

**Stratigraphic Subdivision, Correlation, Paleofaunas,
and Floras of South China Mesozoic to Early Tertiary Red Beds**

Yang Hengren, Wang Zhen, Li Manying, Huang Baoyu
(Nanjing Institute of Geology and Paleontology)

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Translated By Will Downs
Bilby Research Center
Northern Arizona University
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Introduction

Recent extensive regional geologic surveys and general exploration for mineral production in South China Cenozoic “red beds” have attained substantial results in every aspect, including the systematic correlation of regional Mesozoic and Cenozoic stratigraphic sequences.

This text will attempt to provide several interpretations of the stratigraphic subdivision and paleobiology in basins in the South China provinces of Zhejiang, Jiangsu, Anwei, Jiangxi, Hubei, Hunan, Guangdong, and Fujian based upon stratigraphic, invertebrate, and paleobotanical data accumulated within the past ten years.

Stratigraphic Development and Sedimentary Characteristics

The distribution of South China Late Mesozoic to Early Tertiary sediments are extensively distributed, and dominated by “red” terrestrial clastics. Three basin models are recognized based upon their chronological development.

Basin Mode I: The largest of the South China basins are located in Pingyuan, Jiangnan, Hubei Province; and in the Dongting region, Hengyang, Pingyuan, and Subei in Hunan Province, where Early Cretaceous deposition is thick and widespread. Although sedimentation continued through various periods of extension and compression through to the Oligocene, the basins’ depositional continuity is quite distinct despite depositional hiatuses. In Pingyuan, Jiangnan, and Pingyuan, Subei, broad-scale deposition continued from the Neogene into the Quaternary.

Stratigraphic subdivision in the western region of Pingyuan, Jiangnan, is as follows:

Late Tertiary

Guanghuasi Fm.

~~~~~Unconformity~~~~~

### Oligocene

Jinghezhen and Qianjiang fms: Cyclothems of gray to dark gray mudstones and siltstones interbedded with oil-shales, gypsums, marls, and sandstones. Partially interbedded with numerous basalts. Abundant in charophytes, ostracods, and pollen. The Jinghezhen Fm. produces occasional Foraminifera.

-----Conformable contact-----

### Eocene

Jingsha and Pailoukou fms: Sediments are dominated by tan siltstones and mudstones interbedded with sands and gypsums and contain charophytes, ostracods, and pollen. At the western margin sediments alter to sandstones and conglomeratic sandstones with large-scale oblique bedding containing fossil mammals.

-----Conformable contact-----

First unit of Xingouzui Group and Fangjiahe Fm.: Interior basin sediments are dominated by dark gray and black (with a small amount of tan-red) mudstones interbedded with gypsiferous evaporites, oil shales, and marls. At Pingyuan, boundary sediments alter to tan-red siltstones and mudstones interbedded or interfingering with gray-green and yellow-green mudstones and marls. Black mudstones or shales are occasionally noted. Some sections are dominated by marls. Sediments are abundant in charophytes, ostracods, pollen, gastropods, fish and fossil mammals.

-----Conformable contact-----

### Paleocene

First formation of Xingouzui Group and Lingbei Fm.: At Pingyuan, lithologies consist of tan-red mudstones frequently interbedded with evaporites. At the marginal regions these alter to tan-red mudstones, siltstones, and sandstones with interbedded conglomeratic sandstones. Ostracods occasionally occur at the base.

-----Conformable or disconformable contact-----

### **Late Cretaceous**

Paomagang Fm.: Dominated by light tan-red mudstones and siltstones interbedded with gray-green or gray-purple banding. Abundant in charophytes and ostracods.

-----Conformable contact-----

Honghuatao Fm.: Brick red sandstones containing conglomeratic sands with extremely well developed massive oblique bedding.

-----Conformable contact-----

Mengjingtian Fm.: Brick red conglomerates interbedded with sandstone lenses.

-----Disconformity-----

### **Early or Late Cretaceous**

Wulong and Jiadian fms.: Dominated by tan-red sandstones and siltstones with abundant calcareous concretions. Occasionally interbedded with gray-green banding or variegated mudstones. Upper section with well developed cyclothem and lower section as conglomerates. Jiadian Fm. contains charophytes and ostracods.

-----Conformable or disconformable contact-----

### **Early Cretaceous**

Donghu Fm.: Middle and upper sections dominated by gray-green, yellow-gray, and light tan-red sandstones containing conglomeratic sandstones with well developed large-scale oblique bedding. Abundant in fragmentary carbonaceous plants and pollen. Lower section is dominated by conglomerates interbedded with brick red siltstones.

-----Unconformity-----

### **Paleozoic**

On the eastern Subei Plain the stratigraphic sequence is as follows:

#### **Late Tertiary**

Yancheng Group

-----Unconformity-----

#### **Oligocene**

Sanduo Fm.: Tan-red mudstones and siltstones bearing gypsiferous concretions. Partially interbedded with black mudstones and multistoried basalts. Top is dominated by gray-green mudstones. Base consists of sands and conglomerates. Contains ostracods, charophytes and pollen.

-----Conformable or disconformable contact-----

Dainan Fm.: Tan-red sandstones interbedded with gray-green and coffee colored mudstones. In some regions lower section is gray-black and coffee colored mudstones are interbedded with fine sandstones. Base as interbedded conglomerates and mudstones. Contains ostracods, charophytes, and pollen.

-----Conformable or disconformable contact-----

#### **Eocene**

Fourth formation of the Funing Group: Gray-black mudstones interbedded with siltstones, marls, and oil shales. Top as tan-red siltstones and mudstones. Abundant in ostracods, charophytes, pollen, and conchostracans.

-----Conformable contact-----

Third formation of the Funing Group: Gray-white sandstones interbedded with gray-black mudstones containing ostracods, charophytes, and pollen.

-----Conformable contact-----

Second formation of the Funing Group: Gray-black mudstones interbedded with marls and oil shales. To the west, the base is interbedded with carbonatites and is abundant in ostracods, charophytes, pollen, angiosperm macrofossils, gastropods, pelecypods, and conchostracans. Basal carbonatites contain worm burrows and a small amount of Foraminifera.

-----Conformable contact-----

## Paleocene

First formation of the Funing Group: Dark tan-red sandstones interbedded with mudstones and containing gypsum concretions. Top with small amounts of interbedded gray-black mudstones. Contains ostracods, charophytes, and pollen.

-----Conformable contact-----

## Late Cretaceous

Taizhou Fm.: Upper section dominated by gray-black mudstones, lower section as tan-brown mudstones, and sandstones. Base is conglomeratic sandstones. Upper section is abundant in ostracods, charophytes, and pollen.

~~~~~Unconformity~~~~~

Chishan Fm.: Brick red sandstones bearing conglomeratic sandstones and well developed large-scale oblique bedding. Contains charophytes.

~~~~~Disconformity~~~~~

## Late or Early Cretaceous

Pukou Fm.: At the margins of the Plain the middle and upper sections consist of tan-red sandstones and siltstones interbedded with mudstones. Base is fossil wood bearing conglomerates interbedded with andesite. In the interior region the "Pukou Fm." consists of tan-red mudstones and siltstones interbedded with gray-green mudstones and finely laminated gypsum. Contains pollen, charophytes, and ostracods.

-----Conformable or disconformable contact~~~~~

## Early Cretaceous

Gecun Fm.: At Jurong, Sunan, lithology is dominated by purple-red mudstones interbedded with gray-white sandstones and gray-green sand and mudstones to comprise five cyclothem. Upper section consists of thinly laminated interbedded gypsums and coal seams. Contains pollen, charophytes, and ostracods.

~~~~~Unconformity~~~~~

Late Jurassic or Early Cretaceous

Volcanics.

Basin Mode II: This mode is represented by the Yongkang and Jinqiu basins in Zhejiang Province; the Jurong Basin in Jiangsu Province; the Liancheng and Hekou basins of Fujian Province; and the Xinjiang Basin of Jiangxi Province. Basins are narrow in morphology and deposition in several regions is relatively thick. Formation and age of these basins are generally equivalent to or slightly older than those of the first mode and depositional hiatus is also older, or generally in the middle to late Late Cretaceous. Broad-scale sedimentation is absent. A simplified sedimentary sequence within the Yongkang and Jinqiu basins is as follows:

Late Cretaceous

Fifth "formation" of the Qujiang Group: Tan-red conglomerates and sandstones with interbedded brick red conglomerates and sandstones.

~~~~~Disconformity~~~~~

## Early or Late Cretaceous

First through Fourth formations of the Qujiang Group: Upper section as tan-red siltstones and mudstones interbedded with gray-green banded carbonates, concretions, marls, or partial gypsum units. Contains pelecypods, gastropods, conchostracans, ostracods, charophytes and fossil wood. Base dominated by tan-red sandstones with conglomeratic sands and sandy conglomerates interbedded with tuffs and basalts. Contains pelecypods.

~~~~~Disconformity~~~~~

Early Cretaceous

Chaochuan Fm.: Intertonguing tan-red sandy conglomerates, tuffaceous sandstones, and siltstones. Lower section as interbedded yellow-green and black mudstones and shales. Contains pelecypods, gastropods, ostracods, conchostracans, and charophytes.

-----Conformable contact-----

Guantou Fm.: Gray-green and gray-black sandstones, siltstones, mudstones, and shales interbedded with andesitic tuffaceous sandstones and marls. Base as conglomerate. Contains pelecypods, gastropods, and ostracods.

~~~~~Disconformity or unconformity~~~~~

### **Jurassic or Early Cretaceous**

Shouchang Fm.

**Basin Mode III:** This mode is represented by the Sanshui and Nanxiong basins of Guangdong Province and the Chijiang Basin of Jiangxi Province which are moderate to small in scale and generally contain thin sedimentary packages. Basin formation occurred in the middle to late Late Cretaceous and was subjected to orogenic activity in the Late Eocene or Oligocene. Stratigraphic sequence in the Sanshui Basin is as follows:

### **Late Tertiary**

Jinxinggang Fm.

~~~~~Unconformity~~~~~

Oligocene

Huayong Fm.: Upper section as tan-red and gray-green mudstones and siltstones interbedded with sandstones. Middle section as gray-white, gray-purple sandstones interbedded with trachytes and basalts. Lower section as cyclothems consisting of tan-red conglomerates, sandy conglomerates, and sandstone to mudstone complexes interbedded with a small amount of gray-black marls and volcanoclastics. Contains ostracods, charophytes, and pollen.

~~~~~Disconformity~~~~~

### **Eocene**

Third formation of the Buxin Group (including the Xibu Fm.): Upper section as purple-red and light gray moderately coarse sandstones containing gravely sands and sandy gravels. Lower section as intertonguing gray-white fine silty sands and gray-black and tan-red mudstones interbedded with sandy conglomerates. Both sections contain gastropods.

-----Conformable or disconformable contact-----

Second formation of the Buxin Group: Gray-black mudstones, oil shales, siltstones, and sandstones. Base as carbonatites. Contains ostracods, pollen, and charophytes. Base contains worm burrows and a small amount of Foraminifera.

-----Conformable contact-----

### **Paleocene**

First Formation of the Buxin Group: Upper section as tan-red, dark gray mudstones and gypsum bearing siltstones. Lower section as gray or purple-red conglomerates. Upper section produces charophytes and ostracods.

~~~~~Disconformity~~~~~

Late Cretaceous

Dalangshan Fm.: Purple-red sandstones, intertonguing with dark gray, gray-black, and gray-green ashy mudstones and marls. Base as conglomerates bearing conglomeratic sands and sandstones. Produces ostracods, charophytes, and pollen.

-----Conformable contact-----

Sanshui Fm.: Tan-red siltstones and mudstones interbedded with marls and gypsum concretions. Base as conglomerates and sandy conglomerates bearing conglomeratic sands. Produces ostracods, charophytes and pollen.

~~~~~Unconformity~~~~~

### **Early Cretaceous:**

Baihedong Fm.

## Stratigraphic subdivision, correlation, and ages

South China Late Mesozoic to Early Tertiary sediments are extremely fossiliferous in predominantly continental biota such as megafloora, pollen, charophytes, ostracods, conchostracans, pelecypods, gastropods, fish, reptiles, and mammals. More recently, ichnofossils resembling extant marine annelid burrows and Foraminifera have been noted in the second formation of the Funing Group of Jiangsu Province and in the second formation of the Buxin group in the Sanshui Basin of Guangdong Province. This paleontological evidence is extremely valuable toward regional subdivision and correlation in addition to the interpretation of paleogeography and paleoclimatology.

This text is restricted to a discussion of paleobotanical and invertebrate paleontology which are represented by six broad biotic assemblages: (1) Early Cretaceous assemblage, (2) late Early Cretaceous or early Late Cretaceous assemblage, (3) Late Cretaceous assemblage, (4) Paleocene assemblage, (5) Eocene assemblage, and (6) Oligocene assemblage.

### Early Cretaceous biotic assemblage

Sediments representing this phase are represented by the Guantou and Chaochuan fms., Zhejiang Province; Gecun Fm., Jiangsu Province; Guilin Fm, southern Anwei province; Zhoujiadian Fm., Jiangxi province; Dongchao Fm., Hubei Province; Sanyanggong, Daijiachong, and Dawangping fms., in the Dongting region of Hunan Province; and the Dongjing Fm. in the Hengyang Basin of Hunan Province. There are discrepancies between interpretation of correlations and chronological subdivisions due to extensive variations in regional lithologies, inconsistent regional stratigraphic subdivisions, and several stratigraphic units which are poorly fossiliferous and unequally distributed.

**Plant Macro Fossils:** *Frenelcopsis* is a relatively common taxon in the Cretaceous of China. However, a more recent reevaluation indicates that this genus actually represents several genera of plants that have a varying degree of evolutionary relationships significant toward the subdivision and correlation of Cretaceous sediments. Regional Lower Cretaceous sediments in South China produce four species of the genera *Manica* and *Suturovaina*. The oldest occurrence is represented by *M. papillosa* from the fourth to fifth members of the Liupan Group in the Ningxia Autonomous region of North China. In South China first occurrences of similar species are produced from the Guandou Fm. at Xinchang, Suqin, eastern Zhejiang Province and the Shouchang and Sucun fms., Jiangxi Province. *M. cf. parceramosa* (Foutaine) is recorded from the Guantou Fm. of Zhejiang, the Gecun Fm. of Sihong, Jiangsu Province, the lower section of the Ganzhou Group (Zhoujiadian Fm. equivalent), Xingguo, Jiangxi Province, and the lower section of the Shaxian Group, Shaxian, Fujian Province. This species morphologically resembles *M. parceramosa*, which is a significant element in the middle to Late Cretaceous of the North American Potomac Group. The species *M. sparsa* is produced from the Shaxian group. *S. intermedia*, a species which appears more primitive than the genus *Manica* is recovered from a set of variegated clastics equivalent to the Gecun Fm. at Yanziji, Nanjing, Jiangsu,. Cuticle structure of these four species resemble the extant auracarian conifers but needle morphology differs and they may in fact belong to the family Cheirolepidiaceae. Consequently, the plant bearing strata of the Guantou and Gecun fms., the lower Ganzhou, and lower Shaxian groups maybe be regarded as middle Lower Cretaceous.

**Charophyta:** Genera represented include *Flabellochara*, and *Atopochara*, *Euaclistochara*, *Mesochara*, *Obtusochara*, and *Sphaerochara*. The most commonly recorded species are *Atopochara trivolis*, *Flagellochara hanzhouensis*, *Euaclistochara mundula*, *Mesochara symmetrica*, and *Obtusochara cylindrica*. This assemblage has an extensive range as *A. trivolis* is represented in Asia, North Africa, Europe, and North America. Generally, it is an index fossil for

the Lower Cretaceous Aptian Stage, although there are occasional records from the upper Barremian. It also occurs in the Lower Cretaceous sediments of south, northeast, and northwest China. *E. mundula*, *M. symmetrica*, and *O. cylindrica* are recorded in the Aptian of North America and are also noted partially in the Albian. *F. hangzhouensis* is extremely similar to *F. harrisi* from the Aptian of Mexico and the Rocky Mountains region of North America.

This assemblage may be recognized as two complexes in South China: (1) the *A. trivolis* complex is recorded from the Guilin and Yangwan fms. of southern Anwei, and the Shaxian Group in the Ninghua and Hekou basins of Fujian, in addition to occurrences in the Longjing Fm. of Guilin and the Mangang Fm. of Yunnan. (2) The *F. hangzhouensis* complex is represented in the Gecun Fm. in southern Jiangsu and the Sanyanggang Fm., in the Dongting region of Hunan. The Chachuan Fm. of Zhejiang and the Zhoujiadian Fm. of Jiangxi also record *F. hangzhouensis*. These two communities contain generally consistent co-occurring taxa with the exception of *A. trivolis* and *F. hanzhouensis* that have yet to be recorded in either the same region or stratigraphic section and thus an ancestral descendant relationship is excluded. Hence, these two complexes are regarded as communities of a contemporaneous Early Cretaceous assemblage.

**Pollen:** These complexes are derived from the Gecun Fm. of Jiangsu, the Sanyanggang Fm., in the Dongting region of Hunan, and the Donghu Fm. of western Hubei. The Gecun pollen complex has an approximate 74% dominance of gymnosperms with *Classopollis* constituting 40%, *Psophosphaera* constituting 20.8%, and *Monosulcites* constituting 10.4%. Ferns constitute approximately 23% within which the family Schizaceae comprises 9.6%. In addition *Hsuisporites*, *Osmundacidites*, and *Gleicheniidites* constitute approximately 7%. Furthermore, a triple striated angiosperm is present. The Gecun pollen complex closely resembles those from the Canlin Fm., Jixi, Heilongjiang and the Wulin Fm. of Jiaohe, Jilin both in Manchuria. It is also extremely close to that derived from the Sanyanggang Fm. in which gymnosperms account for 54.34 %, dominated by *Classopollis* at 23.29% and secondarily with *Psophosphaera* at 11.66%. Ferns constitute 44.62% dominated by *Schizaeosporites* at 24.25% and secondarily by *Cicatricosisporites* at 10.67% and *Hsuisporites* at 10.67%. In addition *Osmundacidites* is present. These complexes are recognized Aptian/Albian. In the Donghu Fm. ferns dominate the complex by constituting 60-80% of the assemblage with *Schizaeosporites* the most numerous and associated with *Cicatricosisporites*. Gymnosperms occur secondarily at 20-30%, dominated by *Psophosphaera* and associated with *Classopollis* and *Monosulcites*. Angiosperms are extremely rare. This assemblage resembles the characteristic complexes of the Early Cretaceous "Pukou Fm." and the Shenhuangshan Fm. in the Hengyang Basin, northern Jiangsu, with their dominance of ferns, abundant gymnosperms, and depauperate angiosperms that constitute under 14% of their assemblages.

**Ostracoda:** Complexes are derived from the Guantou Fm., Laozhu, Lishui, Youngkang, Jiangsu; and the Dawangping Fm. in the Dongting region of Hunan (Qijiahe Fm. equivalent). The Guantou Fm. of Yongkang contains the three subgenera *Cypridea*: *C. (Cypridea)*, *C. (Morinia)*, and *C. (Bisulcocypridea)* in addition to *Eucypris*, *Ziziphocypris*, and *Darwinula*. The assemblage is dominated by the small *Darwinula* with small amounts of *Eucypris* and *Ziziphocypris*. The taxonomy of *Cypridea* is extremely complex with three subgenera and seven species represented. In the Guantou Fm. of the Laozhu region not only are three subgenera of *Cypridae* present along with *Darwinula* and *Eucypris*, but there is also an additional subgenus *C. (Cyamocypris)*. The assemblage is dominated by 14 species of *Cypridea* and the small *Darwinula leguminella*.

Three species of *Cypridea* are present, among which *C. unicastate* is shared with the middle Zhunbayin Fm. of eastern Mongolia, and in the Chijinbao Fm., Hexizoulang, Gansu Province Fm. and the upper member of the Huihuibao Fm, and the Nenjiang Fm. on the Songliao Plain. *C. (C.) anhuaensis* is recovered from the Shouchang Fm., while *C. (C.) ampullaceous* is recovered from the Lower Cretaceous Mangang Fm. in Yunnan. *C. (Morinia)* resembles Aptian forms recovered from the Matoushan Fm. in Yunnan, the Guilin Fm. in southern Anwei, and the

Qingshankou and Libanen fms. on the Songliao Plain. The first occurrence of the subgenus *C. (Bisulcocypridea)* is late Early Cretaceous but its lineage finally terminates as the species *C. (B.) mononda* in the Eocene. This subgenus also resembles taxa the Mashantou Fm., of Yunnan; the upper member of the Guilin Fm., southern Anwei; and the upper member of the Huihuibao Fm. at Hexizoulang, Gansu. In addition the abundant appearance of the small *Darwinula leguminella* also confirms the ostracods of the Guantou Fm. represent late Early Cretaceous.

The upper member of the Guilin Fm. produces *C. (Cypridea)* and *C. (Bisulcocypridea)*, and is dominated by the subgenus *Cypridea* which is characterized by its small size and distinct gracile cross-hatching ornamentation. This subgenus closely resembles the Aptian *C. diminuta*, *C. pecki* and *C. nititula* from the Wyoming and Idaho region in the western United States. The first appearance of *C. diminuta* is in the early Albian of Arkansas, USA; and the first appearance of *C. pecki* is from the late Early Cretaceous, Nevada, USA, where it co-occurs with *C. (B.) bicostata*. However, several taxa recovered from the upper member of the Guilin Fm. also occur in the Guantou and Matoushan fms. In addition, species of *Cypridea* are also known from the Dongjing Fm. Hangyang Basin, Hunan. The Qijiayuan Fm. at Taoyuan, Hunan (Dawangping and Daijiachong fms. equivalent) produces *C. (Cypridea)*, *Ziziphocypris*, *Metacypris* and *Mongolianella*. Among these, *C. (C.) rostrata* and *Z. simakovi* are recorded from the Zhunbayin Fm. of eastern Mongolia. These aforementioned complexes correlate the Guantou Fm., upper member of the Guilin Fm., and Matoushan Fm. and provide a general late Early Cretaceous correlation to the Dongjing and Qijiahe fms. The Chaochuan Fm. is provisionally regarded Early Cretaceous based upon the single taxon *Cyprides (Merinia) monosulcata zhejiangensis*.

**Conchostraca:** *Cratostracus*, *Ortheastheria*, and *Ortheastheriopsis* dominate the assemblage in the Guantou Fm. As *Cratostrachus* is the most characteristic taxon, the assemblage is referred to as the *Cratostrachus* fauna. These three taxa are also recorded from the Dalazi Fm. in eastern Jilin while the latter two are recorded from the Puchanghe Fm. in Yunnan. The Guantou Fm. also produces a genus that resembles *Aglestheria*, recorded from the beginning of the Late Cretaceous. Consequently, the age is regarded middle to late Early Cretaceous.

**Gastropoda:** *Lioplacodes*, *Brotiopsis*, and *Gyraulus* dominate the fauna of the Guantou Fm. assemblage. The genus *Lioplacodes* is also recorded from the Early Cretaceous Dongfosi Fm. in the Yanji region of Jilong. *Brotiopsis wakinoensis* and *B. (Songyangospira) kobayashii* are found extensively in the Lower Cretaceous of southern Korea and the Lower Cretaceous around Kyushu, Japan.

**Pelecypoda:** Abundant faunas are recognized from the Lower Cretaceous of South China represented by the *Trigonoides-Plicatounio-Nippononaia* fauna (simplified to the *T.P.N.* bivalve complex). Also associated in this complex is *Nakamuranaia* and *Sphaerium*. *Trigonoides* is restricted to the Cretaceous, while the species *T. (Trigonoides) kodairai* and *T. (T.) sinensis* are frequently recorded in the lower Early Cretaceous such as the Guantou, Guilin, Dongjing, Qijiahe fms.; the Matoushan Fm. of Yunnan; the Dalazi Fm., Yanji, Jilin; and the Houshijie Group of Heilongjiang. These taxa also appear in the Early Cretaceous of South Korea. Other subgenera of *Trigonoides* such as *T. (Didymotrigonoides)* are noted in the Early Cretaceous of the Yongfu Group and the Napai Fm. at Fusui, Guangxi Province while *T. (Diversitrigonoides)* is noted from the Cretaceous of Laos and Thailand in addition to the Lower Cretaceous Duoni Fm., in the Heihe river valley of Tibet and the Bali Fm., Fusui, Guangxi.

*Plicatounio* is characteristic off the Lower Cretaceous and in South China is commonly represented by *P. (Plicatounio)*. Furthermore, a new subgenus has recently been described *P. (Acclivisplicatounio)* from the Bali Fm., near Nanan Commune, in the Shiwandashan region of Guangxi, which is characterized by four oblique ridges on the posterodorsal shell surface which intersect with the transverse radial ridges to compose an inverted V-shaped ornamentation. This subgenus is predominantly represented by *P. (P.) multicatus* and *P. (P.) naktongensis* the latter of



which is recorded from the Lower Cretaceous of Korea and western Japan. The former species is extensively distributed in South China within the Guantou, Guilin, Dongjing, and Qijiahe fms. in addition to the Matoushan Fm. of Yunnan. But the latter species is absent in these formations though it is present in the Shaxian Group within the Hekou Basin of Ninghua, Fujian. Further data is required to confirm whether this implies that the two taxa do not coexist although they may share an ancestor descendent relationship. In Japan and Korea there are instances of co-existence although in the majority of cases the two species are in superposition.

In summary, the Early Cretaceous *T.P.N.* bivalve complex is characteristically Asian, being recorded extensively in South China, Japan, Korea, Laos, Thailand, and the Fergana Basin of Uzbekistan. This assemblage allows correlation of the Guantou, Guilin, Dongjing, Qijiahe, Zhoujiadian, the Yunnan-Matoushan, and Guangxi-Nopai fms. to the middle to late Early Cretaceous, or Neocomian to middle or late Aptian.

The Guantou Fm. is correlated to sediments with generally equivalent assemblages such as the *T.P.N.* bivalve complex containing the diagnostic *P. (P.) multicatus*, the *Atopochara trivolvis* and *Flagellochara hangzhouensis* communities. Furthermore, these fossiliferous sediments all maintain either disconformable or unconformable contacts with their underlying strata suggesting deposition after synchronous orogenic activity. A synthesis of chronologic subdivision of the biota described above combined with stratigraphic sequences and structural characteristics suggests that the Guantou and related formations should be regarded middle to late Early Cretaceous or generally Barremian to Aptian, and that the upper formational units such as the Chaochuan, Sanyanggang, and others may be restricted to late Early Cretaceous.

Finally, the problem of clarifying the status of Huangshan Fm. in Jiangxi requires to be addressed. The type section lies west of Gangtian, Huangshan, Shouchang Co., Zhejiang Province, where it consists of a set of dark purple silty mudstones that appear in conformable contact with the underlying Shouchang Fm., its age as Late Jurassic to Early Cretaceous is still controversial and opinions are inconsistent as other strata in Zhejiang are correlated on the same basis. Consequently, these sediments are not included in Table 1, although, here, a synopsis of paleontological complexes, characteristics, chronological subdivision, and correlation is provided below:

**Ostracoda:** The assemblage is dominated by *Cypridea (Morinia)* and associated with *Monosulcocypris*. Morphology of the large dominant taxon includes relatively deep anterodorsal transverse troughs. This genus appears in the middle to late Early Cretaceous lower member of the Guilin Fm., in the Matoushan Fm. of Yunnan as *C. (M.) monosulcata*, and in the Qingshankou Fm. on the Songliao plain as *C. adumbrata*. This appears to correlate to the lower member of the Guilin Fm.

**Gastropoda:** The assemblage is dominated by *Probaicalia* and *Galba*. *Probaicalia* contains four species among which three first appear in the Shouchang Fm. and persist stratigraphically higher. The earliest occurrence of *P. prindae* is from the earliest Cretaceous Valanzhin section in the Lake Baikal region of Siberia. Later, this species was found in the upper Huaya Fm., Donghe Group, Huicheng Basin, Gansu Province. The species *G. mediensis* is predominantly recovered from the Guantou Fm. Taxa from the Shouchang Fm. are also recovered from the Huangshan Fm. in addition further first appearances, and consequently the Huangshan Fm. should be regarded Late Jurassic to Early Cretaceous.

**Pelecypoda:** The assemblage is dominated by *Nakamuranai* and *Sphaerium* in addition to the presence of *Plicatounio?* Pelecypod workers believe that the Huangshan Fm. postdates the Shouchang Fm. and predates the Guantou Fm. based upon the pelecypods and lithologic character. Also, taxa shared with the Guantou Fm. and taxa contained at the top of the Shouchang Fm. are also produced from the Huangshan Fm. and hence some workers believe the unit is lowermost

Cretaceous, or equivalent to the Shaxian Group in the Hekou Basin of Ninghua, Fujian. Others believe it is uppermost Jurassic.

**Conchostraca:** Composed entirely of the genus *Migransia*, some species are shared with the Qujiang Group and Shouchang Fm. but are not characteristic of this unit. Conchostracan data is not abundant and hence cannot be applied to diagnose an age.

### Late Early or early Late Cretaceous biotic assemblage

This assemblage is composed principally of charophytes, macro plants, conchostracans and pelecypods derived from the Jiadian, Shenhuangshan, and Pukou fms, in addition to the third and fourth units of the Qujiang Group.

**Plant macrofossils:** The first occurrence of the early Late Cretaceous *Manica tholistoma* is from the Qingshankou and Quantou fms. on the Songliao plain. In South China, this species, or those resembling it, are recorded in all regions from the third unit of the Qujiang Group, the upper Ganzhou Group (Zhoujiadian Fm.), the upper Shaxian Group in Minxisha Co., and the Pukou Fm., Puzhen, Nanjing.

**Charophytes:** The assemblage includes *Euaclistosphaera mundula*, *Mesochara symmetrica*, *Maedlerisphaera corollecae* and *Obtusochara cylindrica* produced from the “Pukou Fm.” of northern Jiangsu, the third and fourth units of the Qujiang Group and the top of the Jiadian Fm., Zhejiang. These taxa are consistent with both the Early Cretaceous *Atopochara trivolvris* and *Flabellochara hangzhouensis* complexes with the exception of the genus *Maedlerisphaera*.

**Ostracoda:** This complex is produced from the Jiadian Fm. and the third and fourth units of the Qujiang Group. The Jiadian Fm. complex consists of *Eucypris* at 23.3%, *Quadracypris* at 16.7%, *Cypridea* at 13.3%, *Cristocypridea* at 10%, and *Ziziphocypris* at 6.6%. This assemblage differs from those in the early to late Early Cretaceous Guantou, Guilin, and Matoushan fms. and relates more closely to, although differs from, the widely distributed and stratigraphically consistent middle to late Late Cretaceous *Cristocypridea*, *Cypridea*, and *Candona* faunas. It appears that the ostracods from the Nenjiang Fm. on the Songliao Plain are relatively close to those from the third and fourth units of the Qujiang Group, Zhejiang, in addition to the early Late Cretaceous complex from eastern Mongolia. Although the age of the Jiadian Fm. is probably late Early Cretaceous this assemblage is provisionally more appropriately regarded early Late Cretaceous.

The Shenhuangshan Fm. contains the genera “*Lycoperocypris*,” “*Timiriasevia*,” and *Darwinula*, among which the species *L. trosuosus* is recorded from the Quantou, Qingkou, and Yaojia fms. on the Songliao Plain. “*Timiriasevia*” *polymorpha* is recorded from the Early Cretaceous of eastern Mongolia and the former Soviet Union. This formation is thereby regarded early Late Cretaceous.

Ostracod complexes are produced from the third and fourth units of the Qujiang Group. The third unit at Longyou, Quxian Co. and Lanxi, Zhejiang, produces the subgenus *Cypridea* (*Pseudocypridina*) co-occurring with a small amount of *Cristocypridea*. The taxon *C. (P.) lenta* is an early Late Cretaceous member of the Jiadian Fm., in eastern Hubei, while *C. (P.) porrecta* is a member of the Early Cretaceous Nenjiang Fm. *Tanxiella* is a dominant genus derived from the fourth unit of the Qujiang Group in the Yangxi region of Zhejiang. This genus shows some similarity to *Quadracypris* which is extensively recorded from the Jiadian Fm. in eastern Hubei. In summary, the complexes from the third and fourth members of the Qujiang Group differ rather dramatically from those in the middle to late Early Cretaceous Chaochuan and Guantou fms. and more closely compare to the early Late Cretaceous Jiadian Fm. complex.

**Conchostraca:** The third unit of the Qujiang Group produces *Zhestheria*, *Halysesstheria*, and *Nemestheria* in addition to *Sinoestheria*, which although not abundant, is extremely diagnostic. Previously, this genus was recorded from the Hongshuigou Fm. on the western border of the Caidam Basin and the Late Cretaceous sediments of Inner Mongolia. Recently it has been recorded from the Late Cretaceous of Dongjin, Guangxi. Assemblages from the Guilin Fm. of southern Anwei and the Zhoujiadian Fm. of Jiangxi also compare to this complex and are generally equivalent to the early Late Cretaceous Songhuajiang conchostracan fauna.

**Pelecypoda:** *Pseudohydria* cf. *gobiensis*, *Sphaerium* cf. *shantungense* and *S. hantungense* are recorded from the third unit of the Qujiang Group at Longyou, Quxian Co., Zhejiang. The first occurrence of *Pseudohydria* is from the upper Cretaceous Erlian Fm. of Erlian, Guoleming, Yanglin, Inner Mongolia, *S. shantungensis* is a member of the Late Cretaceous Wangzhi Group of Dongjiao, Shandong, all of which indicate an early Late Cretaceous age for the pelecypods of the third member of the Qujiang Group.

Regional biostratigraphic correlation of the aforementioned South China sediments is basically consistent, although there are some slight discrepancies among age assessments. General consensus, however assigns the sediments to early Late Cretaceous although a minority of workers interpret a late Early Cretaceous age. Nevertheless, there is controversy regarding the constraint or ages of the Pukou, Hucun, Chaochuan fms. and the members of the Qujiang Group based upon biostratigraphic evidence that is correlated to North China sediments. Consequently, this text provisionally recognizes these biotic assemblages and their related sediments to late Early or early Late Cretaceous.

### Late Cretaceous biotic assemblage

Late Cretaceous biota are recorded from the upper sediments in the Pukou and Jiadian fms, most extensively represented by charophytes and ostracods and secondarily in several regions by pollen, pelecypods and gastropods.

**Charophyta:** Represented by the *Porochara anluensis-Latochara cylindrica-Charites tenuis* assemblage which may be recognized as both an early or late complex. The early complex is produced from Brick red sandstones of the Gonganzhai Fm. in Hubei and the Chishan Fm. in Jiangsu and characterized by its association with the large genus *Porochara*. *Porochara* is a relatively primitive Mesozoic genus and from a phylogenetic standpoint this large form should represent the youngest record. Closest related taxa are recorded from the Upper Cretaceous of Peru and Argentina. This complex is also extremely similar to the charophyte complex produced from the Upper Cretaceous Mankuanhe Fm. of Yunnan.

Extensively distributed Late Cretaceous complexes are typically produced from the Nanxiong Fm. of Guangdong and the Paomagang Fm. of Hubei. Additional fossiliferous sediments include lacustrine tan-red silty sandstones and mudstones which overlie brick red fluvial sandstones, and which are recognized as the Sanshui Fm., Sanshui Basin, Guangdong; upper member of the Daijiaping Fm., Hengyang Basin, Hunan; and the Fenshuigou and Jiangsutai fms. in the Dongting region. Fossil characteristics include the continued presence of primitive Mesozoic elements such as *Latochara*. The large species of *Porochara* is only occasionally found in the lower sections of these stratigraphic sequences. The genera *Peckichara*, *Gyrogona*, and *Charites*, dominate these and are usually associated with the Tertiary to indicate a replacement by transitional forms from the Late Cretaceous to Early Tertiary. A vast majority of species, however, are characteristic only to this interval while a small amount represent continuation of taxa from the Early Cretaceous and which persist into the basal Early Tertiary. Based upon the transitional nature of the taxa and the distinct dominance of *Peckichara*, *Gyrogona*, and *Charites*, the age of the sediments is initially determined to be latest Cretaceous, but because the large species of *Porochara* are characteristic of older assemblages, the age is adjusted to middle Late Cretaceous.

**Pollen:** Adequate pollen research has been conducted in the Taizhou Fm. where an upper and lower complex are recognized. The first member of the Taizhou Fm. produces nearly equivalent counts of ferns, gymnosperms, and angiosperms. Dominant ferns include *Pterisporites*, *Schizaeosporites* and *Gabonisorites*. Gymnosperms are dominated by *Exesipollenites* with secondary occurrences of *Classopollis*, *Ephedripites*, *Pinuspollenites* and *Rugubivesiculites*. Angiosperms are dominated by *Gothanipollis*, *Plicapollis* and *Ulmipollenites*. Derived taxa are also present as *Aquilapollenites*, *Mancicorpus*, *Translucetipollis*, *Orbiculapollis*, *Proteacidites* and *Wodehousea*. Similar complexes are also found in the Pacific region of the Northern hemisphere and in Siberia including the Edmonton Fm. in Alberta, Canada; several Maestrichtian marine facies in Siberia; and the Chinese Mingshui Fm. on the Songliao Plain which also produces *Aquilapollenites*, *Manoicorpus*, and *Wodehouseia* in addition to several elements shared with the first member of the Taizhou Fm.

The second member of the Taizhou Fm. differs distinctly from the first by being dominated by the gymnosperms *Pinuspollenites*, *Abietineapollenites*, *Cedripites*, *Podocarpidites*, and *Inaperturopollenites*. Angiosperm pollen is represented by the sporate *Ulmipollenites*, *Caryapollenites*, and *Alnipollenites*. The majority of the derived taxa recorded from the first member are extinct here. Ferns are rather diminished in count although *Pterisporites* and *Lygodiumsporites* are recorded. This gymnosperm dominated complex is regarded as Danian, in Age, Latest Cretaceous or earliest Paleocene.

**Ostracoda:** Representative taxa include *Cristocypridea*, *Cypridea* and *Quadracypris*. This fauna may be recognized as a composite of two Late Cretaceous upper and lower sub-complexes with evolutionary tendencies resembling the condition of the charophytes. The lower sub-complex is recorded from the middle member of the Xuannan Fm. in southern Anwei. General regional correlation of this unit equates it with the *Porochara* bearing Antai and Yishan fms. The upper sub-complex also produces several genera, although there are species distinctions. Among these *Cypridea* (*Cypridea*) is a small form, *Quadracypris* has relatively deep medial dorsal troughs, and they are both associated with the particularly large *Mongolianenna*? Furthermore, Cenozoic taxa are extremely rare. The lower sub-complex is regarded middle Late Cretaceous.

The upper sub-complex is produced from strata containing the late Late Cretaceous charophyte complex. Specimens are extremely abundant and dominated primarily by *Cypridea* or *Cristocypridea* with secondary occurrences of *Quadracypris*, and taxa including several Cenozoic genera such as *Candona*, *Limnocythere*, *Eucypris* and *Paracandona*. This suggests a transitional nature between the Mesozoic and Cenozoic, but the fauna is characteristically latest Cretaceous and basically correlative with the Late Cretaceous Songfangtai and Mingshui fms. on the Songliao Plain; the Donggou Fm. in the Junggar Basin of Xinjiang Autonomous Region; and the Upper Cretaceous Upper Nemegt beds in the Nemegt Basin of Mongolia.

**Gastropoda:** Represented by the *Mesolanistes nanxiongensis-Truncatella maxima* complex, this assemblage is vastly dominated by fresh-water prosobranchs and extensively distributed in the Sanshui Fm., Sanshui Basin, and the Nanxiong Fm., Nanxiong Basin, Guangdong; middle member of the Xuannan Fm., Wannan, and Nanxiong Fm., Qingjiang Basin, Jiangxi. The two most common species noted in the Cretaceous Sifangtai Fm. on the Songliao Plain are *Valvata sinensis* and *Truncatella maxima*. Three species which are extremely similar include *Mesolanistes nanxiongensis*, *M. brevispiralis* from the Sifangtai Fm., and the American *M. cretaceous* Yen from the Upper Cretaceous Kaiparowits Fm. *Pachytiloides subtilistriata* is also extremely similar to the American Upper Cretaceous *P. chrysalis* (Meek) and as such, the Chinese sediments are regarded as latest Cretaceous.

**Pelecypoda:** Late Cretaceous pelecypods are relatively scarce in South China but species recorded include *Pseudohyria* cf. *gobiensis*, *Sphaerium shantungense*, *S. xuanchengense* and *S. rectiglobesum* recovered from the Xuannan Fm., Xuancheng, Langxi, southern Anwei and the

“Yishan Fm.,” Jiangyin, Jiangsu. *S. sp.* is recorded from the Nanxiong Fm., Nanxiong, Guangdong and the Daijiaping Fm., Hengyang, Hunan. A majority of these species are also found in the Erlian Fm., Inner Mongolia; Sifangtai Fm. and the Wangshi Group, Ludong Songliao Plain.

Age diagnoses for the five biotic assemblages described above are consistently Late Cretaceous. Charophyte and ostracod complexes may be further subdivided into upper and lower assemblages or sub-complexes. The age of the lower sub-complexes may be middle Late Cretaceous while the upper sub-complexes may represent latest Cretaceous and display transitional phases of speciation. Hence, the following stratigraphic members and formations should represent concurrent deposition: Nanxiong Fm. at Nanxiong, Dabishan and Sanshui fms. at Sanshui, Guangdong; upper member of the Daijiaping Fm., Hengyang Basin and Fenshuigou Fm., Dongting region, Hunan; the Paomagang Fm., Jiangnan Plain, Hubei; and the Taizhou Fm., Jiangsu.

Worthy of notation and deliberation is that several workers have assigned the Taizhou Fm. to the earliest Tertiary for the following reasons:

(1) The lower portion is dominated by brick red sandstones and upper portion by black lacustrine deposits which is typical of the Yishan Fm. Therefore, from a stratigraphic and depositional perspective the red sandstones may be correlated to the latest Cretaceous deposits extensively distributed in South China and particularly the Fengshuigou and Paomagang fms.

(2) From a biostratigraphic perspective, the ostracods are vastly dominated by a *Cypridea* assemblage both taxonomically and numerically that coexist with several taxa intimately associated with the Cenozoic, such as *Ilyocypris*, *Eucypris*, *Limnocythere* and *Candona*. A distinct but small amount of *Quadracypris* has been recovered from the Xiaohekou cross-section and although, to date, *Cristocypridea* is absent, the complex is fundamentally consistent with the upper sub-complex of the Paomagang and Nanxiong fms. The publication “Cretaceous and Tertiary Charophyta from Jiangsu Province” states that the Taizhou Fm. produces relatively numerous Early Tertiary elements that cannot be readily distinguished from the first formation of the Funing Group. However, some of the data appears to be unreliable and the data that is verifiable or collected from surficial exposures appears fundamentally representative of the South China latest Cretaceous complex producing *Latochara* and the more archaic *Collichara* which is extremely rare in the Early Tertiary. Not long ago the Sixth General Investigative Corps of Jiangsu Province recovered the commonly regarded latest Cretaceous *Charites tenuis* and *C. guanpingensis* from the southern end of the province in sediments that may be considered the Taizhou Fm. Finally, pollen evidence from the first member of the Taizhou Fm. may be correlated to latest Cretaceous Maastrichtian sediments although several pollen workers have assigned a Paleocene age to the second member of the formation based upon pollen resemblance to sediments of Danian Age. But it must be remembered that whether the Danian is securely assigned to the Paleocene is still a point of controversy and based upon the data above this text finds it more suitable to assign a latest Cretaceous age to the Taizhou Fm.

### Paleocene biotic assemblage

South China Paleocene assemblages are principally noted from the Shanghu Fm. in the Nanxiong Basin which is abundant in fossil mammals diagnosed as middle Paleocene (Chow and Zhang, 1973; Tong, 1976; and Chow et al., 1977). Invertebrate and plant records include ostracods, gastropods, and charophytes.

**Charophyta:** Represented by the *Grovesichara changzhouensis-Latochara curtula* assemblage, in the Shanghu Fm., this complex contains distinct descendant taxa from the Late Cretaceous. The primitive *Latochara curtula* is descended from forms in the underlying Nanxiong

Fm. Also associated with this flora is *Grovesichara changzhouensis* which is intimately associated with South China Early Eocene sediments, however, its morphology suggests it is a Mesozoic remnant mixed with Cenozoic counterparts. Similar charophyte complexes are unobserved in the first formation of the Funing Group in Jiangsu, the first formation in the Changhe Group, Zhejiang, and the first formation of the Yuanjiang Group in the Dongting region of Hunan. *Latochara* is also absent from the latter group although the primitive *Euaclistochara* is frequently recovered from the underlying Late Cretaceous Fenshuigou Fm. and, consequently, their ages are regarded as generally equivalent.

**Ostracoda:** Also represented in the Shanghu Fm. are *Cypridea*, *Cyprois* and *Parailocypris*. The assemblage consists entirely of new taxa with the exception of a single remnant species from the underlying Nanxiong Fm., *Cypridea (Morinia) xindianensis*. A similar complex is recovered from the first formation of the Funing Group in northern Jiangsu although there are more remnant forms from the underlying Taizhou Fm. but their population is diminished and there is morphological variation. Different ostracod complexes are recovered in southern Jiangsu from the first formation of the Funing Group as well as in Hubei from the Lingbei Fm., the first formation of the Yuanjiang Group in the Dongting region, and the first formation of the Buxin Group in the Sanshui Basin. The frequently encountered Mesozoic *Cypridea* and *Quadracypris* are absent, but other Late Cretaceous taxa are diminished in count and forms intimately related to the Tertiary are present. The assemblage is dominated by *Parailocypris*, *Cypris*, *Ilyocypris* and *Limnocythere*. There is a certain resemblance to the western North American *Cypridea* complex which occurs in the Paleocene Fort Union Fm. and Flagstaff Limestone although the genus *Cypridea* itself is absent. The southern Jiangsu and Hubei complexes resemble the Paleocene White Beds in the Nemegt Basin of Mongolia.

**Gastropoda:** Produced from the Shanghu Fm. in the Nanxiong Basin, Guangdong, they are represented by the *Ptycholchilus bellus-Agallospira multispiralis* complex of fresh water prosobranchs and terrestrial pulmonata. Principle taxa include *Ptycholchilus bellus*, *Nystia luminosa*, *Flumincola guangdongensis*, *Agallospira multispiralis*, *Shanghuspira costata* and *Microlaminatus* sp. Among these, *P. bellus* resembles *Dimorphoptychia* from the Late Cretaceous and Paleocene of North America and Europe, while *Shanghuspira* approaches *Acanthinula* from the Paleocene of Europe. The complexion of the entire assemblage differs from the Late Cretaceous complex in eastern China in addition to Eocene assemblages in China and is consequently recognized as a distinct Paleocene complex.

In summary, the charophytes and a portion of the regional ostracod assemblages (*Cypridea* complex) reflect a mixed assemblage of latest Cretaceous to Early Eocene taxa and based upon North American and Mongolian comparisons they are provisionally assigned a Paleocene age.

An additional discussion of the age of the Dongtang Fm. is warranted. Typical exposures lie at Laochezhan Railway Station in the municipality of Xialiushi, Hengyang Basin, Hunan. It is purported that fragmentary dinosaur eggs are recovered from the stratigraphically equivalent Chejiang Fm. in the same basin, causing several geologists to regard the age as Late Cretaceous. But charophytes and ostracods resemble the Shanghu Fm. in Nanxiong, and the stratigraphic sequence and depositional cycles characterize the Dongtang Fm. as fluvial sandstones with either a conformable or disconformable contact with the underlying Daijiaping Fm. in addition to having a conformable contact with the overlying variegated sediments resembling the Luofozhai Fm. Consequently, the Xialiushi Fm. may be correlated generally with the Shanghu Fm. such that the Dongtang is regarded as probably Paleocene in age.

## Eocene biotic assemblages

Mesozoic taxa have all but become extinct in the Eocene of South China, Cenozoic taxa have begun to become prolific and all orders reach extreme abundance. From a depositional perspective, two regimes are recognized. The lower sedimentary package is universally recognized as a set of widely dispersed black lacustrine sediments with basal interbedded carbonatites. Opinions are relatively consistent regarding subdivision and age of this unit based upon the paleontology. The upper sedimentary package differs from east to west. In the eastern Jiangsu, Jiangxi, and Zhejiang region sediments are dominated by black lacustrine facies with some biotic assemblages that differ from the underlying units but with others that are not readily distinguishable. In the western Hubei and Hunan region the sediments consist of red fluviolacustrine units with assemblages that are distinct from both the underlying units and from those complexes in the east. In the south, in Guangdong and southern Jiangxi, this section is predominantly red with interbedded black sediments that are poorly fossiliferous and hence there is controversy regarding correlation and subdivision.

### Lower Eocene assemblages.

**Plant macrofossils:** The genus *Palibinia* has a relatively broad distribution in South China with five species recorded: *P. angustifolia*, *P. laxifolia*, *P. pinnatifida*, *P. korowinii* and *P. latifolia*. The *Palibinia* complex is recorded from the Wulidui Fm. in the Wucheng Basin of Henan and the Bailiyuan Fm. of Weinan, Shaanxi. Outside of China it is documented from the Babkhyss Fm. in southern Turkmenia which is overlain and underlain by units containing marine pelecypods and Foraminifera with an age recognized by some as the Late Eocene Turkistan stage while others consider this stage Middle Eocene. The derived species *P. korowinii* is shared between the *Palibinia* complex derived from Xiawanpu, Xiangxiang, Hunan, other North China localities, and in Turkmenia. In addition South China produces the derived species *P. angustifolia* which may indicate a younger age of late Middle Eocene. The third formation of the Funing group, second formation of the Qingjiang Group, the Xialiushi Fm., and lower member of the Fangjiahe Fm. are probably Early to Middle Eocene in age as they are dominated by *P. angustifolia* although *P. korowinii* is absent. The second formation of the Buxin Group records not only *P. angustifolia* and *P. laxifolia* but *Marchantia* sp., *Equisetum* sp., *Lygodium kaulfussii*, *Cinnamomum naitoanum*, *Geoperttia ovalifolia*, *Eucommia brevisrostrata*, and *Trapa panula*. *T. Panula* is recorded from the Latest Cretaceous to Paleocene of North America while *L. kaulfussii* and *C. naitoanum* are recorded from the typical mesic Fushun Flora and thus reflect Early to Middle Paleocene. Consequently its age is probably Paleocene to Middle Eocene.

**Charophyta:** Principle genera within the *Peckichara longa*-*Obtusochara elliptica* complex include *Peckichara*, *Stephanochara*, *Neochara*, *Gyrogoma*, *Grovesichara* and *Maedleriella* with *Peckichara* dominating the complex. *P. longa* is extremely similar to *P. coronata*, the latter having a first occurrence in the middle-upper Paleocene and Early Eocene of North America. The species *P. varians* is characteristic of the Lower Eocene Sparnacian Stage of France. *Grovesichara changzhouensis* rather closely resembles *G. kielani* from the "White Beds" of the Mongolian Nemegt Basin only it is larger and in lateral perspective possesses more whorls. *Gobichara deserta* which is abundantly recovered from the second formation of the Funing Group in Jiangsu is also recorded from the Mongolian White Beds. *Maedlerisphaera* is recorded from the Fangjiahe Fm. and second formation of the Xingouzui Group in Hubei in addition to the Luofozhai Fm., Nanxiong Basin, Guangdong. The genus is first recorded from the Thantian Stage of France and later becomes extremely abundant in the Sparnacian to Auversian. As such the *P. longa*-*O. elliptica* charophyte complex is constrained to the Late Paleocene-Early Eocene and due to the prolific nature of *Peckichara* in South China, the age of these sediments is most probably Early Eocene. Sediments containing this flora include the second to fourth formations of the Funing Group in Jiangsu, second formation of the Changhe Group in Zhejiang, second formation of the

Xingouzui Group and Fangjiahe Fm. in Hubei, second formation of the Yuanjiang Group and Xialiushi Fm. in Hunan, and the upper portion of the first formation through second formation of the Buxin Group and the Luofozhai Fm. in Guangdong.

**Pollen:** The *Ulmipollenites-Triporopollenites-Rhoipites* complex is produced from the first through second formations of the Funing group (predominantly from the second formation). The assemblage is characterized by the complete dominance of angiosperms while saccate pollen is relatively rare (nearly absent in the first formation), and ferns are extremely rare. Among the angiosperms are *Ulmipollinites minor*, *Subtriporopollenites granulatus*, *Plicapollis granulatus*, *Quercoidites microhenrici* and *Q. henrici* in addition to several subtropical species. Its age should be Paleocene to early Eocene reflecting a paleoclimate equivalent to that of the South Asian tropics. Pollen complexes produced from the Fangjiahe Fm. and surficial exposures of the second formation of the Yuanjiang Group are comparable to those described above although the angiosperms are dominated by the genus *Myrtaeoidites* and ferns are dominated by *Polypodiaceoisporites*. Ages should be Eocene.

**Ostracoda:** This assemblage is designated the *Sinocypris-Parailocypris-Eucypris-Cyprois-Limnocythere* complex and is predominantly represented by the species, *Sinocypris pulchra*, *S. arca*, *Parailocypris changzhouensis*, *Eucypris fuscata*, *Cyprois xuyiensis*, *C. businensis*, *Limnocythere hubeiensis*, *Cypris "decaryi"* and *C. favosa*. In all the regions, generic distribution is basically the same, or being prolific and abundant although taxonomic dominance varies with location. For instance, the genus *Sinocypris* has only a single occurrence in Hubei Province but occurs abundantly in all other regions. The same phenomenon occurs with the genera *Eucypris* and *Cyprois*. The genera *Limnocythere* and *Cypris* are extremely prolific in the Dongting Basin of Hunan and Hubei where *Cyprinotus* also occurs. *Parailocypris changzhouensis* is universally recovered from this time period and is extremely abundant in the Jiangsu region. Several elements of this complex are comparable to the Wutu Fm. of Shandong, North China, in addition to the Late Paleocene to Eocene Fort Union Fm. Wasatch Fm. and Flagstaff Limestone in the Western United States, in addition to the White Beds in the Nemegt Basin of Mongolia, although the general complexion of the South China complex is basically different. The age is generally recognized as Eocene although a possibility exists that it may be Late Paleocene. This assemblage is represented in basically the same localities that have produced charophyte complexes with the exception of the second formations in the Funing and Buxin groups.

**Gastropoda:** The Fangjiahe Fm. produces *Hydrobia* cf. *marceauxiana*, *Truncatella yidouensis*, *Planorbis hepeiensis*, and *Carychium asprolamellosum*. The second through fourth formations of the Funing Group produce *Valvata changzhouensis*, *Caspia antiqua*, *Sinoplanorbis minuta*, *Parhydrobia macilenta* and *Pseudamnicola opima*. The Luofozhai Fm. in the Nanxiong Basin produces *Polycirsus gracilcostata*, *Bithynia* aff. *lordostoma*, *Circomphalus simplus*, *Opeas luofuensis*, *Nanxiongspira uniptychia* and *Ossimineia* sp. The middle section of the "Shuangta Group" in southern Anwei produces *Theodoxus xuanchengensis*, *Multiscapta raris*, *Archaeozonites luosigangensis* and *Ganeselloides latus*.

*Hydrobia* cf. *marceauxiana* from the Fangjiahe Fm. first occurs in the Eocene of the Paris Basin, France, while *Planorbis hepeiensis* is recorded from the upper section of the fourth member of the Shahejie Fm., Zhuoxian Co., Hebei (nearly correlative to the Hedi Fm. in the Yuanqu Group), and hence the age of the Fangjiahe Fm. is probably Late Eocene. The two species *Pseudamnicola opima* and *Parhydrobia macilenta* from the second to fourth formations in the Funing Group resemble *Bithynia oxyopira* and *Parhydrobia sublata* from the Eocene of the Paris Basin. *Sinoplanorbis minuta* is rather close to *S. spiralis* from the Hedi Fm. of the Yuanqu Group although it has a smaller shell body with an inconspicuous spire and is thus relatively primitive such that the age of the Funing sediments may predate the Hedi Fm. being Early to Middle Eocene. Gastropods from the Luofozhai Fm. are possibly Early Eocene.



Gastropod opercula are known from the Fangjiahe Fm., the second and third formations of the Changhe Group, and the Yuanjiang Group which are diagnosed as the Eocene *Mirolaminatus gracilis*, *M. obliquus*, *M. Validus*, *M. lamellatus*, and *M. lamelloides*.

**Pelecypoda:** Scattered exposures of the second formation of the Funing Group in the Laian region of eastern Anwei produce *Eupera* cf. *sinensis*, *Sphaerium* cf. *solidum*, and *Loxophycodona*? sp. *Eupera* is frequently recorded from the Early Tertiary of Europe, Asia, and North America, *Loxophycodona* is an important taxon in the Paleocene to Early Eocene of Europe, and *Eupera sinensis* has a first occurrence in the Yuanqu Fm. of Shanxi. Thus, the second formation of the Funing Group should predate the Yuanqu Group as early Late Eocene. The second formation of the Buxin Group produces *Eupera* aff. *sinensis* and is considered Eocene.

**Conchostraca:** The second formation of the Funing group records *Perilimnadia jiangsuensis*, *P. gaoyouensis*, and *P. lingtangqiaensis*, and as such may be Paleocene. The upper section of the first formation through the second formation of the Buxin Group records *Paraleptestheria menglaensis*?, *P. baoyuensis* and *Nanhaiestheria sanshuiensis* suggesting an Early Eocene age.

**Worm burrows:** These features are extensively noted in the South China provinces of Jiangsu, Zhejiang, Jiangxi, Hubei, and Hunan in addition to the North Chinese Shandong and Henan provinces. They are predominantly noted in the basal interbedded limestones of the second formation of the Funing Group, second formation of the Buxin Group, second formation of the Yuanjiang Group, and the Xialiushi Fm. Recorded are the ichnotaxa *Sinoditrypa conica*, *Acerrotrupa aggregata*, *Terebella?* *jinhuensis* and *Ethmonaria regularis*. Abundant worm burrows such as these are also noted from the Lower Tertiary marine Qimugen Fm. near Kashgar in the Tarim Basin of Xinjiang Autonomous Region in addition to Tertiary sediments in the Vienna Basin of Austria, the Paris Basin of France, and the London Basin of England where they are all present in either marine or brackish water environments. The worm burrows in the bioliths of the second formation of the Funing Group resemble extant *Polychaeta* burrows and (?) Tertiary forms inside and out of China. Ichnologists believe these should represent saline or brackish biota. Geochemical studies indicate that compared to current marine and terrestrial faces, there are trace elements suggesting marine to marginal marine environments.

**Foraminifera:** Small bodied forams diagnosed as *Milliolides* sp. are noted from the sandy micrites of the second formation of the Funing Group and are also recorded from the bioliths of the second formation of the Funing Group in northern Jiangsu.

**Stromatolites:** Stromatolites are noted in the second formations of the Funing and Buxin groups and the Xialiushi Fm. They are deduced to have formed on a littoral shelf based upon their coexistence with worm burrows and abundant carbonatites.

To summarize the age, subdivision, and stratigraphic relationships of the South China basins to each of the organismal complexes described above, the following conclusions are recognized. (1) The *Peckichara longa*-*Obtusochara elliptica* charophyte assemblages and the *Sinocypris-Paraillyocypris-Eucypris-Cyprois-Limnocythere* ostracod assemblage are extensively distributed and coexist concurrently toward the Early Eocene. These two complexes indicate a general correlation of the following strata: the second formation of the Funing Group (charophytes span the third and fourth formations), second formation of the Changhe Group, Fangjiahe Fm., second formation of the Xingouzui Group, second formation of the Yuanjiang Group, Xialiushi Fm., Luofozhai Fm., and second formation of the Buxin Group (charophytes also encompass the upper portion of the first formation). (2) In general, the age represented by the gastropods, pelecypods, conchostrachans, pollen, and fossil macro plants is Paleocene to Eocene. Opinions are inconsistent regarding precise age correlations between each of the basins as the gastropods suggest the Luofozhai Fm. is probably Early Eocene while the Fangjiahe Fm. and second

formation of the Funing Group predate Late Eocene. Pelecypods indicate the second formation of the Funing Group is Early or Late Eocene, and the second formation of the Buxin Group and Xialiushi Fm. are generally Eocene. Plant macrofossils indicate the second formation of the Buxin Group is possibly Early or Late Eocene while the Xialiushi Fm., lower portion of the Fangjiahe Fm., third formation. of the Funing Group, and second formation of the Qingjiang Group are Early or Middle Eocene. Pollen suggests the first to second formations of the Funing Group are Paleocene to Early Eocene, while the second formation of the Buxin Group is Early Eocene. (3) Conchostracans indicate the second formation of the Funing Group is Paleocene while the second formation of the Buxin Group is Early Eocene.

In conclusion the correlation of the biotic assemblages combined with the stratigraphic sequences and depositional characters in each of the basins suggest the Luofozhai Fm. to second formation of the Xingouzui group and the Fangjiahe Fm. to second formation in the Funing Group are basically correlative and represent the Early to Middle Eocene and perhaps a portion of the Late Eocene.

### Late Eocene Assemblages

**Charophyta:** *Obtusochara jainglingensis*-*Gyrongona qianjiangica* represent this complex associated with the genera *Croftiella* and *Nemegtichara*. Small species dominate the assemblage with a majority of those that occurred only in the Early Eocene now extinct combined with a spectacular decline in one subfamily. This assemblage is unique to China and ubiquitous in South China from above the Early Eocene to below the Oligocene. It occurs in the Jingsha and Deshan (originally named Changde) formations of Hunan, Dainan Fm. of Jiangsu, middle Shuangta Group of Anwei and Pinghu Fm. (?), Chijiang Basin, Jiangxi. In North China this complex is recognized in the Late Eocene fourth member of the Shahejie Fm. In northwestern Hubei it co-occurs in sediments equated with the Pailoukou Fm. which produced the Late Eocene mammal *Eudinoceras* cf. *kholobochiensis*. A small number of species are also noted in the Bartonian of England, and hence the assemblage is provisionally regarded as Late Eocene.

**Pollen:** The third to fourth formations of the Funing Group produce the *Ulmipollenites-proteacidites-pinuspollenites* complex, within which the presence of ferns is very low at 10%, saccate gymnosperms are relatively abundant at 20-25% with frequent counts of *Pinuspollenites*, *Abietinaepollenites*, and *Cedripites*. *Parcisporites parvisaccus* counts are rather high at 5-10% and because of its stable geographic distribution it represents an index taxon. *Ulmus minor* has the highest angiosperm count which may attain 20-50% or more. *Quercoidites* and *Rhoipites* are also rather high but the small *Triporopropollenites* and *Plicapollis* are distinctly diminished in number. Tropical and subtropical flora are represented by the frequently recovered Eocene (perhaps Middle or Late) *Magnolipollis*, *Peltandripites*, *Proteacidites* and *Beanpeeaidites* and though counts are low their presence is geographically persistent. Paleoclimate is presumed to resemble that of the current South Asian tropics.

Pollen complexes indicate the middle to upper sections of the Changhe Group and the middle to upper sections of the Shuangta Group correlate to the third and fourth formations of the Funing Group.

**Ostracoda:** Complexes are recognized as an eastern and western assemblage. The eastern assemblage is represented at Jiangsu and is stratigraphically equivalent to the third and fourth formations of the Funing Group, upper second formation of the Changhe Group, middle portion of the Shuangta Group, and the third formation of the Qingjiang Group in Jiangxi. The western complex is represented at Hubei and equates to the Jingsha and Deshan fms. and the Gaoling Fm. in Hunan and sediments correlative with the third formation of the Buxin Group. Ostracods are extremely rare in the Deshan and Gaoling fms. and the third formation of the Buxin Group. Total

genera within both complexes include *Sinocypris*, *Eucypris*, *Ilyocypris*, *Cyprois*, *Cyprinotus*, *Echinocypris*, and *Cypris*.

The diverse and rich southeastern complex produced from the third and fourth formations of the Funing group in Jiangsu is principally represented by the *Sinocypris funingensis*, *S. nitela*, *Eucypris* “*stagnalis*,” *E. lepingensis*, *Ilyocypris subhanjiangensis*, *Cyprois* aff. *xuyiensis*, *C. buxinensis*, *Candona* (*Lineocypris*) *lubrica*, *Neomonoceratina bullata* and *Cypris* “*decaryi*.” In the west, the complex is distinctly monotonous and not diverse. The Jingsha Fm. in Hubei produces *Cyprinotus subtriangularis*, *C. cicatricosa*, *C. preconcavus*, *Eucypris areacta*, *E. pengzhensis*, *Echinocythere contractus*, and *Cypris* “*decaryi*.”

Both complexes may be distinguished from their underlying counterparts and represent distinctly descendant forms while also being quite distinct from the overlying Oligocene complexes. Several taxa resemble Eocene forms in the Guanzhuang and Yuanqu fms. of Shandong and Shanxi in addition to resemblances shared with forms from the Middle to Late Eocene Colton, Green River, and Uinta fms. of western North America.

**Gastropoda:** Gastropods are produced from the middle of the Shuangta Group as *Theodoxus xuanchengensis*, *Enteroplax? luosigangensis* and *Ganeselloides latas*. Sediments representing the middle portion of this group are extensively distributed and taxonomically diverse. Several taxa resemble those from the Middle Eocene of North China. Other taxa are closely related to those from the Funing Group of Jiangsu. Consequently, the assemblage is recognized as Eocene.

Gastropod opercula are recorded from the Dainan Fm. and middle portion of the Shuangta Group as *Microlaminatus multicirous*, *M. lamellatus*, and *M. multiplanarius*. *M. multiplanarius* is absent in the Fangjiahe Fm. Also recovered from the middle Shuangta Group is *Enteroplax? luosigangensis* which also distinguishes the sediments from the Fangjiahe Fm. Both are Eocene with uncertain stratigraphic affiliations.

**Conchostraca:** Taxa derived from the fourth formation of the Funing Group and the middle portion of the Changhe Group are basically consistent, recording *Fushunograptia changzhouensis*, *F. changheensis*, and *Cixiella serrula*. Ages representing either Late Paleocene or Early Eocene.

**Worm burrows:** Sediments equivalent to the fourth formation of the Funing Group in the Laian district of Anwei and the Xuyi region of Jiangsu contain worm burrows.

In conclusion, ages provided by the biotic communities listed above are generally Eocene. Charophytes, ostracods, and pollen indicate Middle or Late Eocene. But it is important to note that there are distinctions between Chinese southeast and southwest complexes. One interpretation suggests that the Jingsha Fm. in the west correlates to Dainan formation in the east, while another interpretation suggests the Jingsha Fm. correlates to the third and fourth formations of the Funing Group. Further investigations are required to confirm whether the Dainan Fm. is Oligocene.

### Oligocene biotic assemblages

Charophytes, ostracods, pollen, and conchostracans are primarily produced from South China Oligocene sediments. They are comparable to Eocene complexes though distinctly more derived.

**Charophyta:** the *Maedlerisphaera chinensis*-*Hornichara lingjiangensis* complex represents the Oligocene and may further be broken down into northern and southern subcomplexes. The northern subcomplex comprises the Yangzi River Valley and regions north of it. Sediments

include the Sanduo Fm. in northern Jiangsu, the upper Shuangta Group in Anwei, the Qianjiang Fm. in Hubei, and the Xinhekou Fm. in Hunan. This subcomplex may also extend further north into the Dongying Fm. and the second member of the Shahejie Fm. as *M. chinensis* and *Grovesichara* cf. *yangi* (S. Wang) are recorded there and which most closely resemble taxa from the Stampian Stage of Western Europe and the Gancaigou Fm. in the Caidam Basin, Qinghai. The basal Qianjiang Fm. frequently produces charophytes descended from the Late Eocene and resemble Early Oligocene species from Western Europe.

The southern subcomplex is distributed on both flanks of South China mountain ranges from the Limuping Fm., Hengyang Basin, Hunan, and the Huayong Fm. of Guangdong and differs markedly from its northern counterpart with the diverse presence of *Hornichara*. Eocene descendants are also noted in the Limuping Fm.

Each of these two subcomplexes display certain regional characteristics but strata containing both subcomplexes all belong to a second set of light colored Lower Tertiary beds that are equivalent in the regional sedimentary sequence. Additionally, there are several taxa shared between the northern and southern assemblages and in the Linjiang Fm. of Jiangxi (which is also a second lighter set of Early Tertiary deposits) the northern and southern assemblages co-exist with northern taxa more numerous than southern taxa, although the entire assemblage is vastly dominated by species of the southern genus *Hornichara*. Consequently, it may be observed that these floras are biogeographically distinct but contemporaneous and the Linjiang Fm. represents a transition phase between the northern and southern assemblages.

**Pollen:** There are three pollen complexes recognized within the data from the Jiangsu region.

(1) The Dainan Fm. contains the *Taxodiaceapollenites-Pinuspollenites-Caryapollenites* complex, within which, the ferns are least numerous. Saccate conifers constitute 15-20% with *Pinuspollenites* and *Cedripites* commonly noted genera. *Taxodiaceapollenites* and *Inaperturopollenites* generally constitute 20-30% of the assemblage and in some samples may attain 40% with the species *T. hiatus* the most numerous. Angiosperms are represented predominantly by *Ulmipollenites minor*, *Caryapollenites triangulus*, *Ostryoipollenites rhenanus* and *Quercoidites microhenrici*. Paleoclimate resembled the current central Asian tropics.

(2) The first member of the Sanduo Fm. produces the *Taxodiaceapollenites-Charyapollenites* complex, in which ferns are extremely rare and saccate conifers are generally diminished to 10-15%. *Taxodiaceapollenites* and *Inaperturopollenites* have the highest counts which may attain 45% in some samples. There is a relatively high angiosperm presence represented by *Caryapollenites triangulus*, *Ostryoipollenites rhenanus*, *Quercoidites microhenrici* and *Ulmipites*. Paleoclimate was equivalent to central Asian tropics.

(3) The second member of the Sanduo Fm. produces the *Meliaceaeoidites-Retitricolpites-Tricolporopollenites* complex which is vastly dominated by angiosperms at over 80% and gymnosperms and ferns are very rare. Principle genera include *Meliaceaeoidites*, *Euphorbiacites*, *Araliaceoipollenites*, and *Retitricolpites*. Paleoclimate resembled central Asian tropics.

The three pollen complexes described above are represented by *Taxodiaceapollenites* and *Inaperturopollenites* in addition to numerous temperate, certain distinct tropical, and subtropical elements. This flora is broadly distributed among the late Early Tertiary of China including the Changle and Shahejie fms. of Shandong, Jinghezhen Fm. on the Jiangnan Plain, Linjiang Fm., Jiangxi, and the fifth member of the Liangyuan Fm., Anwei. This flora is also prolific within the Early Oligocene of Kazakhstan and at Primorsk Kray in southeastern Siberia.

Consequently, the age of the first and second members of the Sanduo Fm. and the Dainan Fm. is considered Oligocene with each complex possibly representing an early, middle, and late stage.

**Ostracoda:** Two complexes are recognized: a lower complex which encompasses the entire region, and an upper complex which in the east such as Jiangsu may again be divided into two subcomplexes, while in the west such as Hubei, these distinctions are not recognized. The entire Oligocene assemblage is recognized as being descended from Middle to Late Eocene taxa.

The lower complex consists of "*Sinocypris*" *triangulata*, *Limnocythere* "*hubeiensis*," *Cypris* "*decaryi*" and *Paracandona* "*euplectella*." "*S.*" *triangulata* is an extremely stable taxon in lateral extent and in general the complexion of the lower fauna is basically consistent. Strata producing this fauna include the Dainan Fm., third formation of the Changhe Group, upper portion of the Shuangta Group, fourth formation of the Qingjiang Group (perhaps including the third formation), lower member of the Qianjiang Fm, Limuping Fm., and first to second members of the Huayong Fm.

The upper complex is represented consistently by the genera *Limnocythere*, *Cyprinos*, *Cyprinotus*, *Cypris*, and *Pinnocypris*.

In the upper section of the eastern Jiangsu regions two subcomplexes are recognized: the lower subcomplex is produced from the first member of the Sanduo Fm. and the third member of the Huayong Fm. and is represented predominantly by *Limnocythere jiangsuensis*, *Cyprinos formosa* and *Cyprinotus (Heterocypris) formalis*. The Upper subcomplex is produced from the second member of the Sanduo Fm. and the Linjiang Fm., which is correlative with the entire third member of the Sanduo Fm., and comprises *Pinnocypris postacura*, *Cyprinotus (Heterocypris) jiangkouensis*, *C. (Cyprinotus) sinensis* and *Limnocythere jintanensis*.

The upper complex in the western region of Hubei is recorded from the upper member of the Qianjiang Fm. and the Jinghezhen Fm. which record *Cyprinotus jiangkouensis*, *C. "cingalensis"*, *Cyprinos changgangensis* and *Cypris "decaryi."*

It is worth noting that in the upper complexes of both the eastern and western regions the dorsally overlapping *Cyprinotus* and the large *Pinnocypris* are both present (also recorded from the Xinhekou Fm. of western Hunan). *Cyprinotus* is also recovered from the Oligocene Hutaoyuan Fm. of Henan while *Pinnocypris* is documented from the upper members of the "Denghei Group," Yunnan and the Lushan Fm. in Sichuan.

The entire Oligocene ostracod complex resembles that from the Xialuse Fm., Junggar Basin, Xinjiang, and the Oligocene sediments from the western United States.

**Conchostraca:** The Dainan Fm. and middle and upper sections of the Changhe Group produce the Eocene *Paraleptestheria menglaensis* and *P. jintanensis*.

**Worm burrows:** These are noted in exposures of the lower Limuping Fm. and sediments equivalent to the lower (?) Linjiang Fm.

An Oligocene age is concluded from the aforementioned biotic assemblages. Pollen complexes suggest the Dainan Fm., first member of the Sanduo Fm., and second member of the Sanduo Fm. may represent three periods in the Oligocene.

## Conclusions

Analysis of invertebrates and botanical evidence from the Late Mesozoic to Early Tertiary of South China suggest the formation and development of South China basins were subjected to numerous and periodically intense tectonic activity.

The first intense activity occurred in, or prior to, the middle Early Cretaceous and is recognized in the east in the Jurong vicinity of Jiangsu by the hiatus between volcanic complexes (perhaps equivalent to the Niangniangshan Fm.) and the Gecun Fm.; in Zhejiang it is recognized between the Shoujing and Guantou formations; and in Fujian between the Bantou and Shaxian formations. In the west it is recognized beneath the Donghu Fm. in Hubei, and beneath the Dawangping and Dongjing formations in Hunan. Tectonic activity is predominantly represented by folding, an entire regional unconformity, and minor disconformities. This period was the genesis for basin mode I represented on the Subei and Jiangnan plains and basin mode II represented by the Youngkang and Xinjiang basins.

The second intense activity occurred between the end of the Early Cretaceous and early to middle Late Cretaceous and is recognized in the east in Zhejiang between the fourth and fifth members of the Hengjiang group and in Jiangsu between the Pukou and Yishan formations. In the west in Hubei it is noted between the Wulong and Luoqingtan formations, and in the Hengyang Basin of Hunan between the Shenhuangshan and Daijiaping formations. This activity is dominated by orogeny and folding as represented by sandstone and other conglomeratic diluvium and fluvial facies. Sediments may attain several thousands of meters in thickness reflecting an intensely activated paleotopography with a portion of relatively small concurrent basin (basin mode II) uplift. New depositional regions also had their genesis during this time, or slightly later, with the formation of the Nanxiong, Sanshui, and Chijiang basins (basin mode III).

The third intense activity occurred between the Late Oligocene and Neogene as recognized in Jiangsu between the Sanduo Fm. and Yancheng Group, and in Hubei between the Jinghezhen and Guanghuasi formations where, in the entire region, there exists an extensive unconformity. At this time in South China depositional activity ceased on a large scale.

Deposition in the terminal Cretaceous and Eocene orogenic activity occurred in South China though disruption is not conspicuous as a majority of localities only exhibit slight disconformities or continuous deposition reflected by a decrease in sedimentation but coarsening of grain size.

From Early Cretaceous to Early Tertiary the paleoclimate fluctuated generally from tropical to subtropical though a cold spell occurred in an interval between the two. Climate was predominantly dry or slightly dry with the exceptions mesic climatic replacements in the Eocene and Oligocene.

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Table 1. Correlation chart of Late Mesozoic to Early Tertiary sediments of South China

| Age                      | Region                                         |                                                   | Fujian                                                 |                                                 | Zhejiang            |                                                    | Jiangsu         |                 | Southern Anwei                 |                   | Northern Jiangxi                  |              | Hubei         |              |             | Hunan  |  | Southern Jiangxi | Guangdong |  |
|--------------------------|------------------------------------------------|---------------------------------------------------|--------------------------------------------------------|-------------------------------------------------|---------------------|----------------------------------------------------|-----------------|-----------------|--------------------------------|-------------------|-----------------------------------|--------------|---------------|--------------|-------------|--------|--|------------------|-----------|--|
|                          |                                                |                                                   |                                                        |                                                 |                     |                                                    |                 |                 |                                |                   |                                   |              |               |              |             |        |  |                  |           |  |
|                          |                                                |                                                   |                                                        |                                                 |                     |                                                    |                 |                 |                                |                   |                                   |              |               |              |             |        |  |                  |           |  |
|                          |                                                |                                                   |                                                        |                                                 |                     |                                                    |                 |                 |                                |                   |                                   |              |               |              |             |        |  |                  |           |  |
| Oligocene                |                                                | Changhe Group                                     | Fm. IV                                                 | Sanduo Fm.                                      | "Shuangtia Group"   | Linjiang Fm.                                       | ? Yingcheng Fm. | Jinghezheng Fm. | Baiyang Fm.                    | Xinhekou Fm.      | Limuping Fm.                      | Pinghu Fm.   | "Danxia Fm."  | Huayong Fm.  |             |        |  |                  |           |  |
|                          |                                                |                                                   |                                                        | Dainan Fm.                                      |                     | Fm. IV                                             |                 | Qianjiang Fm.   |                                |                   |                                   |              |               |              |             |        |  |                  |           |  |
| Eocene                   |                                                | Changhe Group                                     | Fms. II-III                                            | Funing Group                                    | ? "Shuangtia Group" | Qingjiang Group                                    | ? Yingcheng Fm. | Jingsha Fm.     | Pailoukou Fm.                  | Deshan Fm.        | Gaoling Fm.                       | Chijiang Fm. | Luofozhai Fm. | Buxin Group  | Fm. III     |        |  |                  |           |  |
|                          |                                                |                                                   |                                                        |                                                 |                     |                                                    |                 |                 | Shiziling Fm.                  |                   |                                   |              |               |              |             |        |  |                  |           |  |
| Paleocene                |                                                | Changhe Group                                     | Fm. I                                                  | Funing Group                                    | ?                   | Qingjiang Group                                    | Baishakou Fm.   | Xingouzi Group  | Fm. II                         | Fangjiahe Fm.     | Yuanjiang Group                   | Fm. II       | Xialiusi Fm.  | Shizikou Fm. | Shanghu Fm. | Fm. II |  |                  |           |  |
|                          |                                                |                                                   |                                                        |                                                 |                     |                                                    |                 |                 | Fm. I                          | Yangxi Fm.        |                                   |              |               |              |             |        |  |                  |           |  |
| Late Cretaceous          | Chishi Group                                   | Hengjiang Group                                   | "Mem." V                                               | Taizhou Fm.                                     | Xuannan Fm.         | "Nanxiong" Fm.                                     | Yuntaishan Fm.  | Lumagang Fm.    | Lumagang Fm.                   | Fenshuihou Fm.    | Daijiaping Fm.                    | Upper Mem.   | Nanxiong Fm.  | Dabishan Fm. | Sanshui Fm. |        |  |                  |           |  |
|                          |                                                |                                                   |                                                        | Chishan Fm.                                     |                     | Gonganzhai Fm.                                     | Gonganzhai Fm.  | Honghuatao Fm.  | Luojingtang Fm.                | Lower Mem.        | Baihedong Fm.                     |              |               |              |             |        |  |                  |           |  |
| Late or Early Cretaceous | Chishi Group                                   | Hengjiang Group                                   | "Mem." I-IV                                            | Pukou Fm.                                       | Guilin Fm.          | Zhoujiadian Fm.                                    | Jiadian Fm.     | Jiadian Fm.     | Wulong Fm.                     | ?                 | Shenhuangshan Fm.                 | Upper Mem.   | ?             |              |             |        |  |                  |           |  |
|                          |                                                |                                                   |                                                        |                                                 |                     |                                                    |                 |                 |                                |                   |                                   |              |               |              |             |        |  |                  |           |  |
| Early Cretaceous         | Shaxian Group                                  | Chaochuan Fm.                                     | Guantou Fm.                                            | Gecun Fm.                                       |                     |                                                    | Quanshuihe Fm.  | ?               | Donghu Fm.                     | Sanyangchong Fm.  | Daijiachong Fm.                   | Dongjing Fm. |               |              |             |        |  |                  |           |  |
|                          |                                                |                                                   |                                                        |                                                 |                     |                                                    |                 |                 |                                |                   |                                   |              |               |              |             |        |  |                  |           |  |
| Underlying strata        | Bantou Fm. (J <sub>3</sub> or K <sub>1</sub> ) | Shouchang Fm. (J <sub>3</sub> or K <sub>1</sub> ) | Niangniangshan Fm. (J <sub>3</sub> or K <sub>1</sub> ) | Yantang Fm. (J <sub>3</sub> or K <sub>1</sub> ) |                     | Lengshuiwu Fm. (J <sub>3</sub> or K <sub>1</sub> ) | PZ              |                 | Yichang Lms. (O <sub>2</sub> ) | Banxi Group. (Pt) | Yuantaiguan Fm. (D <sub>2</sub> ) |              | Granite       | MZ           |             |        |  |                  |           |  |
|                          |                                                |                                                   |                                                        |                                                 |                     |                                                    |                 |                 |                                |                   |                                   |              |               |              |             |        |  |                  |           |  |