remnants of shells, brachiopods and echinoderms [4].

Heat-treatment of cherts and flints expands flaking quality and edge sharpness. This technique was used by prehistoric people throughout the world. Its oldest evidence in Europe comes from 24 to 17 thousand years old Solutrean archaeological sites at France and Iberian Peninsula. The following gap in using the technique took more than 6 thousand years before it was used in the Mesolithic around 9 500 years BP.

2. Methods

Similar technique could be identified in the Magdalenian (15,000 - 11,500 uncal BP) of Moravia (Czech Republic) where local Jurassic chert (Olomučany type) was used. Combination the Fourier-transform infrared spectroscopy (FTIR), mass magnetic susceptibility (MSmass) and measurement of isothermal remanent magnetism (IRM). FTIR is suitable to identify heat-treated chert above 300˚C. However, temperatures around 250˚C, are usually sufficient to improve flaking qualities of fine-grained quarzitic materials [5] [6].

3. Results

The magnetic properties of flint in natural state are caused predominantly by magnetite, that is hydrated and oxidized during heat treatment. Majority of flints in the cave Balcarka contain also mainly magnetite, and only one contains also mineral with higher coercivity according to the Kruiver *et al.* [7] method is Goethite.

The iron oxide content of Olomucany chert is much more heterogeneous. The magnetic properties show mixture of magnetite and hematite. The pilot measurement shows that hematite is during heating transformed to a mixture of magnetite and goethite.

4. Discussion

The results imply that the majority of flint artifacts were not heat-treated before clipping. Olomucany chert artifacts contain more magnetite than the control rock-samples, which could be interpreted as a heat treatment before the knapping, later non-intentional heating or quarrying different layers for tool making than are exposed today. The pilot results show that the heat treatment method was not used in the Moravian Magdalenian regularly, the method was not absolutely unknown.

FTIR and MS mass methods generally agree with the IRM acquisition method. Magnetic methods are therefore recommended to be applied in order to identify intentional and unintentional past heat-treatment of cherts and flints.

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Conflicts of Interest

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Reconciliation of the Early Slip History of the Altyn Tagh Fault, Northern Tibetan

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Abstract

Whether the Altyn Tagh fault (ATF) had been extended beyond its current northeastern tip and linked with strike-slip faults in East Asia is a key to understanding the timing and mechanisms of crustal deformation in the northern Tibetan Plateau. We present Late Cretaceous dextral movement affected by Okhotomorsk Block-East Asia collision and a larger sinistral offset since Late Eocene along the ATF based on the provenance analysis of western Jiuxi Basin. Moreover, currently available estimates of offset based on displaced Paleozoic and Jurassic rocks could not represent the maximum offset due to late Cretaceous dextral offset.

Keywords

Altyn Tagh Fault, Jiuxi Basin, Basin Inversion, Cross-Fault Sediment/Source Match, Dextral Strike-Slip

1. Introduction

Large scale displacement and associated crustal thickening along the Altyn Tagh fault (ATF) have exerted a crucial influence on the geology and geography of Tibetan plateau. Although the modern ATF terminates near the Jiuxi Basin, its eastward extension in early slip history is the debate focus [1] [2], which is a key to understanding the timing and mechanisms of crustal deformation in the northern Tibetan plateau.

Furthermore, sedimentary basins adjacent to the ATF have been subjected to Early Cretaceous widespread extension and early Late Cretaceous significant inversion, and Late Cretaceous sequence is missing. Similarly, rift basins experienced analogical inversion in East Asia affected by Paleo-Pacific tectonism during the early Late Cretaceous, such as Yin-Er Basin, East Gobi Basin, Erlian Basin and Songliao Basin, etc. Yang [3] proposed a dextral strike-slip fault system in North China due to the collision of the Okhotomorsk Block with East Asia. In addition, right-lateral movement has been recognized after tectonic inversion in East Gobi Fault Zone [4]. If ATF could extend beyond the Tibetan Plateau and link with strike-slip faults in East Asia, its nature in late Cretaceous will be redefined.

2. Approach and Result

In this study, we investigated sediment source variation in western Jiuxi Basin before and after tectonic inversion. Paleocurrent directions towards the SE-SW in the field, indicating evince sediment main derivation from the opposing side of the ATF. So considering possible strike-slip displacement, potential sediment sources are mountains on the north side of ATF, including Beishan, Dunhuang and Altyn Blocks. Besides, Qilian shan is usually regarded as one of the most important provenance of the Jiuxi Basin.

In terms of Early Cretaceous Samples from the Hongliuxia area, detrital garnet and rutile composition both indicate middle and high grade metamorphic rocks exposed in the provenance. Moreover, a single U-Pb peak age of detrital monazite is at ca. 375 - 440 Ma and 20 - 40 Ma younger than the early Paleozoic peaks of detrital zircon, matching with the timing of metamorphic events in the Dunhuang Block [5].

Late Eocene detrital zircon separated from Hongliuxia and Huoshaogou area are characterized by the absence of Paleozoic and Mesozoic ages, these materials are mainly derived from the Neoproterozoic basement in southern margin uplift of the Xorkol Basin and eastern tectonic melange zone of North Altyn Area [6] [7].

3. Tectonic Implications

1) The results of provenance analysis show Late Cretaceous dextral movement and >450 km sinistral offset since Late Eocene along the eastern ATF near Jiuxi Basin. Relatively, larger sinistral offset along the middle part of ATF means that currently available estimates of offset based on displaced Paleozoic and Jurassic rocks could not represent maximum offset which weakened by late Cretaceous dextral offset.

2) Early Late Cretaceous basins inversion and Late Cretaceous dextral movement along ATF are dominated by the far-field effects of Okhotomorsk Block-East Asia collision during ca 100 - 80 Ma.

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Conflicts of Interest

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The Cretaceous Tectono-Stratigraphic Complexes of Priamurye (Far East of Russia)

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Abstract

Complicated structure of Priamurye is described as series of repeated tectonic plates. Fragments of these plates are presented in the Gorin and Lower Amurian zones. It is typical accretionary complexes. Three main tectono stratigraphic systems can be distinguished: a system of oceanic plate, a system of oceanic plate cover during its approach to the subduction zone (siliceous mudstone), and the overlying terrigenous formations.

Keywords

Tectonic Plates, Cretaceous, Priamurye, Russia

1. Introduction

The structure of Priamyrye was described as synclinal and anticlinal structures on previous geological maps, because of lacking the faunal evidence. Since the determination of microfaunas (like radiolarians), the structure of Priamyrye became clear. It consists of a series of small plates, and presents a giant accretionary system at the East Asian continental margin.

2. Study Area

Studied area is shown in Figure 1.

3. Data and Method

The main Method is geological mapping scale 1:50,000 and 1:200,000.

4. Results

East Asian continental margin (EACM) presents a giant accretionary system stretching for 5000 km and gradually increasing to the east for the last 450

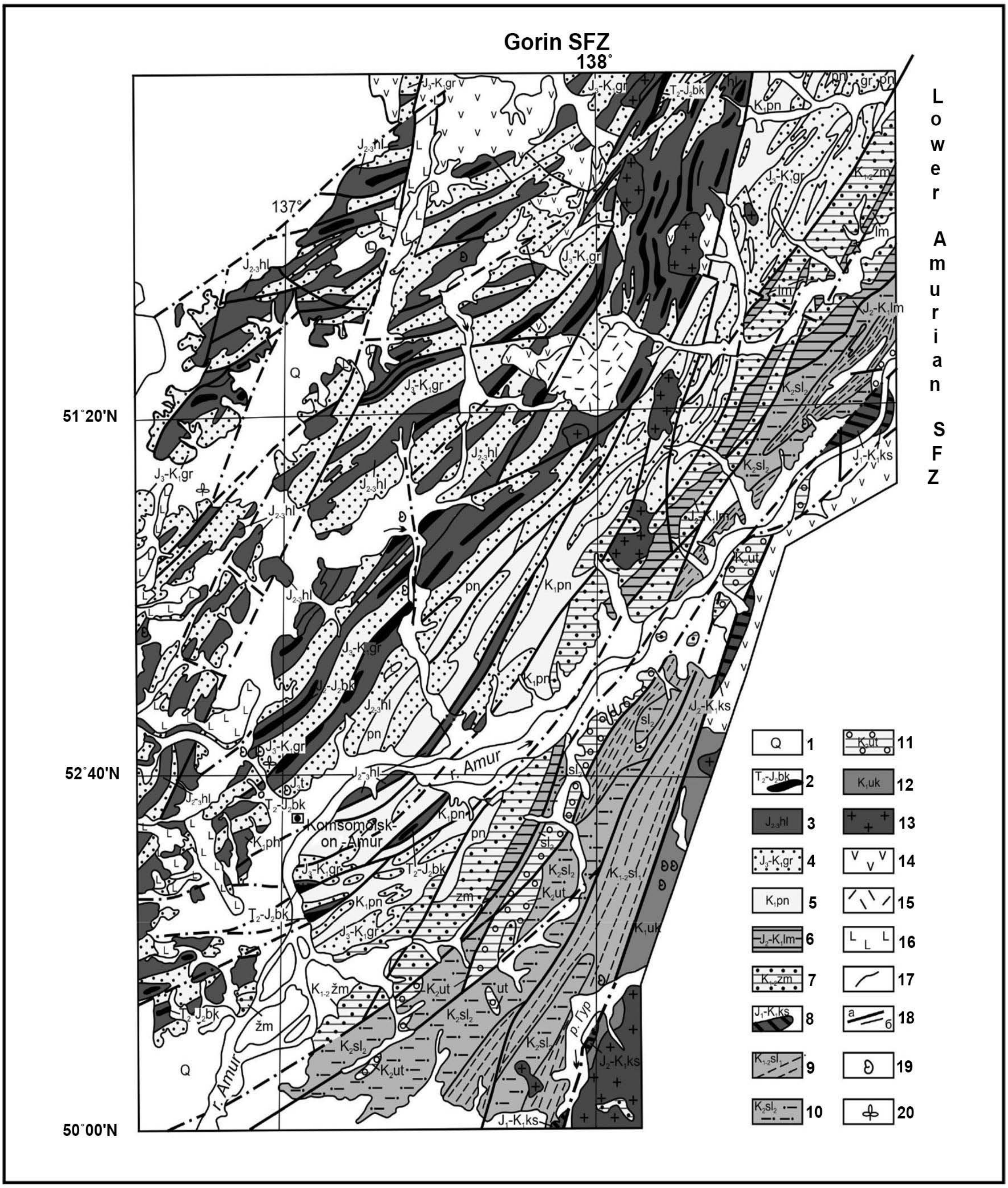

Figure 1. Geologic map of the Amur-Gorin fragment of Late Mesozoicc East Asian margin [1] [2]: Gorin SFZ and Lower Amurian SFZ (Limuri and Chayatyn SFSZ). 1, Quaternary deposits. 2, Boktor unit. 3, Kholvasi unit. 4, Gorin Formation. 5, Pioneer Formation. 6, Limuri unit. 7, Zhormin unit. 8, Kiselevka Formation. 9, Lower Silasinsky subformation. 10, Upper Silasinsky subformation. 11, Utitsky Formation. 12, Uktur Formation. 13 - 15, Upper Cretaceous: 13, Granitoids; 14, Medium volcanites; 15, Acid volcanites. 16, Neogene-Quaternary basalts. 17, Stratone boundary. 18, Faults: a) Major, b) Subordinate. 19. Faunal foundings. 20, Floral foundings.

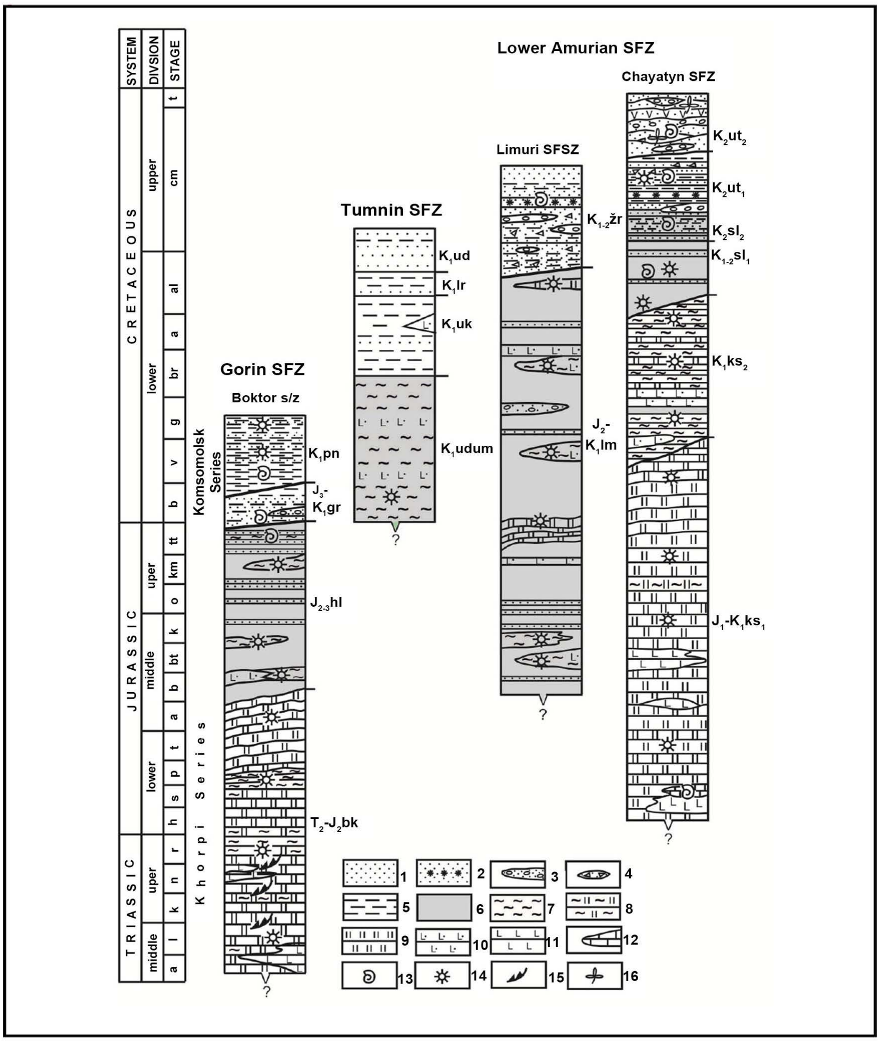

Figure 2. Zonal correlation scheme of lithostratigraphic units. 1, Sandstones. 2, Tufaceous sandstones. 3, Conglomerates. 4, Sedimentation breccia. 5, Siltstones. 6, Clayey shales and aleuropelites. 7, Siliceous-clayey shales. 8, Clayey cherts. 9, Jasper and cherts. 10, Tuff and basic hyaloclastites. 11, Basic lavas. 12, Limestones. 13, Bivalves. 14, Radiolarian. 15, Conodonts. 16, Flora.

million years by accretionary complexes. In Mesozoic, within the boundaries of EACM 6 main periods of accretion are established: T_2; J_1; J_2; J_3; J_3-K_1 and K_1^2, that were previously discussed in general terms. Accretionary complexes are divided into belts or zones (SFZ) as shown in Figure 1.

In Priamurye, three main tectono-stratigraphic systems can be distinguished: a system of oceanic plate, composed of laminar chert, rare volcanites, a system of oceanic plate cover during its approach to the subduction zone (siliceous mudstone), and the overlying terrigenous formations. Fragments of these systems are presented as shown in Figure 2.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Sedimentology and Stratigraphy of Phu Sung Fossil Site of the Lower Cretaceous Sao Khua Formation, Sakon Nakhon Province, Northeastern Thailand

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Abstract

"Phu Sung", a new fossil site in Sakon Nakhon Province was recently reported. Phu Sung fossils are very complete and in very well-preserved condition. They were found in reddish micaceous silty mudstone. The stratigraphy and sedimentology show that Phu Sung succession is a continental deposit in the fluvial system and it is in the Early Cretaceous Sao Khua Formation of the Khorat Group. According to lithology, fossils were deposited in a quiet environment, such as overbank deposit, small pond or oxbow lake margin. Sedimentary structures such as desiccation crack and calcrete indicate semi-arid to arid paleoclimate condition which probably corresponds to the taphonomy or preservation of the fossils.

Keywords

Fluvial Deposits, Sao Khua Formation, Lower Cretaceous, Northeastern Thailand

1. Introduction

The Khorat Group is the Mesozoic non-marine deposit. It is dominated by reddish classic sedimentary rocks including mudstone, siltstone, sandstone and conglomerate [1]. The Lower Cretaceous Sao Khua Formation of the Khorat Group is well exposed in northeastern Thailand (**Figure 1**) and has yielded various vertebrate remains. Stratigraphy and palynology indicate that the Sao Khua Formation is Early Cretaceous in age (Barremian) [2] [3]. Some Sao Khua

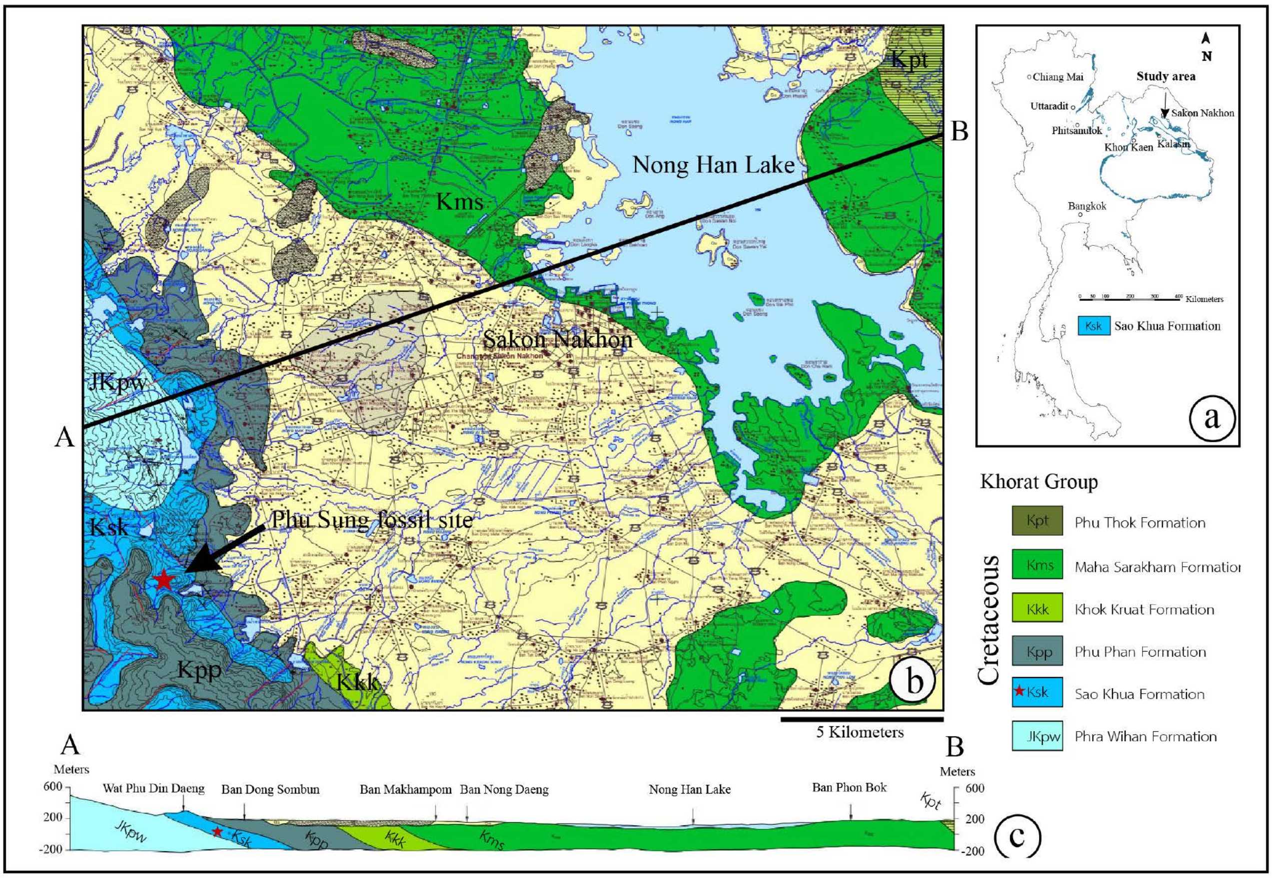

Figure 1. Study area, (a) distribution of the Lower Cretaceous Sao Khua Formation (Ksk), (b) the Phu Sung fossil site, showing in red star and (c) the cross section (line A-B) shows Ksk is underlain by white quartzitic sandstone of Kpw and it is overlain by the sandstone dominated Kpp (Modified from [4]).

vertebrate fossil sites in Sakon Nakon were previously revealed, however, most of the fossils such as fresh water shark, bony fish, turtles, crocodiles, pterosaurs, dinosaurs and lizard eggs were fragmentary. Most recently, a new vertebrate fossil site "Phu Sung" with a good fossil preservation was found near Muang Sakon Nakhon District, Sakon Nakhon Province (**Figure 1**). In this work, we are interested in the sedimentology and stratigraphy of the site to interpret the paleoenvironment of the Phu Sung fossil site.

2. Sedimentology and Stratigraphy

The Phu Sung section is more than 80 meters thick, dominated by reddish micaceous siltstone/mudstone, calcrete horizon and intercalation with sandstone and conglomerate (**Figure 2**). In general, sedimentary strata is NNW-SSE striking (330˚ - 355˚) with gentle dipping (5˚ - 10˚) to NE direction. Although outcrops are not very well exposed, the section seems to be complete and continuous. The Phu Sung section can subdivided into 3 main parts. 1) The lower part (Log1) consists of medium- to thick-bedded sandstone with cross bedding. Sandstones are thinning upward and passing to siltstone dominated at the top. Some individual sandstone bed shows sharp erosive base with mud clast at the

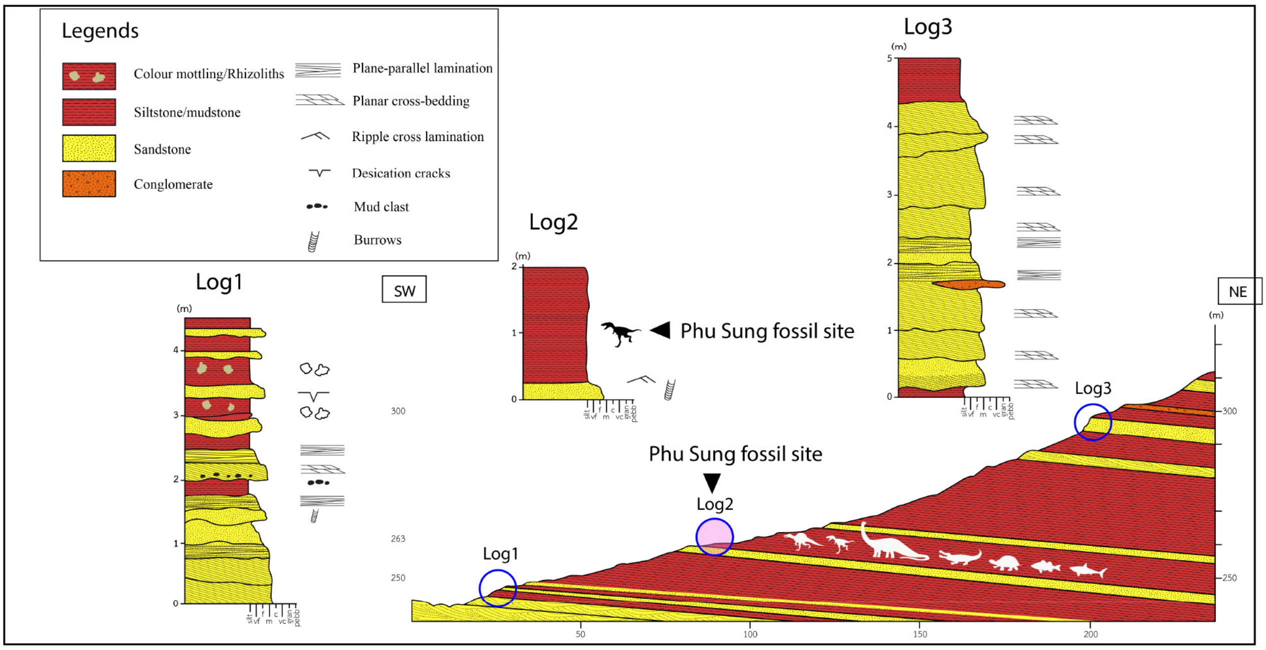

Figure 2. Geological cross section with NE-SW direction and sedimentary logs of the Phu Sung fossil site.

bottom. Vertical bioturbation and desiccation crack can be found. Reddish micaceous siltstone/mudstone with greenish grey to pale grey mottling and rhizoliths present at the top of section. 2) The middle part of the section (Log2), where fossils were found, starts with thin to medium bedded fine-grained sandstone. It is overlain by reddish micaceous siltstone/mudstone. Calcrete nodules are commonly found on recent erosional surface. About 1 meter above a sandstone bed, fossils were found in reddish siltstone. Stratigraphically, fossil-bearing bed is situated approximately 80 - 100 meters below quartzitic sandstone and conglomerate of the Phu Phan Formation. 3) The upper part (Log3) forms as a small cliff of medium- to thick-bedded sandstone. Cross-bedding and planar bedding are commonly found within sandstone. Some lenticular conglomerates present at the base of sandstone. This cross-bedding sandstone is capped atop by reddish siltstone, calcrete horizon and lime-nodule conglomeratic layer. Medium to thick bedded with cross bedding sandstone sets from the lower and the upper part of the Phu Sung succession is interpreted as main channel-filled with high energy environments. While the middle part, where fossils were found in reddish micaceous silty mudstone, is interpreted as overbank deposit swith low energy environments.

3. Conclusion

The Phu Sung succession is a continental deposit in the fluvial system. Fossils were found in reddish silty mudstone, indicating low energy quiet environment (overbank, small pond or oxbow lake margin). Sedimentary structures such as desiccation crack and calcrete indicate arid and semi-arid paleoclimate condition. The taphonomy and the extraordinary preservation of Phu Sung fossils could probably relate to the paleoenvironment and the paleoclimate in the Early Cretaceous.

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Conflicts of Interest

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Overview of Cretaceous Non-Marine Deposits and Their Palaeoclimatic Characteristics in the North of Vietnam

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Abstract

The Cretaceous non-marine deposits play an important role in the history of formation and evolution of Earth's crust in northern territory of Vietnam. According to analyzing results of material composition and depositional environments, these deposits can be divided into three lithofacies assemblages, such as proluvial-deluvial, fluviatile and lacustrine lithofacies. These Cretaceous non-marine sequences in the North of Vietnam indicate a typically continental hot and dry palaeoclimatic regime.

Keywords

Cretaceous, Non-Marine, Lithofacies, Palaeoclimate, Ripple-Marks, Shrinkage Cracks, North of Vietnam

1. Introduction

The Cretaceous non-marine sequences are all located in almost structural zones in northern territory of Vietnam in the various forms, depending on the influence of regional tectonic and erosional regimes. Stratigraphically, in accordance with the differentiation of material composition and the conditions of depositional environments, these sequences can be divided into four stratigraphical units [1]: *i.e.* the Ban Hang Formation (K_1*bh*) in Northeastern area, the Nam Ma Formation (K*nm*) in Muong Te zone, the Yen Chau Formation (K_2*yc*) in Northwestern area and the Phu Co Pi Formation (K_1pc) in North Central Vietnam. Three lithofacies assemblages were distinguished and many palaeoclimatic signals can be reflected.

2. Geological Setting

Although with a stratigraphical discontinuity, the Cretaceous non-marine deposits (350 - 1400 m) in northern Vietnam are characterized by two types of sections:

1) They unconformably overlie on the Lower and Middle Jurassic. In fact, they occur in every geological structure units (the Ban Hang Formation, the Nam Ma Formation and the Phu Co Pi Formation).

2) They unconformably overlie on other older rocks (the Yen Chau Formation).

3. Lithofacies and Depositional Environment Characteristics

Based on material composition and forming conditions, the non-marine Cretaceous of northern Vietnam can be included into the following lithofacies assemblages [2]:

1) Assemblage of proluvial, proluvial-deluvial lithofacies, consisting mainly of breccia-conglomerate, gravel-bearing conglomerate. The rocks of this lithofacies association were formed during the early stage of the sedimentary basin.

2) Assemblage of fluviatile lithofacies, consisting of:

a) Channel facies, composed mainly of poorly to moderately sorted, moderately to poorly rounded polymictic gravelstone, with lenses of gravel-bearing coarse grained sandstone, at some places interbedded with sandstone and sandy siltstone of aluvial lithofacies. The main structure is unclear bedding and monoclinal cross-bedding.

b) Aluvial facies, composed mainly of medium to fine grained sandstone with horizontal ripple-mark bedding structure or monoclinal cross-bedding, directly overlying the rocks of channel lithofacies.

3) Assemblage of lacustrine lithofacies composed of well rounded and well sorted, fine grained sandstone, siltstone, mudstone, gypsum/salt. Their structure is gentle or nearly horizontal, with ripple-marks at some places.

4. Palaeoclimatic Characteristics

Generally, typical Cretaceous non-marine sequences in northern Vietnam are all characterized by multi-provenance terrigenous sediments, from coarse-grained to fine-grained, reddish brown, brownish red in colour, uneven bedded structure. The palaeoclimatic analyses show that they contain many signals indicating a typically continental hot and dry palaeoclimatic regime [3] [4]. The evidence is as follows:

1) The primary red, reddish brown, brownish red colors are by the presence of hematite, goethite, limonite and lepidocrocite which are unevenly scattered in the sediments. Fe_2O_3 content tends to increase in accordance with the decrease of sediment's grainsize;

2) The presence of gypsium/anhydrite and salty trace, is especially in northwestern areas and Muong Te zone. Gypsium/anhydrite exists in these sedimentary

rocks in 3 forms:

a) Thin layers (thickness is ranging from 1 to 14 cm), synsedimentation.

b) Unevenly disseminated, authigenical existence in component of different rocks, such as claystones, silstones, sandstones with content ranging from 3% - 5% to 10% - 15%, significantly to 30% - 35%.

c) Secondary vein/nest type filled in rock fissure systems.

3) Polygonal sand-filled shrinkage cracks on the surface of claystone layers.

4) The Cretaceous non-marine sediments are always very poor in organic material caused by dry and hot continental paleoclimate. The pelecypod fauna consists of species living in fresh and brackish water environment, such as *Hoffetrigonia kobayashi*, *Unio* sp., *Trigonioides* sp., *Cardinioides* sp. [5]. Plant fossils have leaf-shape with entire margins which are as a reflection of droughty palaeoclimate [2].

5) Trace element analysis of 26 samples gives the following values (%): Fe (1.26 - 9.21), Al (1.02 - 11.13), Ti (0.32 - 0.47), Ca (0.42 - 7.43), P (0.045 - 0.080), Co (10 - 21 g/t), Ni (10 - 44 g/t), Cr (40 - 128 g/t), Ba (71 - 869 g/t) and Zr (15 - 420 g/t) [3].

The rare earth element (REE) composition in Cretaceous sedimentary rocks of different sedimentary basins of northern Vietnam as shown in chondride-normalized spider diagram does not display any considerable differentiation. Furthermore, ratio between Ce/La content is always <1.5 (the average ratio based on 43 samples is 1.48) which is characterized for rich of oxygen in continental sedimentation environment.

Clearly, with such signs as mentioned above, the Cretaceous non-marine sedimentary rocks in northern Vietnam are formed under a typical hot and dry palaeoclimatic regime.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Late Cretaceous Climate of the Indian Subcontinent

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Abstract

The Deccan Volcanism during the Late Cretaceous was a globally significant geological event, coinciding with the Cretaceous-Paleogene Boundary. The magma outpouring occurred in three phases. The flora that got preserved during the first phase (30N) was a mixed gymnosperm and angiosperm flora ranging from dry to moist forest vegetation. The second phase (29R) flora is mostly represented by pteridophytes and tropical to sub-tropical angiosperm plant families. The palynofloral records from the third phase (29N) are mostly tropical angiosperms. This floral turn-over is driven by latitudinal shifting of the Indian plate from sub-tropical to tropical zone. It is surmised that the latitudinal shifting of Indian plate during the span of 4 Ma during the Late Maastrichtian led to the development of new ecological conditions favoring successful dominance of angiosperms over gymnosperms.

Keywords

Deccan Volcanic Province (DVP), Pollen, Spores, Plant Mega Fossils, Paleoecology

1. Introduction

The late Cretaceous deposits of India preserves the most important Large Igneous Provinces in the world, covering an area of about 512,000 km^2 in the western and central parts of India. The sediments associated with the Deccan Volcanic Province (DVP) are represented by the infratrappean (Lameta Formation) and intertrappean beds. The magmatic outpouring occurred in three main phases with 6% of the total Deccan volume in phase-1 (base C30n), 80% in phase-2 (C29r), and 14% in phase-3 (C29n) [1]. The duration of intermittent volcanic activity spanned about 4 Ma across the Cretaceous-Tertiary boundary [2]. The palynofloral records from infra and intertrap deposits from most of the areas are poor due to lack of good preservation conditions. Globally, the Late Cretaceous time witnessed the radiation of angiosperm forming nine phytogeographic provinces [3], out of which three lie in India. However, the assessment of their spatial and temporal distribution is difficult due to the paucity of continuous fossil records. Poor preservation conditions hamper the establishment of biostratigraphy and paleoenvironmental reconstruction of DVP associated sediments. However, we attempt to summarize the available mega and micro plant fossil data to infer floral transition and palaeoecological reconstruction during the Late Cretaceous in central India.

2. Palynofloral Assemblages

The igneous basalt flow occurred in three phases. The sedimentary deposits within the first phase mostly comprised of pteridophytic spores and pollens of Gymnosperm families like, Araucareaceae, Podocarpaceae, Corystospermaceae, Cheirolepidaceae and Ginkgoaceae while the angiosperm plant families consist of monosulcate pollen of Arecaceae family. *Aquilapollenites* sp., an angiosperm pollen is an age marker and common pollen of Maastrichtian deposits. There are also few angiosperm tricolpate pollens of uncertain origin.

The second phase witnessed an increase in the angiosperm diversity along with the already existing forms of pteridophytes and gymnosperms. The angiosperm families which make their appearance in this phase are Asteraceae, Caryophylaceae, Normapolles Group pollens and few other pollens such as *Scabrastephanocolpites* spp., *Scollardiaconferta, Triporopollenites cracentis* of unknown affinity [4]. The megafloral record of this phase is richer in comparison to microfossil record and represented by Flacourtiaceae, Icacinaceae, Euphorbiaceae, Capparidaceae, Boraginaceae and Sapindaceae [5] [6]. There are very few records of the third phase deposits like, Lalitpur intertrappean of Uttar Pradesh, and Mumbai intertrappean deposits. The deposits at Lalitpur yielded poor pollen assemblage of *Dandotiaspora* spp., *Spinizonocolpites echinatus, Matanomadhiasulcites* sp. and *Lakiapollis ovatus [7]* while deposits at Mumbai are completely devoid of plant fossils [8].

3. Paleoclimate Reconstruction

The first (30N) and second phase (29R) of basalt flow occurred during Maastrichtian and the third (29N) and final phase marked its presence in Paleocene [1]. The second phase of extensive basalt flow of Deccan Traps comprises 80% of the total basalt flow that coincides with the Cretaceous-Paleogene Boundary (K-Pg). Fossil flora associated with the DVP consists of mega and micro fossil records of pteridophytes, gymnosperms and angiosperms. The pteridophytes mostly grew in waterlogged, swampy and marshy conditions. The gymnosperm fossils recovered from the DVP were from the Lameta Formation below the 30N trap deposits. They mostly belonged to mixed ecological conditions from evergreen (Araucareaceae, Podocarpaceae, Corystospermaceae) to dry land vegetation (Cheirolepidaceae). As far as angiosperms are concerned, the major part of the assemblage was covered by brackish mangrove *Nypa* and *Aquilapollenites* pollen. The other plant fossils from the intertrappean localities associated with the latest Maastrichtian and Danian sequences show dominance of subtropical-tropical angiosperm plant families (Flacourtiaceae, Icacinaceae, Euphorbiaceae, Capparidaceae, Boraginaceae and Sapindaceae, Malvaceae, Meliaceae, Annonaceae, Vitaceae) while some of the pollens belonging to the Asteraceae, Caryophylaceae suggest cool climatic conditions [9]. The transition from gymnosperm-dominated to angiosperm-rich palaeovegetation during Maastrichtian is a significant floral turnover and can be due to climatic changes as a result of shifting of the Indian plate from the subtropical to tropical zone.

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Conflicts of Interest

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Evaluation of Cretaceous Hinterland Weathering and Climate in the Sichuan Basin, SW China

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Abstract

Cretaceous is characterized by high atmospheric CO_2 concentration and a resultantly high temperature. Thus, the Earth system, which operated during the greenhouse condition, can be deduced by the investigation of the paleoclimate during the Cretaceous. However, information of paleoclimate from continental inland-basins is scarce compared to that from continental margin marine-basins. In this research, the changes of weathering condition through the whole Cretaceous Period were reconstructed by analyzing the whole-rock chemical composition and clay mineral composition of mudstone samples collected in the Sichuan Basin, SW China. The reconstructed paleoweathering intensity positively correlates with paleotemperature estimate, indicating that Cenomanian-Turonian stages were climatic optimum in the Sichuan Basin as well. Furthermore, the result suggests a Cenomanian-Turonian extremely high amplitude humidity fluctuation.

Keywords

Cretaceous, Continental Weathering, Fluvial Deposits, Desert Deposits, XRF, XRD, W Index

1. Introduction

Reconstruction of the Cretaceous paleoclimate is important for the understanding of the Earth operating system during the greenhouse conditions. However, paleoclimatic information from continental inland-basins is scarce compared to that from continental margin marine-basins. This situation is also true in the Asian continent; Cretaceous ecosystem and paleoclimate data are accumulating in the Pacific side, while those of the Asian continental side are lacking [1]. Paleoclimate conditions in Asian inland basins are considered to be equally important in order to elucidate the land-ocean climate operating system during the Cretaceous.

In this regard, we investigated the geochemistry and clay mineralogy of the Cretaceous mudstones from the Sichuan Basin, southwestern China, for the aim of paleoclimate evaluation.

2. Geological Setting and Sampling

The Sichuan Basin is located in the western South China Block, where the Cretaceous strata are widely distributed [2]. The depositional age of studied strata ranges from Berriasian to Maastrichtian. Sediments are mostly fluvial to lacustrine origin, however, a broad distribution of aeolian dune sandstones was identified from the Cenomanian to Turonian interval [2]. 50 mudstone samples were collected from the five Cretaceous formations in the Sichuan Basin, covering the Berriasian to Maastrichtian stages. We exclusively sampled fine-grained massive mudstones in order to exclude compositional changes due to the grain-size effect.

3. Analytical Methods

Samples were pulverized using agate motor mill and fused beads were prepared for XRF analysis (ZSX Primus 2; Rigaku, Tokyo, Japan). The whole-rock major element composition acquired by XRF was used to calculate the W index [3] in order to evaluate the hinterland paleoweathering condition. Clay-mineral composition and illite crystallinity were obtained by XRD (SmartLab XRD, Rigaku, Tokyo, Japan). Oriented glass slides of clay minerals finer than 2 μm fraction were prepared for the XRD measurement.

4. Result and Discussion

Geochemical weathering indices (e.g., W value; [3]) demonstrate a significant increase in hinterland paleoweathering from Berriasian (W = 70) to Cenomanian – Turonian (W = 95), and then slightly decrease towards the Maastrichtian (W = 80). This fluctuation pattern of the weathering indices is concordant with the Cretaceous paleotemperature reconstruction curve [4]. Therefore, the present result suggests that the hinterland paleoweathering rate in the Sichuan Basin was governed by global temperature changes. The weathering index reached the maximum value of 95 in Cenomanian-Turonian interval. Furthermore, sediments of Cenomanian-Turonian horizons contained abundant kaolinite mineral, which is a product of hydrolysis decomposition of rock-forming minerals. Both lines of evidence suggest that the Sichuan Basin was under the tropical and pluvious climate during the Cenomanian-Turonian. Note that previous study elucidated an arid climate from amalgamated sandstone facies [2], while the present pluvious climate interpretation is derived from the analysis of intervening piled mudstone facies. When these lines of geological evidence are integrated together, it is reasonable to suggest the development of an alternating pluvious and arid paleoclimate during the Cenomanian-Turonian. The nature and trigger of this extremely oscillating pluvious/arid climate cannot be deduced solely from the present study. However, the timing of this renewed climate system matches with the Cretaceous greenhouse optimum (Cenomanian-Turonian). The development of monsoon-like pluvious/arid paleoclimate in the Sichuan Basin is possibly related to the mid-Cretaceous re-configuration in the global climate system.

5. Conclusion

In this study, the hinterland paleoweathering conditions in Sichuan Basin through the whole Cretaceous were reconstructed. We found that the fluctuation in hinterland paleoweathering intensity is highly positively correlated with the estimated global temperature trend. Therefore, the paleoweathering rate might be controlled by the global temperature. Furthermore, the present result suggests that mudstone facies intercalated in the aeolian sandstone facies record high rates of hinterland weathering intensity. The alternating mudstone and sandstone facies imply the oscillating pluvious/arid paleoclimate during the Cenomanian-Turonian greenhouse optimum.

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Conflicts of Interest

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Late Jurassic-Early Cretaceous Erg Deposits in the Mengyin Basin, Western Shandong Province, China: Inferences about the Wind Regime and Paleogeography

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Abstract

The Late Jurassic-Early Cretaceous Santai Formation, sporadically distributed in western Shandong Province, comprises terrestrial alluvial-eolian successions, which records regional wind patterns and paleogeography in eastern North China. This paper conducts an analysis of eolian stratification, bounding surfaces, facies architecture and paleowind direction of the Santai Formation in the east of the Mengyin Basin, western Shandong Province. Three basic types of eolian stratification are recognized in the Santai Formation, including grainflow strata, wind ripple strata and adhesion strata, and have been grouped into eolian dune and interdune facies associations. The occurrences of reactivation surfaces and superimposition surfaces within eolian dune deposits indicate active compound dunes or draas. The association of adhesion strata with grainflow or windripple strata is the development of a wet eolian system. Cross-strata dip direction indicates different paleowind directions from the lower to the upper part of the Santai paleoerg. The lower part of the paleoerg was characterized by paleowinds blowing from northwest to northeast, whereas the upper part was under the influence of paleowinds consistently towards east to northeast. The identified changes in wind directions possibly suggest wind regime shifts from monsoon circulation to westlies of planetary wind system, which may be related with the collapse of the East China Plateau during the Late Jurassic to Early Cretaceous.

Keywords

Late Jurassic-Early Cretaceous, Santai Formation, Western Shandong

Province, Eolian Succession, Wind Regime, East China Plateau

1. Introduction

The sedimentary record of eolian system, extending from the Archean to the Quaternary, is widespread on earth [1]. It not only contains a large amount of information on paleogeography, paleoclimate and wind regime, but also provides clues on the geological evolution of desert basins and the relative role of allocyclic controls as tectonic and orbital forcing and its effects on preservation [2] [3] [4].

Previous workers have conducted extensive studies on the Precambrian to Cenozoic eolian deposits widely distributed at North America, South America, Africa and western Europe, including macro-micro identification of eolian deposits, bedform reconstruction and modeling, dry/wet/stabilized eolian system reconstruction, atmospheric circulation, and orbital-driven climatic fluctuations [1], and reference therein. In contrast, the studies of eolian deposits in China mainly focus on the Cretaceous, Tertiary and Quaternary, especially the pre-Cenozoic eolian deposits have been poorly studied [4]. The Late Jurassic-Early Cretaceous erg deposits present in the Mengyin Basin would provide an excellent opportunity to analyze the eolian stratigraphic architecture, regional paleogeography and wind regime.

2. Geological Setting

The Mengyin Basin is located at the east of North China Craton as well as western Shandong Province. The Jurassic-Cretaceous fill of the basin, in ascending order, can be subdivided into the Late Jurassic-Early Cretaceous Santai Formation, the Early Cretaceous Laiyang Group and Qingshan Group. The Santai Formation rests unconformably on the mudstone and carbonate rocks of the Late Carboniferous Benxi Formation or Early Permian Taiyuan Formation and is unconformably overlain by conglomerate of the Paleogene Changlu Formation or mudstone of the Early Cretaceous Laiyang Group. It consists of alluvial successions in the southeast of the basin, whereas the eolian sandstone dominantly occurs at the northwest of the basin. Some theropod dinosaur footprints *Grallator* have been found within the alluvial deposits.

3. Eolian Stratification and Sedimentology

Three basic types of stratification have been identified, including grainflow strata, wind ripple strata and adhesion strata, which are arranged into trough and planar cross-bedding and parallel bedding. Grainflow strata, 0.8 - 10 cm thick, commonly present at the upper part of the cross-beds pinch out downward and are characterized by internally structureless or inverse grading. Wind ripple strata occurring at the cross-beddings or parallel beddings, consist of 0.1 - 0.6 cm thick, low angle and horizontal laminations, and usually alternate or merge with grainflow strata. Adhesion strata characterized by adhesion ripples and adhesion wars are 0.2 - 2 cm in thickness and occur at the base of the cross-bedding and parallel bedding. These stratifications have been grouped into eolian dune and interdune facies associations. Eolian dune deposits composed of grainflow, wind ripple and adhesion strata are internally bounded by reactivation surface and superimposition surface, suggesting active compound dunes or draas. Interdune deposits separated from eolian dune deposits with interdune surfaces consists dominantly of wind ripple strata and adhesion strata. The occurrence of adhesion strata in eolian dune and interdune deposits not only indicate high water table level, but also suggest wet eolian system [3].

4. Discussion and Conclusions

The combined analysis of cross-strata dip directions and bedform types indicates various paleowind directions across the outcrop area of the Santai paleoerg. The lower part of the eolian succession was characterized by paleowind blowing from northwest to northeast. Combined with eolian cyclic cross-bedding composed of a regular interaction of grainflow and wind ripple packages, suggesting monsoonal wind regime, similar as the reports from the Upper Jurassic Sergi Formation in Brazil [5]. In contrast, the paleowind direction of the upper part of the eolian succession consistently towards east to northeast, possibly implies westerlies circulation wind regime, consistent with the atmospheric circulation of the middle paleolatitude regions in the Early Cretaceous [6]. The change from monsoon circulation to westlies of planetary wind system indicates northward movement of North China from low to middle paleolatitude regions in the Late Jurassic to Early Cretaceous (coupling with paleomagnetism data from Yi *et al.*, 2019, in press) and the breakup of monsoon wind region prevailed in Pangea supercontinent during the Triassic-Latest Jurassic [7]. The collapse of the East China Plateau in the Late Jurassic to Early Cretaceous may be a paleogeographic factor controlling the erg evolution and atmospheric circulation. The subsequent Early Cretaceous thick fillings of the Jiaolai Basin in the eastern Shandong Province are a sedimentary response to the post-collapse of the East China Plateau.

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Conflicts of Interest

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The Cretaceous Period of Weather Similar to the Present One and Its Diverse "Conchostracan" Fauna

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Abstract

Cretaceous System is widely represented in South America from northeast Brazil to southern Patagonia Argentina. It is characterized by having been a relatively warm climate, with rainfall and marked seasonality which allowed the development of the "conchostracan" populations.

Keywords

Cretaceous, Climate, Fossil Record, South America

1. Introduction

The Cretaceous Period was a period with warm climate [1], with increasingly high sea levels in the epicontinental seas. The average global temperature was near to 18˚C [2]. Despite the greenhouse character of the period, the cooling trend towards the Maastrichtian and the 116 Ma "cold snap" triggered the interest in possible continental Cretaceous glaciations [3].

2. Cretaceous Climate and Bearing "Conchostracan" Faunas

In the Lower Cretaceous, the monsoon circulation of the Pangea culminated, due to the opening of the Atlantic Ocean [4]. The cool interval in the Early Cretaceous is followed by warming lasting until the late Albian [5]. In the continental regions there were changes in atmospheric circulation. Wetter conditions developed and paleoprecipitations increased in tropical areas [6]. Oceanic and continental data suggest equatorial paleotemperatures similar to the present-day [7]. This time was characterized by the presence of areas with prevailing micro-climates. In intracratonic basins (e.g. northeast Brazil), the climate was arid with warm-hot temperatures. This type of arid climate, with heavy rainfall, generated favorable seasonal conditions for the development of a diverse "conchostracan" fauna. Wind patterns shew seasonality leading to more extreme climates over the continents. During the Upper Cretaceous warm weather prevailed, with greenhouse periods, globally averaged temperatures were 6˚C - 14˚C higher than today [8]. The paleoprecipitations increased as a result of the end of the monsoon circulation [9]. In Argentina, the conchostracan bearing units as the Lagarcito Fm. (Lower Cretaceous) was interpreted as a deposit of a shallow and perennial freshwater lake in a semi-arid climate [10]. The Cañadón Calcáreo Fm. (Upper Jurassic - Lower Cretaceous) was referred by [11] to sequences represented swampy areas, with a rich and diverse conchostracan fauna in subtropical seasonal dry climate. In Brazil-Uruguay the units are, the Botucatu Fm = Tacuarembó Fm (Late Jurassic - Early Cretaceous), indicating desert climate [12]. The Santana Fm. (Lower Cretaceous) represent tropical climate with highly dependent on the rainfall in the mating epoch [13] was, favorable to establish "conchostracan" populations. The Bauru Basin (San Carlos Fm) the climate was hot and arid [14]. The climate was warm and very dry, probably desert [14].

3. Conclusion

Finally, the climatic characterization for the Cretaceous of South America, summarized as a warm climate with rainfall and marked seasonality, allowed the development of the "conchostracan" populations so far recorded.

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Conflicts of Interest

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Formation Mechanism of Reduction Spheroids with Dark Cores in Cretaceous Red Beds in Jiaolai Basin, China

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Abstract

Red beds are not entirely red sometimes, in which grey-green spheroids or irregular spots can be found. However, the formation mechanism of grey-green spheroids or irregular spots in red beds is not clear so far. Samples taken from well JK1 in Jiaozhou area of Jiaolai Basin displayed that the reduction spheroids have more Vanadium (V) element, less TFe_3O_4 and Lead (Pb) element, almost the same content of other elements such as FeO and so on, comparing the red parts of the samples. The existence of organisms can explain the existence of green reductive spheres in the red beds formed under the oxidation environment.

Keywords

Red Beds, Reduction Spheroids, Formation Mechanism, Jiaolai Basin, Eastern China

1. Introduction

Color is one of the most important physical indicators of sedimentary rocks, which can be used for dividing rock types, stratigraphic division, analyzing palaeogeographic climate and sedimentary redox state and so on. It also has high landscape values. Red beds have attracted many scholars' attention for the bright color.

Red beds are not entirely red sometimes, in which grey-green spheroids or irregular spots can be found. Green reduction spheroids with dark cores containing enrichments of tellurium (Te) and selemium are found in red beds sediments from Mesoproterozoic successions [1]. There are similar geological phenomena in the Baikouquan Formation of the Mahu depression [2], the Lower Cretaceous Liwaxia Formation in Liupanshan [3], the Cretaceous Heshangpu Formation in Kongtongshan [4], and the Hongtuya Formation of Jiaolai Basin in China. Although the different explanations are given by the researchers, there is a conclusion that red represents the oxidizing environment while green represents the reducing environment. Samples from red beds in Jiaolai Basin were studied in order to ascertain formation mechanism of reduction spheroids in red beds.

2. Materials and Methods

Samples were taken from well JK1 in Jiaozhou area of Jiaolai Basin, which is scientific drilling with 664.7 m depth carried out by Shandong Institute of Geological Survey and Institute of Geology, Chinese Academy of Geological Sciences. K/Pg boundary has been emphatically studied and was determined at 537.4 m depth in JK1 [5]. One sample in red beds with 593.2 m depth has reduction spheroids with dark core clearly (**Figure 1**). The samples are observed under stereoscope and polarizing microscope, and analyzed the content of major and trace element in Analytical Laboratory Beijing Research Institute of Uranium Geology.

3. Result

Either red or green of the samples contacting mutative with no transitional color are original color instead of secondary color under the microscope, because the chromogenic minerals exist in the form of cements. The debris grains are mainly quartz. The red parts of the sample have almost same minerals with the reduction spheroids except the chromogenic minerals, which are confirmed by the microscopic photographs and XRD analysis results. The reduction spheroids have more Vanadium (V) element, less TFe_3O_4 and Lead (Pb) element, almost the same content of other elements such as FeO and so on, comparing the red parts of the samples, according to the analysis results of principal and trace elements. Further, the dark cores have obvious abundant V element comparing the rest area of reduction spheroids due to the electron probe analysis.

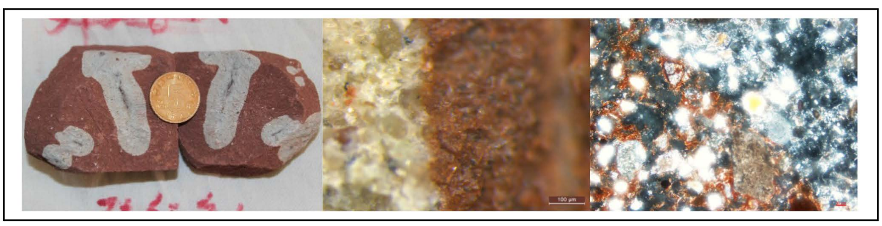

Figure 1. Different scale pictures of sample with 593.2 m depth from well JK1.

4. Discussion

Oxygen penetration into the subsurface, where spheroids develop, would have been relatively shallow, promoting redox boundaries [1]. Formation mechanism of reduction spheroids in red beds from the Baikouquan Formation of Mahu depression is that iron oxide is reduced by osmotic water, leaving a faded light green-gray spot after reduction [2]. Green interbeds in red beds from the Liwaxia Formation of Liupanshan called zebra mudstones, reflect the changes of redox environment. Taken together, reduction spheroids in red beds reflect the limited reduction in oxidizing environment. What is most important is that whether reduction or oxidization happened first.

The samples from red beds of Jiaolai Basin indicated that the distribution of reducing spheres in red beds is irregular, which illustrated that osmotic water generating green reduction spheroids is small probability event. Oxygen penetration into the subsurface, where spheroids develop, can't explain the large scales of red beds (>2000 m thick). However, abundant Vanadium which was an element of atypical biological significance has been found in sea water, sea urchins and other marine organisms, magnetite, asphalt minerals and coal ash [6] [7] [8]. In this way, it was inferred that reduction spheroids with dark cores in red beds are symbols of biological remains or activities, in other words, the dark cores may be fossils. However, we can't decide the biological species so far.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Lithostratigraphy of the Late Cretaceous Khao Ya Puk Formation in Nakhon Thai Region, Thailand: Implication for Depositional Environment

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Abstract

The Khao Ya Puk Formation (>400 m thick) is well exposed in the Nakhon Thai Region, and is subdivided into three members. The Khao Ya Puk Formation overlies conformably on top of the anhydrite layer of the upper rock salt Maha Sarakham Formation. In turn, it is overlain unconformably by the Phu Khat Formation. The Khao Ya Puk Formation is interpreted to have been deposited by freshwater lake area in arid climate inland subkha in the Late Cretaceous. Lithostatigraphically, Khao Ya Puk Formation can be correlated with the Phu Tok Formation that has been deposited in the Khorat-Ubon basin and Udon-Sakon basin of the Khorat Plateau.

Keywords

Khao Ya Puk Formation, Nakhon Thai Region, Lithostratigraphy

1. Introduction

The stratigraphy of the non-marine Khorat Group in the Khorat Plateau has long been studied by many geoscientists. The sequence of the Khorat Group extends beyond the rim of Khorat Plateau to the Nakhon Thai region [1]. The two regions are separated by pre-Cretaceous rocks in the Loei-Phetchabun Fold Belt. The stratigraphy of the upper most part of the red beds is mentioned in Nakhon Thai region, namely, as the Khao Ya Puk Formation. Nonetheless, the detailed lithostratigraphy of the formation is still ambiguous. Therefore, the main objective of this study is focusing on its lithostratigraphy according to three reference sections.

2. Stratigraphy

2.1. Definition and Type Section

The Khao Ya Puk Formation was named by Kosuwan [2] in geological map in scale of 1:50,000 on Thai Royal Survey Department topographic map series L7018 sheet 5143 I & II of Ban Nam Khum and Amphoe Nakhon Thai. The formation thickness is 200-350 meters. The designated type section is broadly located on a local road from Na Khon Thai to Ban Nam Khum, but the detailed lithology was not described. In this study, three reference localities are designated and measured including Khao Kadai Ma temple section, Route No_2195 Na Haeo District-Ban Pak Man section, and Route No_2113 Dan Sai District-Ban Nongsim section.

2.2. Contact

Lower contact: A ground water drill well at Ban Nam Lat, NaKhon Thai District, has proved that the Khao Ya Puk Formation is underlain conformably by the Maha Sarakham Formation [3].

Upper contact: The Khao Ya Puk Formation is overlain unconformably by the Phu Khat Formation [4]. The abrupt facies change between the two formations together with the contrasting detrital zircon age support the interpretation.

2.3. Lithology and Extend

The lower Khao Ya Puk Member is composed of thick bedded reddish brown mudstone, yielding obvious calcrete nodules in the upper part. The middle Khao Ya Puk Member consists of reddish brown sandstone interbedded with shale and siltstone. Giant mud cracks and calcrete nodules occurred in shale beds. Sandstone moderate- to very fine-grained, well sorted, sub rounded to well rounded with cross bedding, sole marks, and mud drape are present. The upper Khao Ya Puk Member is characterized by thick bedded reddish brown sandstone. It is moderate- to fine-grained, well sorted and well rounded with a large cross-bedding and high angle foresets.

The Khao Ya Puk Formation is presented throughout the area of this paper and extends somewhat northeast to north into Uttaradit province and beyond the Thailand border into the Ken Thao area in Laos. In the study area, the formation exposes in Chat Trakan and Nakhon Thai district of Phitsanulok province and Na Haeo and Dan Sai district of Loei province. The thickness throughout the formation is not less than 400 meters.

2.4. Age and Correlation

As the formation is underlain conformably by the mid-Cetaceous rock salt Maha Sarakham Formation [5] and covered by the latest Cetaceous Phu Khat Formation [4], therefore the formation is assigned to the Late Cretaceous. Lithostatigraphically, the Khao Ya Puk Formation can be correlated with the Phu Tok Formation. The rock sequence contains in both formations which have similar lithology showing a coarsening and thickening upward sequence.

2.5. Depositional Environment

The Khao Ya Puk Formation is interpreted to have been deposited by freshwater lake area in arid climate inland subkha in the Late Cretaceous. The lower member is interpreted to be deposited at center of the lake as it is characterized by the thick bedded reddish brown mudstone. The middle member is marginal of the lake as it presents the reddish brown sandstone interbedded with shale and siltstone with the giant mud crack. The upper member is interpreted to be of an aeolian dune and inter-dune environment of the last stage of deposition as it is characterized by well sorted and well rounded sandstone with large scale cross-bedding and high angle foresets with an inverse grade.

3. Conclusion

The 400 m thick Khao Ya Puk Formation can be subdivided into three members. It can be correlated with the Phu Tok Formation in the Khorat Plateau, conformably overlies the Maha Sarakham Formation, and is overlain unconformably by the Phu Khat Formation. It was deposited by freshwater lake area in arid climate inland subkha in the Late Cretaceous.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Landslide Hazard Zoning in Na Heaw District, Loei Province, Northeastern Thailand

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Abstract

Nahaew District in northeastern Thailand, where crops out the Cretaceous Khorat Group, is a priority area for landslide hazard assessment through landslide susceptibility and hazard zoning. Through an interpretation of Google Earth imagery, several landslides were mapped to create landslide inventory map. Parameter maps were constructed and compiled into a database with the landslide inventory. The bivariate (frequency ratio) statistical analysis was used to establish landslide susceptibility maps, which were classified into five susceptibility classes. Another approach was landslide hazard zonation. Urban and rural planning and engineering construction need especially hazard zonation map in medium and local scale. GIS and remote sensing techniques have many advantages in the preparation of the map including regional, medium and local scales. In this study, landslide zonation map was prepared using runout model by assigning engineering properties and Digital Elevation Model (DEM) as well as rainfall data. The result was landslide hazard zonation of the area and can be used for urban planning. The report and recommendation have contributed to local authority.

Keywords

Landslide Assessment, Slope Stability, Hazard Zoning

1. Introduction

Landslide, a significant natural hazard in the high mountain area, has drawn worldwide attention due to increasing awareness of its socioeconomic impacts, as well as, the increasing pressure of urbanization on the mountain environment [1]. Landslide study establishes a significant constraint to development and urban planning. Landslide susceptibility mapping can be the preliminary step in mitigating the damages [2]. Moreover, landslide susceptibility assessment is an important process for prediction and management of natural disasters. It is also a necessary step for integrated watershed management, hazard mitigation, and urban planning in government policies [3] [4]. A landslide susceptibility or hazard map depicts areas likely to have landslides in the future by correlating some of the principal factors that contribute to landslides with the past distribution of slope failures. Recently, DMR has been assigned to study about landslide hazard zonation in Na Haew District, Loei Province, NE Thailand.

2. Study Area

The Na Haew District is located between 17˚16'43'' and 17˚35'43''N latitudes and 100˚49'50'' and 101˚107'36''E longitudes. It covers a total area of approximately 625 km^2. The study area is represented by the rocks of Phu Khat and Khao Ya Puk Formations.

3. Data and Method

In current study, a landslide inventory map was prepared using field surveys, local information, and satellite interpretation obtained from Google Earth software. The landslide scars found in Na Haew District were shown in **Figure 1(a)**.

In this study, nine independent factors were chosen as potentially contributing to landslide susceptibility, slope, elevation, aspect, lithology, distance from drainage, distance from lineaments, NDVI, SPI and land-use. The availability of thematic data varies widely, depending on the type, scale, and method of data acquisition.

For landslide susceptibility mapping within Na Haew we choose statistical approach and frequency ratio methods. The landslide inventory map was compared with the various factor maps using a selected statistical method. By using statistical analysis, the factor and/or combination of factors that have resulted in slope instability in the past are determined. Quantitative predictions can then be made for areas where no landslides are currently present, but which have similar

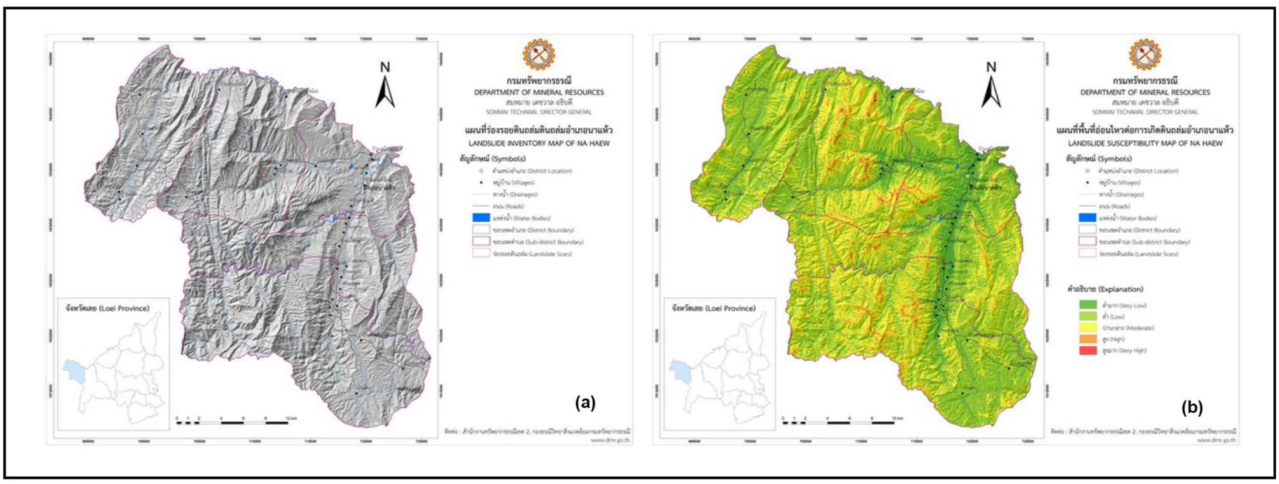

Figure 1. Landslide inventory map (a) and landslide susceptibility map (b) of Na Haew District.

conditions to those where landslides exist. In frequency ratio ananysis the Frequency Ratio value (*Fr*) for each factor's range was calculated by dividing the landslide occurrence ratio by the area ratio. Then, the frequency ratios were summed to calculate the landslide susceptibility index (*LSI*) as shown in Equation (1).

$$LSI = \sum Fr_n \tag{1}$$

4. Results

Once a landslide susceptibility map is created, it is necessary to divide this map into different susceptibility classes. The simplest method is to assign the categories using expert opinion as done by [5]. The most common method for this purpose depends on the optimum bandwidth classification of the histograms of various parameters [6]. However, this is not straight forward as there are no statistical rules which can categorize continuous data automatically [7]. Recently, mathematical methods for data classification have become available in GIS software. In literature, there are many methods used [6] [7] [8]. These are based on manual or natural breaks, equal intervals, or statistical consideration, and can be described as follows. For the susceptibility classification for this study, the natural break method was used, and the susceptibility classes were divided into 5 classes (very low, low, moderate, high, very high) as shown in **Figure 1(b)**.

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Conflicts of Interest

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Study of Rock Mechanic Property and Mineralogy Relationship of the Huai Hin Lat Formation, Sap Phlu Basin, Northeastern Thailand: Implications for Understanding of Shale Gas Reservoir Rock

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Abstract

Thailand is lacked of gas that more information of probable (P2) and possible (P3) reserve data including shale gas can be acceptable to prove (P1) reserve data for new gas field. This research had implicated for understanding of unconventional reservoir rock by rock mechanical, micro-CT, and geochemistry analysis of the Huai Hin Lat Formation. The rock mechanical analysis is composed of average young's modulus, Poisson's ratio, and compressive strength of 1933.79 MPa, 0.1472, and 52.56 MPa. The average porosity of 6.89% consists of 5.41% and 1.48% of closed and open porosities. The average mineralogical results consist mainly of 57.60% and 42.40% of brittle and ductile minerals indicating more elasticity except Bed 6. The Bed 6 is significantly higher quartz (15%) and brittle minerals (64%) indicating to easier fracture are, therefore, lower compressive strength (25.93 MPa), young's modulus (1729.10 MPa) and Poisson's ratio (0.0705). The Beds 3B is slightly higher clay containing slightly higher closed porosity (5.46%) but the Bed 14 is slightly higher brittle mineral indicating to slightly higher open porosity.

Keywords

Compressive Strength, Young's Modulus, Poisson's Ratio, Brittle Mineral, Porosity

1. Introduction

Since 2014, there were 3 gas fields in the Khorat Plateau that only two former gas fields are commercial [1]. Another gas field is the Dong Mun that was newly discovered. It is absolutely proved that a proved (P1) reserve data will belong to a probable (P2) and possible (P3) reserve data by more studying. Some researchers are interested in unconventional gas field especially shale gas. The Huai Hin Lat Formation is one among others that are tried to develop a new shale gas field. Source rock potential is successful by former researchers. Therefore, more understanding rock mechanic properties are key control evaluation of unconventional reservoir rock.

2. Materials and Methods

The Beds 2, 3B, 6, 9, and 14 are suitable to be measured and described based on rocks cropping out in the Ban Nong Sai section, which are composed mainly of shale, mudstone, marl, and limestone [2]. All samples were tested for assessing unconventional reservoir potential with methods as follow. A uniaxial compressive machine was used for measuring compressive strength, Poisson's ratio, young's modulus, and failure mode. A micro computed tomography (Micro-CT) method can be used to analyze the porosity by using Skyscan 1172 from scanned datasets. A Geochemical method can identify minerals by using an X'Pert PRO Dy 2198 basing on X-ray diffraction analysis.

3. Results and Discussion

The compressive strength, Poisson's ratio, and young modulus are shown in **Table 1** with compressive longitudinal splitting [3]. The young's modulus of the Beds 6 and 9 is the lowest and highest, respectively. The high young's modulus is that a rock extremely expands conforming to positive relationship ($R^2 = 0.3849$) as well as compressive strength and young's modulus relationship ($R^2 = 0.3398$). The compressive strength of the Beds 6, 2 and 9 is increasing which suggests a relatively higher ductile property. Moreover, relationship between compressive strength and Poisson's ratio shows positive covariation ($R^2 = 0.9978$), which is very interrelated. It indicates that higher compressive strength relates to higher lateral expansion of sample under loading.

Results of mineralogical analysis are shown in **Table 1** with higher content of clay. Matrixes contain clays of ductile minerals may lead to higher elasticity. Contrastingly, cracks are generated as easier under formation of higher brittle minerals. Clay of the Bed 6 is lower than the Beds 2 and 9 though quartz and feldspar are higher. Therefore, the Bed 6 is easily fractured with lower compressive strength of 25.93 MPa. The Poisson's ratio and young's modulus of the Bed 6 are conformable to compressive strength due to effects of lower elasticity. The ductile mineral of the Bed 2 is remarkably higher than the Bed 6. Conformably, higher elasticity affects the Bed 2 that compressive strength is higher as well as the Bed 9 is the highest.

According to all beds, only the Beds 3B and 14 were scanned for porosity as shown in **Table 1**. The value of clay in Bed 3B is higher than that of the Bed 14.

Table 1. Mineralogic fraction XRD, rock mechanic properties, and porosity data of the Ban Nong Sai section.

Beds	Total minerals (%)						Rock mechanic properties			Porosity (%)		
	Zeolite	Quartz	Feldspar	Calcite	Dolomite	Clay	σ_c (MPa)	ν	E (MPa)	Closed	Open	Total
14	3.00	7.00	20.00	21.00	5.00	44.00	-	-	-	5.35	1.68	7.03
9	2.00	9.00	8.00	31.00	6.00	44.00	66.28	0.1898	2292.73	-	-	-
6	3.00	15.00	10.00	32.00	4.00	36.00	25.93	0.0705	1729.10	-	-	-
3B	2.00	8.00	15.00	21.00	7.00	47.00	-	-	-	5.46	1.28	6.74
2	2.00	6.00	18.00	25.00	8.00	41.00	65.46	0.1812	1779.54	-	-	-
Average	2.40	9.00	14.20	26.00	6.00	42.40	52.56	0.1472	1933.79	5.41	1.48	6.89

Remark: σ_c is compressive strength, ν is Poisson's ratio, and E is young's modulus.

The higher quantitation of clay is conformed to gradually increase of their porosity. Loucks *et al.* [4] suggest that micropores can be generated through fine-grained rocks which are commonly slot-like or interspersed between curved clay plates by shrinkage from higher thermal alteration. Both beds containing closed porosity are slightly similar in quantitation due to effect as is known as clay. Moreover, open porosity of the Bed 14 is higher than another that is associated with higher brittle mineral. It can be fractured as naturally depending on brittle characteristics that affecting to slightly higher open porosity. The porosity of Beds 2 and 9 is similar to that of the Bed 14. Contrastingly, the Bed 6 may be significantly different from others.

4. Conclusions

Average mineralogical results consist mainly of 57.60% brittle mineral and 42.40% ductile mineral (clay) indicating more elasticity except Bed 6. The Bed 6 is of significantly higher percentage of brittle mineral (64%) referring to easier fracture.

The Bed 6 is easily fractured with lower compressive strength of 25.93 MPa as well as young's modulus (1729.10 MPa) and Poisson's ratio (0.0705) due to effects of lower elasticity. The young's modulus and Poisson's ratio of 2292.73 MPa and 0.1898 of the Bed 9, significantly higher than those of the Beds 2 (1779.54 MPa and 0.1812), are remarkably higher than those of the Bed 6. Conformably, higher elasticity affects the Beds 2 and 9 that are of higher values of compressive strength (1779.54 MPa and 2292.73 MPa). The Beds 3B and 14 were scanned for porosity of 6.74% and 7.03%, respectively.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Field Excursion Introduction for IGCP 679 1st International Symposium: Progress in Cretaceous Geology in Shandong Province, China

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Abstract

The non-marine Cretaceous sequences are well developed in the relict basins, *i.e.* the Luxi basin in the west, and the Jiaolai basin in the east of Shandong Province. The Lower Cretaceous Santai Formation (140 - 136 Ma) in the Luxi basin contains aeolian dune deposits, which were formed under the control by westerly. The Cretaceous strata of the Jiaolai basin are divided into three groups: *i.e.* in ascending order, the Laiyang, Qingshan and Wangshi groups. New SHRIMP zircon U-Pb radiometric dating data demonstrated six Cretaceous volcanism episodes. The lower part of the Wangshi Group should be assigned to the upper Lower Cretaceous. An Ir anomaly recovered in the lower Jiaozhou Formation suggests that the Cretaceous/Palaeogene boundary would be in the interval between 537.3 - 537.4 m in the borehole JK1. At last the detailed information about the pre-symposium field excursion was introduced.

Keywords

Cretaceous, Lithostratigrphy, Chronostratigraphy, Shandong Province, China

1. Introduction

The study of Cretaceous geology in Shandong began in the early 1920s. The non-marine Cretaceous strata were originally subdivided into the Santai Serie, Mengyin Serie (including the Laiyang beds, Qingshan beds) and Wangshi Serie, and were assigned a Jurassic-Cretaceous age. Since then palaeontologists begun to find in the Cretaceous strata abundant fossils, like megaplants, bivalves, gastropods, ostrocods, clam shrimps, insects, fish and dinosaurs.. Nowadays, the Cretaceous is divided into the Santai Formation, the Laiyang, Qingshan and Wangshi groups. In recent years, Shandong Province has become a hot research area because of its extremely special geotectonic position. Research interests focus on paleogeography, paleoclimate, paleoecological evolution of the Cretaceous basins, basin forming mechanism, deep dynamic background, subduction of the palaeo-Pacific plate, North China Craton destruction, uplift of the Sulu orogenic belt and tectonic evolution of the Tanlu fault zone [1]. In this paper, we would like to summarise new progress in Cretaceous research in Shandong Province, and to introduce the pre-symposium field excursion.

2. Geological Setting

Shandong Province is located in the east Eurasia and neighbouring the Pacific plate. The Cretaceous continental volcanic-sedimentary relict basins (Luxi basin in the west, Jiaolai basin in the east) straddle the southeast margin of the North China plate, the Tanlu fault zone and the Sulu orogenic belt (**Figure 1**). The Cretaceous strata in the area are continuous, and in contact with the underlain Middle Jurassic and the overlying Eocene with unconformities. They are divided into 22 formations in three groups (**Figure 2**).

3. New Results

The Lower Cretacous Santai Formation in western Shandong is dated as 140 - 136 Ma, and contains Aeolian dune deposits (similar to that recovered in the

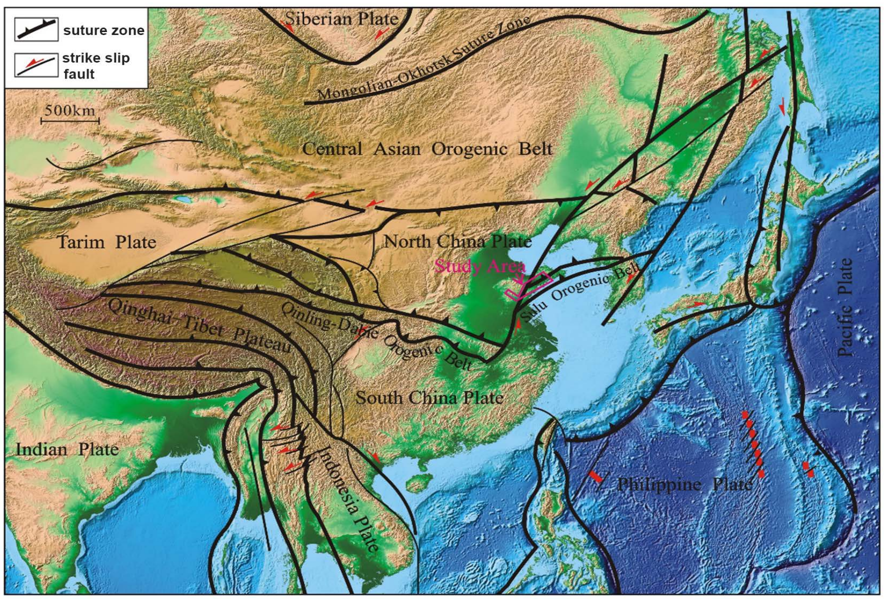

Figure 1. Geotectonic location map of Shandong Province. stratigraphic type sections and well-known fossil sites which would be visited during the pre-symposium field excursion.

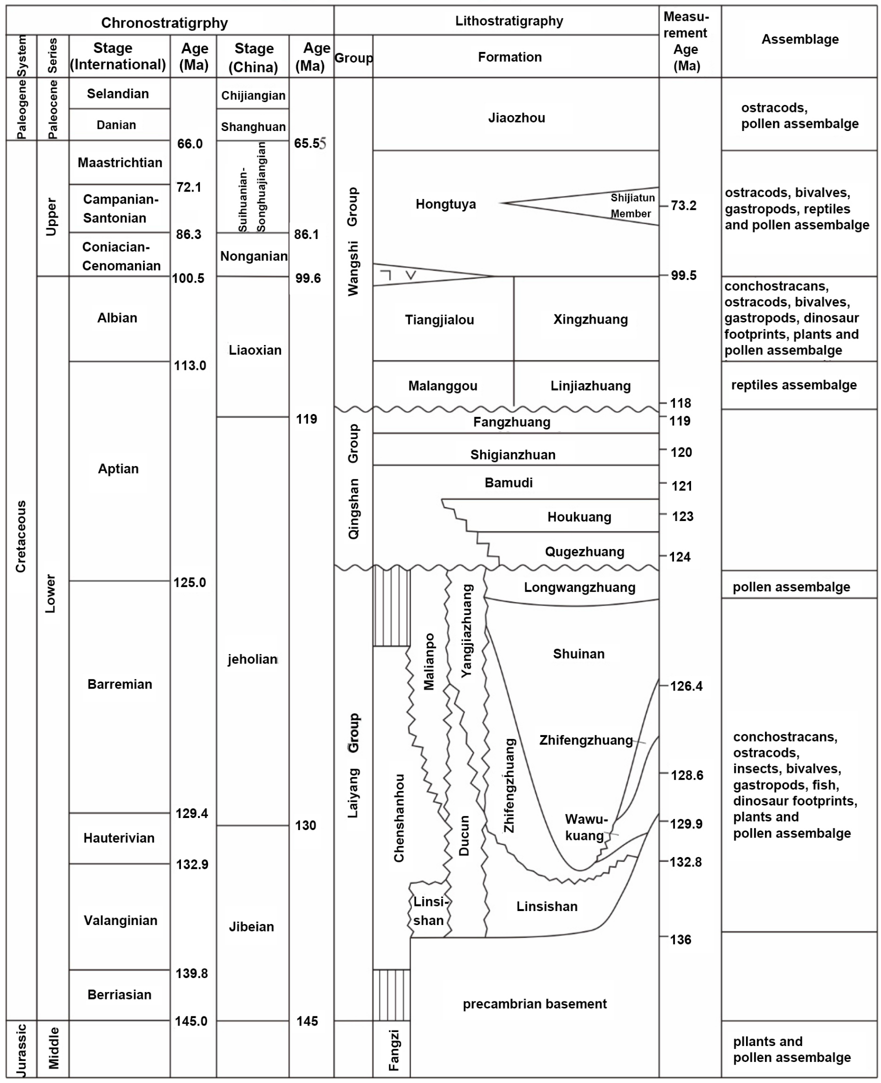

Figure 2. Lithostratigraphic and chronostratigraphic framework of the Jiaolai basin.

Tuchengzi Formation of northern Hebei and the lower Zhidan Group of the Ordos basin), which was formed under arid climate controlled by the westerly. The Qugezhuang Formation is assigned to the Qingshan Group because of its unconformably overlying on the Laiyang Group. The Malanggou and Tianjialou formations are correlated with the Linjiazhuang and Xingezhuang formations of the lower Wangshi Group, and are assigned to the upper Lower Cretaceous (Figure 2). An Ir anomaly with a peak content of 0.37 ng/g in the lower Jiaozhou Formation (borehole JK1 537.3 - 537.4 m) indicates a Cretacous/Palaeogene transition horizon, with abundant Paleocene *Aquilapollenites* species.

4. Pre-Symposium Field Excursion

The field excursion is planned for three days (Figure 3). Day 1: We will first visit the aeolian dune deposits of the Santain Formation exposed in the Red Stone Park of Laicheng district of Jinan city, then go to see the dinosaur footprints of

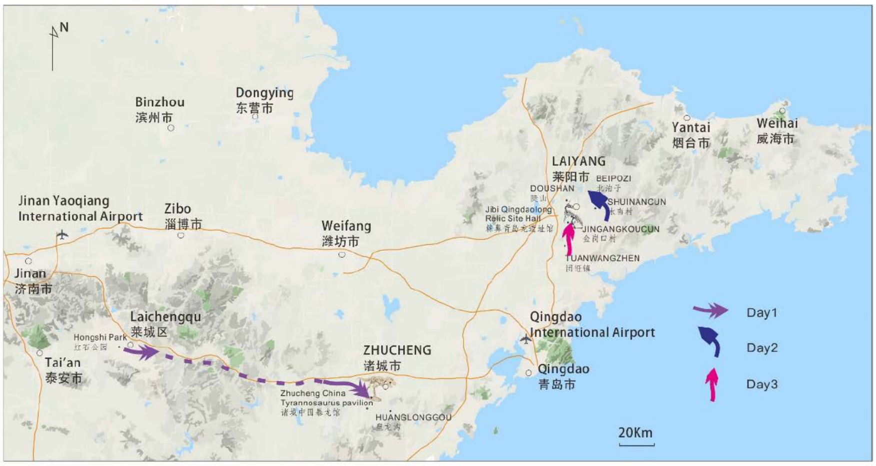

Figure 3. Field excursion route map.

the Yangjiazhuang Formation at Huanglonggou and dinosaur fossils of the lower Hongtuya Formation in Zhucheng. Day 2: fossil insect site of the Shuinan Formation at Tuanwang Zhen, the type section of the Laiyang Group between Zhifengzhuang and Shuinan villages of Longwangzhuang Zhen, and the *Lycoptera* fish fossil site of the Shuinan Formation at Beipozi of Muyudian Zhen, Laiyang. Day 3: type sections of the Houkuang, Bamudi and Shiqianzhuang formations of the Qingshan Group, and the Linjiazhuang Formation of the Wangshi Group between Pomaikou and west Sunjiakuang, the Hongtuya Formation of the Wangshi Group between Jiangjuding and Jingangkou, and the 2nd dinosaur fossil pit and dinosaur museum of Laiyang.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Diversification of Eupolypods in Mid-Cretaceous—Evidenced by Myanmar Amber Forest

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Abstract

The evolutionary history of Eupolypods still remains unclear, especially on its diversification scenarios. In recent years, it has been found that approximately 100 million-year-old Myanmar amber provides a unique source of polypod fossils. Different families and numerous sporangia, spores, and scales have been found in Myanmar amber. These discoveries are nevertheless important because they provided the first unequivocal fossil evidence that the diversity of eupolypod ferns was present already in the mid-Cretaceous Myanmar amber forest. This clearly shows that Eupolypods originated before mid-Cretaceous, probably as early as the Early Jurassic, which is consistent with the recent divergence time estimate based on molecular dating.

Keywords

Mid-Cretaceous, Myanmar Amber, Eupolypods, Divergence Time

In the last two decades, unprecedented progress has been made by employing DNA sequence data and phylogenetic approaches toward a full understanding of the relationships that shape the major branches of the fern tree of life. In 2006, these phylogenetic hypotheses were consolidated and presented in a revised classification for ferns [1]. Smith *et al.* [1] recognized a monophyletic order Polypodiales ("Polypods", **Figure 1**), and most species within the order belong to the Eupolypods, composed of two clades: Eupolypods I and Eupolypods II [2] [3]. Together, the eupolypod lineages include nearly 6000 species—more than half of extant fern diversity.

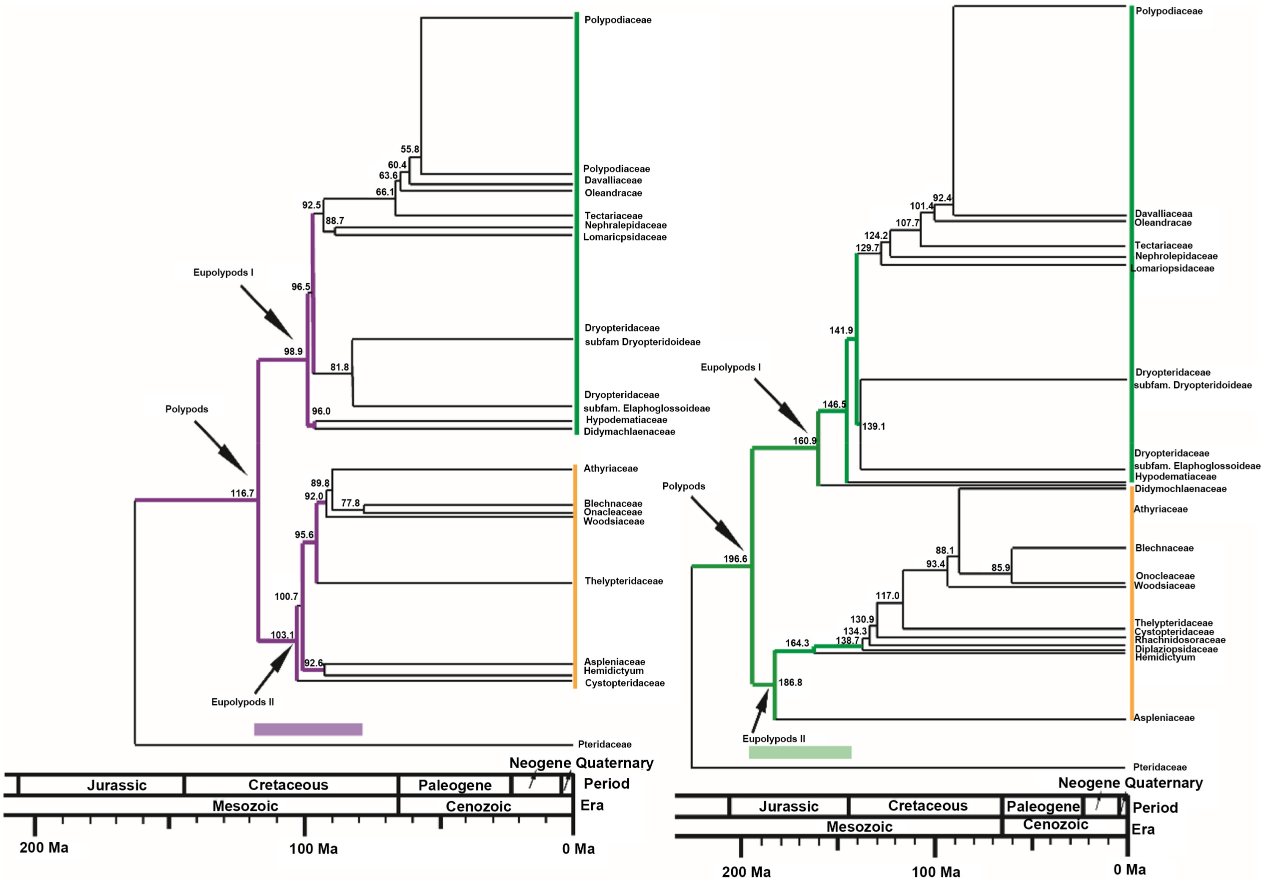

Figure 1. Eupolypod phylogenetic chronology based on the study of [4] (left) and [5] (right). Divergence time estimates for eupolypod lineages are indicated on the left side of the time tree.

However, the evolutionary history of the ferns remains incompletely understood, especially on its diversification scenarios, for example, most DNA-based divergence-time studies indicate that Eupolypods diversification occurred in the Late Cretaceous [2] [4], but Testo and Sundue [5] demonstrated that Eupolypods originated as early as in the Early Jurassic (**Figure 1**). The latter authors thought their age estimates to be much more realistic because they used more taxa (4000 taxa), a more advanced dating algorithm, and many more fossil calibrations with different placements. Although a range of molecular dating methods is now available, they all share a vital dependence on fossils as one of important age calibrations. It is therefore of prime importance to thoroughly document and critically evaluate new and informative fern fossils, especially those fossils from those periods of geologic time that are believed to represent important phases in the establishment and/or radiation of new fern lineages [6]. However, so far, no single study based on fossils from stratigraphic depositions has provided unequivocal evidence for a Cretaceous or pre-Cretaceous occurrence for Eupolypods [2] [7] [8] [9].

In the recent years, it has been found that approximately 100 million-year-old Myanmar ambers provide a unique source of polypod fossils. Eight fossils of

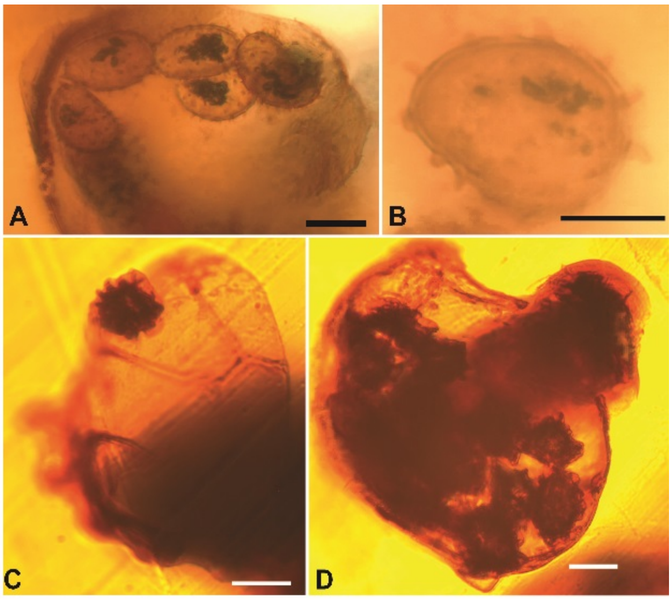

Figure 2. Eupolypod spores (monolete with distinct perine) in Cretaceous Myanmar amber ((A) (B), #2016-03; CD, #2018-67). Scale bars = 20 μm (A) (C) (D), and 10 μm (B).

different families and numerous sporangia, spores, and scales have been found in Myanmar ambers [6] [10]-[15], including eupolypod-like fossil *Cretacifilix fungiformis* [10], the first compelling eupolypod fossil *Holttumopteris burmensis* [6], eupolypod fossil scales, and spores (**Figure 2**). All these findings suggest that a diversity of eupolypod ferns was present already in the mid-Cretaceous Myanmar amber forests, clearly showing that Eupolypods originated before mid-Cretaceous, probably as early as the Early Jurassic, consistent with the divergence time estimates from the study of Testo and Sundue [5]. Myanmar amber is about to become the most important source of new information on mid-Cretaceous fern diversity, as work on the Myanmar amber deposits continues, new fossils will be discovered and described and can be used to refine reconstructions of fern evolution during this important period of geologic time (*i.e.*, the Cretaceous Terrestrial Revolution, [16]), and eventually can be used to piece together the steps and stages in the evolution and radiation of the eupolypod ferns [6].

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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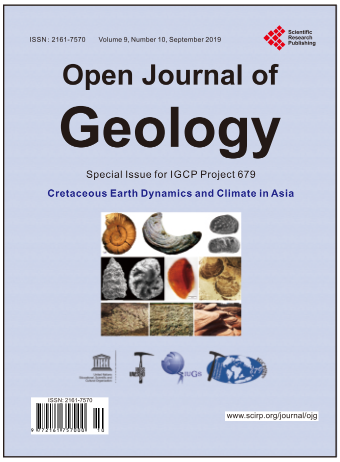

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