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扬子东南大陆边缘晚元古代—早古生代层序地层和盆地动力演化

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扬子板块早古生代的形成和演化对中国古大陆的板块构造演化有重大意义，本文试图通过用新发展起来的露头层序地层方法和沉积盆地演化分析来阐明其变化规律。

在扬子板块的实际调查研究中，发展和开拓了露头层序地层方法和原理，从露头上判别不同沉积体系的界面和成因组合体的性质，追踪海平面变化。研究认为中国南方全球海平面升降的一级周期中，主体海平面上升经过两个超周期：早震旦世两次冰川的溶融增加了海水体积和海水柱的深度，形成一次主体上升；第二次超周期是早寒武世的第一、第二两个沉积层序，代表全球海平面上升达到最大值，完成南方最大一次海侵。中寒武世后为累进式海平面下降。志留纪未结束早古生代海平面一级变化周期。

通过详细的沉积作用研究，并结合大量的其它地质资料，重点解剖扬子板块东南大陆边缘，其早古生代的沉积盆地演化历程是：震旦纪为裂谷拉张，寒武纪到奥陶纪为成熟被动大陆边缘热沉降，志留纪为前陆盆地。并用反剥法技术和盆地模拟分析对其进行深入的地球动力学探讨，提供了世界古老造山带演化的新模型。

SEQUENCE STRATIGRAPHY AND BASIN DYNAMICS OF THE SOUTHEASTERN MARGIN OF THE YANGTZE PLATE IN SOUTH CHINA DURING THE LATE PROTEROZOIC TO EARLY PALAEOZOIC

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ABSTRACT

The formation and evolution of the Yangtze Plate play an important role in the tectonic evolution of China paleocontinent. This paper tries to demonstrate the evolution of the Yangtze Plate during the Early Palaeozoic with the aid of the method of outcrop sequence stratigraphy and sedimentary basin analysis. In the study of the palaeogeography of the Yangtze Plate, the outcrop sequence stratigraphy has been developed, and this kind of new method provides a direct technigue to document the age and physical character of sequence boundaries and sea-level changes. In the first-order cycle of the eustatic changes in South China, the main sea-level rise experienced two supercycles. In the Early Sinian, the melting of glaciers at two times led to the increase in volume of the sea water and in depth of the sea water column, resulting in the first main rise of the sea level. The second supercycle is represented by the first and second Early Cambrian sedimenntary sequences, indicating the maximum rate of the global sea-level rises and the accomplishment of the largest transgression in South China. There occurred a progressive fall of sea level after the middle Late Cambrian, and the Early Palaeozoic first-order sea-level variation cycle was terminated at the end of the Silurian period.

The detailed research on the sedimentation of the southeastern margin of the Yangtze Plate, in combination with a lot of other geological data, has revealed that the evolution of this area in the Early Palaeozoic comprises the rifting in the Sinian, the thermal tectonic subsidence of mature passive continental margin from Cambrian to Ordovician, and the foreland basin bending in the Silurian. The simulation of its tectonic subsidence and dynamics was done by the advanced basin-analysis technique. Especially in the foreland basin, the dynamically quantitative simulation to that in old orogenic belts has been managed to be done and its quantitative parameters managed to be established using the advanced computer program for basin analysis which provides a new model to study the old orogenic belts in the world.

The formation and evolution of the southeastern margin of the Yangtze Plate play an important role in the tectonin evolution of China palaeocontinent. The Late Proterozoic to Early Palaeozoic strata are well developed and exposed in this area, those record the history of the sea-level changes and evolutions of basin formation and dynamics during that period. The detailed analysis of sequence stratigraphy and basin dynamic simulation shows that the margin underwent several stages from the continental margin rift to the mature passsive continental margin and finally to the foreland basin during the Late Proterozoic to the Early Paleozoic.

THE ANALYSIS OF SEQUENCE STRATIGRAPHY ON THE SOUTHEASTERN MARGIN OF THE YANGTZE PLATE

The strata on the southeastern margin of the Yangtze Plate can be divided into two parts: The lower sequence is made up of the Liantuo, Nantuo, Doushantuo, Dengying, Meishucun and Badaowan Formations (the early Qiongzhusi stage in the Early Cambrian), which belong to the sequence of pull-apart rift type with clastic rocks and uncompensated phosphate-black shale as its main rocks. The upper sequence which belongs to a passive continental marginal sequence dominated by carbonates was formed in the thermal subsidence stage from the late Qiongzhusi stage of the Early Cambrian to Early Ordovician time.

The characteristics of incised valley patterns of the clastic sequence in the extensional period of the Sinian

There are two problems in dealing with the determination of the Sinian sequence stratigraphic type and the character of the unconformity at sequence boundary: the first one is the Sinian-Presinian boundary and its nature of contact relationship in craton and submerged zone of the continental margin. The second is the correlation of the Lower Sinian sequences and the recognization of drift sheets.

The Jinningian orogenic movement resulted in the relative falling of sea level and the formation of the largest land in South China from the Phanerozoic onwards. In the Early Sinian, the fluvial and littoral granular gravels within the Presinian foreland basin overlapped unconformably at a high angle on slates and phyllites of the Niuwu Formation, which represent subaerial truncation and exposure, being a sequence boundary unconformity. The inner concave part of the Yangtze Plate and Cathaysia Plate might be the concordant boundary of subaqueous contact. There should be a subaqueous nondepositional hiatus or hard ground surface instead of continuous deposition between it and the underlying Presinian strata. From the viewpoint of the relationship between the regularity of second-order eustasy and orogenic movement, there should be a concordance surface in this area. Therefore, the chronostratigraphic boundary line in the lowermost Sinian is also the boundary unconformity of the first sequence in sedimentary records.

The positive sedimentary records preserved in the Yangtze craton indicate that the alluvial and fluvial conglonerates and sandstones and mudstones in the Chengjiang, Liantuo and Zhitang Formations were the first erosion and levelling surface formed on the Yangtze old land after the Jinningian movement. The age of the Liantuo Formation in the Yangtze Gorges area of Hubei Province is 748±12 Ma, and the time span of negative geological record is about 60 Ma, which is longer than that of positive sedimentary records in the Early Sinian. Therefore, this boundary can be regarded as type I unconformity of sequence boundary.

The Jinningian orogenic movement and the left-lateral strike-slip extension in the Early Sinian caused the continental margin to become a narrow unstable coastal shoreline and graben-horst basin. The terrigenous clastic sediments were transported by glaciers into the graben-horst basin and the stable area in the lower part of the continental shelf to form glaciofluvial and glacial debris sediments.

The Chang'an, Fulu and Jiangkou Formations in eastern Guizhou, western Hunan and northern Guangxi, which have a thickness of 1000—4000 m, might be the low sea-level wedge and fan formed at the time when the falling rate of sea level was greater than the subsidence rate of the basin floor. The thickness of coastal quartz sandstone in the strata of the same chronological age at the craton margin is only about 10 m. So, it indicates that the sequence boundary should be a type I unconformity, and the deep-water area below the continental slope might be a concordant contact (Fig. 1):

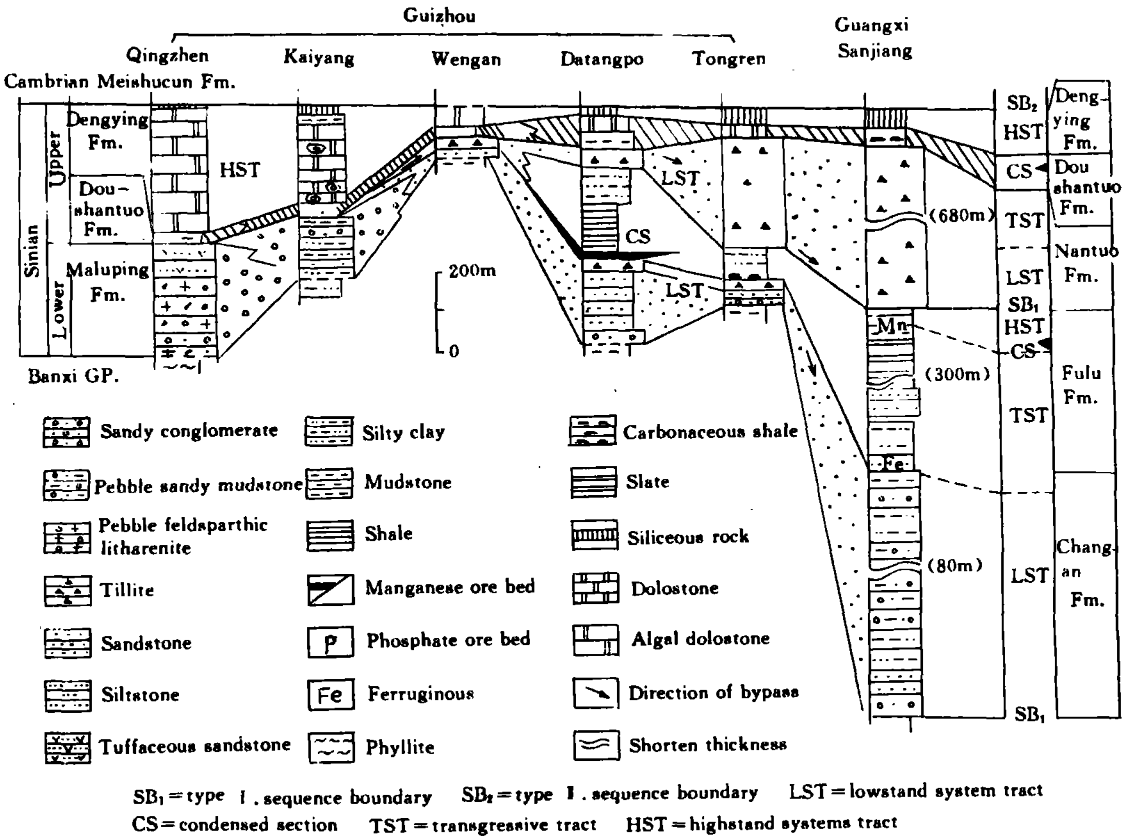


Fig. 1 Correlation between sequence types and depositional systems tracts of the Sinian in South China

There are two layers of the Lower Sinian glacial tillites on the Yangtze craton margin. The lower layer is assigned to the Gucheng Formation (called the Tiesi'ao Formation in eastern Guizhou), which is usually called "small glacier". The upper layer is ascribed to the Natuo Formation, usually called "large glacier". The Datangpo Formation between the two glacial layers, which has a thickness of 10—30 m, is composed of black shales interbedded with carbonate manganesite and tuffs, which were formed under the reducing deep-water condition. the manganese bed in this formation is a group of lenticular bodies and is in conformable and truncational contact with its overlying and underlying strata. Manganese ores occur in nodular, stratified and graded beds, have layered structure and gelatinous texture, and comprise single and colonial plankton and primary radiolaria, indicating that the manganese ores are the sedimentary products of chemical and biochemical processes under planktonic and low-density flow representing the deep-water depositional environment with low-energy and anoxic conditions correspondent to condensed section during the rising of sea level. The siltstones in the upper part of manganesite bed belong to the high-water level depositional system.

Overlying on the drift sheet of the Nantuo Formation is a phosphate layer of the Doushantuo Formation. The bottom layer of the Doushantuo Formation is glauconite-bearing sandy mudstone and glauconite-bearing pebbly phosphorite, and its upper part is massive phosphorudite and algal phosphorites with a thickness of more than 10 m. These sediments also represent the condensed section formed under the condition of the rising of sea level after deglacialtion.

The space-time evolution of glaciation is consistent with the euslatic period of second- or third-order sea-level fluctuations. Primary solid stage of glacier in the continent allowed for the falling of sea level and made continental glaciation migrate seaward to form regressive sediments, resulting in the facial and zonal distribution of continental glacier, littoral glacier, and glacial clastic flow. With the seaward propagation and deglaciation of glacier, the sea level began to rise, resulting in an unprecedented transgression and an unprecedented rising of sea level. Therefore, these two layers of drift sheets can be regarded as lowstand fan bodies.

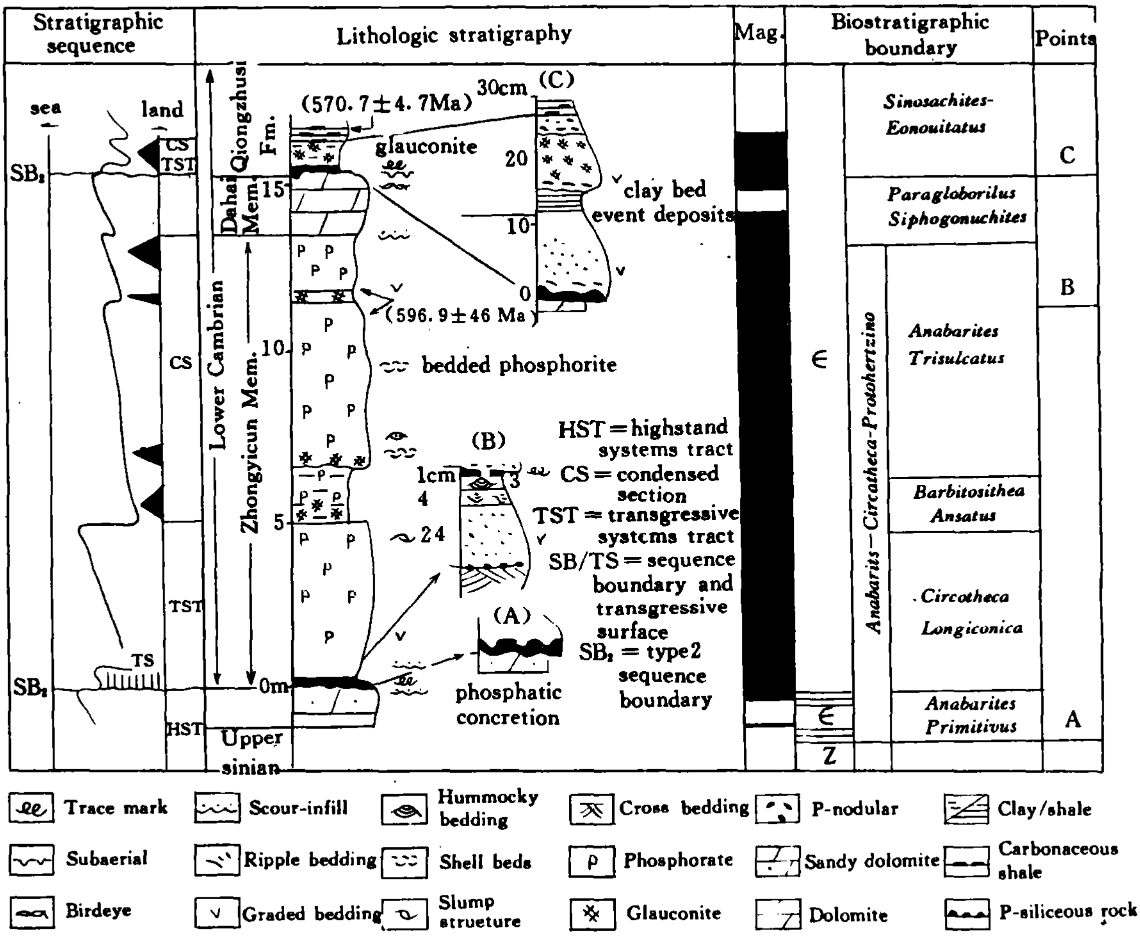
The black shale and phosphatite sequence of extensional pattern in the early Early Cambrian

At the Meishucun and early Qiongzhusi stages of the Early Cambrian, the extensional activity reached its extremity in South China, resulting in the spreading of sea floor and the breaking up of the continent, which made the sea-level rise rapidly, and the sea-floor entered an anoxic environment.

The sequence boundary line of the Lower Cambrian is closely related to stratigraphic boundary line between the Cambrian and Sinian. In the Kunyang section of South China, there exists a change and hiatus in depositional environments between the carbonates of Late Sinian age and the phosphorite of the Lower Cambrian Meishucun Formation. As a chronostratigraphic boundary line, according to the evolution of microbivalve fossils such as hyolithids, the Cambrian-Sinian boundary can be delimited in the inner part of dolomites (Point A) in the upper part of the Upper Sinian Dengying Formation, or in the segment (Point C, Luo Huilin et al., 1984) between black shales in the Qiongzhusi Formation and dolomites in the Dahai Member of the Meishucun Formation (Fig. 2).

The top surface of the dolomites of the Dengying Formation is characteristic of the karst in the Yangtze craton. For instance, the elevation difference of karst solution on the top surface of sandy dolomites is about 1—3 m in Kunyang; the dolomites of the Dengying Formation in Dayong of Hunan Province has no upper part of that and its top surface is of karst character. There are numerous palaeokarst cavities scattered within 5 to 10 cm depths beneath the surface, which are filled with sandy phosphorites and clastic algal dolomites. It can be seen that the strata preserved in the Dengying Formation are relict strata, and its top erosional surface represents nondepositional hiatus, and thus it can be regarded as the boundary unconformity with the first deopsitional sequence in the basal part of the Cambrian strata and should be used as the synchronous chronostratigraphic boundary marked by global falling of sea level.

The sequence boundary unconformity formed by erosion can result from the falling of



Note: the informations of Mag. and fossils follow Lou Huilin, 1984

Fig. 2 Correlation of depositional sequence, lithologic unit and biostratic unit of the Early Cambrian in the Yangtze Plate

relative sea level or land uplifting after tectonism. The following three reasons allow us to consider that the sea level was relatively stagnant and was gradually falling to form the boundary unconformity in the late stage of the Late Sinian.

(1)The dolomites in the Dengying Formation are assigned to the highstand systems tract. Some exposed marks of small palaeokarst cavities and bird's-eye structure can be found in the dolomites.

(2)Except that the dolomites in the Kunyang phosphorite mine district contain terrigenous sands, most of them are alga dolomites without terrigenous clastic deposits, indicating that no orogeny occurred during the Late Sinian.

(3)The lag deposits on the karst surface in the Dengying Formation are all filled with phosphate granules. In some cases, they have thin siliceous and phosphatic cover, but no terrigenous clastic sediments can be found between the upper and lower strata on the margin of the Yangtze Plate. Thus, it can be considered that tectonism might be quite stable and the supplying rate of terrigenous clastic sediments was extremely low.

Manganese nodules, phosphate and glauconite often occur in deep sea with huge bottom flow. In such oceanic district, sediments on the sea-floor are mainly chemical deposits with hard groud structure formed by epidiagenesis and sea-floor cementation. If such sediments and their depositional features were once reworked and winnowed by the bottom flow, evidences of hard ground structure and nondeposition episode should be absent in the sediment records. Such sedimentary fabric character of post-reworking can be found in the phosphorites of the Lower Cambrian Meishucun Formation. Therefore, from the Early Cambrian Meishucun to Qiongzhusi stages, when the upwelling oceanic flow welled up from the spreading center toward Yangtze continental shelf margin in the sea area of South China during the rising of sea level, a phosphorus concentrated area could be formed on the seaward slope of the cratonic margin. The following four features can be clearly seen in phosphorite records.

(1)The fact that the intraclastic phosphorites consist of grains of various sizes indicates that the collophane has undergone several episodes of erosional reworking and winnowing.

(2)The record of proving that the phosphorites are the starved deposit in the hiatus period can be found. For instance, the phosphorus-bearing black silicolites and siliceous collophane with a thickness of 1—3 cm can be found at the bottom of the phosphorite beds in Kunyang, which spread discontinuously on the uneven top surface of sandy dolomites of the Dengying Formation. Fracture detritus can also be obserred on the top surface, indicating that low-rate and low-energy sediments have been reworked. Besides, collophane grains with organic boring structure can be seen under microscope, indicating the low-rate sedimentation of the phosphorites and the existence of nodepositional hiatus.

(3)Typical authigenic glauconite of condensed sedimentation occur on a wide range of scales in the phosphorites, especially in the middle part of the phosphorite ores of the Meishucun Formation.

(4)Except that the phosphorites are intercalated with the clay of suspensional deposition, no terrigenous clastic deposit was found in the phosphorites, indicating that the sedimentation and reworking of the collophane were occurring in the course of transgression and the rising of sea level.

It can be concluded from the tectonic evolution and depositional sequence type on the southeastern margin of the Yangtze Plate that the extensive activity in the Early Cambrian did cause the sea level to rise rapidly, and did lead to the formation of many small nondepositional sections in the deep water zone, thus resulting in the formation of a complex structure consisting of transgressive and condensed deposits. On the southeastern margin of the craton, the depositional environment in eastern Guizhou lies beneath the undisturbed storm wave base, thus preserving original texture of condensed sediments consisting of phosphorous nodule-bearing black shales and silicolites which are in conformable contact with the underlying silicolites in the Upper Sinian Liuchapo Formation. The strata on the southern margin of the Yangtze craton which correspond to the phosphorus-bearing horizon at the bottom of the Qiongzhusi Formation are the reworked phosporite beds in the western part of Sichuan Province, indicating that at the bottom of the Qiongzhusi Formation, the condensed sediments did overlie on the highstand systems tract and that the coast did migrate landward. It follows from the second depositional sequence in the Lower Cambrian that one of the largest transgression and the highest sea level since the Palaeozoic once occurred in the Lower Cambrian in South China. The formation age of the sediments is 570.7±4.7 Ma. If we take 590.9±4.6 Ma as the age of the middle phosphorite bed in the Meishucun Formation in Kunyang during the period of about 40 Ma, phosphorite and carbonate rocks were deposited 40—200 m thick on the western craton margin, while the silicolites deposited in the district beneath the continental slope zone was only several meters. and the condensed sedimentation in the first sequence and the second sequence are superimposed or overlapped each other. There is a concealed time interval of about 30 Ma negative record at the boundary line of the conformable contact.

The depositional sequence on the continental shelf margin in the thermal subsidence stage

(1)The strata in the Lower Cambrian Canglangpu and Longwangmiao Formations are the third sequence, which indicates that the depositional records on the southeastern margin of the Yangtze Plate are the detrital rock shelf. The two units of strata represent a sedimentary assemblage showing that the sediments were subjected to some changes in thickness during the third-order relative changes of sea level. The sandstone, siltsone and mudstone at the base of the Canglangpu and Balang Formations constitute the sediments of the shelf margin, and transit into the deep-water shelf facies assemblage of banded marlite when it goes upward. The intercalated limestone frequently seen in detrital rocks in the middle part of the Canglangpu Formation of the Yangtze craton and the increase of limestone bands in the sediments dominated by mudstone in the shelf marginal area indicate that the sea level began to rise at that time. Thus we can take the first unit of limestone bands as a transgressive surface. The vertical accretion and spatial distribution of carbonates indicate that the southestern margin of the Yangtze Plate was then under the condition of tectonic setting of stable thermal subsidence. The rising rates of sea level and the maximum water depth during this period did not surpass or reach the range and scale of the early Qiongzhusi stage which have the following characteristics.

The area covered by sea water was very small, indicating that the carbonate deposits corresponding to the transgressive surface did not overlie completely on the underlying highstand systems tract.

The transgressive deposits in the Longwangmiao and Qingxudong Formations did develop landward to form the restricted platform and evaporite flat, and develop seaward to form carbonate sediments at the edge of the shelf;the transitional zone between them was carbonate lime mud and algal bioherms,representing a more typical environment of carbonate ramp. Longitudinally,the transgressive system transformed rapidly into the highstand system assemblage.

In the shallow-water district,no condensed sedimentation has been found in the transgressive system. Accordingly,the negative record representing sedimentation hiatus in sedimentary records of the shelf margin might be submarine hard ground structure. Such characteristics of sedimentary records may be an indication showing that the relative rising rates of sea level were lower than the rates of subsidence.

(2)The characteristics of the sequence on the mature passive continental margin in the Late Cambrian.

The Middle to Late Cambrian strata in the Yangtze Plate are a huge carbonate sedimentary body called Yangtze carbonate platform. On the eastern margin of the Yangtze Plate there is a sedimentary wedge-shaped body resulting from foreslope debris flow. From the slope of continental shelf to the bathyal basin,superconcentrated lime-mud turbidity flow deposits can be seen. The time-spatial evolution and the assemblage of these deposits indicate that the Yangtze Plate was developing into a mature passive continental margin during the Middle to Late Cambrian. The depositional domains are in conformable contact, indicating that there is a synchronous correlation between the relative changes of sea level and tectonic subsidence. We have found some indications of regression such as the lowstand system wedge-shaped body formed by debris flows and the evaporites and evaporite flats resulting from the fact that the carbonate seguences within the platform became thinner and thinner from bottom to top. Therefore we suggest that there might be three sequences with three surfaces in the Middle and Upper Cambrian. For example. the Aoxi Formation of the Middle Cambrian is the fourth sequcence,the Huaqiao Formation is the fifth one and the Upper Cambrian is the sixth one for the strata on the plate margin in East Guizhou and West Hunan.

The characteristics of the sequences of compression-foreland basin type

From the Middle Ordovician to the Late Silurian,due to the convergence process of the Yangtze Plate and Cathaysia Plate,the South China rift-valley basin and the southeastern margin of the Yangtze Plate were in the formation stage of the foreland basin.

In the Upper Yangtze Platform and its marginal areas,the lowermost part of litho stratigraphic layers in the Middle and Upper Ordovician is composed of the detrital rocks of the Meitan Formation,representing the lowstand systems tract in the shelf margin deposits formed during the falling of sea level. The overlying strata include nodular limestone,muddy limestone and polygonal limestone in the Shizipu, Guniutan, Miaopo and Baota Formations. Their sedimentary structures and characteristics indicate that they are the sediments deposited in the shallow sea and graded into carbonate ramp during the rising of sea level and transgression. In the continental marginal zone,this bedded black silicolite bed is about several ten meters thick in Dongkou and Qidong of Hunan Province, corresponding to the complex of transgressive deposits and condensed sedimentation formed under the condition of the sea level rise with the highest rate. The strata of the Upper Ordovician in the Upper Yangtze Platform are made up of black shales of the Wufeng Formation and the strata on the continental margin consist of black slates. The property of the depositional system belongs to the complex of condensed and highstand systems tract, indicating that the sedimentary assemblage domain was the product formed under the condition of lower rising rate of sea level.

In the northern segment of the southeastern margin of the Upper Yangtze Platform the characteristics of the sequence on the north of Qidong and Hengyang counties are different from those of the southern segment and the sedimentary assemblage formed under the con-dition when the sea level was rising. The rocks in the lower part of the Middle Ordovician are arkosic quartz sandstone, sandy slate and silty slate characteristic of turbidity deposits. The rocks in the middle part of the Middle Ordovician are the same as those in the lower part but intercalated with black shale and manganese ore beds which may correspond to condensed sedimentation. The rocks in the Upper Ordovician are grayish green calcareous siltstone and mudstone containing banded silicolite of greater thickness. The overlying strata is 658 m thick, consisting of grayish green arkosic quartz sandstone and siltstone and grayish purple coarse sandstone intercalated with flakes of mica and chert pebbles. The grain sizes of the sediments increase from west to east. The fabric and longitudinal combinational characters of the sediments indicate that from the Middle Ordovician onwards, the southeastern margin of the Upper Yangtze Plate simultaneously received the supply of detrital sediments from two massifs, which differed from the single direction supply before the Early Ordovician.

On the other hand, the variations in grain size and filling pattern show that the detrital sediments deposited in the lower part of the southeastern margin of the Upper Yangtze Plate were derived mainly from the thrusting sheet on the Cathaysia Plate, and proximal in character. The input amount of terrigenous sediments was extremely larger than that of the Upper Yangtze Plate.

It can be seen that, owing to the bidirectional supply of terrigenous sediments, two kinds of sequences should be formed at the two sides of the basins located in flexural moat of the Upper Yangtze Plate and the foreland basin. The western side represents the depositional assemblage in which the deposits become progressively finer from bottom to top, while the eastern side represents the depositional assemblage in which the deposits become progressively coarser from bottom to top. In the Lower Silurian, the depositional systems are composed of black shale of the Longmaxi Formation and more than 1000 m thick turbidites of the Zhoujiaxi Group should represent the lowstand deposition system with wedge-shaped bodies and turbidite fan on the shelf margin formed during the falling of sea level . On the one hand, the foreland basin on the Upper Yangtze Plate moved backward under the influence of load subsidence and the thrusting of southeastern subduction zone . Under the influence of the resistance of rigid nucleus of the Yangtze Plate, the margin of the Upper Yangtze Plate upwarped and tilted, causing the strata of Lower Silurian to overlie unconformably on the Middle to Upper Ordovician and resulting in the formation of unconformable sequence boundary . In the meantime, the foreland basin was constrained by the rigid nucleus and became narrow . The Middle Silurian might have a sedimentary system assemblage of getting coarser and shallower from bottom to top . From the end of the Late Silurian to the beginning of the Early Devonian, the foreland basin began fo rejuvenate, causing the sea water to retreat from the Yangtze continent and the sea level in South China to fall synchronously with orogenic tectonic rejuvenation.

THE GEODYNAMIC EVOLUTION OF SOUTHEASTERN MARGIN OF THE YANGTZE PLATE

From Sinian to Silurian period, the southeastern margin of the Yangtze Plate had gone through the rifting stage($Z-\in_1^2$), the mature stage of passive continent margin($\in_1^3-O_1$), and the closed orogenic stage (O_2-D_1) (Fig. 3), with a time span of 400 Ma . Dynamic mechanism of tectonic subsidence and the evolution of the basin on the continental margin has been reconstructed by means of back stripping calculation (Fig. 4).

(1) It can be seen from the tectonic subsidence curve of the Upper Yangtze Plate margin that two stages of subsidence occurred between the carbonate platform, and the deep sea basin; one occurred during 800 to 700 Ma of the Early Cambrian indicating that the variation in the subsidence of the basin was caused by the rifting of the continental margin.

(2) The margin of the Middle and Lower Yangtze Plate had been a "concentrated zome" of tectonic evolution. The tectonic subsidence either on the carbonate platform or in the region between the slope and basin are all very conspicuous. Especially the gradient of these two tectonic subsidence curves between 700—600 Ma is much more steep, which can be taken as an evidence that the south Pangea was in the process of disintegration in the Presinian period. In addition, mutational changes in subsidence took place from the Ordovician to Silurian indicating that the foreland of the marginal basin in the Middle—Lower Yangtze area had been subjected to downwarping and that the formation time of the foreland basin was earlier than that of the Upper Yangtze Plate margin.

(3) The feature of tectonic subsidence curve of the northwest margin of the Cathaysia Plate is similar to that of the Yangtze Plate margin. Tectonic subsidence and subsidence curve show that these two tectonic subsidence stages did occur on the continental margin of the Yangtze Plate; the early stage occurred in the Early Sinian. Rifting extension was the tectonic driving force of the basin; the late stage occurred in the Late Sinian to the early stage of Early Cambrian with very high subsidence rate and with the break-up of the Pangea as its driving force, causing the Yangtze Plate to separate from the Cathaysia Plate.

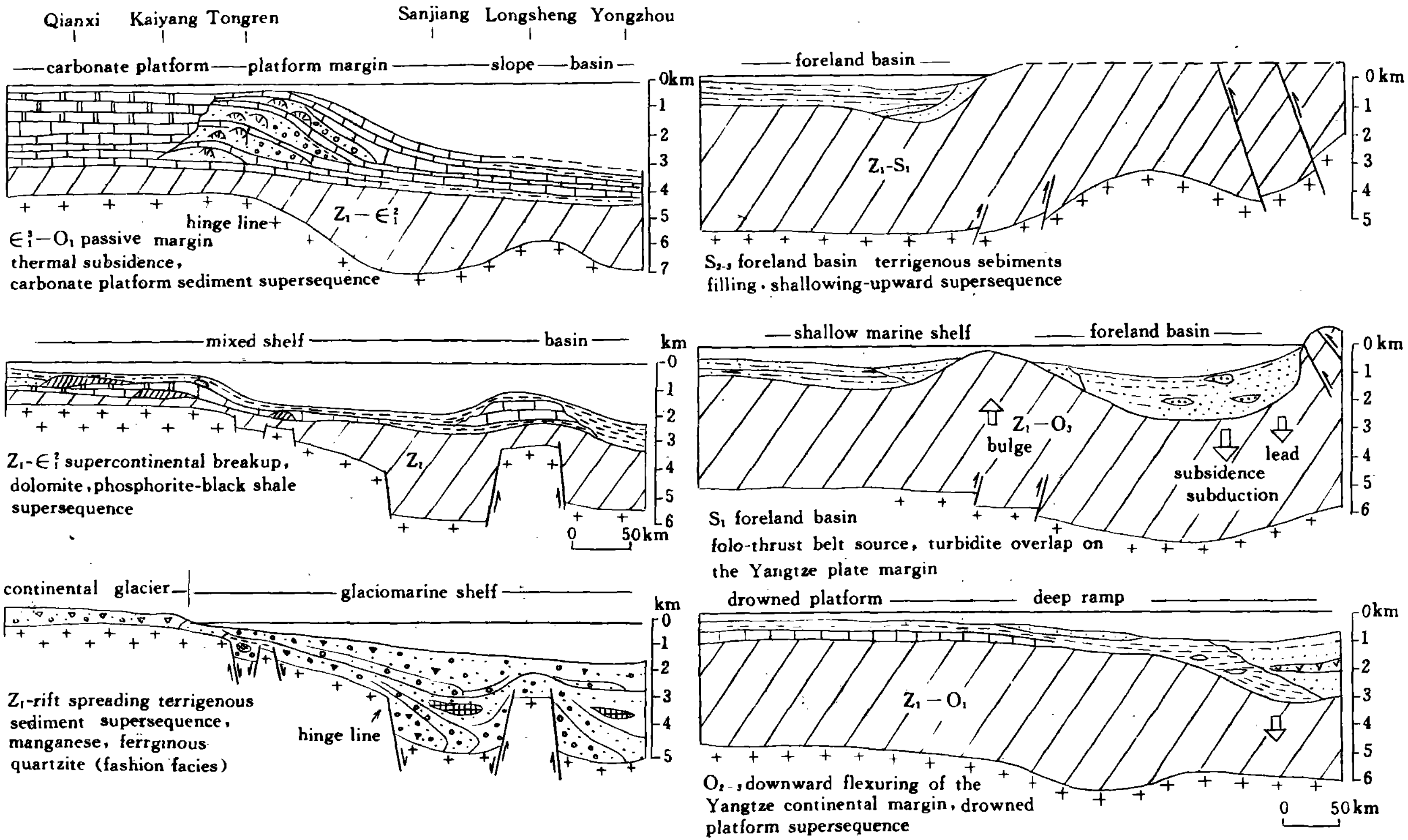


Fig. 3 Sedimentary basin evolution of the southeastern margin of the Yangtze Plate in South China during the Palaeozoic

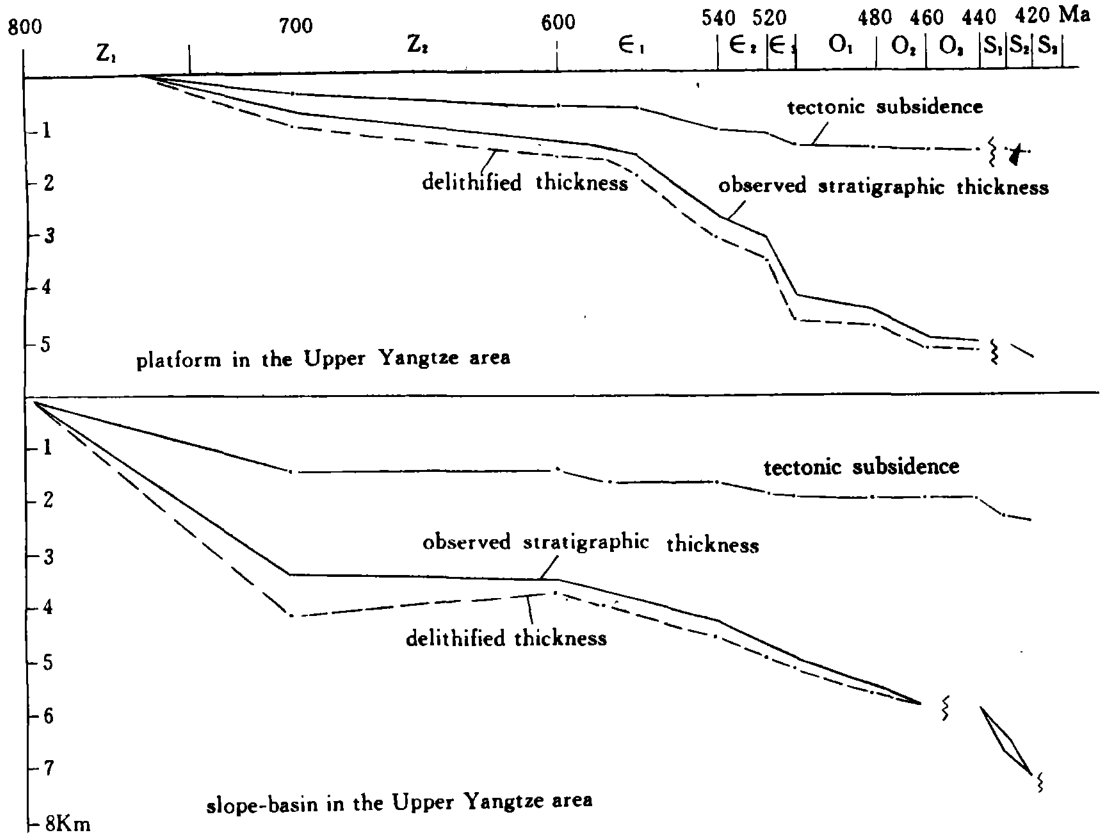


Fig. 4 Tectonic subsidence curves of the Yangtze Plate in South China in the Early Palaeozoic

The tectonic subsidence from the end of the Late Cambrian to the Early Ordovician was the mark of the first collision of the Yangtze Plate with the convex part of the Cathaysia Plate margin during Yunanian movement. The sharp subsidence curve indicates that the foreland basin was subjected to subduction and migration in the Middle Ordovician and Silurian times.

(4)The simulation of the foreland basin by using computer.

Based on the depositional records of the southeastern margin of the Yangtze Plate and the geophysical data of South China from Late Ordovican to Silurian times we have used computer to analyze and make dynamic simulation on the foreland basin by the help of American Professor L. Royden of Massachusetts Institute of Technology.

The geodynamic mechanism for the formation of the foreland basin is that the thrust nappe overloaded on the thinned outer crust of the continental margin and this overloading process went on in a short geological period. Thus, we can regard lithospheric plate as an elastic plate. If the flexural deformation of the elastic plate is consistent with the basal morphology of the sedimentary basin, then we can determine precisely the nature of the foreland basin, the thickness of the elastic plate and the loading amount and flexural moment and make out the geodynamic model of the foreland basin.

The Nanhua orogenic belt is similar to other ancient orogenic belt in the world. The normal gravity anomaly in the upwarped foreland area produced during plate collision, whereas the negative gravity anomaly produced during the flexuring of foreland in the isostasy stage after the orogenic belt was formed. In this case, using gravitational data and Moho depth based on Yuan Xuecheng's data(1989), we obtained the Moho depth of 42 km at the center of the Yangtze Plate, 40 km in Longhui of Hunan Province, 35 km in Hengyang, and 30 km in Xinguo to Hengdong. The result of computer simulation shows that when the thickness of the elastic plate is 70 km, the flexuring amplitude of the plate is coincident with the basal morphology of the Yangtze foreland basin.

Flexural modeling of the net deflection can be used to examine the flexural behavior of the underlying lithosphere and the loads that act on the lithosphere to produce the observed deflection. If the lithosphere is assumed to behave as a thin elastic sheet, then it is possible to use an inverse method to solve jointly for a best fitting solution to the gravity anomalies and present-day basin geometry. This method can also be used(without gravity anomalies)to solve for a best fitting solution to the reconstructed basin geometries for various times in the past. The method employed here is an expansion of techniques developed by Royden(1988), Moretti and Royden (1988), and Kruse(1989)and solves simultaneously for the initial depth, the net deflection, and the resulting Bouguer gravity anomalies.

In two dimensions the equation for the net deflection of a thin elastic plate overlying an inviscid fluid(in the absence of horizontal compression) is

$$D\frac{\partial^4}{\partial x^4}[w(x)-w_{in}x)]+[(\rho_m-\rho_i)]g[w(x)-w_{in}(x)]=w_{in}(x)(\rho_i-\rho_{wa})g+t(x)\rho_i g \quad (1)$$

Definitions and values for the variables in the equations in this paper are given in Table 1. The first term on the right-hand side represents the replacement of the water with density ρ_{wa}(or air if $w_{in(x)}$ is above sea level)that initially lay between $w_{in(x)}$ and sea level by infilling material(sediment, thrust sheets, etc.)with density P_i. The second term on the right-hand side of (1)represents the topographic load due to mountains of height $t_{(x)}$. The general solution for the plate deflection can then be written

$$w(x)=w_{in}(x)+w_p(x)+\sum_{k=1}^{4}A_k f_k(x) \quad (2)$$

where

$$\left.\begin{cases} f_1(x)=\cos(x/a)_e-(x/a) \\ f_2(x)=\sin(x/a)_e-(x/a) \\ f_3(x)=\cos(x/a)_e(x/a) \\ f_4(x)=\sin(x/a)_e(x/a) \end{cases}\right\} x_1\leq x\leq x_2$$

and

$$\left.\begin{cases} f_1(x)=0 \\ f_2(x)=0 \\ f_3(x)=0 \\ f_4(x)=0 \end{cases}\right\} x<x_1 \text{ or } x>x_2$$

α is a flexural parameter that depends on the flexural rigidity of the lithosphere, and $w_p(x)$ is any particular solution to the inhomogeneous differential equation (1), which incorporates known loads corresponding to terms on the right-hand side (Fig. 5)

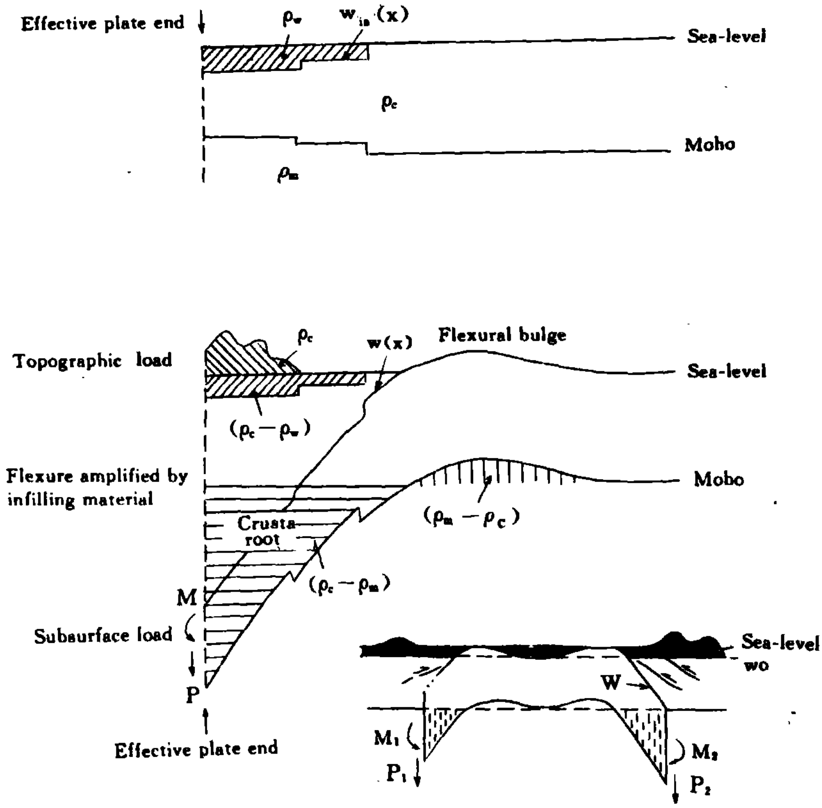


Fig. 5　Foreland basin plate geometry model (after Royden, 1993)

ρ_w = density of water; ρ_c = density of crust; ρ_m = density of mantle; $w_{in}(x)$ = initial depth prior to deflection; $w(x)$ = depth after deflection; M = bending moment per unit length; P = vertical shear force per unit length; Wo = initial depth constrained to be uniform over some interval $x_3 \leqslant x \leqslant x_4$

By simulation quantitative analysis, it is considered that the southeastern margin of the Yangtze Plate was a foreland basin with old thermal history and with low relief during the Late Ordovician to Silurian times and in the period when the Yangtze Plate downthrusted toward the Cathaysia Plate.

According to the geodynamic model for the formation of the foreland basin (Fig. 6) and assuming that the thickness of the elastic plate is 70 km, the width of the foreland basin is 445 km, the maximum thickness of the sedimentary body is 4.7 km, we have the following calculating results: the thrusting load of the foreland basin received is $5.0421 \times 10^{20} - 1.0284 \times 10^{21}$ N, flexural momentum is 1.1×10^{9} Nm/s, flexural force moment is $2.77 \times 10^{26} - 5.546 \times 10^{26}$ Nm.

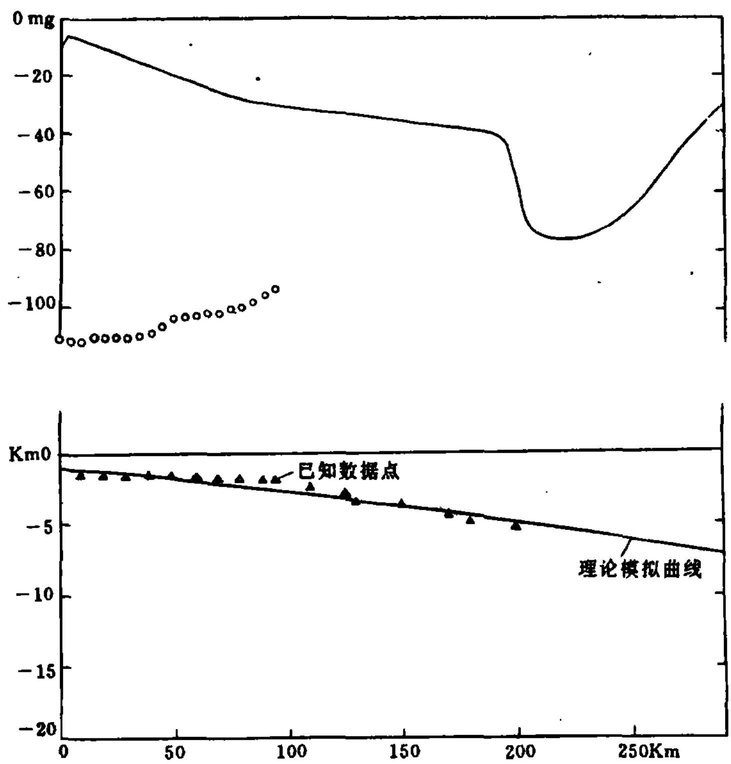


Fig. 6 Computer simulation of the foreland basin on the southeastern margin of th^e Yangtze Plate

REFERENCES

Kruse, S.E. and Royden, L.H., 1994. Bending and unbending of an elastic lithosphere; the Cenozoic history of the Apennine and Dinarde foredeep basins. Tectonics, Vol.13, No.2, pp. 278—302

Liu Baojun, 1980. Sedimentary Geology. Geological Publishing House, 1980.

McKenzie, D., 1987. Some remarks on the development of sedimettary basins. Earth and Planetary Science Letters, 40(1978)25—32.

Stockmal, G. et al., 1986. Geodynamic models of convergent margin tectonics; Transition from rifted to overthrust belt and consequences for foreland basin development. Bull. AAPG, 70(2); 181—190.

Xu Xiaosong et al., 1990. Manganese deposits of the Proterozoic Datangpo Formation, South China; genesis and paleogeography. Publs. int. Ass. Sediment. (1990)11. 39—50.

Xu Xiaosong, 1991. The Late Proterozoic to Early Paleozoic sedimentary sequences and sea-level changes in the Yangtze Plate. Bull. Chengdu Inst. Geol. M. R., Chinese Acad. Geol. Sci. pp.105—124.

Xu Xiaosong, 1987. Characteristics and environments of the Sinian evaporites in southern Sichuan, China. Lecture Notes in Earth Sciences, 13; 23—29.