GEOSCIENCE FRONTIERS 2(3) (2011) 409–419

available at www.sciencedirect.com

China University of Geosciences (Beijing)

GEOSCIENCE FRONTIERS

journal homepage: www.elsevier.com/locate/gsf

ORIGINAL ARTICLE

Ramp facies in an intracratonic basin: A case study from the Upper Devonian and Lower Carboniferous in central Hunan, southern China

Longyi Shao*, Dongdong Wang, Houan Cai, Hao Wang, Jing Lu, Pengfei Zhang

State Key Laboratory of Coal Resources and Safe Mining, and School of Geosciences and Surveying Engineering, China University of Mining and Technology (Beijing), Beijing 100083, China

Received 9 May 2011; accepted 10 June 2011
Available online 8 July 2011

KEYWORDS
Intracratonic basin;
Carbonate ramp;
Southern China;
Lower Carboniferous;
Upper Devonian

Abstract Detailed studies on Late Devonian to Early Carboniferous carbonate rocks in central Hunan, southern China have led to the recognition of 25 lithofacies which can be grouped into: (1) inner ramp peritidal platform, (2) inner ramp organic bank and mound, (3) mid ramp, (4) outer ramp, and (5) shelf basin facies associations. The peritidal platform facies association dominates the Zimenqiao Formation (Namurian A or late Datangian) and is characterized by gypsum and dolostone-containing sequences, indicating a peritidal platform environment. The other four facies associations dominate the Menggongao Formation (late Famennian), Liujiatang Formation (Tournaisian or Yangruanian), Shidengzi Formations (early Visean or early Datangian). Five upward-shallowing cycles were distinguished in these three Formations. The predominant facies associations developed in each Formation demonstrate an overall transgression–regression cycle in the Late Devonian to Early Carboniferous in central Hunan. The overall transgressive sequence was preserved in the Shaodong, Menggongao, and Liujiatang Formations, and the overall regressive sequence was preserved in the Liujiatang, Shidengzi, Ceshui and Zimenqiao Formations.

* Corresponding author. Tel./fax: +86 10 62331248x8523.
E-mail address: ShaoL@cumtb.edu.cn (L. Shao).

Peer-review under responsibility of China University of Geosciences (Beijing).
doi:10.1016/j.gsf.2011.06.003

ELSEVIER Production and hosting by Elsevier

1. Introduction

Carbonate rocks in geological history have preserved abundant information on the evolution of the Earth (Meng and Ge, 2004; Le Guerroue and Cozzi, 2010; Purohit et al., 2011; Jiang et al., 2011). The Late Devonian to Early Carboniferous period is known for its tectonic activities, frequent sea level changes, climatic variations, and world-wide coal accumulations (Han and Yang, 1980; Bishop et al., 2010). The sediments of these stages have been studied in detail in most parts of the world and many hypotheses have been proposed for the depositional history, glacio-eustacy, plate tectonics, evolution of Earth's biota and global time-correlations (Johnson, 1982; Wu, 1982; Wright, 1986, 1994; Zhou and Flügel, 1986; Leeder, 1988; King, 1990; Grossman et al., 2002; Racki, 2005). The hydrocarbon potential of the Lower Carboniferous has also attracted great interest (Saltzman, 2003; Stasiuk and Fowler, 2004).

The Late Devonian to Early Carboniferous strata are well exposed in central Hunan, southern China, which are characterized by thin to thick-bedded carbonate rocks intercalated with clastic coal measures. During the Late Devonian to Early Carboniferous, the central Hunan belonged to the South China biogeographical Province (Wang, 1985; RGSH, 1987), with abundant shallow marine fossils preserved in the carbonate rocks as well as a good hydrocarbon potential in these strata (Guo et al., 2008).

Many published and unpublished reports have dealt with the Late Devonian to Early Carboniferous sections in central Hunan, but most of them only deal with biostratigraphy, structural geology, and general geological mapping (Wang, 1985; RGSH, 1987; CCSC, 2000a,b). Preliminary work on lithofacies and paleogeography was done by the petroleum industries, all of whom interpret the Late Devonian to Early Carboniferous in the central Hunan area as deposits of a shallow marine environment (Qiu, 1987; HPPT, 1979). Detailed sedimentological studies are scarce or unavailable. Studies by Beijing Graduate School of China Institute of Mining and Technology (HACG, 1987) have provided lithological descriptions and isotopic data on the Late Devonian to Early Carboniferous carbonate rocks. The present study shows that the Late Devonian to Early Carboniferous strata in central Hunan are far more complex. For example, storm deposits are common, a variety of trace fossils are present, and a variety of limestones and dolostones and upward-coarsening and thickening carbonate sequences have yet to be described. This wealth of new geological information holds clues for new interpretations of the depositional history.

2. Geological setting

The central Hunan was tectonically a part of the intracratonic basin within the Late Paleozoic South China Plate (Liu et al., 1993; Ma et al., 2009). Paleotectonic and paleogeographical reconstructions of the Late Paleozoic in southern China indicate the development of two basins, the Jiangnan and Dian-Qian-Gui Basins, between the Yangtze and Cathaysian blocks (Wang and Jin, 2000). The tectonic background of the whole Jiangnan region was traditionally regarded as part of the Huanan para-platform (Huang et al., 1981). Hsü et al. (1988) interpreted the Paleozoic and Mesozoic rocks in the Huanan area (the easten part of South China) as the Huanan fold belt; the result of a Mesozoic orogeny with sutures on the eastern and western sides of the Jiangnan Basin. Rowley et al. (1989) pointed out that the depositional sequences of the Jiangnan Basin were formed upon a pre-Sinian suture from the Sinian to the Silurian and from the Devonian to the Triassic rocks. Therefore, it is generally regarded that, in the southern China, there were three tectonic zones during the Paleozoic: the Yangtze continental block, Cathayian continental block and the South China extensional basin between these two blocks. The central and southern Hunan province constituted a part of the Jianan extentional Basin.

Paleogeographically the central Hunan area was a part of the South China sea during the Late Devonian to Early Carboniferous (Wang, 1985; Shao et al., 2003). The South China sea was surrounded to the north by the Upper Yangtze oldland, to the south by the Yunkai oldland, and to the east by the Cathaysian (Zhe-Min) oldland (Wang, 1985). The central Hunan was situated near the Xuefeng oldland which was a part of the Upper Yangtze oldland. The depositional environment was a shallow water shelf (Shao, 1997).

The Late Devonian to Early Carboniferous strata studied in this paper include the Late Devonian Shaodong Formation and Menggongao Formation, and the Early Carboniferous Liujiatang Formation, Shidengzi Formation, Ceshui Formation and Zimenqiao Formation (Wang et al., 1987; RGSH, 1987; CCSC, 2000a,b). The Shaodong and Menggongao Formations belong to latest Famennian. The Liujiatang Formation belongs to Yanguanian (correlates to Tournaisian). The Shidengzi, Ceshui and Zimenqiao Formations belong to Datangian (correlates to Visean and Namurian A). These strata are currently preserved in a series of NNE-SSW oriented synclines (Fig. 1). The lithologies are as follows (from top to bottom):

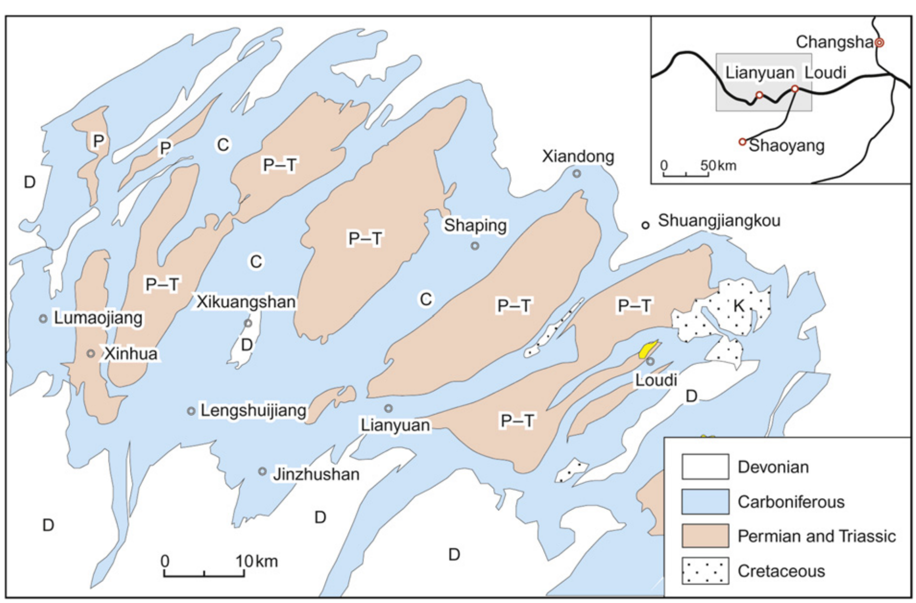


Figure 1 Simplified geological map of central Hunan, southern China.

Table 1 Lithofacies of the Late Devonian and Early Carboniferous carbonate rocks in central Hunan, southern China.

Lithofacies	Principal grains	Grain content (%)	Facies belt	Stratigraphic distribution					
				D_3s	D_3m	C_1l	C_1sh	C_1c	C_1z
1. Gypsum-dissolved breccia	Angular gravel	60	Supratidal						+
2. Calcirudite	Calcirudite intraclasts		Intertidal						+
3. Calcarenitic grainstone	Calcarenitic intraclast	60−70	Barrier shoal				+		+
4. Sandy oolitic grainstone	Oolite, quartz sand	65	Barrier shoal					+	
5. Graded calcarenitic-bioclastic grainstone and packstone (tempestite)	Bioclast, calcarenitic intraclast	50−70	Mid ramp		+	+			
6. Graded echinoderm-bioclastic grainstone and packstone (tempestite)	Echinoderm, bioclasts	50−70	Mid ramp		+				
7. Graded shelly bioclastic grainstone and packstone (tempestite)	Bivalve, brachiopods	30−60	Outer ramp			+			
8. Foraminifer-bioclastic grainstone	Foraminifers, echinoderm	70	Inner ramp				+		
9. Foraminifer-bioclastic packstone	Foraminifers, echinoderm, brachiopods	50−65	Barrier shoal				+		+
10. Pellet-bioclastic packstone	Fecal pellet, bioclasts	50−70	Inner ramp		+		+		+
11. Burrowed bioclastic packstone	Echinoderm, brachiopods	50−70	Inner ramp				+		+
12. Laminated carbonaceous bioclastic packstone	Fine bioclasts	60	Intertidal			+			
13. Burrowed bioclastic wackestone	Echinoderm, brachiopods	10−40	Inner ramp, mid ramp	+	+	+	+	+	+
14. Spicula-bioclastic wackestone	Bioclasts, spiclues	15−30	Mid ramp			+			
15. Burrowed clayey lime mudstone		<10	outer ramp			+			
16. Silty lime mudstone with oolitic and calcarenitic bands	Oolite, quartz, calcarenitic intraclasts	<10	Intertidal						+
17. Laminated calcisiltite	Calcisiltite, ostracods	55	Supratidal						+
18. Stromatolitic micrite			Intertidal					+	+
19. Homogenous micrite			Intertidal						+
20. Coral bafflestone			Inner ramp organic bank and mound			+	+		+
21. Penecontemporaneous micritic and calcisiltitic dolostone			Supratidal						+
22. Penecontemporaneous ferrous stromatolitic micritic dolostone			Supratital, intertidal					+	
23. Post-penecontemporaneous calcareous dolostone with fossil residues			Inner ramp				+		
24. Dark gray calcareous shale			Shelf basin and outer ramp			+	+		
25. Calcareous mudstone with body fossils			Shelf lagoon				+		+

D_3s - Shaodong Formation; D_3m - Menggongao Formation; C_1l - Liujiatang Formation; C_1sh - Shidengzi Formation; C_1c - Ceshui Formation; C_1z - Zimenqiao Formation.

Zimenqiao Formation: consists of stromatolitic, oolitic and bioclastic limestones, dolostones, and evaporites, with a thickness of about 150 m.

Ceshui Formation: consists of quartz arenites, sandy conglomerates, siltstones, mudstones with siderite, stromatolitic and bioclastic limestones. The Lower member of this Formation contains some economic coal seams. The thickness of this Formation is about 110 m.

Shidengzi Formation: consists of thick-bedded to massive bioclastic limestones with intercalation of thin to thick-bedded calcareous shales. The thickness is about 110 m.

Liujiatang Formation: consists of middle to thin-bedded bioclastic limestones, muddy limestones and calcareous shales with the thickness of 360 m.

Menggongao Formation: consists of massive bioclastic limestones intercalated with middle-bedded alternated bioclastic limestones and calcarenites. The thickness is about 60 m.

Shaodong Formation: mainly consists of mudstones with marine fossils and intercalated with quartz arenites and siltstones. The thickness is about 200 m.

Sedimentological investigations into the Late Devonian to Early Carboniferous sections in central Hunan allow a general environmental interpretation for these Formations (Shao, 1997). The Shaodong and Ceshui Formations consist mainly of clastic rocks and they were formed in the offshore muddy shelf system and back-barrier logoonal system respectively. The Zimenqiao Formation is characterized by the gypsum and dolostone and was formed in a peritidal and offshore ramp system under a dry climate. The other three Formations, Menggongao, Liujiatang, and Shidengzi, were formed in an offshore carbonate ramp depositional system.

3. Facies analyses of the carbonate rocks

3.1. Lithofacies characteristics

The outcrop sections at Xikuangshan and Xiandong of central Hunan show that the carbonate rocks in the Upper Devonian to Lower Carboniferous are mainly bioclastic limestones and

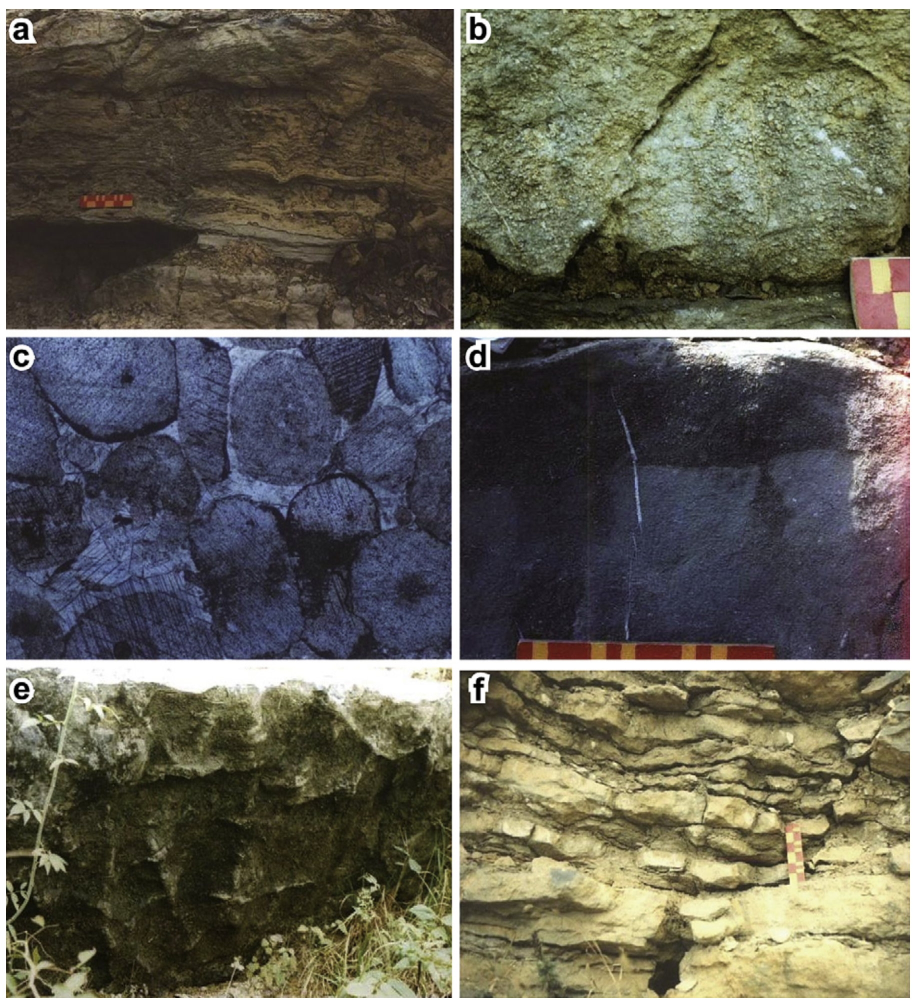


Figure 2 Photographs showing depositional characteristics of the Upper Devonian and Lower Carboniferous carbonate rocks in central Hunan. a - Stromatolites in Lower Carboniferous Zimenqiao Formation, from Xikuangshan section; scale in centimeters; b - Crinoid-bioclastic grainstone in Menggongao Formation, Shuangjiangkou section, representing basal lag of the tempestite; scale in centimeters; c - Photomicrograph of b, and the spary calcite cement can be seen; the view is 3 mm wide; d - Escaping structures at the base of the bioclastic grainstone tempestite of the Menggongao Formation at the Xiandong section; scale in centimeters; e - Trace fossil Thallassinoides at the base of the thick-bedded limestone in Shidengzi Formation at Xiandong section; the view is 2 m wide; f - thinly interbedded limestone and calcareous shale, with gutter casts (arrows) at limestone base, Liujiatang Formation, Xikuangshan section; scale in centimeters.

dolomitic limestone. Dolostones are common in the Zimenqiao Formation. The textural types of limestone range from grainstone, packstone, wackestone, lime mudstone to boundstone. Grains in limestones are bioclasts, oolites, intraclasts, and faecal pellets. Bioclasts are mainly fragments of the organisms such as echinoderm, brachiopods, coral, mollusks, ostracods, bryozoan and foraminifers. Halite pseudomorphs, stromatolites, hummocky cross stratification, graded bedding and lamination are common in some beds. A total of 25 lithofacies for these carbonate rocks have been recognized (Table 1).

3.2. Facies association

Based on the lithofacies analyses for the Xikuangshan and Xiandong sections, five facies associations can be outlined, including inner ramp peritidal, inner ramp organic bank and mound, mid ramp, outer ramp and shelf basin facies associations.

3.2.1. Inner ramp peritidal facies association

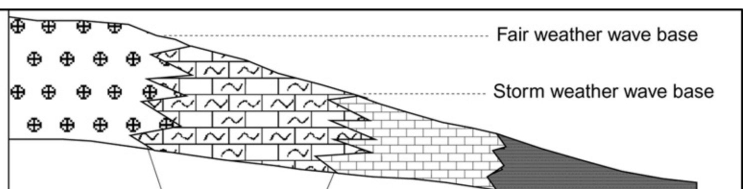
The lithologies of this facies association are mainly gypsum, anhydrite, dolosiltite, stromatolitic limestone, micritic limestone, calcilutites, and calcareous mudstone. Sedimentary structures include wavy to horizontal stromatolites (Fig. 2a), bird's eye fenestrae, mud cracks, halite pseudomorphs, penecontemperaneous micritic dolomite, gypsum and anhydrite beds, micritized oolite bands in micritic limestone, and storm lamination in calcilutites. Calcareous mudstone contains abundant whole body fossils like corals and brachiopods, and typical trace fossil *Rhizocorallium* sp. The lithofacies of this facies association include: (1) gypsum and anhydrite dissolution collapse breccia; (2) laminated calcisiltite; (3) penecontemporaneous micritic and calcisiltitic dolostone; (4) penecontemporaneous ferrous stromatolitic dolostone; (5) stromatolitic micrite; (6) silty lime mudstone with oolitic and calcarenitic bands; (7) homogenous micrite; (8) sandy oolitic grainstone; (9) calcirudite (tidal channel deposits); and (10) calcareous mudstone with body fossils. This facies association characterizes the major parts of the Zimenqiao Formation in central Hunan.

All the sedimentary structures such as stromatolites, bird's eye fenestrae, mud cracks, halite pseudomorphs, penecontemperaneous dolomites, gypsum and anhydrite beds, and storm laminations indicate an inner ramp peritidal platform environment under an arid climate. In modern Pursian, gypsum, anhydrite and dolomites are present in supratidal environments, stromatolites are present in the intertidal environments and the calcareous mudstone represents the subtidal environments (Purser, 1973).

3.2.2. Inner ramp organic bank and mound facies association

This facies association is mainly characterized by small lenticular biohermal reefs, typically several meters wide and 1 m high. The reef builders are mainly corals, including single or complex corals, which take part of baffling in the reefs. *Pseudouralinia* sp., *Guizhouphyllun* sp. and *Yuanophyllum* sp., *Lithostrotion* sp., and *Syringopora* sp. The contents of corals range from 15% to 30%. The matrix between the corals are the bioclasts and micrites. The associated deposits are

Cross section



Facies belt	Inner ramp organic bank and mound	Mid ramp	Outer ramp	Shelf basin
Environmental conditions – Depth	shallow →			deep
Environmental conditions – Photic	photic →			weak photic or aphotic
Environmental conditions – Oxygen	oxygenated →			poorly oxygenated
Environmental conditions – Energy	stronger wave	weak or intermittent storm current		quiet
Lithology	limestone	limestone intercalated with calcareous shale		calcareous shale intercalated with limestone
Color of rocks	light grey	light grey	dark grey	greyish black
Thickness of single bed	massive or thick bedded	thick-bedded	mid-bedded	laminated or thin-bedded
Bioturbation	medium	strong	medium	weak
Trace fossil	*Rhizocorallium Ass.*		*Chondrites Ass.*	
I.R. content	11.21%	15.62%	8.27%	48.34%
TOC content	0.28%	0.19%	0.40%	0.84%
Textural types of limestone	boundstone packstone	packstone wackestone	wackestone lime mudstone	calcareous shale argillaceous limestone
Grain types	bioclast, oolite	bioclast, pellet, calcarenite	bioclast, calcarenite	bioclast
Bioclasts	crinoid, coral, foram, brachi.	crinoid, brachi., foram.	ostracod, spicula	

I.R.-Insoluble residue; TOC-Total organic carbon

Figure 3 The offshore ramp depositional model of the Late Devonian to the Early Carboniferous in central Hunan.

thick-bedded bioclastic packstone and sometimes calcarenitic grainstone. The lithofacies includes: (1) coral bafflestone, (2) foram-bioclastic packstone, (3) calcarenitic grainstone, and (4) laminated carbonaceous bioclastic packstone (intertidal). These units are found in the Menggongao and Liujiatang Formations at the Xiandong section and the Liujiatang and Shidengzi Formations at Xikuangshan section. Bioclastic packstones characterize the upper part of the Zimenqiao Formation in all sections.

The small scale reef bodies do not provide a distinct facies zonation. Coral bafflestoens, together with lack of fore-reef breccia, indicates a weak to middle wave activity and the lack of the shelf break. Compared with the characteristics of the ramp deposits described in Ahr (1973), Read (1985), Tucker (1985) and Burchette and Wright (1992), we believe that these bioherms represent inner ramp deposits which were formed in the shallow part of a gently sloping ramp. Bioclastic packstone is a part of the shoal deposits which is adjacent to the peritidal environments.

3.2.3. Mid ramp facies association

This facies association is characterized by the thick-bedded limestones with the single bed thickness more than 0.5 m. The limestones contain whole body fossil and fossil fragments such as brachiopods, corals, echinoderms, ostracods and foraminifers. The fossil fragments are major grains in the limestone, with contents ranging from 30% to 60%. The textural types of limestone are mainly wackestone and packstone, with intercalation of grainstones. Some echinoderm-bioclastic grainstones (Fig. 2b and c) are developed with erosional bases, graded beddings, hummocky cross stratifications, escaping structures (Fig. 2d). Trace fossils identified in this facies association include *Rhizocorallium*, *Thalassinoides*(Fig. 2e), *Zoophycos, Planolites*, and *Chondrites* (Shao and Liu, 1994). The lithofacies in this association include: (1) foram-bioclastic packstone; (2) peloidal-bioclastic packstone; (3) bioturbated bioclastic packstone; (4) burrowed bioclastic wackestone; (5) foram-bioclastic grainstone; (6) graded echinoderm-bioclastic grainstone and packstone; and (7) post-penecontemporaneous calcareous dolostone with fossil residues. This facies association is developed in the upper part of the Menggongao Formation, the middle part of the Liujiatang Formation and the Shidengzi Formation in most parts of central Hunan.

The storm deposits are well developed in this facies association, especially those typical of proximal tempestites which are represented by the echinoderm-bioclastic grainstone and packstones at the top of the Menggongao Formation in Xiandong-Shuangjiangkou region. These grainstones are developed with erosional base, graded bedding, hummocky cross stratification, escaping structures, and shallow water fossils are typical proximal tempestites (Aigner, 1982). The amalgamation of storm beds are common and intercalated shale deposits are relatively thin. The fossils in this facies association are all stenohaline organism, indicating a normal marine conditions. The packstone and wackestone texteures indicate a moderate wave energy and the associated graded grainstones suggest the frequent influence of storm wave. This facies association represents the deposits in the mid ramp between fair-weather wave base and storm-weather wave base. The sufficient supply of bioclasts and intraclasts from adjacent bank and shoal and the strong disturbance of storm wave will result in the formation of thick-bedded coarse-grained tempestites with common amalgamation of storm beds.

3.2.4. Outer ramp facies association

This facies association is represented by the thin-bedded and graded calcarenitic and bioclastic grainstone and packstones. The textural types of limestones in the tempestites range from grainstone to lime mudstone with the calcarenitic intraclasts and the bioclasts of brachiopods, echinoderms, pelecypods, gastropods and foraminifers. The trace fossils are less common and only *Chondrites* and small *Thalassinoides* are occasionally found. The limestone beds are thin-bedded (less than 10 cm) and intercalated with very thin-bedded calcareous shale (Fig. 2f). These limestone beds are mostly interpreted as proximal tempestites (Shao and Zhang, 1993). Their bottom and top surfaces are gently undulated and sometimes nodular. The graded beddings are evident for this kind of tempestites. The lithofacies in this facies association include: (1) burrowed bioclastic wackestone; (2) spicular-bioclastic wackestone; (3) burrowed clayey lime mudstone; (4) graded calcarenitic-bioclastic grainstone and packstone (tempestite); and (5) dark gray bioclastic calcareous shale. This facies association has been found in the upper part of the Menggongao Formation and the lower part of the Liujiatang Formation of the Xikuangshan and Lengshuijiang region and the middle part of the Menggongao Formation of the Xiandong and Shuangjiangkou region.

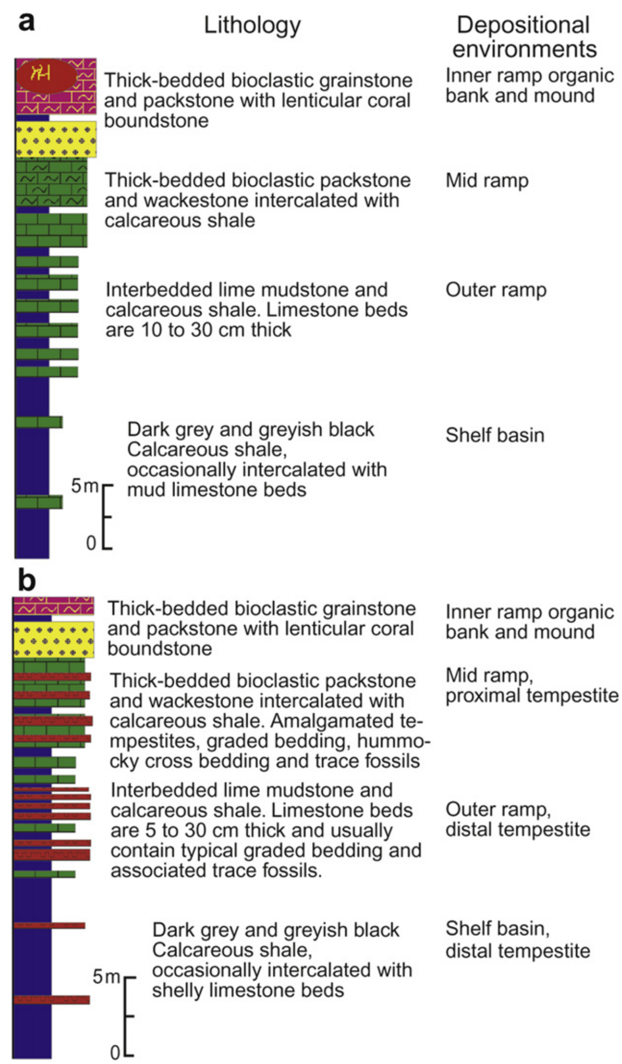


Figure 4 The ideal shallowing-upward ramp successions in the Late Devonian to Lower Carboniferous in central Hunan. (a) a fair-weather ramp succession of the Shidengzi Formation at Xiandong section; (b) a storm-dominated ramp succession of the Menggongao and Liujiatang Formations at Xikuangshan section.

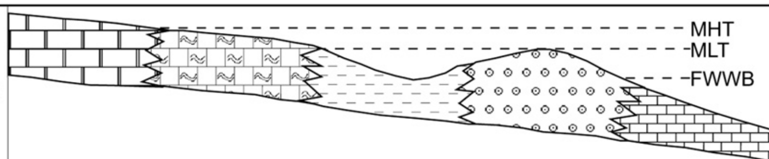
This facies association represents the deposits in the outer ramp which is developed below the storm-weather wave base. Less strong bioturbation and less developed in-situ fossils indicate a deeper water condition which is not favorable for the organism development. However, the strong storm wave can disturb the bottom and form thin-bedded proximal tempestites.

3.2.5. Shelf basin facies association

This facies association is typically represented by the calcareous shale-dominated sequences. The shale is dark in color and rich in organic matter with total organic carbon between 1% and 2% (Shao, 1997). The limestones mainly occur as the thin-intercalated beds in these sequences. The limestone beds are generally 10–30 cm thick and contain little bioclasts. The shelly packstones and wackestones are scarcely found in the limestone beds, which represent the distal tempestites. They are thin-bedded (only 2–5 cm thick) or nodular. These shelly tempestites have many similarities with the coquina described by Kreisa and Bambach (1982) such as erosional base, gutter cast, graded bedding, and shelter porosity. The nodular tempestites are believed to be the filled gutter cast structures or pocket structures. The associated trace fossils are very rare and only *Chondrites* can be occasionally recognized. The lithofacies in this facies association include: (1) dark gray bioclastic calcareous shale; (2) burrowed clayey lime mudstone; (3) graded shelly grainstone and (4) packstone (tempestite). They are mainly developed in the upper part of the Liujiatang Formation.

The dark colored shale is rich in organic matter, suggesting an anoxic environment. The very rare storm deposits indicate scarce storm influence. The sedimentary characteristics suggest that the depositional environment for this shale-dominated sequence was situated below the storm-weather wave base, and only very strong storm wave can disturb the bottom sediments.

Cross section



Facies belt	Supratidal sabkha	Intertidal	Lagoon	Barrier shoal	Offshore shelf (mid ramp)
Water energy	storm tide	strong tide	weak tide	strong tide and strong wave	weak wave and storm wave
Lithology	gypsum, anhydrite, dolostone	stromatolitic and bioclastic limestone	calcareous mudstone, clayey limestone	oolitic limestone, bioclastic limestone	bioclastic limestone, clayey limestone
Colour of rocks	white, light gray	gray	grayish yellow	gray	dark gray
Sedimentary structure	bird's eye, mudcrack, halite pseudomorph, storm lamination	stromatolite, bird's eye	horizontal lamination	cross bedding or massive	thick-bedded
Trace fossil	*Chondrites*		*Rhizocorallium*		*Zoophycos*
I.R. content	12.6%	24.1%	59.5%	11.2%	15.6%
TOC content		0.03%	0.32%	0.28%	0.19%
Textural types	calcirudite, dolosiltite	lime mudstone, packstone	wackestone	grainstone packstone	wackestone packstone
Grain types	calcisiltitic intraclasts	bioclasts, oolites, intraclasts	bioclasts	bioclasts, oolites, intraclasts, quartz	bioclasts
Fossils	ostracods	cyanobacteria -algalaminate	brachiopods, corals, crinoids	brachiopods, corals, crinoids, foraminifers, bivalves	brachiopods, corals, crinoids, foraminifers, bivalves

I.R.-Insoluble residue; TOC-Total organic carbon

Figure 5 The peritidal model and its facies characteristics of Lower Carboniferous Zimenqiao Formation in central Hunan.

3.3. Depositional models

The carbonate rocks in the Menggongao, Liujiatang, and Shidengzi Formations are characterized by inner ramp organic bank and mound, mid ramp, outer ramp and shelf basin facies associations. These facies associations represent a typical offshore ramp model. The environmental conditions and depositional characteristics of each facies belts are summarized in Fig. 3.

In these ramp dominated Formations, typical shallowing-upward successions were commonly developed. The two types of shallowing-upward successions are the fair-weather ramp succession without tempestites and the storm – dominated ramp succession with many tempestites (Fig. 4).

The fair-weather ramp successions were mainly developed in the Shidengzi Formation (Fig. 4a). The lower part of the succession is mainly composed of dark gray and grayish black, calcareous shale, occasionally intercalated with muddy limestone beds. The middle part is dominated by the interbedded lime mudstone and calcareous shale, with the limestone beds are 10–30 cm thick. The upper part consists of thick-bedded bioclastic packstone and wackestones intercalated with calcareous shale. The top of the succession is normally developed with thick-bedded bioclastic grainstone and lenticular coral boundstone. The shallowing-upward trend is represented by an overall facies change from shelf basin, outer ramp, mid ramp through the inner ramp.

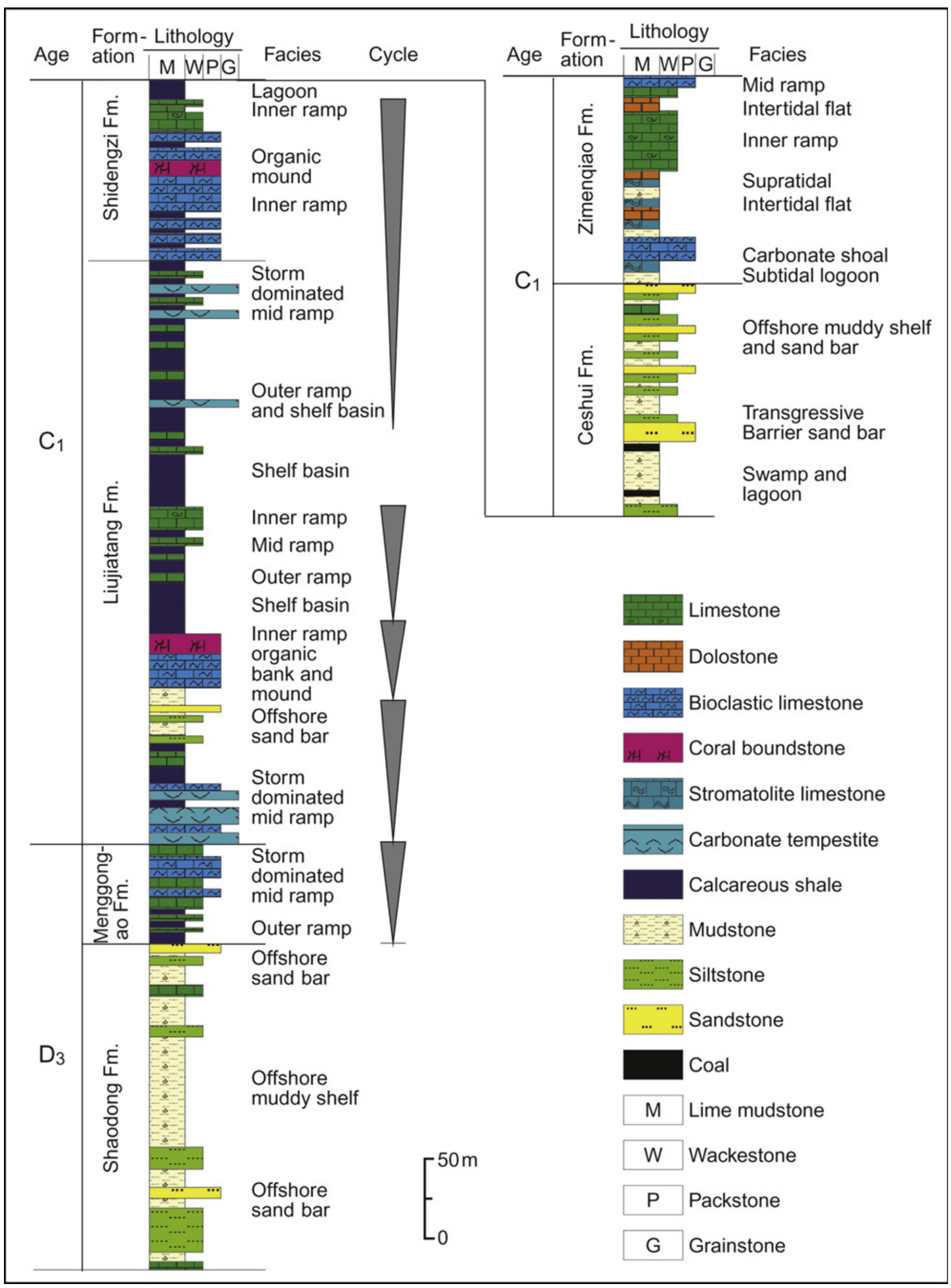


Figure 6 Vertical facies variations of the Late Devonian (D_3) and Lower Carboniferous (C_1) at Xikuangshan section of central Hunan.

The storm-dominated ramp successions are commonly seen in the Mengongao and Liujiatang Formations (Fig. 4b). The lower part of the succession is dominated by the dark gray and grayish black calcareous shale, occasionally intercalated with shelly limestone beds. The middle part is composed of interbedded lime mudstone and calcareous shale, and the limestone beds are 5–30 cm thick, and usually contain typical graded bedding and associated trace fossils. The upper part is typically the thick-bedded bioclastic packstone and wackestone, intercalated with calcareous shale. Amalgamated tempestites, graded bedding, hummocky cross bedding and abundant trace fossils. The top of this succession is dominated by thick-bedded bioclastic grainstones. The shallowing-upward trend is also represented by an overall facies change from shelf basin, outer ramp, mid ramp through the inner ramp.

The depositional characteristics of the Zimenqiao Formation is very different from the Menggongao, Liujiatang, and Shidengzi Formations. It is mainly characterized by the inner ramp peritidal facies association. This facies association can be further subdivided into supratidal, intertidal, lagoon, barrier shoal and offshore mid ramp facies belts. These facies belts constitute a typical inner ramp peritidal model. The environmental conditions and depositional characteristics of each facies belt are summarized in Fig. 5.

4. Sedimentary evolution of the central Hunan during the Late Devonian to Early Carboniferous

4.1. Palaeoclimates

The Late Devonian to Early Carboniferous in central Guangxi was well developed with coal, limestone with coral and other fossils, tempestites, and phosphorite in some Formations, which are good indicators of warm and humid climates. During the later stage of the Early Carboniferous (the top part of the Ceshui Formation and the Zimenqiao Formation, which correspond to the late Visean and Namurian A), the palaeoclimate changed to arid, as manifested by intertidal stromatolites and supratidal sabhka gypsum and dolomites. The large-scale coal accumulation during the deposition of the Ceshui Formation (Shao et al., 1992) decreased with the major transgression (forming the thick-bedded sandstone in the middle of the Ceshui Formation) and finally ceased due to the arid climate (Shao et al., 1992). The Early Carboniferous warm climates coincides with the palaeomagnetic data which suggest that the palaeolatitude of the southern China is 4.1° N (Wu et al., 1997). The oxygen isotope compositions with $\delta^{18}O$ values of −2 to −8 per mil give a temperature of 15–25 °C (Shao, 1997).

4.2. Depositional environment evolution and sedimentary cycles

The detailed facies logging for the Xikuangshan section is shown in Fig. 6. The carbonate rocks in the Menggongao, Liujiatang, and Shidengzi Formations are mainly thin to thick-bedded limestones and dark calcareous shales with many upward-shallowing sequences. According to vertical facies distribution, five upward-shallowing cycles are roughly recognized (Fig. 6). Cycle 1 takes up the Menggongao Formation and was developed from outer ramp and shelf basin to inner ramp environments. Cycles 2 takes the lower part of the Liujiatang Formation and represent a shallowing process from outer ramp and shelf basin to inner ramp and to offshore clastic sand bar environments. Cycles 3 takes up the middle part of the Liujiatang Formation and the environment changes from outer ramp and shelf basin to inner ramp organic mound. Cycle 4 takes up the upper part of the Liujiatang Formation and the environment changes from outer ramp and shelf basin and shelf basin to inner ramp. Cycle 5 takes up the top of the Liujiatang Formation and the Shidengzi Formation and represents a process from outer ramp and shelf basin environment to inner ramp environment.

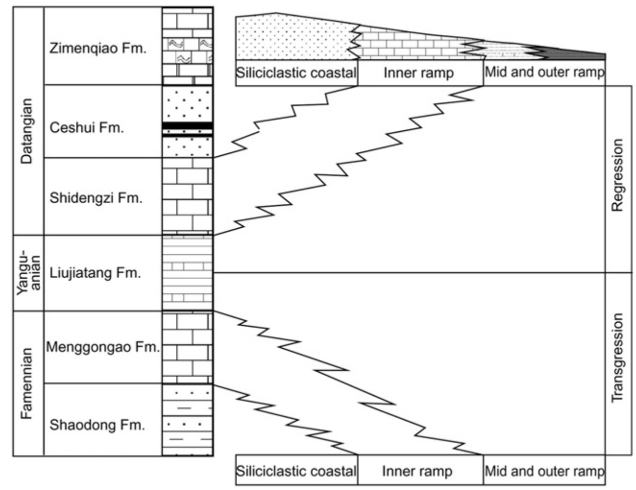


Figure 7 An overall transgressive – regressive cycle in the Upper Devonian and Lower Carboniferous of central Hunan.

According to Fig. 6, the predominant depositional environments of each Formation can be summarized as follows: the Shaodong Formation formed in the offshore muddy shelf environment (Shao, 1997); the Menggongao Formation in inner ramp and mid ramp; the Liujiatang Formation in outer ramp and shelf basin; the Shidengzi Formation in inner ramp; the Ceshui Formation in clastic shoreline barrier-lagoon environments (Shao et al, 1992); and the Zimenqiao Formation in inner ramp peritidal environments. The overall transgressive sequence was preserved in the Shaodong Formation, Menggongao Formation, and Liujiatang Formation, and the overall regressive sequence was preserved in the Liujiatang Formation, Shidengzi Formation, and Ceshui Formation (Fig. 7). Two kinds of distinctive carbonate systems are developed in different time intervals of Late Devonian to Early Carboniferous in central Hunan. The offshore ramp depositional system of the central Hunan may be comparable to the general carbonate ramp setting of the Early Carboniferous in North America and western Europe (Ahr, 1989; Wright, 1994). Many similarities exist between them such as thick offshore bioclastic carbonates, large volumes of carbonate mud, the lack of peritidal sequences, and the absence of reef builders capable of building steep-fronted platform margins (Wright, 1994). The peritidal depositional system dominating the late Datangian stage (Namurian A) represents another setting of the Early Carboniferous in central Hunan.

5. Conclusions

The Late Devonian to Early Carboniferous in central Hunan, southern China consists mainly of carbonate rocks intercalated with clastic coal measures. Carbonate rocks in the Menggongao, Liujiatang, Shidengzi Formations (corresponding to late Famennian to early Visean) are characterized by the upward-shallowing sequences ranging from calcareous shale to bioclastic wackestone and packstones. The carbonate rocks of the Zimenqiao Formation (corresponds to Namurian A) are characterized by the dolostone and stromatolitic limestone intercalated with gypsum and anhydrides.

A total of 25 lithofacies have been recognized and five facies associations have been further described. The inner peritidal platform facies association dominates most parts of the Zimenqiao Formation and includes supratidal, intertidal, subtidal lagoon, barrier shoal, offshore inner ramp facies belts. The inner ramp organic bank and mound, mid ramp, outer ramp and shelf basin facies associations occur in the Menggongao, Liujiatang, and Shidengzi Formations.

The five upward-shallowing cycles have been recognized from the Menggongao, Liujiatang, and Shidengzi Formations. The predominant facies associations developed in each Formation demonstrated an overall transgression–regression cycle in the Late Devonian to Early Carboniferous in central Hunan. The overall transgressive sequence was preserved in the Shaodong, Menggongao, and Liujiatang Formations, and the overall regressive sequence was preserved in the Liujiatang, Shidengzi, Ceshui and Zimenqiao Formations.

Acknowledgments

This study is supported by the National Natural Science Foundation of China (No. 41030213) and the Major National S&T Program of China (2011ZX05009-002). The authors are grateful to Mrs. Fengying Zhang for her invaluable help in editing figures. This paper is submitted in celebration of the outstanding contributions to geology of Prof. Xianghua Meng on the advent of his 80th birthday.

References

Ahr, W.M., 1973. The carbonate ramp - an alternative to the shelf model. Transcations, Gulf Coast Association of Geological Societies 23, 221–225.

Ahr, W.M., 1989. Sedimentary and tectonic controls on the development of an early Mississippian carbonate ramp, Sacramento Mountains area, New Mexico. In: CREVELLO, P.D., WILSON, J.L., SARG, J.F., J.F., READ (Eds.), Controls on Carbonate Platform and Basin Development. Special Publication, Society of Economic Paleontologists and Mineralogists, 44, pp. 203–212.

Aigner, T., 1982. Calcareous tempestites: storm-dominated stratification in upper Muschelkalk limestones (middle Trias, SW-Germany). In: Einsele, G., Seilacber, A. (Eds.), Cyclic and Event Stratification. Springer, Berlin, pp. 180–198.

Bishop, J.W., Montañez, I.P., Osleger, D.A., 2010. Dynamic Carboniferous climate change, Arrow Canyon, Nevada. Geosphere 6 (1), 1–34.

Burchette, T.P., Wright, V.P., 1992. Carbonate ramp depositional system. Sedimentary Geology 79, 3–57.

Compilation Committee of Stratigraphy of China (CCSC), 2000a. Stratigraphy of China, Devonian System. Geological Publishing House, Beijing. 119pp (in Chinese).

Compilation Committee of Stratigraphy of China (CCSC), 2000b. Stratigraphy of China, Carboniferous System. Geological Publishing House, Beijing. 138pp (in Chinese).

Grossman, E.L., Bruckschen, P., Mii, H.S., Chuvashov, B.I., Yancey, T.E., Veizer, J., 2002. Carboniferous Paleoclimate and Global Change: Isotopic Evidence from the Russian Platform. In Carboniferous Stratigraphy and Paleogeography in Eurasia. Institute of Geology and Geochemistry, Russian Academy of Sciences, Urals Branch, Ekaterinburg, pp. 61–71.

Guo, J.H., Kuang, L.X., Zhu, R., Zhou, X.K., Luo, X.P., Qi, K.L., 2008. Gas accumulation conditions of lower Carboniferous in Yangjiashan region of Lianyuan Sag. Journal of Central South University(Science and Technology) 39 (1), 178–184 (in Chinese with English abstract).

Le Guerroue, E., Cozzi, A., 2010. Veracity of neoproterozoic negative C-isotope values: the termination of the Shuram negative excursion. Gondwana Research 17, 653–661.

Han, D., Yang, Q., 1980. Coalfield Geology of China, vol. II. China Coal Industry Press. 415pp (in Chinese).

Hsü, K.J., Sun, S., Li, J.L., Chen, H.H., Pen, H.P., Sengor, A.M.C., 1988. Mesozoic overthrust tectonics in South China. Geology 16, 418–421.

Huang, J., Ren, J., Jiang, C., Zhang, Z., Qin, D., 1981. Tectonics and Its Evolution in China. Science Press, Beijing (in Chinese with English abstract).

Hunan Administration of Coal Geology and Beijing Graduate School of China Institute of Mining and Technology (HACG), 1987. The Carboniferous Deposits and Coal Measures in Hunan Province. Memoir of Coal-bearing Strata and Geology of Carboniferous–Permian in China. Science Press, Beijing. 305–321 (in Chinese with English abstract).

Hunan Petroleum Prospecting Team (HPPT), 1979. Middle to Early Carboniferous Lithofacies Paleogeography and Its Relationships with Hydrocarbon Potentials in Central Hunan. An internal report of Hunan Petroleum Prospecting Team (in Chinese).

Jiang, G., Zhi, X., Zhang, S., Wang, Y., Xiao, S., 2011. Stratigraphy and paleogeography of the Ediacaran Doushantuo formation (ca. 635–551 Ma) in south China. Gondwana Research 19, 831–849.

Johnson, G.A.L., 1982. Geographical changes in Britain during the Carboniferous period. Proceeding of Yorkshire Geological Society 44, 181–203.

King Jr., D.T., 1990. Probable influence of early Carboniferous (Tournaisian-Early Visean) geography on the development of Waulsortian and Waulsortian-like mounds. Geology 18, 591–594.

Kreisa, R.D., Bambach, R.K., 1982. The Role of Storm Processes in Generating Shell Beds in Paleozoic Shelf Environments. In: Einsele, G., Seilacher, A. (Eds.), Cyclic and Event Stratification. Springer, Berlin-Heidelberg-New York, pp. 200–207.

Leeder, M.R., 1988. Recent developments in Carboniferous geology: a critical review with implications for the British Ises and N.W. Europe. Proceeding of Geological Association 99, 73–82.

Liu, B., Xu, X., Pan, X., Huang, H., Xu, Q., 1993. Sedimentary Crust Evolution and Mineral Formation of South China. Science Press, Beijing. 236pp (in Chinese with English abstract).

Ma, Y.S., Chen, H.D., Wang, G.L., 2009. Atlas of Tectonic Sequences and Lithofacies Paleogeography of Southern China. Science Press, Beijing. 301pp (in Chinese with English abstract).

Meng, X.H., Ge, M., 2004. Sequences, Events, and Evolution of the Sino-Korea Plate. Science Press, Beijing, pp. 360–368 (in Chinese with English abstract).

Purohit, R., Sanyal, P., Roy, A.B., Bhattacharya, S.K., 2011. ^{13}C enrichment in the Palaeoproterozoic carbonate rocks in the Aravalli supergroup, northwest India: influence of depositional environment. Gondwana Research 18, 538–546.

Purser, B.H., 1973. The Persian Gulf. Springer-Verlag, New York. 47lpp.

Qiu, Z.J., 1987. Basic features of carbonate source rocks of southern China. Hunan Geology 5 (2), 21–29 (in Chinese with English abstract).

Racki, G., 2005. Toward understanding Late Devonian global events: few answers, many questions. In: Over, D.J., Morrow, J.R., Wignall, P.B. (Eds.), Understanding Late Devonian and Permian-Triassic Biotic and Climatic Events - Towards an Integrated Approach. Developments in Palaeontology and Stratigraphy, 20, pp. 5–36.

Read, J.F., 1985. Carbonate platform facies model. Bulletin of American Association of Petroleum Geologist 69, 1–21.

Regional Geological Survey of Hunan Province (RGSH), 1987. Late Devonian to Early Carboniferous Strata and Biota. Geological Publishing House, Beijing. 200pp (in Chinese with English abstract).

Rowley, D.B., Ziegler, A.M., Nie, S.Y., 1989. Comment and reply on Mesozoic overthrust tectonics in South China. Geology 17 (4), 384−387.
Saltzman, M.R., 2003. Organic carbon burial and phosphogenesis in the Antler Foreland Basin: an out-of-phase relationship during the Lower Mississippian. Journal of Sedimentary Research 73 (6), 844−855.
Shao, L.Y., 1997. Sedimentology and Geochemistry of the Lower Carboniferous in Central Hunan, Southern China. China University of Mining and Technology Press, Beijing. 208pp (in Chinese with English abstract).
Shao, L.Y., Liu, Q.F., 1994. Trace fossils and their environmental distribution for Lower Carboniferous in central Hunan, southern China. Journal of Stratigraphy of China 18 (3), 170−180 (in Chinese with English abstract).
Shao, L.Y., Zhang, P.F., 1993. Lower Carboniferous tempestites in central Hunan, southern China. Scientia Geologica Sinica(Overseas Edition) 2, 417−428.
Shao, L.Y., Zhang, P.F., Gayer, R.A., Chen, J., Dai, S., 2003. Coal in a Carbonate Sequence Stratigraphic Framework: The Upper Permian Heshan Formation in Central Guangxi, Southern China. Journal of the Geological Society, London 160. 1−15.
Shao, L.Y., Zhang, P.F., Liu, Q.F., Zheng, M.J., 1992. Lower Carboniferous Ceshui Formation in central Hunan, southern China: depositional sequences and episodic coal-accumulation. Geological Review 38 (1), 52−59 (in Chinese with English abstract).
Stasiuk, L.D., Fowler, M.G., 2004. Organic facies in Devonian and Mississippian strata of Western Canada Sedimentary Basin: relation to kerogen type, paleoenvironment, and paleogeography. Bulletin of Canadian Petroleum Geology 52 (3), 234−255.
Tucker, M.E., 1985. Geological Society. Shallow-marine Carbonate Facies and Facies Models, 18. Special Publications, London. 147−169.
Wang, G.X., Jing, Y.J., Zhuang, J.L., Zhang, C.F., 1987. The Devonian-Carboniferous boundary of benthonic facies in central Hunan. Geological Review 33 (4), 299−309 (in Chinese with English abstract).
Wang, H., 1985. Atlas of the Palaeogeography of China. Cartographic Publishing House, Beijing.
Wang, Y., Jin, Y., 2000. Permian palaeogeographic evolution of the Jiangnan basin, south China. Palaeogeography, Palaeoclimatology, Palaeoecology 160, 35−44.
Wright, V.P., 1986. Facies sequences on a carbonate ramp: the Carboniferous limestone of south Wales. Sedimentology 33, 221−241.
Wright, V.P., 1994. Early Carboniferous carbonate systems: an alternative to the Cenozoic paradigm. Sedimentary Geology 93, 1−5.
Wu, H., Kuang, G., Wang, Z., 1997. Preliminary study on Late Palaeozoic tectonic sedimentary settings in Guangxi. Scientia Geologica Sinica 32, 11−18 (in Chinese with English abstract).
Wu, X.T., 1982. Storm generated depositional types and associated trace fossils in Lower Carboniferous shallow marine carbonates of Three Cliff Bay and Ogmore-by-sea, South Wales. Palaeogeography, Palaeoclimatology, Palaeoecology 39, 187−202.
Zhou, Z.C., Flügel, E., 1986. Carbonate ramp deposition: middle to upper Carboniferous microfacies of eastern Anhui and southern Jiangsu, China. Facies 14 (1), 201−233.