Chapter 2
Meso-Neoproterozoic Stratigraphic Sequences in the Yanliao Faulted-Depression Zone, North China Craton

Shixing Zhu, Huaikun Li, Lixin Sun, and Huan Liu

Abstract The Precambrian sedimentary strata in the Yanliao Faulted-Depression Zone (YFDZ) on the North China Craton is the most-developed Meso-Neoproterozoic sequences in China. The sequences consist of the Pt_2^1 Changchengian, Pt_2^2 Jixianian, Pt_2^3x Xiamaling Formation and Pt_3^1 Qingbaikouan, which are traditionally subdivided into 12 formations and 43 members. This chapter aims to review the history and the state of art of the studies on the stratigraphic sequences in aspects covering the tempo-spatial distribution, lithostratigraphic correlation, geochronology and palaeontology. Some important aspects have been discussed in detail. As the oldest unmetamorphosed sedimentary sequence in China, the Changchengian (1670–1600 Ma) shows a regional micro-angle unconformity with the underlying Dahongyu Formation of Jixianian (1600–1400 Ma) with a local conformity at the Dahongyu depocenter. Therefore, both Changchengian and Jixianian should be referred to a set of basically continuous sedimentary strata in the Jixian stratotype section. The Changchengian may be attributed to the aulacogen clastic deposition in the early stage of the YFDZ related to early breakup of the Supercontinent Columbia.

Keywords Yanliao faulted-depression zone (YFDZ) · Changchengian · Jixianian · Xiamaling formation · Qingbaikouan · North China craton (NCC)

2.1 Introduction

The Yanliao Faulted-Depression Zone (YFDZ) is geographically situated at the Yanshan Mountain on the west of Liaohe River regions, and geologically located at the middle segment in the northern margin of the North China Craton (Fig. 2.1), which used to be termed as the "Yanliao Subsidence Zone" or the "Yanshan Paraplatform" in literatures.

Tectonically, the YFDZ includes five depressions (i.e., Liaoxi, Jibei, Jidong, Jiangxi and Xuanlong Depressions) and two uplifts (i.e., Shanhaiguan and Mihuai

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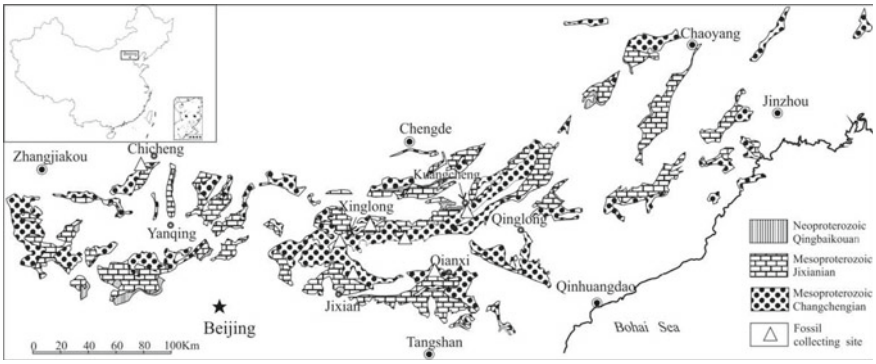


Fig. 2.1 the sketch map showing the distribution of the proterozoic strata in the yanliao faulted-depression zone (YFDZ)

Uplifts; cf. Figure 11.13 in Chap. 11). Stratigraphically, the Precambrian sedimentary strata in the YFDZ consist of the Meso-Neoproterozoic stratigraphic sequences, i.e., Pt_2^1 Changchengian, Pt_2^2 Jixianian, Pt_2^3x Xiamaling Formation and Pt_3^1 Qingbaikouan, in the Regional Stratigraphic Chart of China. In the last decade, great advances have been made on research of the Meso-Neoproterozoic strata in the YFDZ.

2.2 Historical Review

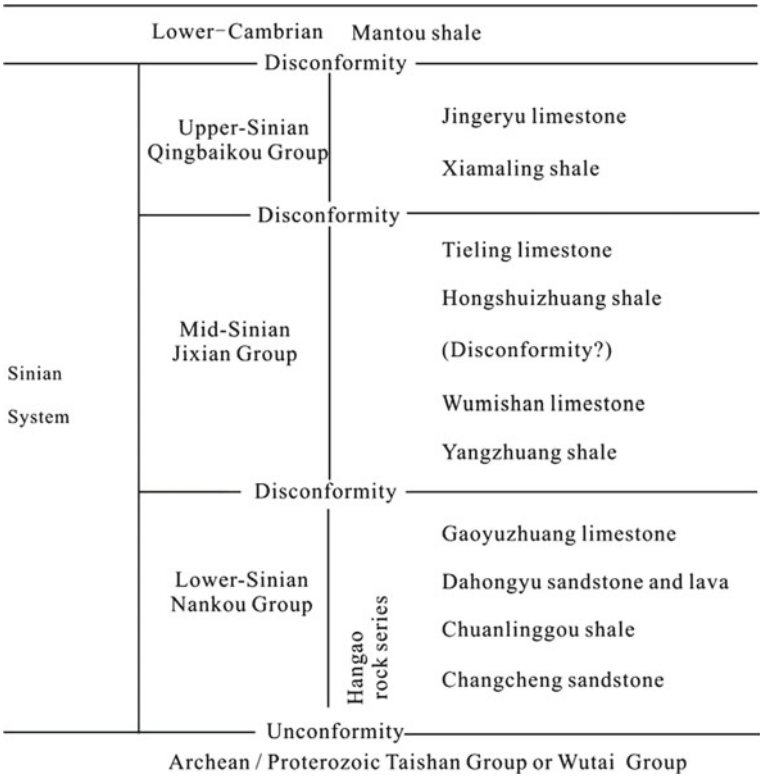
The geological studies on the Precambrian sequences in the YFDZ has started since 1922. The Precambrian strata in the area used to be named as "Sinian System", "Sinian Suberathem", "Middle to Upper Proterozoic" and Meso-Neoproterozoic respectively in four different periods, witnessing the research progresses on the Precambrian stratigraphy not only in this area, but also in whole the China.

2.2.1 "Sinian System" Period

The word "Sinian" was initially coined as a tectonic term by Punpelly (1866), and then was used as a stratigraphic term (Richthofen 1882). As a stratigraphic unit, the word "System" was formally defined for "a suite of unmetamorphosed or slightly metamorphosed rocks unconformably overlying the high-grade metamorphosed Wutai System, disconformable underlying the fossil-bearing Lower Cambrian Mantou shales" by Grabau (1922). Although the Nankou section at north Beijing was the earliest investigated "Sinian System" section in the Yanshan Mountain (Tien 1923), while the Jixian section at the southern slope of the eastern Yanshan Mountain has been traditionally used as the stratotype section for the "Sinian System" in China.

The Jixian stratotype section is located in the north of the Jixian District in Tianjin. As a very thick and unmetamorphosed Precambrian sedimentary sequence between the Archean and Cambrian, the Jixian section was initially investigated by Kao C. S., Hsiung Y. H. and Kao P. in 1931 (Kao et al. 1934). It was subdivided into three groups with ten litholostratigraphic members in ascending order (Table 2.1), the Lower Sinian "Nankou Group" (including the "Changcheng quartzite", "Chuanlinggou shale", "Dahongyu quartzite and Lava" and "Gaoyuzhuang limestone"), the Middle Sinian "Jixian Group" (the "Yangzhuang shale", "Wumishan limestone", "Hongshuizhuang shale" and "Tieling limestone") and the Upper Sinian "Qingbaikou Group" (the "Xiamaling shale" and "Jing'eryu limestone"; Table 2.1), and the "Sinian System" unconformably overlies the Archean/Proterozoic Taishan or Wutai Groups, and disconformably underlies the Lower Cambrian "Mantou shale" (Kao et al. 1934). Among the above three groups of "Sinian System", the stratigraphic contacts are disconformable as well. Kao et al. (1934) also noted that there might be a disconformable contact between the "Wumishan limestone" and "Hongshuizhuang shale".

Table 2.1 Subdivision of the Jixian "Sinian system" (Kao et al. 1934)



Since the Gao C. S.'s pioneer work in 1934, the major research advances on the "Sinian System" in the Yanshan Mountain are summarized as follows.

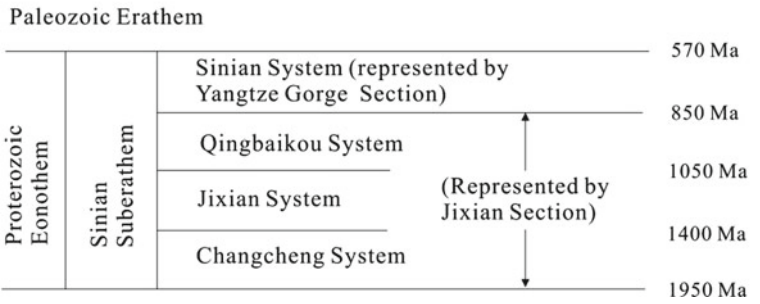
(1) Due to the discovery of trilobite fossils from the upper "Jing'eryu limestone" at the Mingtombs section in the Changping District, north Beijing, Zhang W. Y. and Li T. B. doubted the "Jing'eryu limestone" as Cambrian strata in 1935, and named the trilobite-bearing limestone as the "Changping Formation" belonging to the Early Cambrian in age (Zhang 1935). Sun (1957) confirmed that the upper "Jing'eryu limestone" in the Jixian stratotype section is referred to the Lower Cambrian with an unconformable contact over the "Sinian System". Meanwhile, the tectonic movement corresponding to the unconformity was named as "Jixian Movement" with standard site at the Fujunshan Hill in the north of the Jixian District. While the Cambrian interval of the upper "Jing'eryu limestone" was renamed as the Fujinshan Formation based on local tablet inscription (Wang 1963; Xiang and Guo 1964).
(2) Shen and Liao (1958) considered that the Gaoyuzhuang Formation appears as a conformable contact with its overlying Yangzhuang Formation, and a disconformable contact with its underlying Dahongyu Formation, so that the Gaoyuzhuang Formation should be assigned into the Middle Sinian "Jixian Group" in the stead of the Lower Sinian "Nankou Group" in Table 2.1.
(3) Wang (1963) referred the "Sinian System" of the Jixian section to the Precambrian age in North China, which would be older than the Eocambrian "Sinian System" represented by the Yangtze Gorge section in South China.

2.2.2 "Sinian Suberathem" Period

Owing to the dispute on stratigraphic correlation of the "Sinian System" between South and North China, a National Precambrian Symposium was held in Beijing in 1975, and a National Sinian Stratigraphic Subdivision Chart was tentatively established in the symposium, based on which, it was proposed that the "Sinian System" of South Sinian (represented by the Yangtze Gorges section) was placed above the "Sinian System" of North China (represented by the Jixian section), both constituted the "Sinian Suberathem" of Proterozoic Erathem, which was subdivided into four chronostratigraphic units, i.e., "Sinian System" (in Yangtze Gorge section as the stratotype), "Qingbaikou System", "Jixian System" and "Changcheng System" (in Jixian section as the stratotype) in descending order (Table 2.2; Wang et al. 1980a, b).

Now that the basal interval of the original "Jing'eryu limestone" consists of terrestrial siliciclastic rocks, and thus as a new stratigraphic unit, it used to be alone called as "Longshan sandstone", "Longshan Formation" (Qiao 1976) and "Changlongshan Formation" (Compilation Group of Regional Stratigraphic Table in Beijing 1977) respectively, resulting in the terminologically inconsistent names. Finally, Xing et al. suggested to rename the terrestrial siliciclastic as Luotuoling Formation.

Table 2.2 The subdivision and timescale of the "Sinian Suberathem" in China (Wang et al. 1980a, b)



Since 1975, more stratigraphic sections of the "Sinian Suberathem" in the YFDZ have been investigated in detail. In addition to the Jixian section (Chen et al. 1980), the results of Mingtombs section in north Beijing (Wang et al. 1980a, b) and sections in the western and eastern segments of the Yanshan Mountains (Du and Li 1980; Xu and Cui 1980) have been reported. The main progresses during the period are summarized in Table 2.3.

Table 2.3 The subdivision and timescale of the "Sinian Suberathem" in Jixian section (Chen et al. 1980)

		~~ Jixian Movement (~850 Ma)
Qingbaikou System	Jingeryu Formation	Jingeryu Subformation: Limestones
		Changlongshan Subformation: sandstones
		Yuxian Uplifting
	Xiamaling Formation	Sandstones and shales
		Qinyu Uplifting (~1050 Ma)
Jixian System	Tieling Formation	Laohuding Subformation
		Tieling Uplifting
		Daizhuangzi Subformation
	Hongshuizhuang Formation	shales
	Wumishan Formation	Various dolomites (from bottom to top: Luozhuang, Mopanyu, Ershilipu and Shanpoling subformations)
	Yangzhuang Formation	Red mud-dolomites
		Luanxian Uplifting (~1400 Ma)
Nankou System	Gaoyuzhuang Formation	Various dolomites (from bottom to top: Guandi, Sangshuan, Zhangjiayu and Huanxiusi subformations)
		Qinglong Uplift
	Dahongyu Formation	Sandstones and volcanic rocks
		Xingcheng Uplifting (~1700 Ma)
Changcheng System	Tuanshanzi Formation	Dolomites
	Chuanlinggou Formation	Shales
	Changzhougou Formation	Conglomerates and sandstones
		~~ Lvliang Uplifting (~1950 Ma)

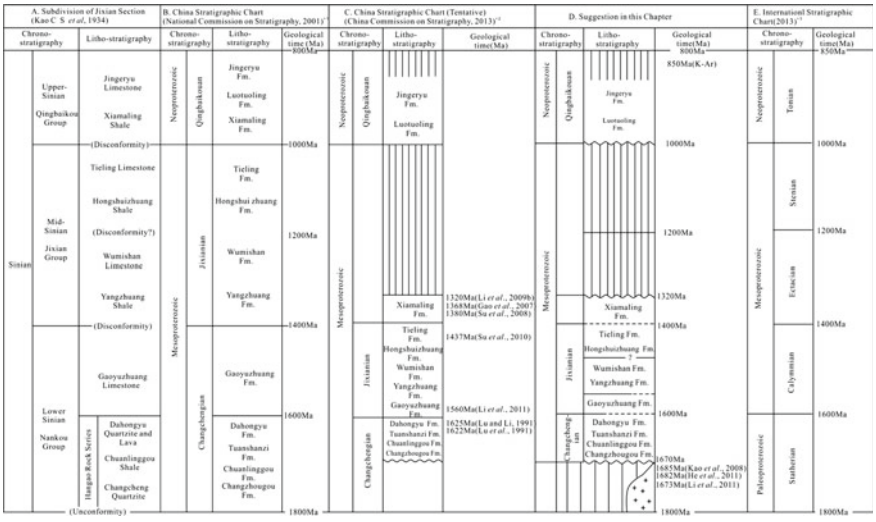
2.2.3 *"Middle to Upper Proterozoic" Periods*

The term of "Sinian Suberathem" had to be abandoned in China, which was officially approved by National Commission on Stratigraphy of China during a special meeting on Precambrian in 1982. The "Sinian System" was specifically redefined to cover the "Sinian System" strata in Yangtze Gorges section as one stratotype in Yangtze Craton (South China), while another stratotype in Jixian section represents original "Sinian System" in North China Craton, and based on the stratigraphic subdivision scheme of Kao et al. (1934; Table 2.4a), which is further divided into "Changchengian Jixianian and Qingbaikouan" systems from bottom to top with a duration of 1800–800 Ma (Table 2.4b; China Commission on Stratigraphy of China 2001).

Hereafter, the standard Middle to Upper Proterozoic Stratigraphy Chart of North China consists of three systems with twelve formations in the Jixian stratotype section, east Yanshan Mountain was established.

In 1998, the National Commission on Stratigraphy of China released an official notice on the recommendation of Geological Time Scale of China. In the timescale, the Proterozoic Eon/Eonothem is subdivided into Palaeoproterozoic, Mesoproterozoic and Neoproterozoic Era/Erathem. The Mesoproterozoic Era/Erathem is further subdivided into the Changchengian (1800–1400 Ma) and the Jixianian (1400–1000 Ma), the Neoproterozoic Era/Erathem was subdivided into the Qingbaikouan (1000–800 Ma) and the Sinian (800–600 Ma). Ever since, the three periods/systems in the Jixian stratotype section was used as the official chronostratigraphic units in

Table 2.4 Brief historical summary of the Proterozoic stratigraphy in the Yanliao Faulted-Depression Zone



Note: *1. National Commission on Stratigraphy of China (2001); *2. Editorial Board on China Stratigraphic Chart 2013; *3. International Commission on Stratigraphy 2013

the stratigraphic chart of China (China National commission on Stratigraphy 2001; Table 2.4b).

2.2.4 The Stratigraphic Chart of China in 2013

Over the last decade, along with application of improved geochronology, great advances have been achieved on chronostratigraphy and stratigraphy, particularly on the new geological age constraining of Xiamaling Formation and Changchengian. The National Commission on Stratigraphy of China issued a new Stratigraphic Chart of China in 2013 (Editorial Board on China Stratigraphic Chart 2013; Table 2.4C). The major revision in the new chart includes:

(1) The Xiamaling Formation (1400–1320 Ma) is placed in the middle of the Mesoproterozoic rather than the lower of the Neoproterozoic Qingbaikouan.
(2) A long period of hiatus (1320–1000 Ma) between the Xiamaling Formation and the Qingbaikouan is recognized.
(3) As the highest horizon of Jixianian, the position of Tieling Formation is moved from the top of the Mesoproterozoic to the middle-lower horizon of the Mesoproterozoic.
(4) The Meso-Neoproterozoic stratotype of Jixian section in YFDZ contains four stratigraphic units: Pt_2^1 Changchengian (1700–1600 Ma), Pt_2^2 Jixianian (1600–1400 Ma), Pt_2^3x Xiamaling Formation (1400–1320 Ma) and Pt_3^1 Qingbaikouan (1000–780 Ma) in ascending order.
(5) The boundary of the Changchengian and Jixianian was changed from the boundary between the Gaoyuzhuang and Yangzhuang Formations to that between the Dahongyu and Gaoyuzhuang Formations, which shows a regional disconformable contact with local conformable contact at the depocenter of Dahongyu Formation.

2.3 Meso-Neoproterozoic Stratigraphic Sequences

In accordance with the China Stratigraphic Chart (tentative; Table 2.4c; Editorial Board on China Stratigraphic Chart 2013), the Meso-Neoproterozoic sequences in the YFDZ are briefly described as follows (Fig. 2.2).

2.3.1 Changchengian (Pt_2^1)

The Changchengian in Jixian stratotype section is mainly distributed at the Xiaying area in Jixian Distract, Tianjin, and its lower interval generally is typical aulacogen siliciclastic rocks, and the middle-upper interval mainly comprises muddy and

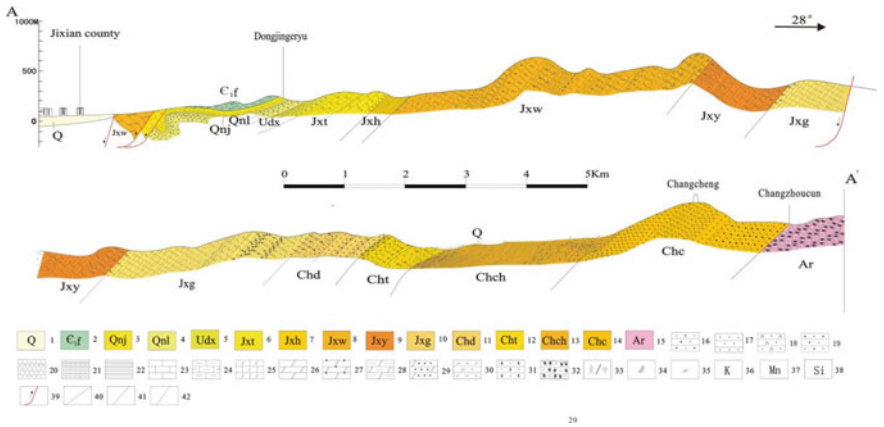


Fig. 2.2 Meso-Neoproterozoic lithostratigraphic sequence of the Jixian Section 2.1. 1. Quaternary; 2. Lower Cambrian Fujunshan Formation; 3. Qingbaikouan Jing'eryu Formation; 4. Qingbaikouan Luotuoling Formation; 5. Xiamaling Formation; 6. Jixianian Tieling Formation; 7. Jixianian Hongshuizhuang Formation; 8. Jixianian Wumishan Formation; 9. Jixianian Yangzhuang Formation; 10. Jixianian Gaoyuzhuang Formation; 11. Changchengian Dahongyu Formation; 12. Changchengian Tuanshanzi Formation; 13. Changchengian Chuanlinggou Formation; 14. Changchengian Changzhougou Formation; 15. Neoarchean Zunhua Group-complex; 16. sandy conglomerate; 17. sandstone; 18. quartzose sandstone; 19. unequal grain sandstone; 20. fine-grained sandstone; 21. silty shale; 22. shale; 23. Limestone; 24. muddy limestone; 25. dolomitic limestone; 26. dolostone; 27. sandy dolostone; 28. silt-bearing muddy dolostone; 29. dolomitic sandstone; 30. carbonate breccia; 31. K-rich trachyte; 32. hornblende plagioclase gneiss; 33. columnar stromatolites; 34. microbial (algae) layer; 35. glauconite; 36. potassium; 37. manganese dolostone; 38. chert nodules and cherty layer; 39. reverse fault; 40.disconformity; 41. unconformity; 42. conformity

carbonate rocks, and the upper interval mainly consists of siliciclastic rocks and potassium-rich volcanic rocks, with a total stratigraphic thickness of 2525 m and an age of 1670–1600 Ma. It includes following four formations, i.e., Changzhougou, Chuanlinggou, Tuanshanzi, and Dahongyu Formations in ascending order.

The Changchengian is distributed at both southern and northern sides of the Shanhaiguan submarine uplift in the middle-eastern segment of YFDZ as well as at the surrounding Changping-Huairou submarine uplift in the western segment of YFDZ. The Changchengian appears as a NE-trending distribution controlled by the Yanliao Faulted-Depressions (Fig. 2.3), and unconformably overlies the Archean metamorphic rocks and unconformably underlies the Jixianian strata. It includes four formations as follows.

2.3.1.1 Changzhougou Formation (Pt_2^1c or Chc)

It was formerly known as "Changcheng quartzite" (Kao et al. 1934), "Nankou Series" (Shen and Liao 1958), "Huangyaguan Formation" (Chen and Lu 1963) and "Changzhoucun Formation" (Yu et al. 1964) respectively. Finally, it was formally

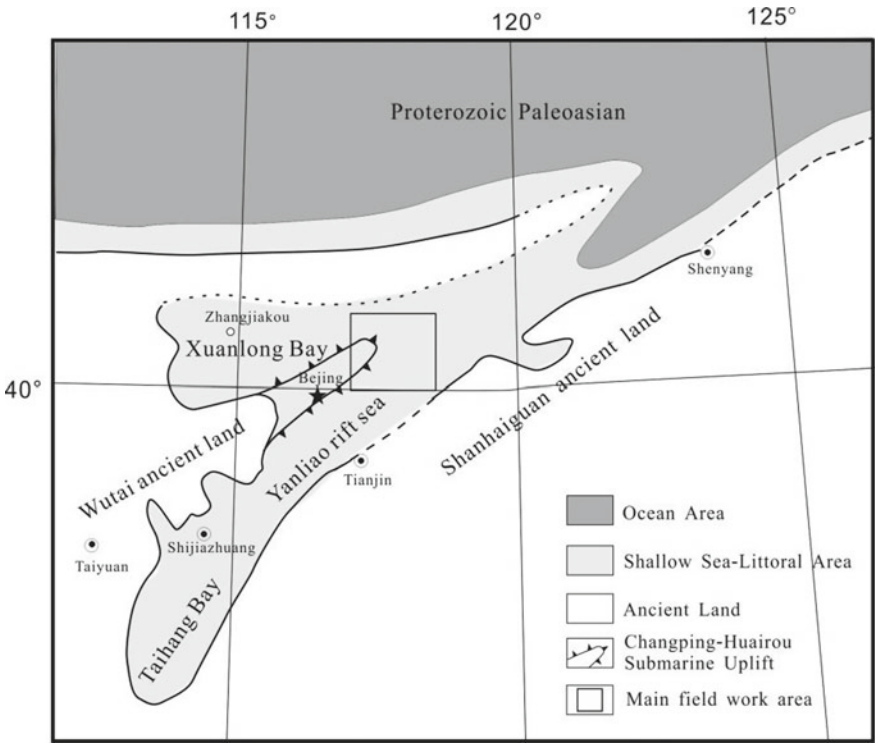


Fig. 2.3 Tectonic-palaeogeographic map of the Changchengian in the YFDZ (Wang 1985)

renamed as the Changzhougou Formation during the field seminar on the "Sinian System" in Jixian section in 1964 (North China Institute of Geosciences 1965), and its stratotype section is established at Xiaying area, Jixian District, Tianjin (China Stratigraphy Code Editorial Board 1999).

Taking the Jixian section as an example, the Changzhougou Formation is composed of siliceous sandstone with stratigraphic thickness of 859 m. It can be subdivided into three members, i.e., the fluvial conglomerate and bebbly coarse feldspathic quartzose sandstone as the lower member (Chang-1 Member), the littoral shoal light-purple quartzified sandstone and white sedimentary quartzite as the middle member (Chang-2 Member) and the tidal zone slaty and wedge feldspathic quartzose sandstone interbedded with lamella silty shale as upper member (Chang-3 Member; Fig. 2.4). The Changzhougou Formation (ca. 1670 Ma) unconformably overlies on the Archean Zunhua Group-complex (2458 Ma) consisting of the garnet-hornblende-plagiogneiss (Fig. 2.5).

The Changzhougou Formation appears as following changes in the YFDZ:

(1) Stratigraphic thickness varies greatly, it can be more than 1000 m thick, e.g. 1065 m at Xinglong, 2048 m at Kuancheng and 1286 m at Pingquan in Jibei Depression from west to east, and it is significantly thinner and only ca.

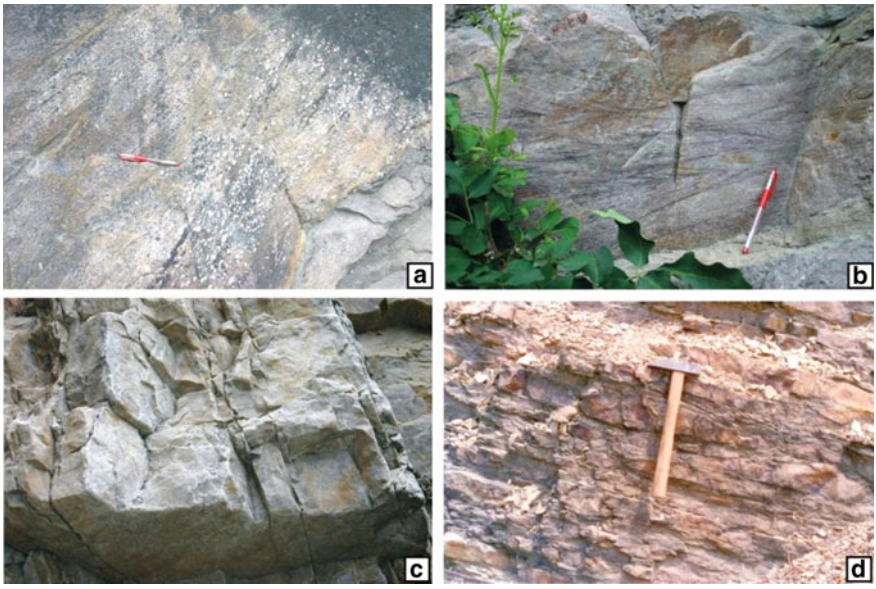


Fig. 2.4 The lithological characteristics of the Changzhougou formation at Changzhougou Valley in the north of Jixian District, Tianjin. **a**. Conglomerate and gravel-containing coarse feldsparthic quartzose sandstone (Chang-1 Member); **b**. the fluvial cross bedding showing facies (Chang-1 Member); **c**. thick-bedded to massive light-purple quartzified sandstone and white feldspathic quartzose sandstone (Chang-2 Member); **d**. slaty feldspathic quartzose sandstone (Chang-3 Member)

100 m at the edge of the faulted-depression and around the Changping-Huairou submarine uplift (in Jingxi to Xuanlong Depressions).

(2) In the centrality of YFDZ (such as Xinglong, Kuancheng and Pingquan in Jidong to Jibei Depressions), the lower interval of the Changzhougou Formation is generally fluvial coarse deposits predominated by conglomerate and coarse feldspathic quartzose sandstone; while surrounding the Changping-Huairou submarine uplift, the fluvial deposition does not exist except for the basal conglomerate, and it is mainly composed of marine quartzose sandstone with dolostone or dolomitic stromatolites at the top.

(3) In the centrality of YFDZ, there is black fine-grained sediments with carbonaceous shale and sandy shale near the middle interval of the formation; in Pangjiapu area, the formation is only 173.7 m thick and composed of lagoon sandstone and shale in the Chang-1 Member.

(4) At the Xuanhua-Longguan area (in Xuanlong Depression) of YFDZ, there are multiple layers of ferruginous sandstone within the quartzose sandstone of Chang-2 Member, even ferrilites composed of ferruginous stromatolites are enriched to constitute the famous Xuanlong hematite at the top of Chang-2 Member.

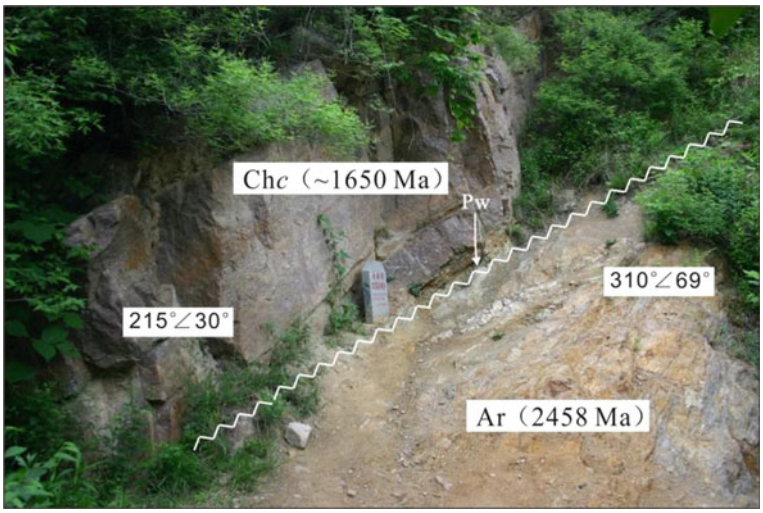


Fig. 2.5 The photograph of unconformable contact (Pw) between the Changzhougou Formation (Chc) and Neoarchean gneiss (Ar). Ar. Neoarchean garnet amphibolite gneiss; Chc. pebbly and feldsparthic course-grained quartzose sandstone at the base of the Changzhougou formation; Pw. palaeosoil layer

2.3.1.2 Chuanlinggou Formation (Pt_2^1ch or Chch)

The "Chuanlinggou shale" was originally named by Kao et al. in (1934), later renamed as the Chuanlinggou Formation in 1959. Geomorphologically, the Chuanlinggou shale forms low hills obviously distinguished from the high mountain terrain of the Changzhougou Formation.

In Jixian section, the Chuanlinggou Formation is composed of the 889 m thick mudstone. It overlies conformably the Changzhougou Formation (Fig. 2.6) and can be subdivided into three members: the lower member (Chuan-1 Member) consists of interbedded yellowish- and greyish-green lenticular sandstone, siltstone and silty illite shales; the middle member (Chuan-2 Member) is characterized by yellowish-green and black shales and silty illite shales; the upper member (Chuan-3 Member) is predominated by black illite shales intercalated by siltstone and fine-grained sandstone as well as some carbonaceous dolostone (Fig. 2.7).

In the Jixian section, magmatic rocks are often found in the Chuanlinggou Formation, which consist of plagioclase-porphyry and hornblende-kersantite with some orthophyre and volcanic breccia. Part of magmatic rocks are subvolcanic rocks of Dahongyu-age or the sills intruded into bedrocks during the Yenshanian (ca. Jurassic–Cretaceous time).

The Chuanlinggou Formation appears as obvious variations of stratigraphic thickness (30–1000 m) and lithofacies in the YFDZ. It can be generally divided into three kinds of lithofacies zones (Fig. 2.8):

Fig. 2.6 The photograph of conformable contact between the Chuanlinggou (Chch) and Changzhougou (Chc) formations at the Mouth of the Changzhougou Valley

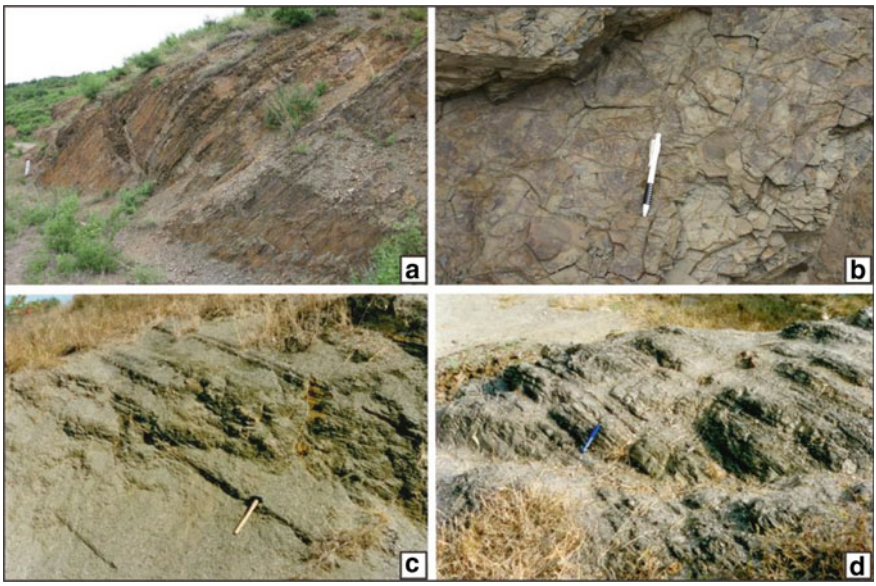


Fig. 2.7 The outcrop photographs of the Chuanlinggou formation near Guojiagou and Liuzhuangzi Villages. **a**. sandy shale with intercalations of thin-bedded fine-grained sandstone at Chuan-1 Member; **b**. the "mud-cracks" (?) at the Chuan-1 Member; **c**. the green shale of the Chuan-2 Member; **d**. the black shale intercalated with thin-bedded siltstone and fine-grained sandstone at Chuan-3 Member

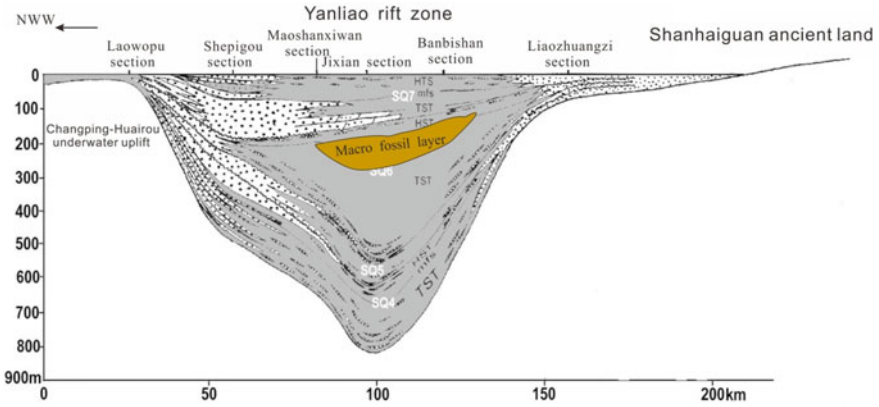


Fig. 2.8 The sketch showing facies changes of the Chuanlinggou formation in YFDZ (Huang et al. 2000)

(1) Barrier island sand-bodies of lagoon basin facies, or the sediments interbedded by multi-bed barrier sand-bodies, each bed is 10-dozens meters thick, but the total stratigraphic thickness would be up to 800–1000 m, especially for the sediments of lagoon basin facies mainly developed in Chuan-2 Member.
(2) With the thinnest stratigraphic thickness, the Chuanlinggou Formation of the Laowopu section isonly 30 m thick at Mingtombs and Xuanlong on the west of the Changping-Huairou submarine uplift (in Jiangxi-Xuanlong Depressions). It is mainly composed of dark-grey, light-purple and greyish-green thin-platy to liminal fine-grained sandstone, siltstone and silty shales with lenticular- and wavy-beddings, and locally developed shrinkage cracks.
(3) In the Mingtombs section and Xuanhua-Longguan zone on the west of the Changping-Huairou submarine uplift zone (in Jingxi-Xuanlong Depressions), and even in the southern segment of the Taihang Mountains (on the shorth of Jingxi Depression), the Chuanlinggou Formation is just dozens meters thick and characterized by the black carbonaceous shale in Chuan-1 Member, the emerald-green potassium-rich shale in the Chuan-2 Member, and the reef-like stromatolitic dolostone dominated by *Eucapsiphora*, etc. in the Chuan-3 Member (Zhu and Chen 1992; Zhu 1993).

The Chuanlinggou Formation is rich-in Acritarches at Jixian, Kuancheng and Pangjiabao, including various unique eukaryotic algal fossils, such as *Leioarachnitum, Trachyarachnitum, Diplomembrana, Schizospora, Goniocystis, Qingshania, Foliomorpha* etc. (Fig. 2.9).

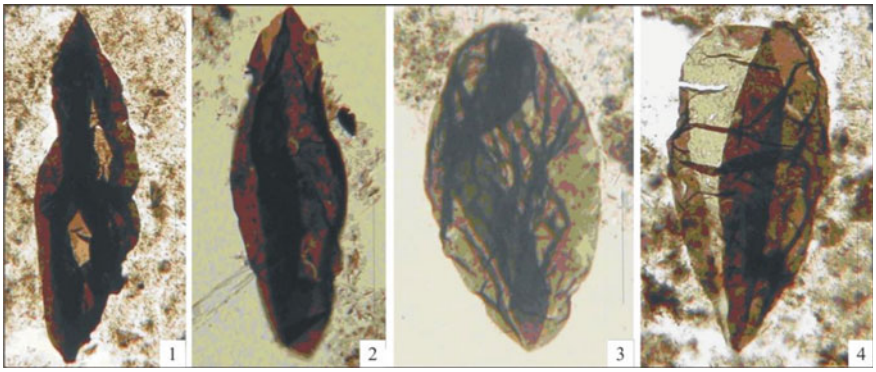


Fig. 2.9 The Microphotographs of Spindle or olive-like acritarch fossils from the Chuanlinggou formation. 1. *Leioarachnitum* sp.; 2. *Leioarachnitum apertum*; 3. *Scapha rugosa*; 4. *Leioarachnitum sinitum*

2.3.1.3 Tuanshanzi Formation (Pt_2^1t or Cht)

It is formerly known as the upper carbonate rocks of the original "Chuanlinggou shale" named by Kao et al. (1934). The regional geological surveying team of Hebei Province found the corresponding carbonate rocks in Jixian section at the Tuanshanzi Village, and proposed a new name of the Tuanshanzi Formation in 1960, which was accepted as a formal lithostratigraphic unit during the symposium on the "Sinian System" in Jixian section in 1964.

The Tuanshanzi Formation in Jixian section is 518 m thick and has conformable contacts with the overlying and underlying strata. It is subdivided into two members. The lower member (Tuan-1 Member) is a 269 m thick greyish-black muddy and silty dolostones interbedded with dolomitic mudstone, which contains straight rhythmic layers due to its variable muddy or sandy contents in dolostones (Fig. 2.10a). Since higher iron content in ankerite, the weathering surface of dolostone often appears as yellowish-brown colour. Abundant carbonaceous fragments and macroscopic algal fossils have often been found in the muddy dolostones. The lithofacies analysis indicates a restricted subtidal and lower energy sedimentary environment, i.e., freshening lagoon facies, in Tuan-1 Member.

While the upper member (Tuan-2 Member) is a 146 m thick dolostone interval with interbedded dolostone, sandy dolostones and dolomitic sandstone, intercalated by quartzose sandstones and sandstone. The Tuan-2 Member mainly shows as medium- to thin-bedded, and the bedding would be gradually thinning upwards (Fig. 2.10b), and ripple marks and mud cracks are common at this interval (Fig. 2.10d), even salty pseudomorphic crystals as well as chute- and scour-molds are sometimes observed on the basal surface of the thin-bedded salty-dolostone. In addition, the stromatolitic bioherms occur in the middle of the Tuan-2 Member (Fig. 2.10c). Therefore, the Tuan-2 Member should be attributed to the sediments of salty intertidal-supratidal environments.

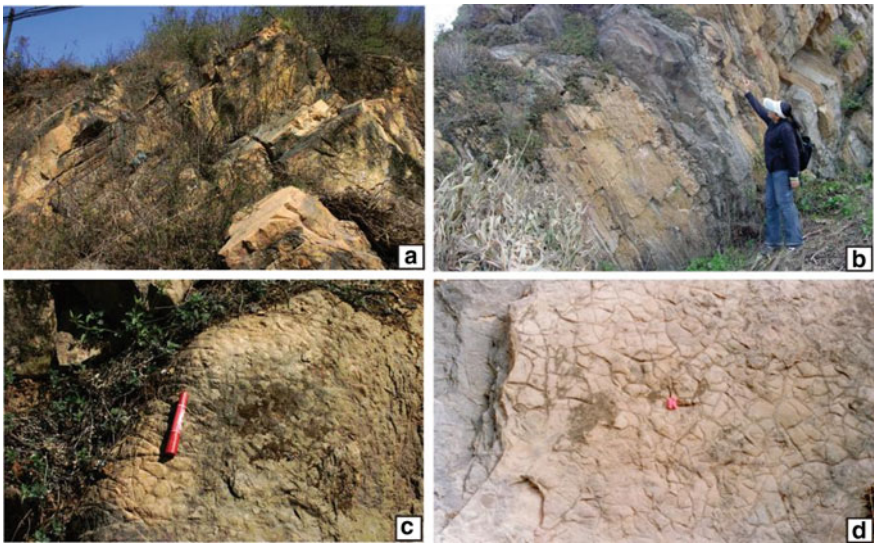


Fig. 2.10 Field photographs showing sedimentary features of the Tuanshanzi formation near Tuanshanzi Village and Dahongyu Valley at Xiaying in Jixian. **a**. The massive and thick-bedded dark-grey ferruginous dolostone in Tuan-1 Member; **b**. the thin-bedded sandy dolostone intercalated by thin-bedded sandstone in the lower Tuan-2 Member; **c**. a stromatolitic bioherm in the middle Tuan-2 Member; **d**. the mud cracks in the upper Tuan-2 Member

The Tuanshanzi Formation exhibits following stratigraphic changes in the YFDZ:

(1) The thickest sequences could be up to a few hundred meters respectively at Jixian, Xinglong and Kuancheng areas (in Jidong-Jibei Depressions).
(2) On the Changping-Huairou submarine uplift (in Jingxi-Xuanlong Depressions) and its west side as well as in Qianxi County (in Jidong Depression), its stratigraphic thickness is significantly thinner, even less than 100 m. In these areas, the Tuan-1 Member is mainly composed of purple ferriferous dolostone, muddy and sand-bearing dolostones and stromatolitic dolostone; while the Tuan-2 Member is chert-stripped dolostone and siliceous stromatolitic dolostone.
(3) In the north of Pinggu (in Jingxi Depression), two layers of ca. 1 m thick K-rich trachyandesite with amygdaloidal structure are intercalated at the upper and middle parts of the Tuanshanzi Formation.
(4) Rhyolitic tuffs are often interbedded within the lower Tuan-1 Member at the Hongqidian (in Jingxi Depression) and Xinglong (in western Jibei Depression), while the interbeds of green K-rich shale occurs at Kuancheng (in central Jibei Depression).

Relatively speaking, the Tuanshanzi Formation is poor in microflora, but the megascopic algal fossils and fossil fragments are abundant in the Tuan-1 Member, especially for the algae of *Tuanshanzia* and *Changchengia* (Fig. 2.11; Zhu and Chen

1995; Yan and Liu 1997), which may mark the first radiation of megascopic multicellular organisms for the early life on the Earth. Regionally, the stromatolitic lithoherms are commonly distributed in the Tuanshanzi Formation mainly for *Gruneria*, *Xiayingella* etc. (Zhu et al. 1978; Tianjin Institute of Geology and Mineral Resources 1980; Zhu and Chen 1992).

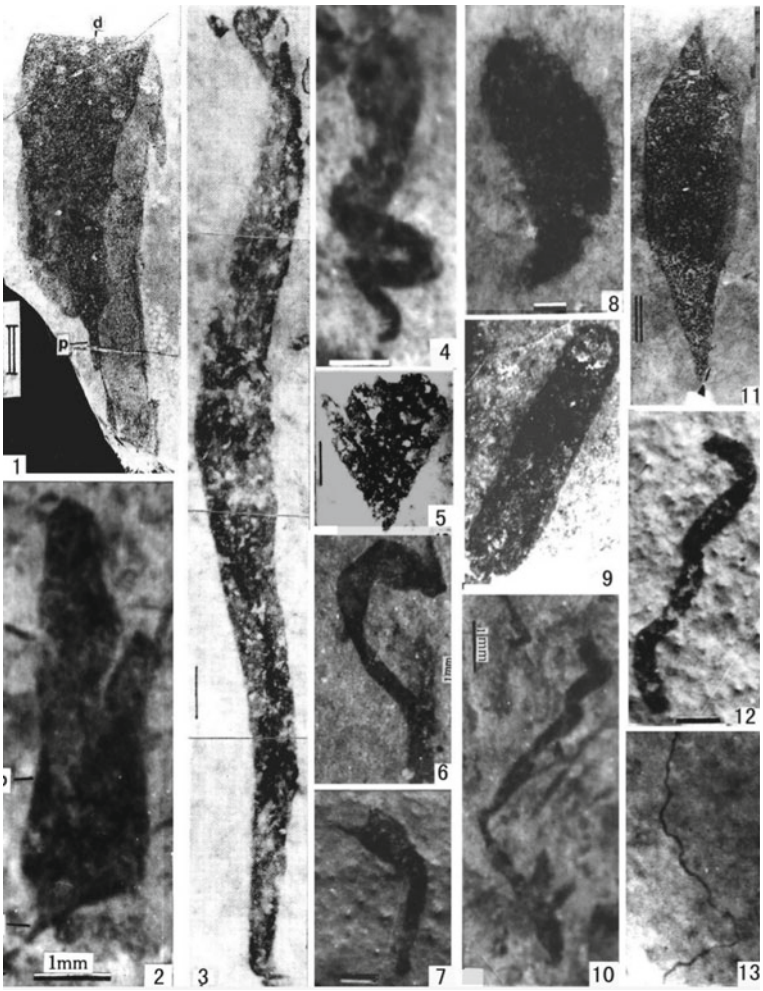


Fig. 2.11 The microphotographs of macroalgal fossils in the Tuanshanzi Formation①. 1, 2. *Changchengia stipitata* (Yan); 3, 4. *Tuanshanzia fasciaria* (Yan); 5. *Eopalmaria pristina* (Yan); 6, 11. *Lanceoforma* sp.; 7. *Longfengshania* sp.?; 8. *Glossophyton* sp.?; 9. *Tawuia* sp. ?; 10. *Vendotaenia* sp.?; 12. *Grypania* sp.; 13. *Tyrasotaenia* sp.?. Scale bars: single lines:1 mm long; double line: 10 mm long. ① Zhu S X, Sun S F, Huang X G. 2006. The multicellular biota from the Mesoproterozoic Changcheng System in Yanshan Mountain. Research Report (in Chinese), slightly modified

The distributional area of Tuanshanzi Formation generally appears as the geomorphological features of low hills, which shows a slightly higher terrain than the distributional area of Chuanlinggou Formation andesitic lava' by Kao et al. (1934) and the "Dahongyu bed" by Shen and Liao (1958).

2.3.1.4 Dahongyu Formation (Pt_2^1d or Chd)

It was named after the "Dahongyu quartzite", and it was renamed as Dahongyu Formation by the First National Conference on Stratigraphy in 1959.

The Dahongyu Formation in Jixian section is 408 m thick and dominated by quartzose sandstone, and intercalated by the volcanic rocks and dolostone (Fig. 2.12). It can be subdivided into three members. The lower member (Da-1 Member) is mainly composed of thick-bedded white quartzose sandstone with the interbeds of purplish-red siltstone, light-green siliceous stripped sandy dolostone, dolomitic quartzose sandstone and bright green K-rich shale. The middle member (Da-2 Member) consist of K-rich mafic volcanic lava (Fig. 2.13b), breccia and agglomerates intercalated by a small amount of quartzose sandstone and tuff. The upper member (Da-3 Member) is the thick-bedded to massive black and white cherty stromatolitic dolostone and chert beds. In above sandstone, the cross beddings, ripple marks and mud cracks are in common. The Dahongyu Formation is conformable contact with the underlying Tuanshanzi Formation in Jixian section and adjacent areas (Fig. 2.13a).

The stromatolites of the Dahongyu Formation are mainly developed in the cherty dolostone of Da-3 Member, most of which are silicified. The main types of stromatolites composed of conical stromatolites, similar to the stromatolitic assemblage in the overlying Gao-1 Member with lager individual and siliceous basic layers, such as *Conophyton dahongyuensis* (Tianjin Institute of Geology and Mineral Resources 1980). In the Dahongyu Formation, microfossils are relatively poor and only found within the muddy interbeds of the Da-1 Member. However, 14 species of 8 genera of Acritarchs have been recently identified (Zhu et al. 1994) and abundant unicellular eukaryotic microfossils have been found in the chert beds of the Da-3 Member.

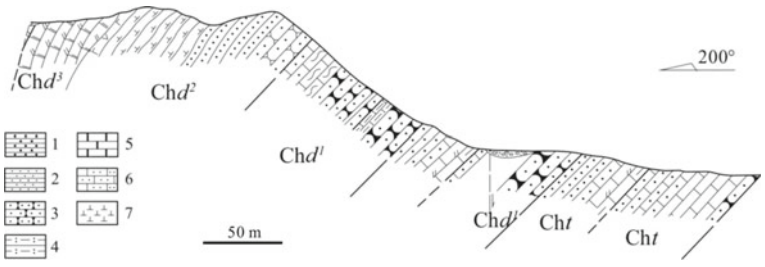


Fig. 2.12 Measured section of the Dahongyu formation at the Dahongyu Valley in the north of Jixian District. Cht. Tuanshanzi formation; Chd. Dahongyu formation. 1. medium-grained sandstone; 2. fine-grained sandstone and siltstone; 3. quartzose sandstone; 4. silty illite shale; 5. dolostone; 6. sandy limestone; 7. K-rich mafic volcanic rocks

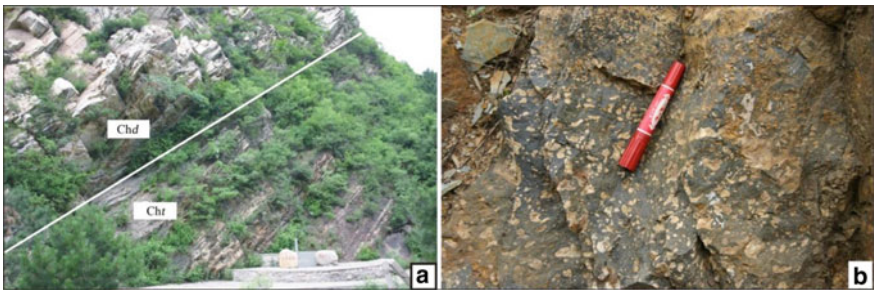


Fig. 2.13 The photographs of sandstone and the volcanic rocks in the Dahongyu formation. **a**. The Dahongyu formation (Chd) contacts conformably with the Tuanshanzi formation (Cht); **b**. the K-rich mafic volcanic rocks with amygdaloidal structure in the Da-2 member

A zircon U–Pb age of 1625 ± 6 Ma was reported at the top of the K-rich volcanic lava in the Da-2 Member, providing age constrain (ca.1600 Ma) for the top of the Dahongyu Formation (Lu and Li 1991). The age is recently confirmed by the new U–Pb SHRIMP ages of 1622 Ma and 1625 Ma for the samples from the same outcrop (Lu et al. 2008; Gao et al. 2008a, b, c).

The regional stratigraphic characteristics of the Dahongyu Formation are as follows:

(1) The volcanic rocks are mainly found at Jixian section and its adjacent area, e.g., Pinggu and Xinglong (Jibei Depression) in the middle segment of YFDZ, and at the local area in the eastern segment of YFDZ, e.g., Luanxian (Jibei Depression).
(2) Similar to the underlying formations, the Dahongyu Formation is thicker in Jixian, Kuancheng and Xinglong (in Jidong-Jibei Depressions) where the stratigraphic thickness can be generally up to several hundred meters (e.g., 450 m thick at Kuancheng). While the thickness of Dahongyu Formation would be significantly thinning on the west of Jixian, e.g., only 81 m at the Mingtombs section and 112 m at Pangjiapu section (in Jingxi Depression).
(3) The lithology of the Dahongyu Formation is consistent in YFDZ, which usually forms mountain terrain with medium altitude.

2.3.2 *Jixianian (Pt_2^2)*

The Jixianian is equivalent to the Mesoproterozoic Calymmian of the International Stratigraphic Chart (1600–1400 Ma; Table 2.2d). It consists of the Gaoyuzhuang, Yangzhuang, Wumishan, Hongshuizhuang and Tieling Formations in ascending order. Except for the Hongshuizhuang Formation which is mainly composed of shale, Jixianian is mainly characterized by carbonate sequence and regional disconformable contacts with the underlying Dahongyu Formation and with the overlying Xiamaling

Formation except for the local conformity at the depocenter of Dahongyu Formation (Table 2.4c).

2.3.2.1 Gaoyuzhuang Formation (Pt_2^2g or Jxg)

It was formerly known as "Gaoyuzhuang limestone" by Kao et al. (1934), and then renamed as Gaoyuzhuang Formation by the 1st National Conference on Stratigraphy in 1959. Since then it have subdivided into four subformations, namely the Guandi, Sangshuan, Zhangjiayu and Huanxiusi Subformations, by Chen et al. (1980), or ten members (Gao-1 to Gao-10 Members) by Zhu et al.[1]. Totally its stratigraphic thickness in Jixian section would be up to 1596 m.

(1) **Guandi Subformation** (i.e., Gao-1 and Gao-2 Members): The ca. 3 m thick quartzose sandstone and 4 m thick greyish-purple sandy shale with mud cracks are at its base interval. Upwardly, it is chert- stripped, -knobby and -stromatolitic dolostones of the intertidal-supratidal subfacies (Fig. 2.14a). It can be subdivided into two members: the lower member (Gao-1 Member) is rich-in siliceous clasts, and the upper member (Gao-2 Member) is rich-in manganese. Totally the subformation is 267 m thick.

(2) **Sangshu'an Subformation** (i.e., Gao-3 Member): Its lower interval is composed of the manganese-rich siltstone or silty-shale of the intertidal-subtidal subfacies (Fig. 2.14b), locally containing small-size manganese ore, and the upper interval is characterized by the thick-bedded manganese-rich limy-dolostones. The subformation is 282 m thick.

(3) **Zhangjiayu Subformation** (i.e., Gao-4 to Gao-8 Members): It is about 700 m thick and mainly composed of dark micritic-dolostone, limy-dolostone and dolomitic-limestone of subtidal subfacies. Knobby-limestone, gliding and molar-tooth structures are often observed (Fig. 2.14c, d). Organic fragments are enriched within the laminated-bedding and sometimes preserved as megascopic algal fossils such as *Grypania* Walter and *Parachuaria* Sun (Du and Tian 1985; Walter et al. 1990; Sun 2006; Sun et al. 2006; Du et al. 2009). The Gaoyuzhuang macrofossil assemblage is reported in this subformation (Zhu et al. 2016).

In this subformation, the greyish-black micritic-dolostone rich-in organic matter can be attributed to over-mature hydrocarbon source rock. The subformation can be further subdivided into six members, i.e., Gao-3 to Gao-8 Members in ascending order.

(4) **Huanxiusi Subformation** (i.e., Gao-9 and Gao-10 Members): The subformation is 347 m thick. It has two members. The lower member (Gao-9 Member) consists of the medium- to thick-bedded coarse-crystal dolomitic limestone, with bituminous and bituminous brecciated dolostones at the base.

[1] Zhu S X, Sun S F, Sun L X, Liu H. 2009. Mesoproterozoic carbonate palaeontological study. Tianjin: Tianjin Institute of Geology and Mineral Resources (in Chinese).

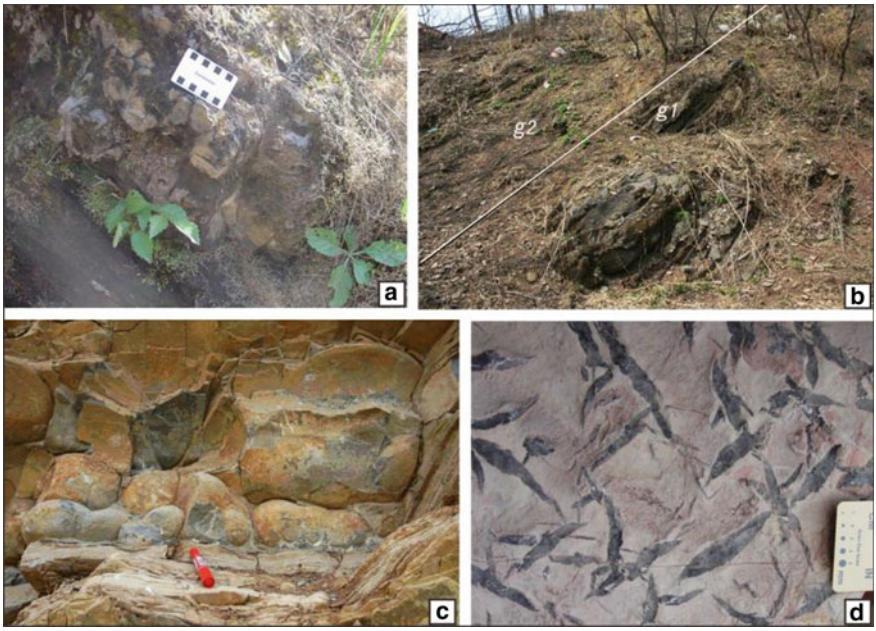


Fig. 2.14 Field photographs of the Gaoyuzhuang formation in Jixian section. **a**. Silicic stromatolite dolostone in the Guandi subformation; **b**. the boundary between the chert-stripped dolostone (g1) at the top of the Guandi subformation and manganese silty shale (g2) at the base of the Shangshuan subformation; **c**. knobby-limestone in the lower interval of the Zhangjiayu subformation; **d**. the "molar tooth structure" in the upper interval of the Zhangjiayu subformation

While the upper member (Gao-10 Member) is thick cherty coarse-crystal dolostone with large concentric- and interlocking-nodules and multiple layers of karstic-breccia.

Based on regional geological observation and isopach map, the distribution of Gaoyuzhuang Formation is as follows (Fig. 2.15):

(1) The stratigraphic thickness of Gaoyuzhuang Formation varies between 80 and 1990 m with a depocenter at the Jixian-Qianxi (in Jidong Depression), where its stratigraphic thickness would be more than 1900 m (at Qianxi).
(2) While the stratigraphic thickness is gradually thinning along the SE-direction and tending to zero line towards Shanhaiguan Uplift as well as along NW-direction up to the stratigraphic denudation boundary towards Chongli-Longhua Faulted-Belt along the northern boundary of YFDZ.
(3) The stratigraphic isopach shows a NW-striking in the west segment, a EW-striking in the middle segment and a NE-striking in the east segment of YFDZ.
(4) In comparison with the distribution of other Changchengian formations, the Gaoyuzhuang Formation not only has larger distributional range, but also there is limestone sedimentation within the middle interval of Zhangjiayu Subformation,

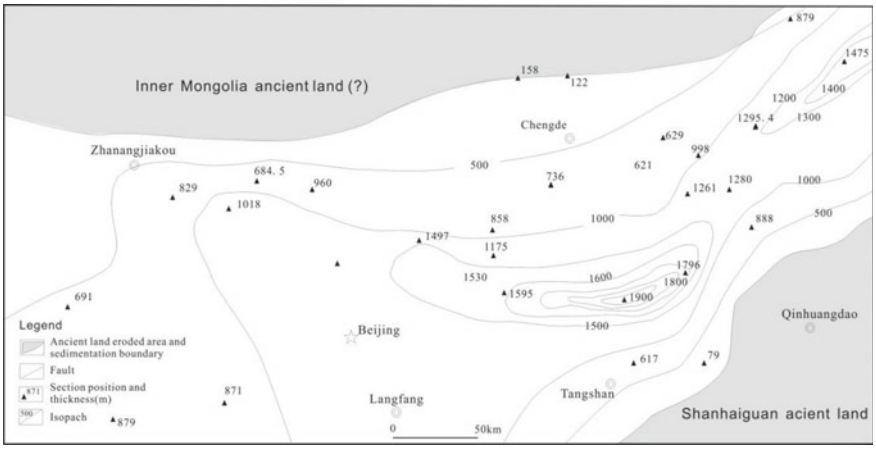


Fig. 2.15 Isopach map of the Jixianian Gaoyuzhuang formation in YFDZ

even both knobby-limestone of basin facies and slump structures of clinothem are observed.

The dolomitic strata of Gaoyuzhuang Formation often appear as mountain terrain with medium elevation.

2.3.2.2 Yangzhuang Formation (Pt_2^2y or Jxy)

It was originated from the "Yangzhuang shale" named by Kao et al. (1934) after the name of Yangzhuang Village in the north of Jixian. The Yangzhuang Formation is characterized by a striking purplish-red or brick-red silty dolostone (Fig. 2.16).

The Yangzhuang Formation can be subdivided into three members. In addition to the purplish-red and greyish-white muddy dolostones (so called "soft dolostones") in Yang-2 Member, its upper and lower members (Yang-1 and Yang-3 Menbers) are interbedded with cherty-nodule and stripped stromatolitic dolostones, dark-grey bituminous dolostone and siliceous dolostone (so called "hard dolostones") so as to become the rhythmic layering of soft- and hard-dolostones in Jixian section.

Based on regional geological observation and stratigraphic isopach map, the distributional characteristics of Yangzhuang Formation are as follows (Fig. 2.17):

(1) The stratigraphic thickness of the Yangzhuang Formation varies from 12 to 770 m. Its depocenter is also located at the Jixian-Qianxi in Jidong Depression with the thickness of up to 500 m and more.
(2) Its thickness is thinning from a few hundred meters to zero meter towards NE- and NWW-directions so that its isopach distribution along NE- and NWW-strikes respectively in the east and west segments of YFDZ, which was constrained by the Shanhaiguan and Inner Mongolia ancient lands (Fig. 2.17).

Fig. 2.16 Outcrop photograph of the purplish-red and greyish-white muddy dolostones in Yangzhuang formation at Jixian section

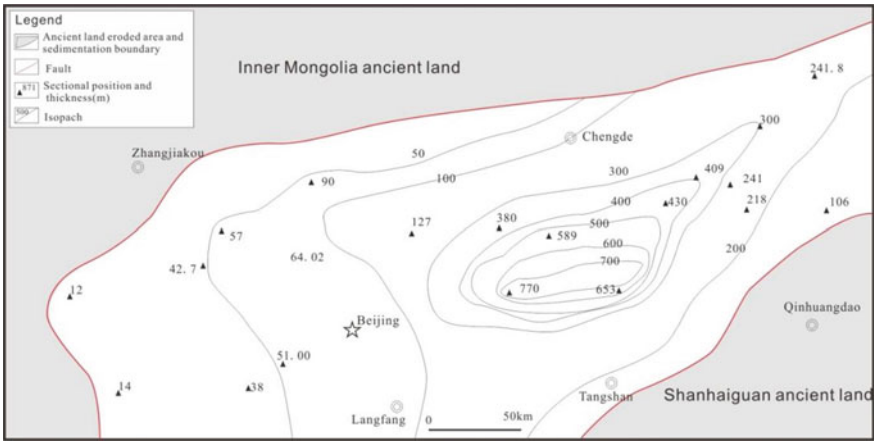


Fig. 2.17 Isopach map of the Jixianian Yangzhuang formation in YFDZ

(3) In the west segment of YFDZ, its thickness is mostly less than 100 m on the west of Miyun (in Jingxi Depression), and it would be thinner further westwards, even the Yangzhuang Formation was no longer deposited on the west of Xuanhua-Yangyuan (in the west of Xuanlong Depression).

(4) The purplish-red strata of Yangzhuang Formation are mainly distributed around the Jixian and Qianxi (in Jidong Depression) as well as Kuangcheng (in Jibei Depression) and Xinglong (in Xuanlong Depression) from east to west in the YFDZ, while the purplish-red strata disappear in the far-east and far-west

segments of YFDZ so that it is hard to distinguish the Yangzhuang Formation from its overlying Wumishan Formation.

(5) The Yangzhuang Formation has conformable contact with the underlying Gaoyuzhuang Formation, but unconformable contact in some areas, e.g., Luanxian (in Jibei Depression).

2.3.2.3 Wumishan Formation (Pt_2^2w or Jxw)

It was named after "Wumishan limestone" of Kao et al. (1934). The Wumishan Formation is composed of various dolostones and contains following characteristics:

(1) The Wumishan Formation is huge-thick up to 3416 m so as to be the thickest lithostratigraphic unit of the Meso-Neoproterozoic sequence in Jixian stratotype section.

(2) Its carbonate rocks are predominated by dolomitic microbiolites accounting for 80–90% of the total thickness for the formation. The microbiolites often show as brown pisiform, sphaeroideous and spotted laminations which are stringed into the basic rhythmic layer of some stromatolites.

(3) The sedimentary rhythms are extremely well developed. In fact, the huge-thick Wumishan Formation is superposed by sedimentary rhythms and sedimentary cycles with different orders (Fig. 2.18), among which, the most basic sedimentary rhythmic layer comprises five rhythmic units (Units A to E) in ascending order (Fig. 2.19):

Fig. 2.18 Photograph of rhythmic dolostones in the Wumishan formation near the Sangyuan Village in the north of Jixian district

Fig. 2.19 Photograph shows five rhythmic units of a basic rhythmic layering in the Wumishan formation near the western Wangzhuang Village in the north segment of Jixian section. Units A to E constitute one basic sedimentary rhythmic layering

① Unit A (basal zone), the sandy muddy or micrite dolostone with mud cracks and salty pseudomorphic crystals of upper supratidal subfacies;
② Unit B (lower zone), lamellated siliceous-stripped microcrystal dolostone of intertidal subfacies, containing stratiform and arched stromatolitic types of microbolites, commonly known as "algal-mat dolostone" or "lower algal-mat layer";
③ Unit C (medium zone), thick-bedded to massive dolosparlite of subtidal subfacies, containing microbiolite of cotted and conical stromatolites.
④ Unit D (upper zone), lamellated siliceous-stripped microcrystal dolostone of intertidal subfacies, containing stratiform and arched stromatolitic types of microbolites, which is referred to the lower part of "upper algal-mat layer";
⑤ Unit E (top zone), light siliceous-stripped microcrystal dolostone of supratidal subfacies (freshwater leached zone), also containing light silicified stratiform and arched stromatolite, commonly attributed to the upper part of "upper algal-mat zone".

Based on incomplete statistics, it is indicated that the Wumishan Formation in Jixian section is totally composed of more than 400 sedimentary rhythms. According to the assemblage of the basic rhythmic units and different sedimentary cycles, the Wumishan Formation can be further subdivided into four subformations with eight members. The basic characteristics of these subformations are as follows.

(1) **Luozhaung Subformation** (i.e., Wu-1 and Wu-2 Members): It is totally 860 m thick. The lower interval is characterized by the rhythmic layers of grey thromboltic-dolostone, algal-mat dolostone and dolomitic shale; the middle

interval comprises the rhythmic layer of stromatolitic dolostone, algal-mat dolostone and dolomicrite; the upper interval consists of the rhythmic layer of algal-mat dolostone, dolomicrite, silty muddy dolostone and dolomitic shale; the top interval contains dolomitic breccia and silicalite. The subformation is rich-in ministromatolites *Pseudogymnosolen* and *Scyphus*, etc.

(2) **Mopanyu Subformation** (i.e., Wu-3 and Wu-4 Members): With stratigraphic thickness of 766 m, the Subformation consists mainly of thick-bedded to massive thrombolite-dolostone, stromatolitic- dolostone, chert-thrombolite or banded micritic-dolostone, algal-mat dolostone and dolomitic shale. Generally, there is a layer of siliceous crust or red-bed on the top of each rhythm. The subformation is characterized by the big to huge conical stromatolites, such as *Conophyton lituum, Jacutophyton furcatum,* etc.

(3) **Ershilipu Subformation** (i.e., Wu-5 and Wu-6 Members): It is 963 m thick. The basal interval is the purplish-red sandy muddy dolostone, dolomitic sandstone and sparite-dolorudite. The lower interval consists of the rhythmic layer of the greyish-white dolomicrite, algal-mat dolostone and dolomitic shale intercalated with oolitic silicalite and sparite-dolorudite. The upper interval is the rhythmic layer of the grey massive thrombolite-dolostone, algal-mat dolostone, stromatolitic dolostone, muddy dolostone and dolomitic shale. The subformation contains abundant conical and columnar types of stromatolites, such as *Conophyton lituum*, *C. shanpoulingense*, *Colonnella* cf. *discreta*, etc.

(4) **Shanpoling Subformation** (i.e., Wu-7 and Wu-8 Members): It is 827 m thick. The basal interval is grey dolomitic quartzose sandstone. The lower interval is mainly composed of greyish-while lime-dolostone intercalated by chert-stripped dolomicrite. The upper interval is light-grey chert-banded limy-dolostone, microbial mat dolostone and thick-bedded stromatolitic dolostone. The stromatolites are abundant in the subformation, representing respectively by a few columnar *Colonnella* near the bottom, the conical *Conophyton* and *Jacutophyton* in the middle, and the medium-sized columnar *Pseudochihisienella inconspicua, Wumishanella changzilingensis* and *Paraconophyton inconspicum* at the top. Glauconite infillings in the spaces between of stromatolitic columns are common at top of the subformation.

Regionally, the variation of stratigraphic thickness and lithofacies in Wumishan Formation are as follows:

(1) The total stratigraphic thickness of the Wumishan Formation varies from 650 m to 3330 m (Fig. 2.20). Its thickest one is up to 3368 m at Qinglong (i.e., in Jidong Depression).

(2) In the east segment of YFDZ, its isopach line appears as NE-striking extension with the maximal depocenter distributed around Jixian (in Jidong Depression), where the Wumishan Formation thicker than 3000 m and the stratigraphic thickness is gradually thinning from 910 to 43 m along SE-direction from the Shanhaiguan-Tangshan towards the Shanhaiguan ancient land.

(3) In the west segment of YFDZ, its isopach line appears as EW-striking extension, the stratigraphic thickness is also gradually thinning along W-direction, even

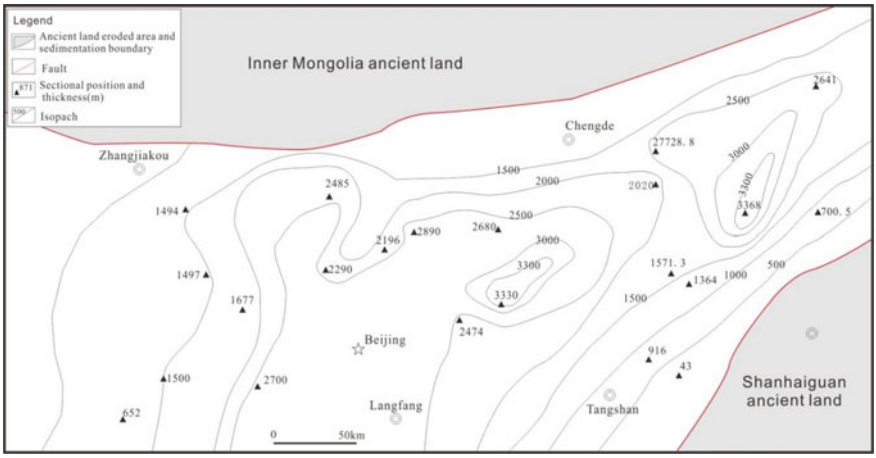


Fig. 2.20 Isopach map of the Jixianian Wumishan formation in YFDZ

reaching a zero isopach line on the west of Xuanhua-Yangyuan adjacent to the Taihang ancient land (i.e., in the Xuanlong-Jingxi Depressions).

(4) In the northern marginal area of YFDZ, the variation of stratigraphic thickness is still uncertain, probably due to denudation and the influence of Chongli-Longhua palaeo-faults.

(5) As a whole, the isopach map of Wumishan Formation shows a palaeo-structural framework of two depressions with larger settlement range and two uplifts with smaller settlement range from west to east in YFDZ, which were alternately distributed probably due to the superposition of the NE-trending faulted-depressions on the NW-trending faulted-depressions. Among both depressions, one depocenter is at Qinglong with the maxima stratigraphic thickness of 3368 m, another at Jixian with maxima thickness of 3330 m.

The Wumishan Formation has conformably contact with the underlying Yangzhuang Formation.

2.3.2.4 Hongshuizhang Formation (Pt_2^2h or Jxh)

It was renamed from the "Hongshuizhuang shale" (Kao et al. 1934) after the name of the Hongshuizhuang Village in the north of Jixian District.

The Hongshuizhuang Formation is mainly composed of black, dark-grey and yellowish-green shales with the stratigraphic thickness is 131 m in the Jixian section, and can be subdivided into two members. The lower member (Hong-1 Member) is dominated by yellowish-green thin-bedded muddy dolostone intercalated by dark-grey thin mudstone rich-in organic matter. The upper member (Hong-2 Member) consists mainly of black, grey and yellowish-green shales with simatic- and pyrite-nodules and lenticular dolostone (Fig. 2.21).

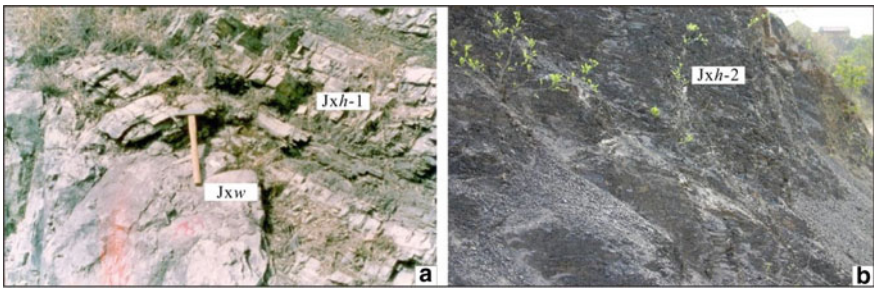


Fig. 2.21 The photographs show the lithology of the Jixianian Hongshuizhuang formation in the Jixian section near the Hongshuizhuang Village in north of Jixian District. **a**. The Hong-1 Member (Jxh-1) composed of thin bedded muddy dolostone with interbeds of black shale and its conformable contact with underlying Wumishan formation (Jxw); **b**. the Nong-2 member mainly consisting of black shale (Jxh-2)

Based on the analyses of stratigraphic isopach map, the Hongshuizhuang Formation shows following variations (Fig. 2.22):

(1) The extensional orientation of its isopach lines is along the NEE-direction in the east Segment of YFDZ and the NWW-direction in the west segment, showing the stratigraphic thickness varies from 40 to 140 m and a depocenter distributed from Kuancheng (in Jibei Depression) through Jixian to Qinglong (in Jidong Depression) with maximal thickness of 130–140 m at Qinglong.
(2) Owing to the constraint of Shanhaiguan ancient land, the stratigraphic thickness tends to vary from 130 to 0 m along the SE-direction from Shanhaiguan to Tangshan (in Jidong Depression) in the east segment.

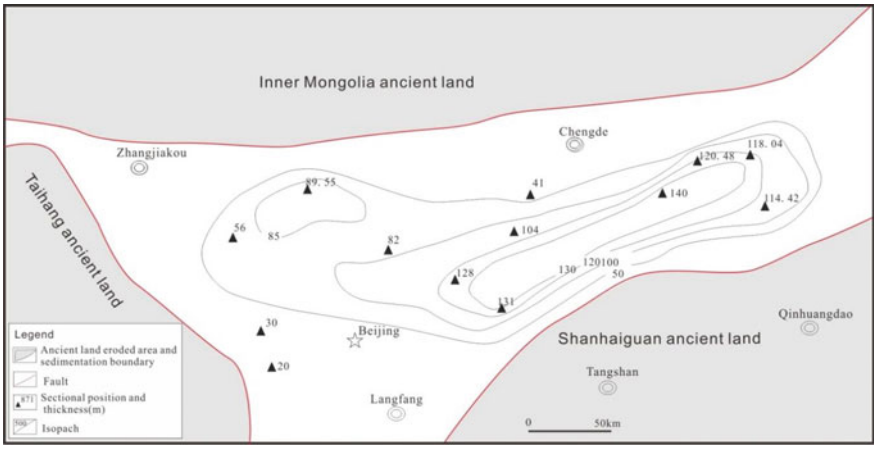


Fig. 2.22 Isopach map of the Jixian Hongshuizhuang formation in YFDZ

(3) In the west segment, the stratigraphic thickness would thin out westwards with the thickness from 130 to 0 m, even it has been denuded out on the west of Xuanhua-Yangyuan (in Xuanlong Depression) obviously due to the control of Taihang ancient land.
(4) Along the northern border of YFDZ, the stratigraphic variation would be uncertain, probably showing a zero isopach line, due to the influences of denudation and the Chongli-Longhua palaeo-faults.

The dark-grey muddy dolostone of the lower Hongshuizhuang Formation directly overlap on the underlying stromatolitic dolostone of the Wumishan Formation with a disconformable contact of mutational change.

2.3.2.5 Tieling Formation (Pt_2^2t or Jxt)

It is mainly a carbonate sequence. Kao et al. (1934) had originally called it the "Tieling limestone" after the name of Tieling Village in the north of Jixian District. In view of the lithological variation between its two stratigraphic intervals, Chen et al.(1980) presented a clear depositional hiatus and the reversal of palaeomagnetic poles. Accordingly, the Tieling Formation has been subdivided into two subformations or members, i.e., the Daizhuangzi and Laohuding Subformations (or Tie-1 and Tie-2 Members) in ascending order.

(1) **Daizhuangzi Subformation** (i.e., Tie-1 Member): With total stratigraphic thickness of 153 m, its basal interval is marked by the greyish-white thin-bedded or lenticular quartzose sandstone, and the lower interval consists of brown manganiferous stromatolitic intradolostone and manganiferous dolomicrite with rudaceous and sandy clasts intercalated by thin greyish-green shale. The upper interval is characterized by the variegated shales intercalated by manganiferous dolostone. This sub-Formation (Tie-1 Member) is conformably in contact with the underlying Hongshuizhuang formation (Fig. 2.23).

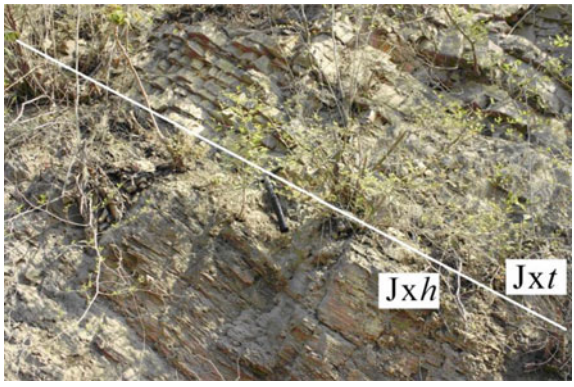


Fig. 2.23 The conformable contact between Tieling formation (Jxt) and Hongshuizhuang Formation (Jxh) in the north of Jixian District

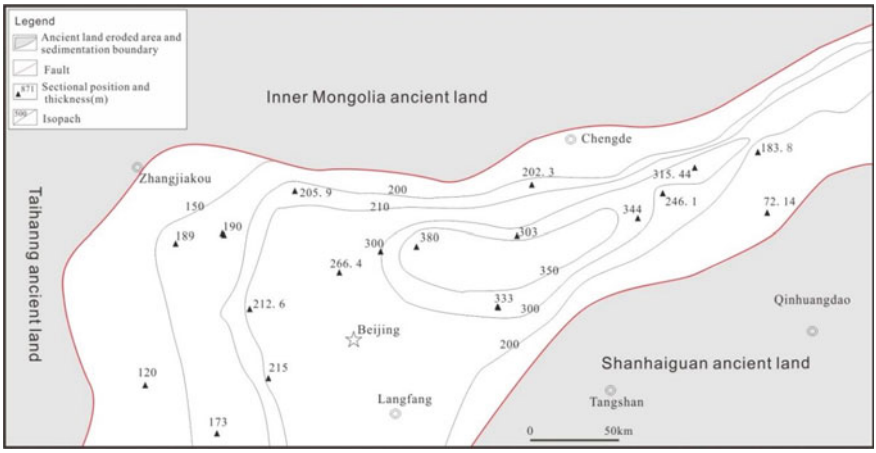


Fig. 2.24 Isopach map of the Jixian Tieling formation in YFDZ

(2) **Laohuding Subformation** (i.e., Tie-2 Member): It is a limestone sequence with a thickness of 181 m in the Jixian section. Its lower interval mainly consists of lime-dolostone, dolomitic limestone and wormkalk-calcirudite, and the upper interval is almost composed of stromatolitic limestone except for the muddy and dolomitic limestone at its top.

Based on the analyses of stratigraphic isopach map, the Tieling Formation shows following variations (Fig. 2.24):

(1) The stratigraphic thickness of Tieling Formation varies from 120 to 380 m. Its depocenter with thickness of 330–380 m is located in the Miyun-Kuancheng-Jixian area, where the maximum thickness is up to 380 m in Miyun County (in Jingxi-Jibei-Jidong Depressions; Fig. 2.24).
(2) The distribution range of Tieling Formation would be similar to that of the underlying Hongshuizhuang Formation (cf. Figures 2.22 and 2.24). But the Tieling Formation is completely absent due to the long-term erosion before the deposition of the overlying Luotuoling Formation on the east of Zunhua (in Xuanlong Depression).
(3) In the east segment of YFDZ, its isopach line shows a NE-Orientational extension, and the stratigraphic thickness is thinning SE-towards from 300 m to zero m along the Shanhaiguan to Tangshan (in Jidong Depression) because of the constraint of Shanhaiguan ancient land.
(4) In the west segment, the isopach line extends along EW-direction, the thickness gradually thins out westwards, and it would tend to zero line on the west of Xuanhua-Yangyuan (in Xuanlong Depression) due to the influence of the Taihang ancient land.

2.3.3 *Xiamaling Formation (Pt_2^3x)*

The Xiamaling Formation was named after the "Xiamaling shale" reported by Ye (1920) based on the outcrop section near Xiamaling Village in the Mentougou, Beijing (in Jingxi Depression).

The Xiamaling Formation in the Jixian section is a suite of fine-grained clastic sediments with the largest thickness of 168 m at Luotouling in Jixian (Fig. 2.25). At its basal interval, granule conglomerates can be seen. The lower interval is mainly composed of grey or greyish-purple coarse sandstone, greyish-black silty-shale and siltstone commonly with cross-beddings and ripple marks. The upper interval is predominated by the greyish-black and yellowish-green silty-shale intercalated with fine-grained siltstone. The formation is in disconformable contact with the underlying Tieling Formation.

According to the field investigation and isopach map analysis, the stratigraphic characteristics of the Xiamaling Formation are summarized as follows (Fig. 2.26).

(1) The stratigraphic thickness of Xiamaling Formation varies generally from 100 to 537 m. Its distributional orientation is nearly EW-direction, which is controlled by the Shanhaiguan ancient land on the Southeast side, the Inner Mongolia ancient land on the Northwest-North side, and the Taihang ancient land on the West side (Fig. 2.26).
(2) The isopach center/depocenter is located geographically at the Zhaojiashan section at Huailai (in Xuanlong Depression) in west segment of YFDZ, where the maximum stratigraphic thickness of Xiamaling Formation is up to 545 m (Fig. 2.26).

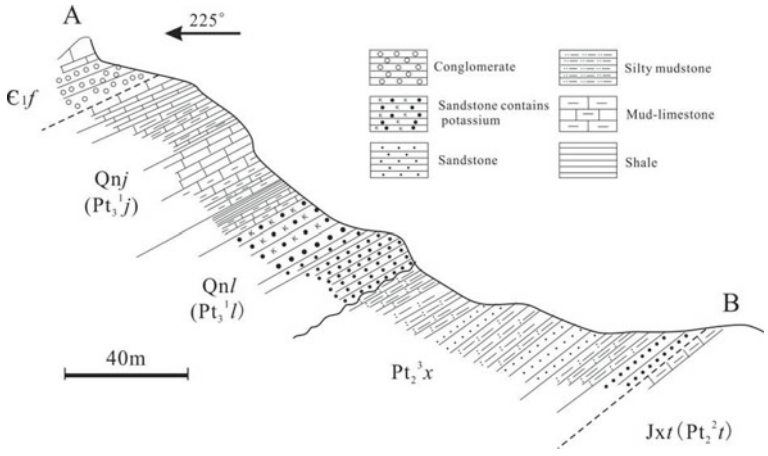


Fig. 2.25 the measured Luotuoling to Laoguading geological cross-section in Jixian. $Pt_2^2 t$. Jixianian Tieling formation; $Pt_2^3 x$. Xiamaling Formation; $Pt_3^1 l$. Qingbaikouan Luotuoling Formation; $Pt_3^1 j$. Jing'eryu Formation; $\epsilon_1 f$. Lower Cambrian Fujunshan formation

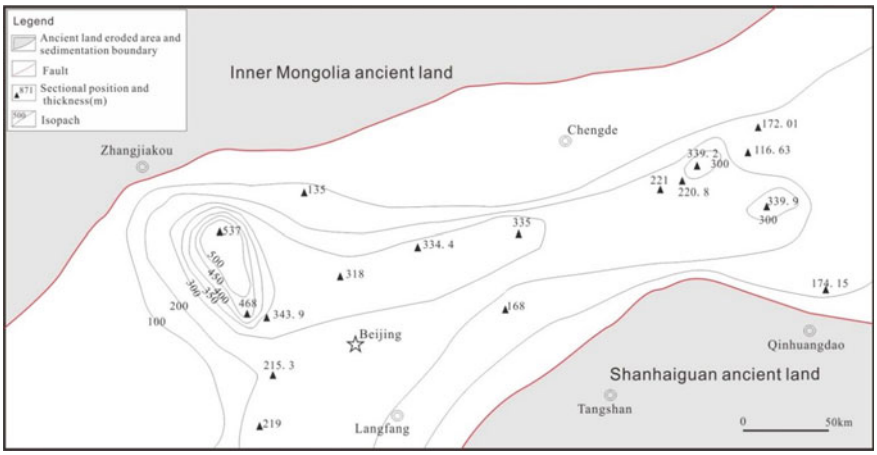


Fig. 2.26 Isopach map of the Xiamaling formation in the YFDZ

(3) The Xiamaling Formation in Xuanlong Depression can be subdivided into four members in ascending order: ① Xia-1 Member ($Pt_2^3x^1$) sandy shale; ② Xia-2 Member ($Pt_2^3x^2$) greyish-green shale; ③ Xia-3 Member ($Pt_2^3x^3$) black shale; and ④ Xia-4 Member ($Pt_2^3x^4$) variegated shale intercalated with marl (Fig. 2.27).

(4) In comparison, the Xiamaling Formation at Jixian section in Jidong Depression (the east segment of YFDZ) is only equivalent to the Xia-1 Member plus the basal interval of Xia-2 Member of the Zhaojiashan section in Xuanlong Depression. At Kuancheng section in Jibei Depression (the middle segment of YFDZ), the Xiamaling Formation only represents part of the Xia-1 Member of the Zhaojiashan section.

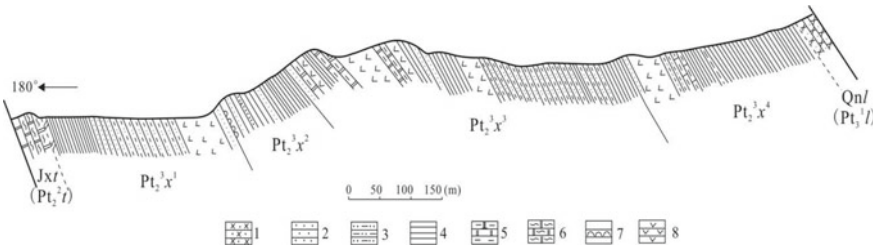


Fig. 2.27 The measured Zhaojiashan cross-section of Xiamaling formation (Pt_3^1x) at Huailai County in west segment of YFDZ (Du and Li 1980, modified). 1. Quartzose sandstone; 2. sandstone; 3. muddy siltstone; 4. shale; 5. muddy dolostone; 6. siliceous banded and striped dolostone; 7. sandstone with iron nodules. Pt_2^2t. Tieling formation; Pt_2^3x. Xiamaling formation; Pt_3^1l. Luotuoling formation

2.3.4 *Qingbaikouan (Pt_3^1 or Qn)*

The Qingbaikouan is named after the original "Qingbaikou Group" from Kao et al. (1934), and includes two Formations, i.e., Luotuoling and Jing'eryu Formations (Table 2.4).

2.3.4.1 Luotuoling Formation (Pt_3^1l or Qn*l*)

It unconformably overlays the Xiamaling Formation (Fig. 2.28). On a regional scale, the stratigraphic contact relationship seems to be a generally micro-angular unconformity. In Jixian stratotype section, the Luotuoling Formation is mainly composed of siliciclastic rocks with stratigraphic thickness of 118 m. It can be subdivided into two members in ascending order:

(1) **Luo-1 Member**: It consists mainly of a sandstone interval which includes:

① Yellowish-brown medium- to thick-bedded, bebbly feldspathic quartzose sandstone and lenticular granule conglomerate as the basal interval.
② Feldsparthic quartzose sandstone intercalated by greyish-yellow muddy siltstone as the lower interval, in which the large tabular-, wedge-, chevron- and herringbone-cross-beddings, ripple mark and mud cracks on bedding surface of muddy siltstone are well-developed.

Fig. 2.28 The micro-angular unconformable contact between Luotuoling (Qnl) and Xiamaling formations (Pt_3^1x) at the Xiazhuangzi Village in the north of Jixian district). Pt_2^3x. shales at the top of the Xiamaling formation; Qn*l* (Pt_3^1l). basal conglomerate and bebbly feldsparthic coarse sandstone of the Luotuoling formation

③ Greyish-white thick-bedded to massive glauconitic quartzose sandstone intercalated by light-grey medium- to thin-bedded quartzose sandstone and grey shaly silty-shale as the middle interval.
④ Greyish-white thick-bedded to massive quartzose sandstone intercalated by greyish-green silty-shale as the upper interval, containing megascopic carbonaceous fossils represented by *Longfengshania* (Du and Tian 1985; Du et al. 2009) and other microscopic acritarchs.

(2) **Luo-2 Member**: It is characterized by the variegated shale consisting mainly of greyish purple, greyish-black and greyish-green shales.

2.3.4.2 Jing'eryu Formation (Pt_3^1j or Qn*j*)

It is equivalent to the lower part of the original "Jing'eryu limestone" (Kao et al. 1934).

The Jing'eryu Formation in Jixian section is mainly a set of marine carbonate deposits with a total thickness of 112 m. Its lower interval consists of grey or greyish-purple thin-bedded marl with a basal granule- and glauconitic coarse sandstone of 10–20 cm thick. The middle interval comprises grey and egg-cyanic thick-bedded micritic limestone intercalated by marl. The upper interval is characterized by grey thin-bedded muddy and limy dolostone, dolomitic limestone intercalated by purplish-red shale.

The stratigraphic contact between the Jing'eryu Formation and its underlying Luotuoling Formation is generally regarded as conformable, but it could not be excluded that there still is short-term depositional discontinuity between both formations according to the presence of a thin-bedded glauconitic bebbly coarse sandstone on the contact plane (Fig. 2.29). The Jing'eryu Formation is overlain by the Lower Cambrian Fujunshan Formation with a micro-angular unconformity that marks the famous "Jixian Movement" (Fig. 2.30).

A few of megascopic carbonaceous compressions have been found in the greyish-green thin limestone near the base of the Jing'eryu Formation at the Dongjingyu Village in Jixian, such as *Chuaria circularis* and *Shouhsienia shouhsiensis* (Zhu et al. 1994).

At the north ridge to the west of Jing'eryu Village, the Lower Cambrian Fujunshan Formation is composed of ① brow to red palaeo-weathering crust, ② breccia-bearing coarse sandstone or carbonate-cemented breccia, ③ bituminous oncolitic limestone, and ④ massive leopard limestone in ascending order. The leopard limestone contains trilobites represented by *Redlichia chinensis* Walcott and *Megapalaeolenus fengyangensis* Chu.

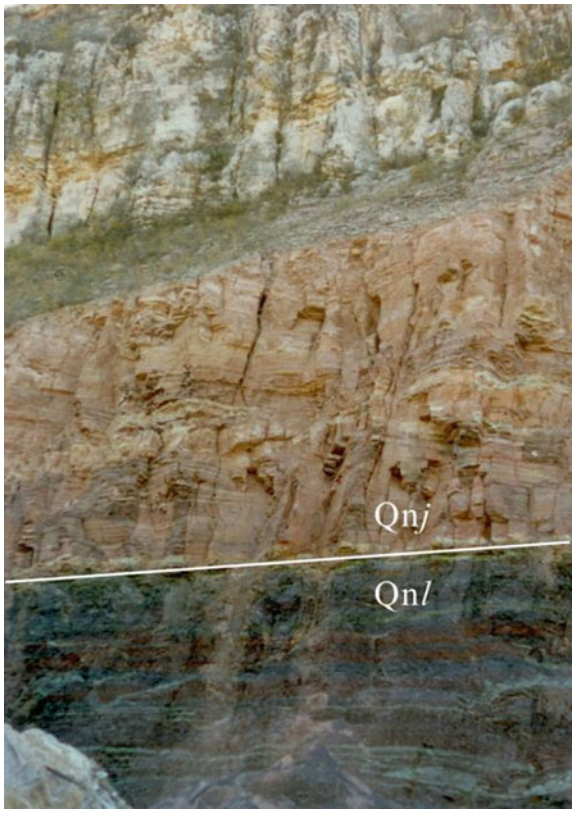


Fig. 2.29 The Jing'eryu formation (Qn*j*) and its contact relationship with the underlying Luotuoling formation (Qn*l*)

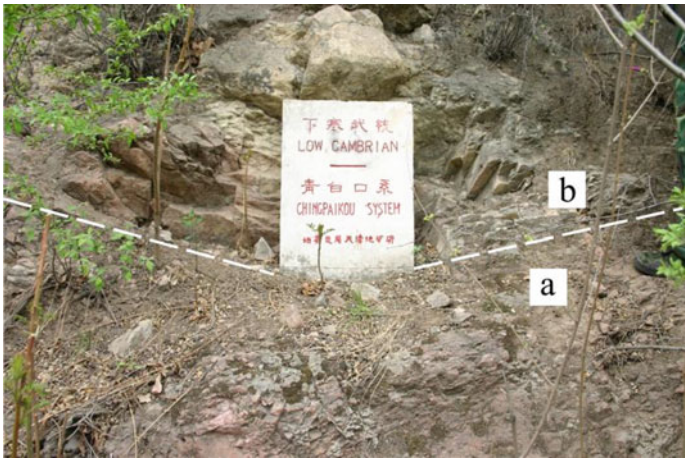


Fig. 2.30 The lower Cambrian Fujunshan formation (**b**) and its underlying Jing'eryu formation (**a**) at the Beiling in Jixian District. The white dash-line shows the micro-angular unconformity

2.4 Geochronology and Chronostratigraphy

In comparison with the "Chinses Stratigraphic Chart 2001" (Table 2.4b; China Commission on Stratigraphy 2001), the "Chinese Stratigraphic Chart 2013" (Table 2.4b) has been updated to reflect the advances on the Meso-Neoproterozoic geochronology and lithostratigraphy in the YFDZ during the past decades, which are summarized as follows.

2.4.1 Stratigraphic Boundary and Dating Between the Xiamaling Formation and Qingbaikouan

Previous stratigraphic studies indicated that the Xiamaling Formation in YFDZ is bounded by the unconformities with both underlying Tieling and overlying Luotuoling Formations and a geological age about 1000–900 Ma. Therefore, the Xiamaling Formation used to be referred to the base of the Neoproterozoic Qingbaikouan. The previous dating includes the following date:

(1) A K–Ar age of 1050 Ma from the glauconite in the upper Tieling Formation (Zhong 1977);
(2) An age of 956 Ma from the illitic shale in the Xiamaling Formation (Yu and Zhang 1984);
(3) A Pb-Pb age of 879 ± 18 Ma from the lower Xiamaling Formation at Xishan, west Beijing (Qiao 1976).

However, a number of new dating results have been published from the Xiamaling Formation in recent dozen years, which are summarized as follows.

(1) The SHRIMP zircon U–Pb ages of the bentonitic beds within the Xia-3 Member, i.e., 1368 ± 12 Ma and 1370 ± 11 Ma at western Beijing in the Jingxi Depression (Gao et al. 2007a, b), and 1366 ± 9 Ma at the Zhaojiashan section of the Xuanlong Depression (Gao et al. 2008a, b, 2009).
(2) The SHRIMP zircon U–Pb ages 1379 ± 12 Ma and 1380 ± 36 Ma of K-bentonite from Xiamaling Formation in above two locations (Su et al. 2008).
(3) The SIMS baddeleyte U–Pb ages of 1327.5 ± 2.4 Ma and 1327.3 ± 2.3 Ma for the gabbro-diabase sills intercalated within the Xiamaling Formation at Kuancheng and Pingquan in Jibei Depression[2](cf. Chap. 10).
(4) The SHRIMP zircon U–Pb age of 1320 ± 6 Ma for the diabase sill of the Xiamaling Formation at the Kuancheng in Jibei Depression (Li et al. 2009).
(5) A SHRIMP zircon U–Pb age of 1372 ± 18 Ma of the K-bentonite in the Xiamaling Formation at the border area between Jibei and Liaoxi Depressions was also reported by Su et al. (2010).

[2] Wang T G, Zhong N N, Zhu S X, et al. 2009. Petroleum prospectivity and reginal play predication of the lower stratigraphic assemblage in North China Platform (internal report). Beijing: China University of Petroleum-Beijing.

(6) A SHRIMP zircon U–Pb age of 1437 ± 21 Ma of the K-bentonites in the underlying Tieling Formation is dated (Su et al. 2010).

To sum up, the above geochronologic results of Xiamaling Formation are on the basis of isotopic dating using different minerals such as baddeleyte, zircon and bentonite, and all the ages just in between 1400 and 1320 Ma. According to this duration of age, therefore, the Xiamaling Formation should be attributed to the Middle Mesoproterzoic, rather than the Early Neoproterozoic Qingbaikouan as considered previously. If the glauconite K–Ar age of ca. 1000 Ma or 900 Ma from the basal Luotuoling Formation is reliable (Yu and Zhang 1984; Qiao and Gao 1997), and then it should have a long-term stratigraphic break of 320–420 Ma between the Mesoproterozoic Xiamaling and the Neoproterozoic Luotuoling Formations.

2.4.2 Stratigraphic Boundary Between the Changchengian and Jixianian

As shown in Table 2.4a and b, the boundary between the Changchengian and Jixianian was originally designated at the stratigraphic boundary between the Gaoyuzhuang and Yangzhuang Formations (Kao et al. 1934; China Commission on Stratigraphy 2001), Because Kao et al. (1934) considered that the stratigraphic contact relationship between the Gaoyuzhuang and overlying Yangzhuang Formations is paraconformable and the contact between the Gaoyuzhuang and underlaying Dahongyu Formations is conformable at Jixian stratotype section.

In the early 1950s, Shen and Liao first pointed out that the Gaoyuzhuang Formation has a disconformable contact with the underlying Dahongyu Formation, and a conformable contact with the overlying Yangzhuang Formation. Accordingly, they initially proposed that Gaoyuzhuang Formation should be assigned to the Jixianian in the stead of Changchengian (Shen and Liao 1958).

However, the above significant point of view did not cause wide-spread concern. In view of its importance, the present author has focused on the stratigraphic contact relationship, and carried a review and regional reinvestigation. The results of new observation are emphasized as follows.

2.4.2.1 The Contact Relationship of Gaoyuzhuang Formation with Its Overlying and Underlying Strata

The regional disconformable contact between the Jixianian Gaoyuzhang and its underlying Changchengian Dahongyu Formations (Table 2.4d) is confirmed by field geological evidences in most areas of the YLDZ except for the depocenter of Jibei Depression at Kuancheng (north Hebei) where a local conformable contact is observed (Fig. 2.31d). The following geological observations could provide evidences for the above-mentioned stratigraphic contact relationship.

Fig. 2.31 The basal contact of the Gaoyuzhuang formation. **a**. the basal quartzose sandstone of the Gaoyuzhuang formation truncates the conical stromatolites on the top surface of the Dahongyu formation, Xiaohongyugou Valley, Jixian section; **b**. the weathering crust on the top of the Dahongyu formation, Xiazhuangzi Village, Qianxi County; **c**. the basal conglomerate at the base of Gaoyuzhuang formation, Matiyu Village, Qianxi County; **d**. the thick-bedded basal sandstone of the Gaoyuzhuang formation conformably overlays the thin-bedded sandstone at the top of the Dahongyu formation, Yamenzi Villagy, Kuancheng County

(1) The conical stromatolite Conophyton dahongyuense was truncated at the top surface of the Dahongyu Formation by the basal quartzose sandstone of its overlying Gaoyuzhang Formation in Jixian stratotype section (in Jidong Depression; Fig. 2.31a).
(2) The ferruginous weathering crust is often seen at the top of the Dahongyu Formation in the eastern and western YLDZ (in Jidong and Xuanlong Depressions; Fig. 2.31b).
(3) A 2–5.6 m thick basal conglomerate bed is found at the base of the Gaoyuzhuang Formation in Qinglong and Qianxi (in Jidong Depression; Fig. 2.31c).
(4) The Gaoyuzhang Formation often overlaps the Palaeoproterozoic or Archean metamorphic strata at the marginal areas of the YLDZ such as the Taihang and Wutai Mountains, showing an overlap sequence.

In a word, the above evidences indicate that the stratigraphic boundary between Gaoyuzhuang Formation and its underlying strata should be a regional disconformity or overlap unconformity, indicating a crustal movement before the sedimentation

of Gaoyuzhuang Formation previously called as "Qinglong Uplifting", which is characterized by one Gaoyuzhang basal conglomerate bed at the south of Qinglong (in Jidong Depression; Chen et al. 1980).

Although another Yangzhuang basal conglomerate bed is also found at Taoyuan (in Jidong Depression) and somewhere else, its gravels mainly consist of gneiss, basic and acid volcanic rocks with the maximal grain-size up to 40 cm, showing an obvious local disconformable contact relationship between the Yangzhuang and its underlying Gaoyuzhuang Formations, and marking the crustal movement called as "Luanxian Uplifting". As contrast with the "Qinglong Uplifting", however, the "Luanxian Uplifting" only results in a local-scale disconformity between the Mesoproterozoic Yangzhuang and Gaoyuzhuang Formations.

Moreover, the Yangzhuang Formation with the interbeds of the purplish-red muddy dolostone also shows a comformable contact relationship with the underlying Gaoyuzhuang Formation in the Jixian section (Figs. 2.31d and 2.32) where the "Luanxian Uplifting" would be inexistent so that the Yangzhuang Formation can only be distinguished by the occurrence of purplish-red sandy and muddy dolostone as the sole identification marker.

In addition, even the Yangzhuang Formation lacks the purplish-red sandy and muddy dolostone, and its lithology is similar to that of the upper Gaoyuzhang Formation in the western and northern YLDZ, in this case, the Yangzhuang Formation can hardly be distinguished from the Gaoyuzhuang Formations, in between sometimes there only is a layer of 1–2 m thick white silicalite (or siliceous crustation) at the base of Yangzhuang Formation.

From the point of view of the lithostratigraphy in the YLDZ, the contact relationship between Yangzhuang and Gaoyuzhang Formations is principally regional conformable with a few local exceptions (Fig. 2.32; Table 2.4d). Therefore, it is

Fig. 2.32 Conformable contact between the Gaoyuzhuang formation (Jxg) and its overlying Yangzhuang formation (Jxy) in the Jixian section

very reasonable to assign the stratigraphic boundary between the Jianxianian and its underlying Changchengian at basal surface of the Gaoyuzhang Formation.

2.4.2.2 The Age for the Boundary Between Jixianian and Changchengian

A single grain zircon U–Pb age of 1625 ± 6 Ma from the volcanic lava intercalated within the middle of Dahongyu Formation in Jixian has provided an age constraining on the top boundary of the Dahongyu Formation to ca. 1600 Ma (Lu and Li 1991). This age was confirmed by new zircon SHRIMP U–Pb ages of 1622 Ma and 1625 Ma sampled from same outcrop (Lu et al. 2008; Gao et al. 2008a, 2009).

As described above, although there is a regional disconformity between Gaoyuzhang and Dahongyu Formations, a nearly conformable contact is also observed at the depocenter of sedimentary depression in the YLDZ (in Jibei Depression), suggesting that the depositional break between the Gaoyuzhang and Dahongyu Formations continued not so long. Therefore, the age of 1600 Ma is roughly equivalent to the age for the Jixianian basal boundary. The basal age of the Jixianian is supported by a SHRIMP zircon U–Pb age of 1559 ± 12 Ma and a LA-MC-ICPMS zircon U–Pb age of 1560 ± 5 Ma from the volcanic ask bed at the upper Gaoyuzhang Formation in the west YLDZ (Li et al. 2010).

Since the Jixianian spans a time from 1600 Ma to 1400 Ma (Table 2.4d), it is equivalent to the Calymmian in the International Stratigraphic Chart (Table 2.4e).

2.5 Conclusions and Perspectives

(1) The Meso-Neoproterozoic strata in the YLDZ are subdivided into three systems plus one individual formation, i.e., Pt_2^1 Changchengian (incl. Changzhougou, Chuanlinggou, Tuanshanzi and Dahongyu Formations), Pt_2^2 Jixianian (incl. Gaoyuzhuang, Yangzhuang, Wumishan, Hongshuizhuang and Tieling Formations), Pt_2^3x Xiamaling Formation as well as Pt_3^1 Qingbaikouan (incl. Luotuoling and Jing'eryu Formations) in ascending order.

(2) The Xiamaling Formation is newly attributed to the Middle Mesoproterozoic strata based on the ages (e.g., 1368 Ma from the ash beds in its lower interval and 1320 Ma from the diabase sill in its middle-upper interval).

(3) There is a long-lasting depositional break (from 1320 Ma to 1000 Ma, ca. 320 Ma,) between the Mesoproterozoic Xiamaling and Neoproterozoic Luotuoling Formations. The regional micro-angular unconformity at the base of the Qingbaikouan may reflect a tectonic movement related to the Greenville Orogeny that led to formation of the Supercontinent Rodinia.

(4) The Changchengian (1670–1600 Ma) is the oldest unmetamorphosed sedimentary sequence in China. It is predominated by siliciclastic sequence which represents the deposition in the early stage of the Yanliao Faulted-Depression Zone

(YFDZ) related to the early breakup of Supercontinent Columbia and also to the earliest radiation of megascopic multicellular organisms for the early life on the Earth.

(5) The stratigraphic contact relationship between the Changchengian Dahongyu Formation and its overlying Jixianian Gaoyuzhuang Formation appears as a regional disconformity with local conformity at the Dahongyu depocenter. Both Changchengian and Jixianian should be referred to a basically continuous sedimentary sequences in the Jixian stratotype section, and as a very complete Calymmian sequence it should be attributed to the Mesoproterozoic Erathem.

(6) As the stratotype, the completeness of Meso-Neoproterozoic strata from Changchengian through Jixianian to Qingbaikouan at the Jixian section must be reassessed, it is fully qualified as the candidate for the global stratotype of the Calymmian System.

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