[PS]Deposition and Evolution of the Carbonate Platform-Slope-Basin in Middle Permian Yangsingian Series (Kungurian-Capitanian) in the North Margin of the Yangtze Basin, China*

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Abstract

The Yangtze Basin is located between the Qinling-Dabie orogenic belt and the Cathaysia landmass, and it was a part of the eastern Paleo-Tethys Ocean in the Permian. The study region is located in the north margin of the Yangtze Basin (the NMYB), and has a length of more than 1,000 km from east to west and a width of 70-450 km from north to south. The Yangsingian Series in the study region is equivalent to Kungurian Stage-Capitanian Stage. The Series, 200-500 m thick, is composed of mostly carbonate rocks such as megaconglomerates/megabreccias, calcarenites grainstones, packstones/wackestones etc., secondly cherts and clastic rocks. The Yangsingian Series has abundant fossils, such as algae, coral, brachiopod, foraminifera, echinoderm, fusulinid, ammonoid, radiolarian and sponge spicules etc.

The study region during the Middle Permian was a marginal sea. To the north, there was an open sea; to south and southwest, there were massive and chain carbonate platforms. The carbonate slope was situated between the platforms and the open sea, and it was north-northeast dipping, more than one thousand kilometers in length, and hundreds of kilometers in width.

The carbonate platform was an open-limited sea platform; it was mainly composed of bioclastic grainstone, packstone /wackestone, and micritic limestone, tens to hundreds of meters thick. On the platform, carbonate shoal sediments rarely developed; the shore-lagoon located on the edge of the platform mainly developed fine-grained clastic rocks and coal line or thin coal seams. The carbonate slope may belong to a new type of slope, a deposition-onlapping slope, which is also a gravelly to sandy slope. The slope can be divided into the upper, middle and lower slope. The upper slope, with a steep angle of 10-20º, was composed of grain-supported mud-free to mud-bearing megaconglomerates, which were mostly derived from the deposition of the debris flow. The middle slope, with a gentle slope angle of 5-10º, was composed of grain-supported or matrix-supported megaconglomerates, calcarenites, packstones/wackestones and layer cherts. There are diverse types of deposition processes in

the middle slope, which include deposition of debris flow, contour current, upwelling flow, and in situ deposition. The lower slope, with a slope angle of less than 5º, developed siliceous shale, carbonaceous shale and calcarenites, with isolated limestone and chert nodules. The lower slope developed the deposition of contour current, upwelling flow, debris flow, suspension and avalanche. The sediments of the basin and margin were mostly composed of thin-bedded cherts, various kinds of shale, bearing manganese and phosphorus. They mainly formed under a layered stagnant anoxic depositional environment.

The study region in Middle Permian went through the carbonate platform-slope-basin depositional evolution, which can be divided into two major cycles and four secondary cycles. The major role controlling the cyclic sedimentation is sea-level changes, followed by tectonic activities. The activities of the Permian faults in the study region and the extension of the Paleo-Tethys Ocean to east were under the same tectonic setting. The development of the Middle Permian carbonate slope probably provides the evidence for the rapid expansion of the Paleo-Tethys Ocean eastward.

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The study region in Middle Permian went through the carbonate platform-slope-basin depositional evolution, which can be divided into two major cycles and four secondary cycles. The major role controlling the cyclic sedimentation is sea-level changes, followed by tectonic activities. The activities of the Permian faults in the study region and the extension of the Paleo-Tethys Ocean to east were under the same tectonic setting. The development of the Middle Permian carbonate slope probably provides the evidence for the rapid expansion of the Paleo-Tethys Ocean toward east.

1. THE INTRODUCTION

The study region is located in the north margin of the Yangtze Basin (the NMYB), and it is bounded by the Qinling-Dabie orogenic belt and Tan-Lu fault on the north, by from Sichuang Guangyuan, Chongqing to Hubei Changyang and Jiangnan fault on the south, and it reaches Songpan Block to west and extends to Huang Sea to east. It has a length of more than 1000 km in east-west, a width of 70-450 km in south-north(Fig.1). The Permian lithology and sedimentaryf acies had the largest changes in the time and space in the geological history of the Yangtze Basin; the platforms and basins were spaced, slopes developed, and the deep water and shallow water deposition was mutual conversion (Li et al, 2008). Recent studies have shown that the Permian is one of the most important source rocks of oil and gas in South China, and Permian Maokou and Changxing formations have become one of the main output layers in Puguang Gas Field (Ma, 2007), meanwhile, the Permian is also one of the most important ore-bearing strata of copper multi-metal ores in the middle-lower reaches of the Yangtze River (Chang et al., 1991; Zhai et al., 1992). The Permian is considered to be the second biggest transgression stage in the geological history of South China, and it is also the eastward expansion stage of the Paleo-Tethys Ocean (Wu, 1999). The Permian deposition-tectonic evolution of the Yangtze Basin was constrained by the Paleo-Tethys Ocean development, so, the Permian deposition processes not only recorded the sea level changes, the evolution of the basin structure dynamics, also did the evolution history of the Paleo-Tethys Ocean.

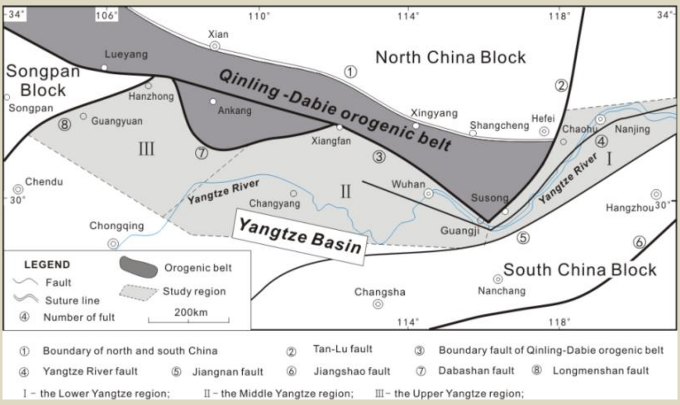
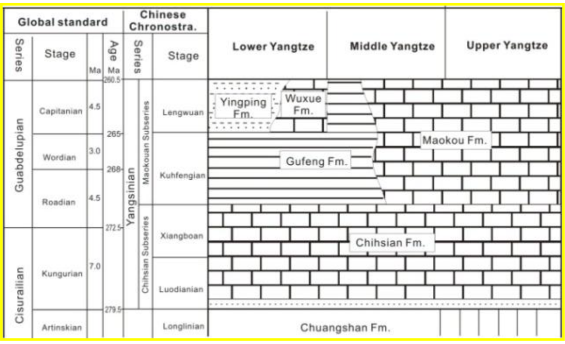


Fig. 1 Location of the study area and the geological framework

The Yangtze Series in the NMYB has wide distribution, good outcrop, easy accessibility, and well developed carbonate slope, which makes it possible to become a nature laboratory of studying carbonate slope of geological history. The paper focuses on the Yangsingian Series in the NMYB, and the study mostly includes facies characteristics, sedimentary sequences, depositional processes and model, and the evolution history of the platform-slope-basin.

Tab.1 Stratigraphic framework of the Middle Permian in the north margin of the Yangtze Basin



2 . THE STRATIGRAPHIC OUTLINE

The Yangxingian Series in the NMYB has clear boundaries on its top and bottom. It lies above the Chuangshanian carbonate rocks and under the Lopingian clasts or carbonate rocks in unconformity, and the latter unconformity is regarded as the result of the Dongwu Movement (Wu, 1994). The Yangsingian Series, 200-500 m thick, with abundant fossils, includes Chihsian, Gufeng, Maokou, Yanqiao and Wuxue formations, and consists of mostly carbonate rocks, secondly siliceous rocks and clasts (Tab.1).

3. FACIES CHARACTERISTICS AND INTERPRETATION OF ORIGINS

3.1 Carbonate Rocks

Megaconglomerate/Megabreccias Facies.- The gravels of the megaconglomerates are composed of light gray packstone, wackestone and bioclast grainstone, and the matrix is mostly composed of calcarenites. Three main types of megaconglomerates can be identified, based on their supported types and matrix contents.

Fig. 2 Characteristics of the megaconglomerate facies in the Yangsingian Series of the NMYB

A- grain-supported, matrix-free, Chihsian Fm., Hubei Jianshi;

B- grain-supported, matrix-free, Chihsian Fm., Anhui Wuwei;

C- grain-supported, poor matrix, Chihsian Fm., Anhui Chaohu;

D- grain/mud-supported, rich in matrix, Maokou Fm., Hubei Changyang;

E- grain/mud supported, rich in matrix, Chihsian Fm., Hubei Daye.

The hammer is 30 cm in length, and the lens cap diameter is 8.2 cm.

Type 1 megaconglomerate is grain-supported, with less than 5 percent of matrix. It is also called mud-free conglomerates (Figure 2A, B).

Type 2 megaconglomerate, 40-100 cm thick, is grain-supported, with 5-20 percent of matrix. The grains are subangular to subrounded, vary in size. They are generally 20-40 cm in size, and maximum up to more than 200 cm (Figure 2c).

Type 3 megaconglomerate, middle-thick bedded, is gain- or matrix-supported, and has high matrix contents of 20-50 percent. The grains are ellipsoidal, pillow-shaped, or nodular, generally 20-50 cm in size, with apparent bedding-parallel orientation. The calcarenites make up not only the matrix, but also interlayers of 5-30 cm thick between megaconglomerates. The light-colored gravels being scattered in the dark matrix look like eyeballs, so the type 3 megaconglomerate is conventionally called “eyeball limestone” (Figure 2d, e).

Limestone Grainstone.- The limestone grainstone(Figure 3a, b), light gray, thick bedded-massive of 60-250 cm thick, has 60-90 percent of grains, which are composed of bioclast, calcarenite, intraclast and oolite etc.

Packstone.- The packstone is light gray, thick bedded-massive of 50-150 cm thick, grain-supported or mud-supported, with chert nodules.

Wackestone.- The wackestone is gray-dark, thin-middle bedded of 10-20 cm thick, matrix-supported.

Calcarenite.- The calcarenite (Figure 3c, d), 5-30 cm thick, has gray-brown weathered surface and dark gray-dark fresh surface, and contains a little mud and siliceous. Generally, It looks like plats due to weathering. The calcarenite, in layer or lenticular forms, develops horizontal laminae and gentle ripple bedding.

Splitting limestone.- The splitting limestone, thick bedded-massive of 150-250 cm, consists of broken light grey bioclast limestones. The interfaces between fragments are clear. The fragments are almost a cube, 15-20 cm in size, no visible displacement, and matrix-free among the fragments (Figure 3e).

3.2 Siliceous Rocks

The siliceous rocks in the study area can be divided into three types, thin-bedded, layered, and nodular or banded cherts (Figure 4a, b, c, d).

3.3 Siliciclastic Rocks

Siliciclastic rocks in the study region consist mainly of siltstone and shale, secondly of sandstone, and shale bearing phosphorus nodular. They mostly formed in beach-lagoon or deep water basin environments.

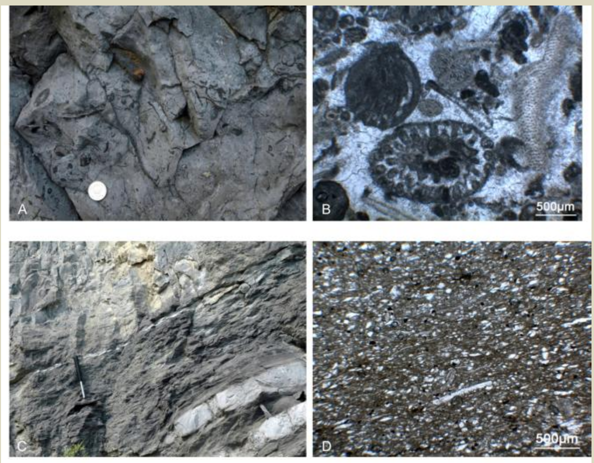


Fig. 3 Characteristics of some limestone facies in the Yangsingian Series of the NMYB

A- outcrop of the Maokou Fm. bioclastic grainstones in Hubei Changyang;

B- micrograph of the Maokou Fm. grainstone limestone, sparry calcite cement, in Hubei Daye;

C- outcrop of the Chihsian Fm. calcarenites, in Hubei Changyang;

D- micrograph of the Chihsian Fm. calcarenite, in Hubei Changyang;

E- outcrop of the Maokou Fm. spitting limestone, in Sichuang Guangyuanm.

The coin diameter is 2.5 cm, and the hammer is 30 cm in length.

4. MAJOR TYPES OF SEDIMENTARY PROCESSES

The Yangsingian Series in the NMYB develops a variety of processes (Fig. 5), which include mostly the depositions of the *in situ*, the debris flow, the contour flow and the upwelling current, secondly the suspension and the avalanche. The *in situ* deposition developed mostly on the carbonate platform, secondly on the middle slope. The debris flow and contour flow deposition extensively developed on the carbonate slope. The upwelling current deposition did on the middle to lower slope and the basin. The suspension sedimentation developed mainly on the lower slope and basin, secondly on the middle slope, and the avalanche sedimentation did in the slope and basin environment.

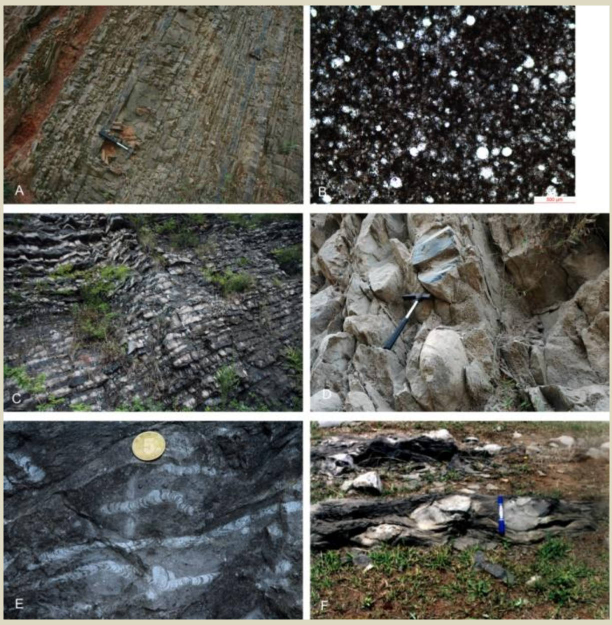


Fig. 4 Characteristics of some chert facies etc. in the Yangsingian Series of the NMYB

A- The Gufeng Fm. thin-bedded cherts, in Hubei Daye;

B- Micrograph of the thin-bedded chert, with rich radiolarian fossils, in Hubei Daye;

C- The Maokou Fm. layer cherts, as interlayers between packstones, in Hubei Daye;

D- Chert nodules in the calcarenites in the upper limestone member of the Chihsian Fm., in Anhui Chaohu;

E- Trace fossil- *Zoophycos* distributing in the Chihsian Fm. calcarenites, in Hubei Changyang;

F- Limestone nodules in the calcarenite, in the upper chert member of the Chihsian Fm., in Anhui Chaohu.

The hammer is 30 cm in length, the coin diameter is 2 cm, and the marker pen is 14 cm in length.

5. DEPOSITIONAL ENVIRONMENTS AND FACIES ASSOCIATIONS

The Yangshingian Series in the NMYB developed mainly carbonate slope deposition, secondly deposition of carbonate platform, basin, and beach-lagoon.

5.1 Carbonate Platform and Platform Margin Deposition

Shallow carbonate platform sediments are composed of mostly limestone grainstone and packstone, secondly wackestone, generally tens to one hundred meters thick, and develop in the Maokou, Wuxue and Chihsian formations.

5.2 Carbonate Slope Deposition

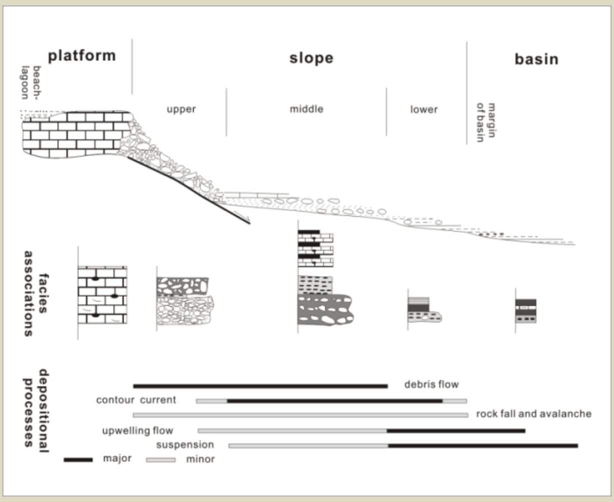


Fig. 5 Deposition-onlapping slope model of the Middle Permian in the north margin of the Yangtze Basin

Over the years, according to the carbonate microfacies and biota characteristics, the Chihsian Formation carbonate rocks have been considered to be a shallow-water carbonate platform. (Yang, 1989; Feng et al, 1991; Lu et al., 1991). In recent years, in addition to the early sporadic carbonate slopes or gentle slope reported (Zhao et al., 1992; Mou et al., 1997；Wang and Jin, 2000; Li et al., 2001，2002, 2008), we found that the Middle Permian carbonate slope deposition extensively develops in the region, and the megaconglomerates and calcarenites as the signs of carbonate slope deposition have large thickness and wide distribution. The sediments of slope are generally tens of meters thick, a thickness exceeding one hundred meters found in Hubei Changyang. The carbonate slopes mostly developed in the Chihsian and Maokou formations. Based on the petrofacies characteristics, the carbonate slope can be divided into the upper, middle and lower of slope, among which middle slope mostly developed (Figure 5).

The upper slope mainly developed type 1 and 2 of megaconglomerates and a little of calcarenites (Figure 2a-c), and the megaconglomerates occupy more than 80 percent of the slope sediments, each association of slope sediments is a few to tens of meters thick (Figure 6). The terrain was generally steep, the gravels were from the platform margin, and transported to the upper slopes to form the megaconglomerates mostly by the debris flow deposits.

The middle slope sediments have both facies associations; the most common association consists mostly of type 3 megaconglomerates and calcarenites, and interlaying packstone/wackestone. The association is tens to a hundred meters thick, 40-50 percent of the association is composed of the megaconglomerates, and the rest is composed of the calcarenites and packstone/wackestone. The gravels of megaconglomerates were sourced from matter of

A large number of evidences support that the calcarenites developing on the middle of carbonate slope formed by the contour current deposition, which is some similar to modern Straits of Florida, where sediments of contour current are approach 600 m in thickness and up to 60 km in width and 100 km in length (Coniglio and George, 1992). Trace fossil Zoophycos, which has been considered to develop in deep water slope and basin environments (Tucker and Wright, 1990), has been found in the calcarenites of various field outcrops (Wang et al., 2012).

The other facie association developing on the middle slope consists of packstone/wackestone interlaying layer cherts and chert bands, about 7-20 m thick. This middle slope has a gentler angle, lacks debris flow sediments.

The lower slope sediments are mostly composed of siliceous shale, calcareous shale and calcarenites, among which some isolated nodules of limestone and chert, 20-60 cm in size, were scattered (Figure 4 g). The shales were formed by suspension deposition, the limestone nodules were from the rock fall and avalanche deposition, the chert nodules came from the deposition of the upwelling current, and the calcarenites belong to contour current deposition.

5.3 Basin and Basin Margin Deposition

The basin sediments are mostly composed of the thin-bedded chert, shale (mudstone), and marl, and are rich in pyrite nodules, sponge spicule and radiolarian fossils. The sediments have high contents of vanadium and nickel and high V/(V+Ni) ratio (0.91-0.98), which indicates that the basin was a deep water, stratified anoxic environment (Hatch and Leventhal, 1992; Li and Jin, 1995).

6. DEPOSITIONAL MODEL OF THE CARBONATE SLOPE

The Yangtze basin in Middle Permian was a marginal sea. To north, there was an open sea (roughly at today's Qinling-Dabie orogenic belt), which was the eastward extension of Palaeo-Tethys Ocean. To south and southwest, there were massive and chain carbonate platforms. The carbonate slope situated between the platforms and the open sea was about north and northeast-dipping, more than one thousand kilometers in length, hundreds of kilometers in width (Figure 1). As we all know, two types of carbonate slopes, depositional and bypass slopes have been distinguished (Coniglio and George, 1992). Drzewiecki and Simo (2002) put forward another onlapping slope. The Middle Permian carbonate slope in the NMYB may belong to a new type of slope, deposition-onlapping slope (Figure 5). The megaconglomerates formed by the debris flow, a few to tens of meters thick, developed on the upper slope, which displays a depositional feature of the slope; the both associations are respectively composed of calcarenites and megaconglomerates, tens to a hundred meters thick, and the association of the wackestone/packstone, interlaying layer chert, a few to tens of meters thick, they developed on the middle of slope, which displays the features of a onlapping slope. The calcareous shale and siliceous shale formed under normal suspension deposition, interlaying calcarenite formed by contour current deposition, they developed on the lower slope.

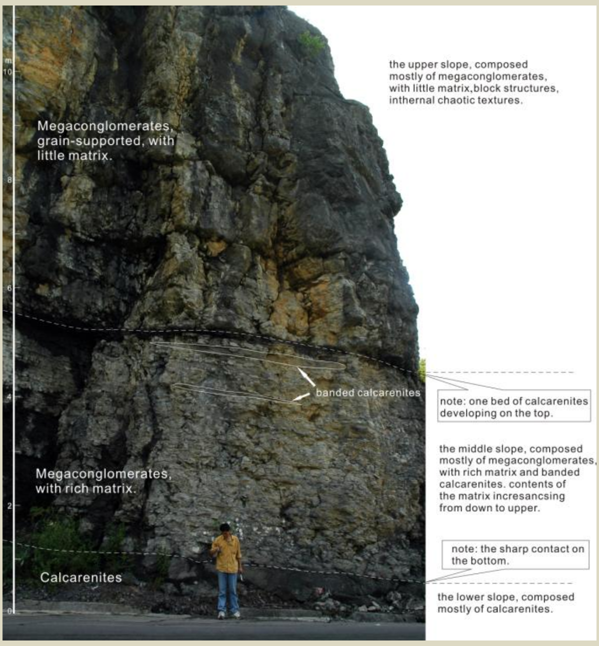


Fig. 6 Sedimentary sequences of the carbonate slope in the Maokou Fm. on the State Road 318 in Jianshi County of Hubei Province

Synthesizing the relationship between depositional products and slope angles for carbonate slope (Drzewiecki, 2002) and the angle against the dominant sediment fabric (Kenter, 1990), the paper suggests that combining sediment fabric with depositional products may be used to determine the geometric features of a carbonate slope. In the study region, the upper slope developed the sediments of debris flow, with grain-supported and no or little matrix, so, it may have a steeper angle about dip 10-20º; the middle slope developed megaconglomerates with grain-supported and matrix, and calcarenites formed by contour flow, so, it may have a gentle angle about dip 5-10º; the lower slope mainly develops muddy sediments, and may have a angle less than 5º.

The slope depositional environment often had sudden changes, the Hubei Jianshi section taken as an example (Figure 6).

7. DEPOSITIONAL EVOLUTION AND CONTROL FACTORS

The Yangsingian Series in the NMYB went through carbonate platform-slope-basin depositional evolution, which can be divided into two major cycles, and four secondary cycles (Figure 7, Table 2). The major cycles develop in the Kungurian Stage and Guabdelupian Series, and last 7 Ma and 12 Ma respectively, which is coincided with two secondary order cycles in Jiangnan basin (Wang and Jin, 2000), and the four secondary cycles are coincided with Ross and Ross' and the Salt Range (Pakistan)'s sea-level change curves (Ross and Ross, 1995; Mertmann, 2003), which implies that the sea-level change might control the cyclic sedimentation.

Permian fault activity of the NMYB is not an isolated geological event, and it may show that the stretching and tension of the basin and eastward extension of the Paleo-Tethys Ocean were under the same tectonic setting. Many studies have shown that the activities of synsedimentary faults may control the development of the carbonate platform, slope and basin. In the middle and lower reaches of theYangtze River, the Middle Permian deposition is closely related with two large faults, the Yangtze River fault and the Jiangnan fault, the former is also known as the Wuduhe fault in the Middle Yangtze. Therefore, the sedimentary evolution of carbonate platform- slope – basin in the study region was controlled by mostly the sea level changes, followed by tectonic activities. At the beginning of the Chihsian Subepoch, extensive onlap deposition was derived from sea-level rising, and strong tectonic activity led to differential uplift, and formation of the platform, slope, and basin pattern, and continued to the end of the Luodianian Age. From Xiangboan Age to Gufeng Age, the development of allochthonous megaconglomerates and Cryptospirifer represent once again transgression. This causes the northern marginal basin of the study region and the south Dianqiangui basin linked together.

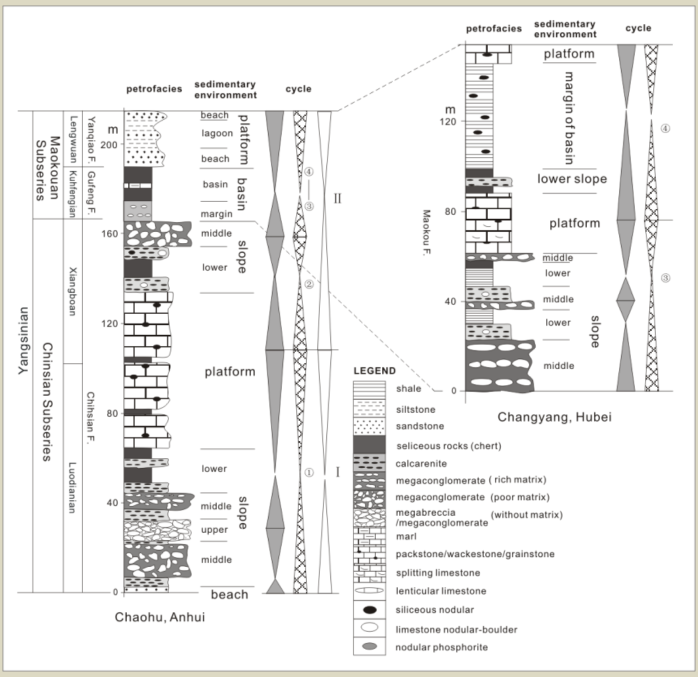
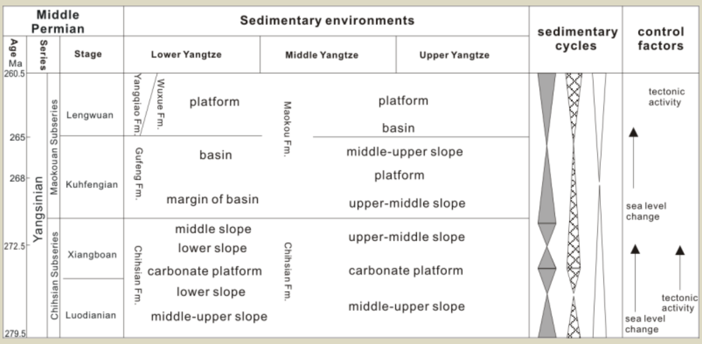


Fig. 7 Petrofacies, sedimentary environments and cycles of Middle Permian in the north margin of the Yangtze Bsain

In the study region, unconformity contact between Late Permian Lopingian and the Middle Permian Yangsingian is due to the decline of the global sea level or the crust uplift which was resulted from the Emeishan eruption of the volcanic province.

8. THE CONCLUSIONS

The Yangsingian Series in the NMYB is mostly of marine carbonate rocks, secondly cherts and clastic rocks, 200-500 m thick. The carbonate rocks include four main types of the megaconglomerates/megabreccias, calcarenites, bioclast limestones and micritic limestones, secondly marls and splitting limestones. The megaconglomerates/megabreccias are divided into three types of mud-free, mud-bearing and rich in mud. Based on their occurrence, the siliceous rocks are divided into thin-bedded cherts, layer cherts, and nodular cherts. The detrital rocks include fine sandstone, siltstone, shale, siliceous shale, calcareous shale and manganese shale etc.



Tab. 2 Deposition cycles and their control factors of the Yangtze Series, in the north margin of the Yangtze Basin

The study region in Middle Permian was a marginal sea. To north, there was an open sea (roughly at today's Qinling-Dabie orogenic belt), which was the eastward extension of Palaeo-Tethys Ocean. To south and southwest, there were massive and chain carbonate platforms. The carbonate slope situated between the platforms and the open sea was about north and northeast-dipping, more than one thousand kilometers in length, hundreds of kilometers in width. The carbonate platform was an open-limited sea platform.

The carbonate slope may belong to a new type of the deposition-onlapping slope, a gravelly to sandy slope. The slope can be divided into the upper, middle and lower of slope; the upper slope, with a steep slope angle of 10-20º, is composed of grain-supported mud-free to mud-bearing megaconglomerates, which are derived from the deposition of the debris flow; the middle slope, with a gentle slope angle of 5-10º, is composed of grain-supported or matrix-supported megaconglomerates, calcarenites, and packstone/wackestone and layer cherts. There were diverse types of deposition processes, which include depositions of debris flow, contour current, upwelling flow, and *in situ* deposition; the lower slope, with a slope angle of less than 5º, develops siliceous shale, carbonaceous shale and calcarenites, with isolated limestone nodules and chert nodules. The deposition processes include depositions of contour current, upwelling flow, debris flow, suspension and avalanche deposition.

The sediments of the basin and its margin are mostly composed of thin-bedded cherts, various kinds of shale, bearing manganese and phosphorus, and they mainly formed under a layered stagnant anoxic depositional environment. The depositions of suspension and upwelling current are the main.

The Yangsingian in the NMYB went through carbonate platform-slope-basin depositional evolution, which can be divided into two major cycles and four secondary cycles. The major cycles developed in the Kungurian Age and Guabdelupian Epoch, and last 7 Ma and 12 Ma respectively. The major cycles are coincided with two secondary order cycles in Jiangnan basin, and the four secondary cycles are coincided with Ross and Ross' and the Salt Range (Pakistan)'s sea-level change curves. Major role in control of cyclic sedimentation is the sea-level change, followed tectonic activity. The Permian fault activity in the NMYB and to east tension and extension of the Paleo-Tethys Ocean were under same tectonic setting, and the development of the Middle Permian carbonate slope may provide the evidence for the east rapid expansion of the Paleo-Tethys Ocean.

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References

Coniglio, M., and George, R.D., 1992. Carbonate Slopes. In: Walker R G, James N P. (eds., 1992): Facies model: Response to sea level change. 349-374. Geological association of Canada

Drzewiecki, P.A., 2002, Depositional processes and sequence Stratigraphic interpretation of Cretaceous carbonate slope deposits, Southcentral Pyrenees, Spain, AAPG Annual Meeting,

Drzewiecki, P.A., and Simo, J.A., 2002. Depositional processes, triggering mechanisms and sediment composition of carbonate gravity flow deposits: examples from the Late Cretaceous of the south-central Pyrenees, Spain. *Sedimentary Geology* 146, 155-189

Feng, Z.Z., Yang, Y.Q., Jin, Z.K., He, Y.B., Wu, S.H., Xin, W.J., Bao, Z.D., and Tan, J., 1996. Lithofacies paleogeography of the Permian of South China. *Acta Sedimentologica Sinica* 14, 1-10 (in Chinese)

Flügel, E., 2004. Microfacies of Carbonate Rocks, Analysis, Interpretation and Application. Berlin: Springer-Verlag, 1-976

Gawthorpe, R.L., 1986. Sedimentation during carbonate ramp-to-slope evolution in a tectonically active area: Bowland Basin (Dinantian), northern England. *Sedimentology* 33, 185-206

Hatch, J.R., and Leventhal, J.S., 1992. Relationship between in ferred redox potential of the depositional environmental and geochemistry of the upper Pennsylvanian (Missourian) Stark Shale Member of the Dennis Limestone, Wabaunsee County, Kansas, USA. *Chemical Geology* 99, 65-82.

Jiang, N.Y., 1994. Permian palaeogeography and geochemical environment in Lower Yangtze Region, China. Beijing: Petroleum Industry Press, 94-95 (in Chinese)

Jin, Y.G., and Shang, Q.H., 2000. The Permian of China and its interregional correlation. In: Yin H F, Dickions, J M, Shi G R and Tong J N. (eds., 2000): Permian-Triassic Evolution of Tethys and Western Circun-Pacific,71-98

Kametaka, M., Takebe, M., Nagai, H., Zhu, S., and Takayanagi, Y., 2005. Sedimentary environments of the Middle Permian phosphorite-chert complex from the northeastern Yangtze platform, China; the Gufeng Formation: a continental shelf radiolarian chert. *Sedimentary Geology* 174, 197-222

Kametaka, N., and Hiroyoshi, S., 2007. Palaeoenvironmental implication of resedimented limestones shed from Mississippian–Permian mid-oceanic atoll-type buildup into slope-to-basin facies, Akiyoshi, Japan, *Palaeogeography, Palaeoclimatology, Palaeoecology* 247, 329-356

Kenter, J.A.M., 1990. Carbonate platform flanks: slope angle and sediment fabric. *Sedimentology* 37, 777-794

Li, S.Y., Hong, T.Q., Jin, F.Q., Liu, H., and Hu, Y.Q., 2001. Allochthonous carbonate rocks in the swine limestone member of Permian Chihsian Formation of Chaohu, Anhui. *Journal of Stratigraphy* 25, 69-74 (in Chinese)

Li, S.Y., Meng, Q.R., Wan, Q., Kong, W.L., and He, G., 2008. Deposition of carbonate slope and ore-forming in Permian strata in the Middle-lower Reaches of the Yangtze River, east China. *Acta Petrologica Sinica* 24, 1733-1744 (in Chinese)

Makoto, I., 1997. Spatial variation in turbidite to contouite continuums of the Kiwada and Otadai Formations in the Boso Peninsula, Japan: an unstable bottom current system in a PlioPleistocene forearc basin. *Journal of Sedimentary Research* 67, 571-582

Mertmann, D., 2003. Evolution of the marine Permian carbonate platform in the Salt Range (Pakistan), *Palaeogeography, Palaeoclimatology, Palaeoecology* 191, 372-384

Metacalfe, I., 2006. Permian tectonic framework and palaeogeography of SE Asia, *Journal of Asian Earth Science* 20, 551-566

Mou, C.L., Qiu, D.Z., Wang, L.Q., and Wan, F., 2000. Sediemntary facies and palaeogeography and oil-gas of the Permian sequences in the Hunan-Jiangxi-Hubei region. Bejing: Geological Press, 151

Philips, J., Watts, N., and Mcllreath, I., 2008. Carbonate slope and basin deposits: A review of models, worldwide examples and their relevance to the Western Canadian sedimentary basin. *CSPG CSEG CWLS Convention*, 673-675

Shanmugam, G., 1996. High density turbidity currents: are they sandy debris flows? *Journal of Sedimentary Research* 66, 2-10

Shi, G.R., and Chen, Z.Q., 2006. Lower Permian oncolites from South China: Implications for equatorial sea-level responses to Late Palaeozoic Gondwanan glaciation. *Journal of Asian Earth Sciences* 26, 424–436

Thurman, H.V., 1988. Introductory oceanography (Fifth edition). Columbus, Ohio: Merrill Publishing Company, 515

Tucker, M.E., Wright, V.P., and Dickson J.A.D., 1990. Carbonate Sedimentology. London: Blackwell Scientific Publications, 228-283

Wang, Y., and Jin, Y.G., 2000. Permian palaeogeographic evolution of the Jiangnan Basin, South China. *Palaeogeography, Palaeoclimatology, Palaeoecology* 160, 35-44

Wright, V.P., and Burchette, T.P., 1996. Shallow-water carbonate environments. In: Reading H G (eds., 1996): Sedimentary Environments: Process, Facies and Stratigraphy (Third edition). Blackwell Scientific Publications, Oxford, 325-394