Progress in the Research of Dinosaur Eggs

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Introduction

Dinosaur eggs available for study have been preserved either as fossilized calcareous egg shell or remnant impressions in sedimentary rocks. Currently, global discoveries of these fossils are relatively few. Because these fossils are protective mechanisms for embryos, their morphology and structure share no characteristics with osteological fossils, and as they do not reflect a relationship to the mother, it is extremely difficult to diagnose which taxon produced them. To date, these fossils have not been considered to be of value towards the disciplines of paleontology and stratigraphy, and have been considered only as a rare fossil occurrence.

China has the most frequently abundant dinosaur egg burials in the world; however, under the reactionary social system of former China that was controlled and pillaged by imperialism, only several dinosaur eggs were recovered from Erlian, Inner Mongolia, and southern Liaoning Province. After the foundation of the People's Republic, following the socialist revolution and the vigorous developments of socialist construction, abundant recognition was finally given to the study of dinosaur eggs through the discoveries of many nests, relatively complete fossil eggs, and a large amount of fragmentary egg shell within the provinces of Shandong, Guangdong, Jiangxi, the Xinjiang Autonomous Region, and other localities. Particularly since the proletariat Cultural Revolution, and following the extensive developmental work in the South China Red Beds, more recent important discoveries were made from such extensive regions as central, southern, and eastern China, where eggs have been found to be of important practical use in determining the Cretaceous-Tertiary boundary within the red beds of South China, and hence have created a host of new questions relating to dinosaur egg research.

Within the past several years, and particularly with the aid of microscopy, preliminary observations of dinosaur eggshell fragments indicate an abundant assemblage of dinosaur egg morphotypes in the Late Cretaceous deposits of China that display a distinct stratigraphic distribution pattern. As a result, these are now undoubtedly significant toward sedimentological as well as paleontological research. This paper presents several superficial hypotheses presented for constructive criticism regarding concepts about dinosaur egg taxonomy and evolution; age, subdivision, and correlation of dinosaur-egg-bearing sediments; and Cretaceous climatic fluctuation trends.

Problems Concerning Dinosaur Egg Taxonomy

Nomenclature and taxonomy are fundamental aspects of dinosaur egg research in addition to being the initial problem to be solved. The phylogenetic description of fossil eggs by many workers in the past was generally founded on the basis of the dinosaurs coexisting with them, or else made by designating the specimens with the generalized term 'dinosaur eggs'. An exception was a taxonomic division made upon the basis of several morphological characteristics. Specimens discovered and treated in this manner became increasingly numerous, accompanied by the growth of skepticism among workers who questioned the applicability of this archaic system of dinosaur egg taxonomy. This is understandable considering that usually fossils of dinosaurs rarely coexist with fossil eggs. Even when this condition does occur, the eggs have been associated with numerous dinosaurs, creating a difficulty in adequately or reasonably deciphering which dinosaur produced which egg morphotype. Moreover, there is the possibility that the dinosaurs derived from these fossil eggs have yet to be discovered or may be represented by their fossil eggs alone.

The absence of a reliable scientific basis or synthesized phylogenetic methodology has created a situation in which a single morphotype may have several species names. This is exemplified by specimens derived from the People's Republic of Mongolia and China that are elliptical in shape and display an external surface ornamentation as delicate, chain-shaped corrugated striations and designated by some as *Protoceratops* eggs, by others as *Elongatoolithus*,

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The absence of a reliable scientific basis or synthesized phylogenetic methodology has created a situation in which a single morphotype may have several species names. This is exemplified by specimens derived from the People's Republic of Mongolia and China that are elliptical in shape and display an external surface ornamentation as delicate, chain-shaped corrugated striations and designated by some as *Protoceratops* eggs, by others as *Elongatoolithus*, by some as Angusticanaliculate, hadrosaur eggs, or other appellations. This has created immense difficulties toward the diagnosis and correlation of dinosaur eggs.

Within recent years renewed research with the application of microscopy has been conducted upon the fossil dinosaur eggs from the Chinese localities of Jiayang, Shandong Province, and Nanxiong, Guangdong Province. The results have been the discovery of an extreme diversity in microscopic structure. Moreover, specimens initially diagnosed as *Oölithes spheroides* may now be recognized to comprise at least eight species morphotypes. Additionally, they may be arranged into a systematic complex of different grades based upon their degree of similarity or difference. In this manner, specimens initially diagnosed as *Oölithes elongatus* may be clearly distinguished as at least three species morphotypes. These morphotypes should have been produced by three different dinosaur taxa, as microstructure diversity among the dinosaur eggs cannot be due to individual variation as suggested from data derived from research on eggshells produced by several reptile and avian taxa. However, as noted previously, morphological characteristics of eggshells do not reflect maternal consanguinity, and thus it is difficult to apply dinosaur nomenclature to validate fossil eggshells. This adequately explains why original taxonomic techniques are obsolete in relation to recently discovered facts, for prior techniques do not comply with correct channels of methodology and surely affect the rate and quality of the work.

It is believed here that relationships as well as taxonomic differences exist among the many groups of dinosaur eggs known. If one begins with the comparison of cross-sectional morphology to determine the taxonomic position, then erects a potentially consistent evolutionary direction and ancestral relationship, the practical application of using the systematic taxonomy of dinosaur eggs would be of value both empirically and theoretically toward the elusive evolutionary patterns of eggshells, subdivision of geologic ages, facies studies, and other aspects. Further careful consideration of this aspect was undertaken by Z.K. Zhao (1975), who made preliminary suggestions regarding the principles of dinosaur egg taxonomy and nomenclature, in addition to dinosaur egg systematic relationships. That is to say, it is possible to erect a taxonomic system from subdivided classification zones based upon a hierarchy of dinosaur eggs according to their morphological features or characteristics, including general morphology, size, surface ornamentation, microstructure, and more. Binomials, as universally used in the biological world, should be formally adopted as the applied nomenclature, with the scientific name being composed of a generic and species designation. In order to express the concept of a fossil egg category, and in order to avoid confusion with other systematic classifications, the generic suffix *oolithus* is hereby proposed as the standard.

There are no living representatives of the Class Dinosauria due to their complete extinction at the terminus of the Mesozoic Age. Consequently, dinosaur egg research requires the support of knowledge obtained from morphological studies of extant avian eggs and calcareous shells derived from several taxa of reptiles. But attention must be given to several problems that arise when conducting a taxonomic diagnosis based upon comparative morphologies of eggshell cross-sections, as listed below:

(1) Eggshells are the reproductive byproducts of an environmental adaptation within a distinct phase of vertebrate evolutionary history. Structure and function have become perfected through continuous evolution and development over a long and slow evolutionary process. The concluding evolutionary trend was derived from the lowest grade to the highest, and the simple to the complex. This is not equivalent to stating that it may be necessary to combine the age of appearance because in several circumstances simplified forms are absent.

(2) Taxonomic ranking based upon morphological characteristics of eggshells may not be arbitrarily subdivided or synonymized, but must embody the concepts of different adaptive directions through the course of their evolutionary history, or developmental phase.

Consequently, to erect a taxonomic position at the species, genus, or family rank, one must not only apply the correlation of similarities or dissimilarities between one taxon and another, but should also consider important distinctions from many aspects such as functional morphology, derived character states, and divergence timing.

(3) Microstructure including the mammillary layer, palisade layer, and respiratory pores constitute the fundamental units of the eggshell and frequently differentiate morphological composition. Currently, research results in distinguishing different species of dinosaur egg cross-sections are advanced through the support of microscopy, and confirm the distinct presence of morphological and variation patterns. Generally speaking, microstructure is relatively stable data applicable to dinosaur egg systematic taxonomy, and may provide a strong basis for the erection of taxa particularly at the generic and higher taxonomic positions. However, during fossilization, eggshell microstructure is frequently damaged by geologic processes. But on any large-scale fossil specimen it is possible to recover well-preserved microstructure.

(4) The determination of normal and abnormal structure is a factor. Pathological and physiological hindrances give rise to eggshell abnormalities, with numerous data present among avian and several reptile taxa. It is interesting that similar abnormalities have been noted on several dinosaur eggs, such as a double eggshell abnormality and other phenomena exhibited on *Macroolithus yaotunensis* and the dinosaur eggs from southern France (Megaloolithidae). Most recently, the double shell abnormality has been observed in several dinosaur eggs from Xixia, Henan. Therefore, the attention to normal and abnormal structure not only facilitates the objective diagnosis for a taxonomic assignment, but also provides data for the disciplines of paleopathology and paleophysiology.

Utilizing the aforementioned recommendations for dinosaur egg taxonomy and nomenclature, it is first necessary to initiate the diagnosis and taxonomy of the dinosaur eggs discovered from each locality in China. Two family names have already been erected, the Elongatoolithidae (Zhao, 1975) and the Faveoloolithidae (Zhao and Ding, 1976). Here it is necessary to amend the spherical eggs found at Laiyang, Shandong Province. In the past there were abundant efforts conducted upon this taxonomic group of fossil eggs, and there is no doubt that these are clearly distinct from the Elongatoolithidae, Faveoloolithidae, and the dinosaur eggs from southern France (the Megaloolithidae). Based upon their size, morphology, striated ornamentation, microstructure, and other factors, these should represent another small branch in the systematic evolution of dinosaur eggs, and consequently are hereby erected as a new family, the Spheroolithidae, as organized and described below:

Spheroolithidae Fam. nov.

Nearly elliptical in shape, relatively small, longitudinal diameter in the range of variation of between 70-100 mm. Greatest transverse diameter in the range of variation between 60-80 mm. External surface ornamentation with small tuberosities. Shell is composed of the palisade and mammillary layers. Respiratory pores are crevice shaped and irregular. Arrangement sequence within the nest is uncertain.

Spheroolithus gen. nov.

Mammilla are cone shaped, irregularly patterned in lateral cross-section, and have well-developed lacunae. The thickness of the mammillary layer is approximately one-third the thickness of the shell. The respiratory pores are inflated at their center.

1. *Spheroolithus chiangchiungtingensis* (=*Oölithus chiangchiungtingensis)* (Young, 1954, Zhao and Jiang, 1974).

2. ?*Spheroolithus megadermus* (=Oölithus megadermus) (Young, 1959; Zhao and Jiang, 1974).

***Paraspheroolithus* gen. nov.**

Mammilla are nearly columnar in shape, and in cross-section are generally elliptical. Mammilla arrangement generally assembled from two or more clusters. Lacunae relatively conspicuous only between the mammillary complexes. Respiratory pores are irregular.

3. *Paraspheroolithus irenensis* (=*Oölithes irenensis*) (Young, 1954, 1965; Zhao and Jiang, 1974).

***Ovaloolithus* gen. nov.**

This taxon is nearly elliptical in shape, with tightly arranged columnar mammillae. Palisade layer is compact with a crystal structure between the prismatic columns radiating externally. Mammillary and palisade layers display a thickness ratio of approximately 1:1. Respiratory pores are relatively straight and gracile.

4. *Ovaloolithus chinkangkouensis* (=*Oölithes chinkangkouensis* Complex A) (Young, 1954; Zhao and Jiang, 1974).

5. *Ovaloolithus tristriatus* (=*Oölithus chinkangkouensis* Complex B) (Zhao and Jiang, 1974).

6. *Ovaloolithus mixtistriatus* (=*Oölithes chinkangkouensis* Complex C) (Zhao and Jiang, 1974).

7. *Ovaloolithus monostriatus* (=*Oölithes chinkangkouensis* Complex D) (Zhao and Jiang, 1974).

8. *Ovaloolithus laminadermus* (=*Oölithes laminadermus*) (Zhao and Jiang, 1974)

As previously mentioned, data on the dinosaur eggs from southern France have been extensively produced by the research of Lapparent (1957), Schwarz et al. (1961), Erben (1970), and others. The establishment of a new family, the Megaloolithidae, is hereby proposed. Family diagnosis is as follows:

Megaloolithidae Fam. nov.

The eggs are large and round, with both transverse and longitudinal diameters over 100 mm. External surface ornamentation as compact, small, and swollen projected striations. Egg shell is composed of circular cones with clearly demarcated boundary lines.

With the exception of the Megaloolithidae from France, the currently known dinosaur eggs from Asia and North America may all be assigned to the three families Elongatoolithidae, Faveoloothidae, and Spheroolithidae. Furthermore, according to the taxonomy proposed here, each species of dinosaur egg currently known may be distinguished and assigned within an easily recognizable sequential system. Moreover, it will be possible to assign dinosaur eggs discovered in the future to this taxonomic sequence. With careful consideration to taxonomic positions at the family level and higher, it is necessary to make an advanced fundamental and synthesized analysis. But as material has just been accumulated and research just begun, it is currently only possible to make a diagnosis to the family level. Higher categories must be left for later discussions.

II Evolutionary Problems Relating to Dinosaur Eggs

What was the origin and development of the dinosaur egg? This is the fundamental and necessary topic for discussion affecting the progress of the taxonomic research. Currently, a comprehensive explanation cannot be provided as material has only recently been accumulated, and only a simple discussion based on data previously obtained is possible.

As early as the middle 1950s, Cadob (1970)* conducted research on the microstructure of avian and dinosaur eggs, and proposed a preliminary hypothesis for the evolutionary sequence of the eggshell. He suggested that when reptiles first invaded the terrestrial realm they laid eggs similar to those of turtles, or shells with a structural complex composed of spherical crystals. Later this form basically differentiated into a shell with a double layered-rounded, columnar and needle-shaped structure (or composed of a palisade layer and mammillary layer). Finally, the development of the egg advanced to develop from the rounded columnar morphology to the three-tiered avian structure (composed of the mammillary layer, the palisade layer, and a protective membrane).

More recently, Erben (1970) applied X-ray diffraction and scanning electron microscopy to study microstructure and mineral complexes contained in the extant and fossilized calcareous shells of reptiles and birds. The results were the discovery that the mineral sequence of turtle eggs is composed of an aragonite complex, those of crocodiles are composed of a calcite complex, shells of birds are composed of a calcite complex with a small amount of aragonite, and dinosaur eggs are estimated to be fundamentally similar to birds. Additionally, all shells contain miniscule amounts of octacalcium phosphate ($Ca_8H_2(PO_4)_6◊H_2O$).

The fundamental structural unit composing the microstructure of these eggs (mammilla) is predominantly needle or plate-shaped microcrystalline assemblages. Chelonian eggs display a microcrystalline complex composed of a fanned configuration of needles. Erben believed this structure possibly represented an ancestral morphotype within the phylogeny of eggs. The fundamental structural unit of extant crocodillians are plate-shaped microcrystalline assemblages that may possibly represent a derived morphotype. Avian eggshells represent an advanced, three-tiered morphotype with the nucleus of the mammilla, at inception, composed of a needle-shaped aragonitic layer of microcrystalline assemblages that externally transform into a layer of calcitic, plate-shaped microcrystalline assemblages. In the palisade layer of the same egg, these plate-shaped microcrystals are formed in an intersecting configuration during the process of their horizontally directed inception, and thus have been designated the "zone of fish bone pattern." The palisade layer with a Neognathae pattern is relatively well developed, while a layer with a Ratitae pattern is comparatively inferior. This appears to represent two different developmental directions in the Class Aves. Dinosaur eggshell composition is fundamentally consistent with avian eggshell microstructure.

Based upon the results described above, Erben believed the ancestral reptiles, the Pseudosuchia, laid eggs with a shell structure basically similar to that of the Chelonia, or an aragonitic, needle-shaped fan configuration. Later, the Crocodylia, Dinosauria, and Aves eggshell structure developed in different evolutionary directions.

Due to the paucity of fossil material, the hypotheses of Cadob and Erben were derived from data based on studies of individual variation. Consequently it was impossible to recognize the valuable implications provided within the evolutionary process of dinosaur eggs.

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* This text was completed in the middle 1950s, but not published until 1970.

Among the three egg morphotypes currently known in China, two of them, the elongatoolithids and spheroolithids, are fundamentally consistent with avian shells by their composition of a mammillary layer and palisade layer. Therefore, it is possible to recognize this as a derived condition. The Faveoloolithdae differ structurally from the former two by displaying a unified palisade and mammillary layer that has yet to be divided, and this shell is composed of a calcitic microcrystalline complex with respiratory pores fully dispersed in a honeycombed fashion. This type of structure is inferior to that of the Elongatoolithidae and Spheroolithidae as a temperature regulating device or a mechanism to protect an embryo from undergoing damage in the event of a relatively large environmental fluctuation. As a result, regardless of whether an analytical approach is taken from either a compositional or a mechanical perspective, the Faveoloolithidae are recognized as representing a primitive morphotype.

Most recently, a relatively significant dinosaur egg assemblage dominated by faveoloolithids was discovered by the Twelfth Brigade of the Geologic Office of Henan Province at the localities of Xixia, Neixiang, and others, that is relatively significant. This new faveoloolithid taxon not only differs morphologically, but displays a microstructure distinct from *Faveoloolithus ningxiensis*. This set of specimens is currently undergoing study, but based on preliminary observations of several eggshell taxa it is clearly evident at the point nearest to the interior part of the shell that the walls of the respiratory pores have been broken into innumerable and irregularly shaped isolated bodies (Figure 1). This is extremely interesting in its similarity to the individual bodies displayed in the mammillary cross-section of the spheroolithid taxon *Spheroolithus chiangchiungtingensis* (Figure 2), and illustrates the distinct possibility of a phylogenetic relationship between the two.

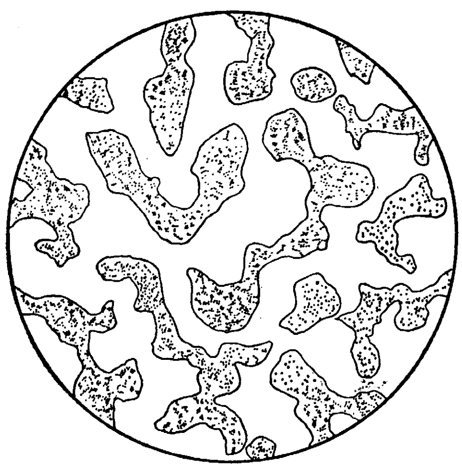

Figure 1. Faveoloothidae gen. et sp. nov. cross-section near internal surface

Figure 2. *Spheroolithus* cross-section at center of the mammillary layer

Within the evolutionary process of the spheroolithids, the mammilla gradually alter from an irregular morphology to that of an oval shape, as viewed in *Spheroolithus, Paraspheroolithus,* and the later developed *Ovaloolithus* (Zhao and Jiang, 1974).

Furthermore, from observations of the mammillary layer cross-sections from each species within the Elongatoolithidae and Spheroolithidae, the mammilla are nearly oval, although they are basically derived from a complex of several irregularly shaped units. This also illustrates the distinct possibility of a phylogenetic relationship between them.

For these reasons, it is plausible that the Faveoloolithidae are a morphotype constituting an ancestral side branch within the evolutionary sequence of dinosaur eggs. That is to say, it is not possible that the ancestral dinosaur egg morphotype conforms to Erben's hypothesis of a structure similar to that of a turtle. Rather, the possibility that the ancestral form conforms to the structure of the Faveoloothidae is much stronger. The long and slow history involving the evolutionary sequence of these eggs suggest that the inception of the mammilla arose from the gradual division into irregularly formed independent bodies from the interior to the exterior of the shell. From this foundation later development progressed into appropriately different directions. A general illustration of this hypothesis may be seen in Figure 3.

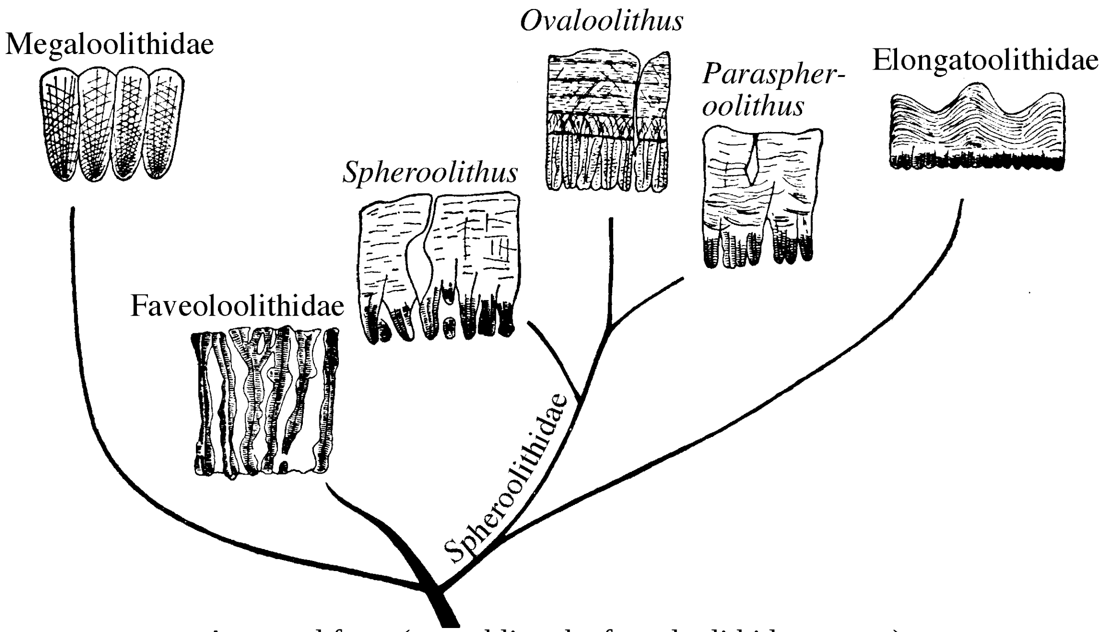

Figure 3. Schematic diagram illustrating the phylogenetic development of dinosaur eggs

The results from recent field excursions illustrate the extreme abundance of dinosaur eggs in the Red Beds of South China. Due to their ease of discovery they may be practically applied to solving the problems of the Cretaceous-Tertiary boundary and the subdivisions of the Red Beds. The current data suggest that the dinosaur eggs of China are derived from the Cretaceous Epoch. Because the fossil egg-bearing sediments are deposited in isolated terrestrial basins, and the co-occurrence of eggs with osteological material is generally sparse to non-existent, it is impossible to recognize a direct relationship between the eggs and bones within the same depositional sequence. Moreover, among the current problems are questions of whether it is possible to use fossil eggs as a basis for subdivision and correlation.

In their advanced research on the dinosaur eggs of Laiyang, Sandong Province, Zhao and Jiang (1974) believed the middle division of the Wangshi Group bearing *Spheroolithus* could be distinguished and subdivided from the upper division of the Wangshi group bearing *Ovaloolithus*. Most recently, preliminary observations have been conducted at such dinosaur egg localities as Guangdong, Jiangxi, Xinjiang, and Henan. Due to the differences of geologic ages, geographic distribution, and other factors, the diagnostic characters of these dinosaur egg complexes are distinguishable, illustrating that they may be used as a paleontological foundation for advanced stratigraphic subdivision and correlation of Late Cretaceous sediments. However, only a portion of taxa are described with a much larger portion currently undergoing study. An introductory taxonomic record of dinosaur-egg-bearing localities is presented below. The localities constitute the Wangshi Group of Laiyang, Shandong Province, the Nanxiong Formation of Guangdong

Province, the Subashen Formation of Turpan in the Xinjiang Autonomous Region, and the Hugang Formation of the Liguanqiao Basin and Xixia Basin at Xiquan, Henan Province.

1. Laiyang, Shandong Province, Wangshi Group: Fossil eggs are produced from the middle and upper divisions. Lithology consists of an approximately 2,000 m thick set of coarse red sands and siltstones unconformably overlying the Early Cretaceous Qingshan Group.

The Wangshi Group is principally distributed in the Honglanbu and Jingangkou region. Fossil eggs recorded include:

Spheroolithidae
- *Paraspheroolithus irenensis*
- *Ovaloolithus chinkangkouensis*
- *Ovaloolithus tristriatus*
- *Ovaloolithus mixtistriatus*
- *Ovaloolithus monostriatus*
- *Ovaloolithus laminadermus*

Elongatoolithidae
- *Elongatoolithus andrewsi*
- *Elongatoolithus elongatus*
- ?*Macroolithus* sp.

The middle division of the Wangshi Group is principally distributed in the regions of Zhaotuan, Hongtuya, and Jiangjunding. Fossil eggs include:

Spheroolithidae
- *Spheroolithus chiangchiungtingensis*
- ?*Spheroolithus megadermus*
- *Paraspheroolithus irenensis*

Elongatoolithidae
- *Elongatoolithus andrewsi*

2. Nanxiong Basin, Guangdong Province, Nanxiong Formation: Sediments consist of a set of approximately 1300-2900 m of purple-red sandy conglomerates, muddy sandstones, and sandy mudstones unconformably overlying Mesozoic granites. Fossil dinosaur eggs include:

Spheroolithidae
- *Ovaloolithus* cf. *chinkangdouensis*
- *Ovaloolithus laminadermus*
- *Ovaloolithus* sp. nov.

Elongatoolithidae
- *Macroolithus rugustus*
- *Macroolithus yaotunensis*
- *Elongatoolithus andrewsi*
- *Elongatoolithus elongatus*
- *Nanshiungoolithus chuetienensis*
- Elongatoolithidae gen. et sp. nov.

Subashen Formation,* Turpan Basin, Xinjiang Autonomous Region: The formation consists of massive coarse conglomerates. Dinosaurs are present in addition to fossil eggs, principally including:

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* Renjie Zhai, Jiajian Zheng, and Yongsheng Tong, 1978, The Tertiary System of the Turpan Basin. *Institute of Vertebrate Paleontology and Paleoanthropology Monograph Number 30, Series. I*

Spheroolithidae

Ovaloolithus cf. *chinkangkouensis*
Ovaloolithus sp. nov.
Paraspheroolithus cf. *irenensis*
?*Paraspheroolithus*

4. Liguanqiao Basin, Xiquan, Henan Province, Hugang Formation: Exposures are principally distributed south of Hugang, Yuhuangding, and Shiguguan, in addition to the Haoping and Xijia regions. Sediments consist of a set of red conglomerates grading to calcareous siltstones and fine sandstones approximately 500 m thick and unconformably overlying the Hanwu Series. Fossil eggs principally include:

Elongatoolithidae

Macrooolithus yaotunensis
Elongatoolithus andrewsi
Elongatoolithus elongatus

Xixia Basin Henan Province: Sediments occur at the southern side of the eastern range of the Qinling Mountains within Xixia County, and consist of a set of purple grading to variegated conglomerates, siltstones, and sandy mudstones, and over 3000 ft thick. Fossil eggs include:

Faveoloothidae

Faveoloolithidae gen. et sp. nov.

Spheroolithidae

Paraspheroolithus cf. *irenensis*
Paraspheroolithus sp. nov.

Family indeterminate

Placoolithus cf. *taohensis* gen. nov.*

From the enumerated list of fossil eggs provided above, it may be observed that *Paraspheroolithus* has been recovered from the upper and middle divisions of the Wangshi Group in the Xixia Basin, in addition to the Subashen Formation of Xinjiang. It is particularly abundant in the middle division of the Wangshi Group within the Xixia Basin. *Elongatoolithus andrewsi* is observed in the middle and upper sections of the Wangshi Group, the Nanxiong Formation, and the Hugang Formation, with relatively many appearances in the upper section of the Wangshi Group, Nanxiong Formation, and Hugang Formation. Both Faveoloolithidae gen. et sp. nov. and *Placoolithus* cf. *taohensis* are found only in the Xixia Basin. *Spheroolithus* is found only in the middle division of the Wangshi Group, whereas *Ovaloolithus, Macroolithus,* and *Elongatoolithus elongatus* are found in the upper division of the Wangshi Group, in addition to the Nanxiong Formation, the Subashen Formation, the Hugang Formation, and others. Consequently, it is possible to determine three individual chronologic complexes.

The first dinosaur egg faunal complex is characterized by the Faveoloolithidae and *Placoolithus* observed in the middle and upper members of the purple-red grading to variegated conglomerates, siltstones, and sandy mudstones of the Xixia Basin (Twelfth Brigade of the Geologic Office of Henan Province, 1975). The second complex is represented by *Spheroolithus* observed in the middle division of the Wangshi Group. The third complex is characterized by the presence of *Ovaloolithus, Marcoolithus,* and *Elongatoolithus* observed from such lithologies as the

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* Formal Latin nomenclature has yet to be provided for the provisional taxon *Placoolithis* cf.*taohensis*, preliminary description of which was made in 1974 by members of the Twelfth Research Brigade of the Henan Province Office of Geology, who found the eggshells in the Hetao Basin Red Beds of Xichuan. Further observations have been made on this fossil, and it is believed that it may represent a new genus. A more detailed diagnosis is provided in a separate paper.

upper division of the Wangshi Group, the Nanxiong Formation, the Subashen Formation, and the Hugang Formation.

The geologic ages of these localities were generally assigned to the middle to Late Cretaceous, with the exception of the Hugang Formation in the Liguanqiao Basin and the red lithologic systems in the Xixia Basin which were later corrected.

Formerly, the Hugang Formation in the Liguanqiao Basin was generally considered as the lower member of the Early Tertiary Yuhuangding Formation. However, after the discovery of dinosaur eggs by the Twelfth Brigade of the Geologic Office of Henan Province in 1974, its age was verified as being Late Cretaceous. As a result of this reevaluated subdivision the deposits were designated the Hugang Formation. The dinosaur eggs from the Hugang Formation include *Elongatoolithus elongatus* and *Macroolithus yaotunensis*, two species assignable to the aforementioned third complex, and notable elements within the dinosaur egg fauna of the upper division of the Wangshi Group and the Nanxiong Formation. Consequently, the ages of all these lithologies may be contemporaneous. A discussion is now required regarding the age of the Xixia Basin sediments that contain the dinosaur egg fauna characterized by the presence of the Faveoloolithidae.

The age of the dinosaur-egg-bearing sediments in the Xixia Basin was formerly based upon a characteristic pollen complex dominated by genera of short-needled conifers, the Cupressaceae, the hemlock *Cycas*, and spores of the creeping fern *Lygodium*, in addition to small amounts of the *Cycad* order, the *Bennettitales* order and *Ginkgo*. Moreover, a distinct amount of angiosperm pollen is present. As a result, the age of this complex was considered Early Cretaceous (Song et al. 1965, pp. 204-205). However the Twelfth Brigade of the Henan Geologic Office recently conducted analysis upon new spore samples collected from this basin to discover that although the taxonomic identifications were similar to those made previously, from a ratio approach they believed the rocks to be Late Cretaceous.

With regard to the dinosaur eggs, the earliest observation of *Faveoloolithus* is from the red sandy conglomerates of the northern Gobi Desert on the Ologoi-Ulan-Chab Plateau in the People's Republic of Mongolia, believed to be between Early and Late Cretaceous (Sochava, 1969). Most recently this family of eggs has also been recovered in China from the vicinity of the Chahan Obo yurt encampment by Bayinwulashan, Azuo County, in the Ningxia Islamic Autonomous Region. However as the material is sparse the age is merely determined to be Cretaceous (Zhao and Ding, 1976). Recently, a new faveoloolithid morphotype was found co-occurring with *Paraspheroolithus* in the Xixia Basin. Moreover *Paraspheroolithus* is a commonly observed taxon shared between both China and Mongolia in the upper Cretaceous in addition to fragments found in North America. Therefore, the age of the dinosaur egg fauna from the Xixia Basin may easily be assigned to the Late Cretaceous.

From another aspect, among the dinosaur eggs produced from several of the Xixia Basin's neighboring regions such as the Xiaguan Basin, the Taohe Basin in Xichuan, and the Liguanqiao Basin, the former two produce dinosaur eggs characteristic to those of the Xixia Basin, while the fossil eggs from the Hugang Formation of the Liguanqiao Basin clearly differ from the former two, but are generally similar to those from the upper division of the Wangshi Group and the Nanxiong Formation. This also suggests that the faveoloolithid-bearing sediments of the Xixia Basin cannot be equivalent to the Hugang Formation in the Liguanqiao Basin, and that the age of the sediments should be relatively earlier than the Hugang Formation.

From the perspective of the function, structure, and morphology of the faveoloolithid eggshell, as has previously been suggested, this egg morphotype undoubtedly represents a primitive condition, also suggesting the possibility that its age should be older than the others.

In conclusion, one is inclined to believe that the age of the Xixia Basin Red Beds characteristically dominated by the Faveoloolithidae possibly represents the earliest stage of the Late Cretaceous. The age of the middle Wangshi Group characterized by the presence of *Spheroolithus* may represent middle Late Cretaceous. Finally, the Upper Wangshi Group, Nanxiong Formation, Subashen Formation, Hugang Formation, and others bearing *Ovaloolithus*, *Macroolithus*, and *Elongatoolithus* should represent the late stage of the Late Cretaceous.

Table I. Stratigraphic Correlation Chart Of Late Cretaceous Dinosaur Eggs

		Shandong	Henan	Guangdong	Xinjiang
Late Cretaceous	Late	Upper Wangshi Group	Hugang Fm.	Nanxiong Fm.	Subashen Fm.
	Middle	Middle Wangshi Group			
	Early		Xixia Basin red beds		

IV. Relationships to Late Cretaceous Climatic Change in China

From the perspective of global conditions, the Late Cretaceous is always referred to as being relatively warmer. However, there is much evidence to illustrate that the climate during this period underwent noticeable changes.

According to the paleoclimatic diagram edited by U.M. Ceiman, an arid climate was prevalent during the Cretaceous, attaining its maximum development during the Late Cretaceous. In China, this period was nearly completely dominated by an arid climate, and particularly in the late Cretaceous, where the phenomenon is more pronounced. Liu and Zhang (1959), however, believed that from the perspective of the red-colored Cretaceous sediments and the pyroclastic deposits extensively distributed in the southern part of the country, the ambient temperature during this period was relatively high, but the zone of aridity had not yet spread to encompass the entire ccountry.

Recently, developments of investigations in marine geology and extensive microfossil research verify an extremely large global climatic change at the end of the Cretaceous, or approximately at the end of the Maastrichtian Stage, when there was a decline in temperature and relatively distinct climatic zone demarcations. Worsley (1971) believed this was possibly due principally to the lowering of the atmospheric carbon dioxide content as a result of increased photosynthetic activity undertaken by planktonic and algal elements that form the Cretaceous sediments.

A discussion of this problem from the angle of dinosaur eggs will now be undertaken. The eggshell is a protective body encasing an embryo and is a by-product for the adaptation to the environment of terrestrial life for reptiles. Its principal function is to prevent the evaporation of internal moisture and mechanical injury to the fetus, in addition to providing the function of atmospheric interchange for the development of the embryo, thereby creating a relatively stable environment for fetal development. Through a long-term evolutionary process following an uninterrupted change in the environment, the structure of this mechanism has also changed and developed in an uninterrupted manner. To reiterate, the adaptation for change in the structure of the eggshell is dependent upon environmental change, and particularly reflects climatic fluctuation.

Consequently, it is possible to practically apply dinosaur eggs as indicators of several paleoclimatic fluctuations.

Regarding the Late Cretaceous Faveoloolithidae from the early stage, Spheroolithidae from the middle stage, and Elongatoolithidae from the late stage, the structure of the faveoloolithids has yet to separate into the mammillary and palisade layers, and its most prominent characteristic is the well-developed respiratory pore system in a honeycombed morphology. The spheroolithid egg is composed of a mammillary and palisade layer, with well-developed mammillary lacunae and irregular respiratory pores that are frequently inflated at their center. However, the amount of individual surficial spiracles is less than upon the surface of the faveoloolithid. The elongatoolithids are also composed of a mammillary and palisade layer with the mammilla arranged in an extremely constricted arrangement. The palisade layer is also very compact, and respiratory pores are relatively gracile, straight, and even fewer in number than on the surface of the others. It is not difficult to see that for the functions of evaporation prevention and the maintenance of a stable temperature for the embryo, the spheroolithids are more effective than the faveoloolithids, and the elongatoolithids are even more effective in these functions.

It is reasonable to believe from the descriptions above that the Faveoloolithidae are adapted to a tropical climate, while the Spheroolithidae and Elongatoolithidae are more adapted to an environment with a lower temperature and drier climate. Therefore, from their temporal distribution, the faveoloolithids were only able to exist into the early Late Cretaceous, illustrating that the climate during that time was still relatively tropical, with a gradual drying and possibly cooling tendency from the middle Late to late Late Cretaceous. As the faveoloolithids were not adapted to these environmental changes, they were gradually replaced by the sphereoolithids and elongatoolithids. Consequently, although the Late Cretaceous is generally referred to as being temperate, developmental trends from the early to late periods, at least in China, possibly fluctuated gradually from a tropical climate to a drier and relatively colder climate.

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A meager amount of research has been conducted on the dinosaur eggs from the end of the Mesozoic. Definitive results have been obtained but they are very incomplete and not mature enough to solve many problems. As noted under the erudition of Chairman Mao Zedong: "A true conceptualization requires the frequent and repeated passage from the material to the ethereal, and from the ethereal back to the material, upon which it passes from application to comprehension and from comprehension back into application. Only then does the conceptualization become realized." Consequently, a large amount of work is required for a comprehensive conclusion.

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