Chapter 1. Introduction: The Yangtze platform, overview

The Precambrian/Cambrian transition is one of the most exciting periods in Earth's history because it records unique major changes in atmosphere and ocean chemistry, and in life's evolution. It is marked by the first occurrence of complex animals during the Ediacaran and a spectacular increase in their diversity, with the first occurrence of most extant phyla during the Cambrian. Thus, the understanding of the bioradiation conditions will bring answers to understand a part of modern evolution. Worldwide, Proterozoic sediments are rarely exposed sufficiently well to allow sedimentary analysis, correlation, and multidisciplinary approaches. However, on the Yangtze platform, tectonics and erosion have affected Ediacaran formations only moderately. Moreover, the Yangtze platform revealed an astonishing and unique fossil record with (for example) metazoan embryos of the Weng'an phosphorite mine (Xiao et al., 1998; Martin et al., 2003). Thus, the Yangtze platform combines indispensable conditions for a good understanding of the Ediacaran and Cambrian bioradiations.
The sedimentary research group within the Sino-German program "From 'Snowball Earth' to the Cambrian bioradiation…" had the purpose to construct a framework correlation between shelf and slope sections, between the fossiliferous but stratigraphically discontinuous shallow-water sections to the potentially continuous but fossil-free deep-water sections.

This chapter is a presentation of the Ediacaran Yangtze platform (central China) and of the specificity of the Ediacaran and early Cambrian system. It introduces the studied area by describing the locations of the visited sections, the stratigraphic framework of my work, and the tectonic setting.

1. Study area

1.1. Location

During two field seasons of six weeks each in 2002 and 2003, I visited more than 30 sections, amongst which I selected 22 sections for a detailed sedimentary analysis. These sections are located along the southern margin of the Yangtze platform in Hunan, Hubei, and Guizhou Provinces between 32°N and 26°N (Fig. 1). Data of local literature (Bureau of Geology and Mineral Resources, 1987, 1988, 1990) are used to complete my data set. The visited sections have been arranged in two transects. The northern transect (1) includes seven sections from central Hubei province to the northern border of Hunan province, through the Yangtze platform shelf environment (Fig. 1 and 2). The southern transect (2) involves thirteen sections and trends NW-SE through central Hunan province in the Yangtze platform slope environment (Fig. 1 and 2). The outcrop quality of visited sections in Guizhou province rarely allowed a detailed sedimentary analysis. Nonetheless, some of these sections have been integrated in the general facies map (Chapter 2, Fig. 13) of the platform.

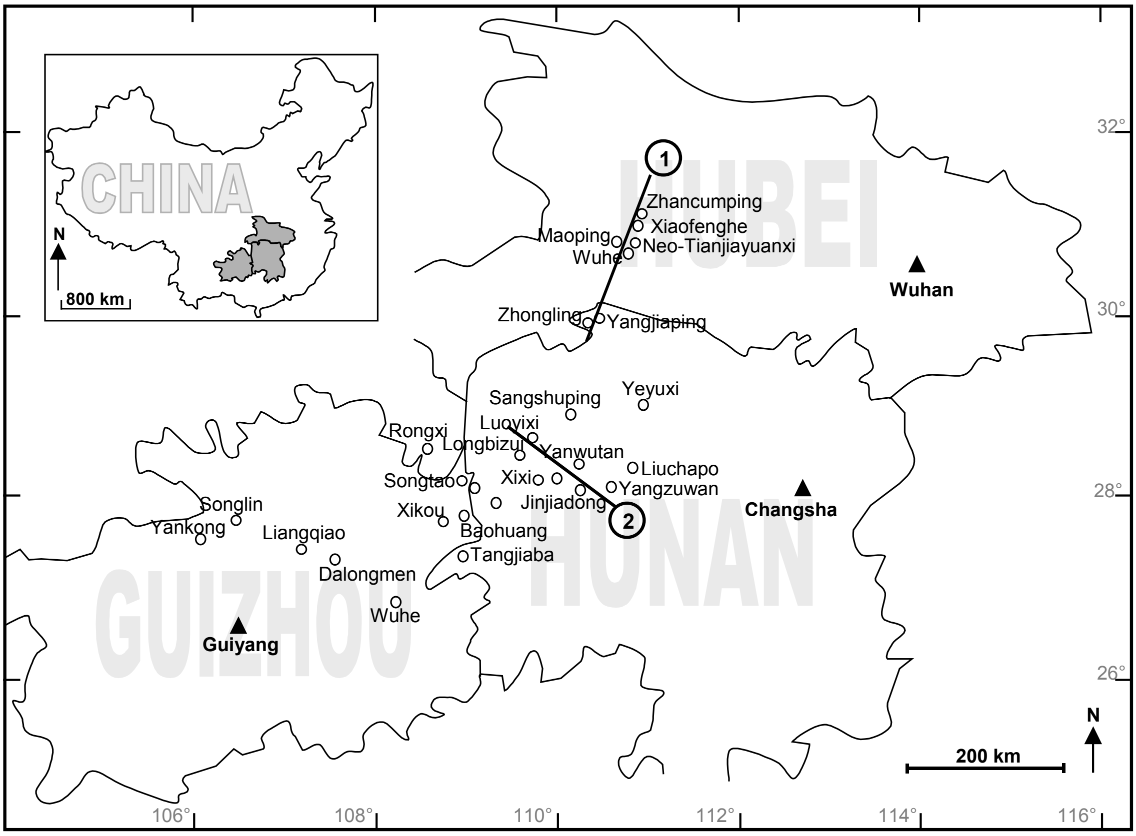

Fig. 1. Location of visited sections on the southern margin of the Yangtze platform. Line No. 1 corresponds to the shelf transect studied in Chapter 3. Line No. 2 is the slope transect studied in Chapters 4 and 5.

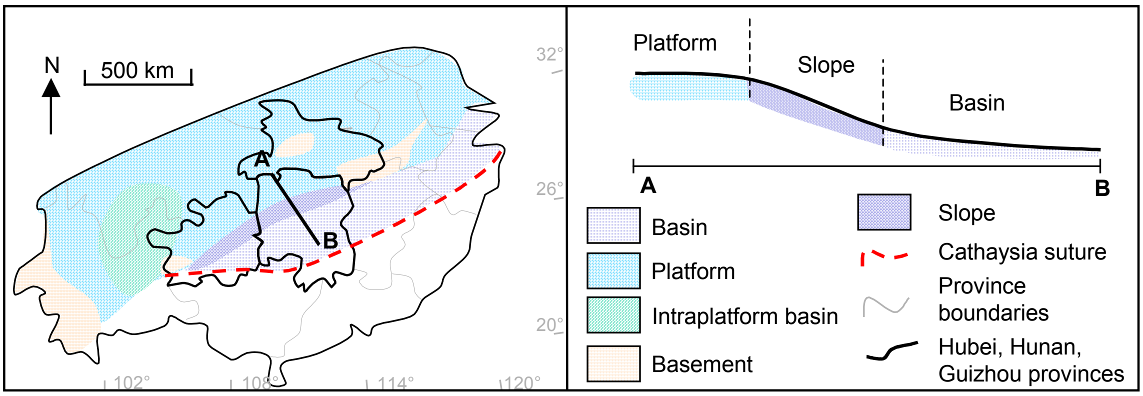

Fig. 2. Previous paleoenvironmental reconstruction (after Steiner, 2001).

1.2. Stratigraphic succession on the southern margin of the Yangtze platform

In the regional stratigraphy of the Yangtze platform, different names are used for almost the same time period based on geographical or lithological changes (Fig. 3 and 4). In order to simplify the following discussion, I chose to use only the names of the formations described below. Erdtmann and Steiner (2001) propose a complete review of equivalent formation names.

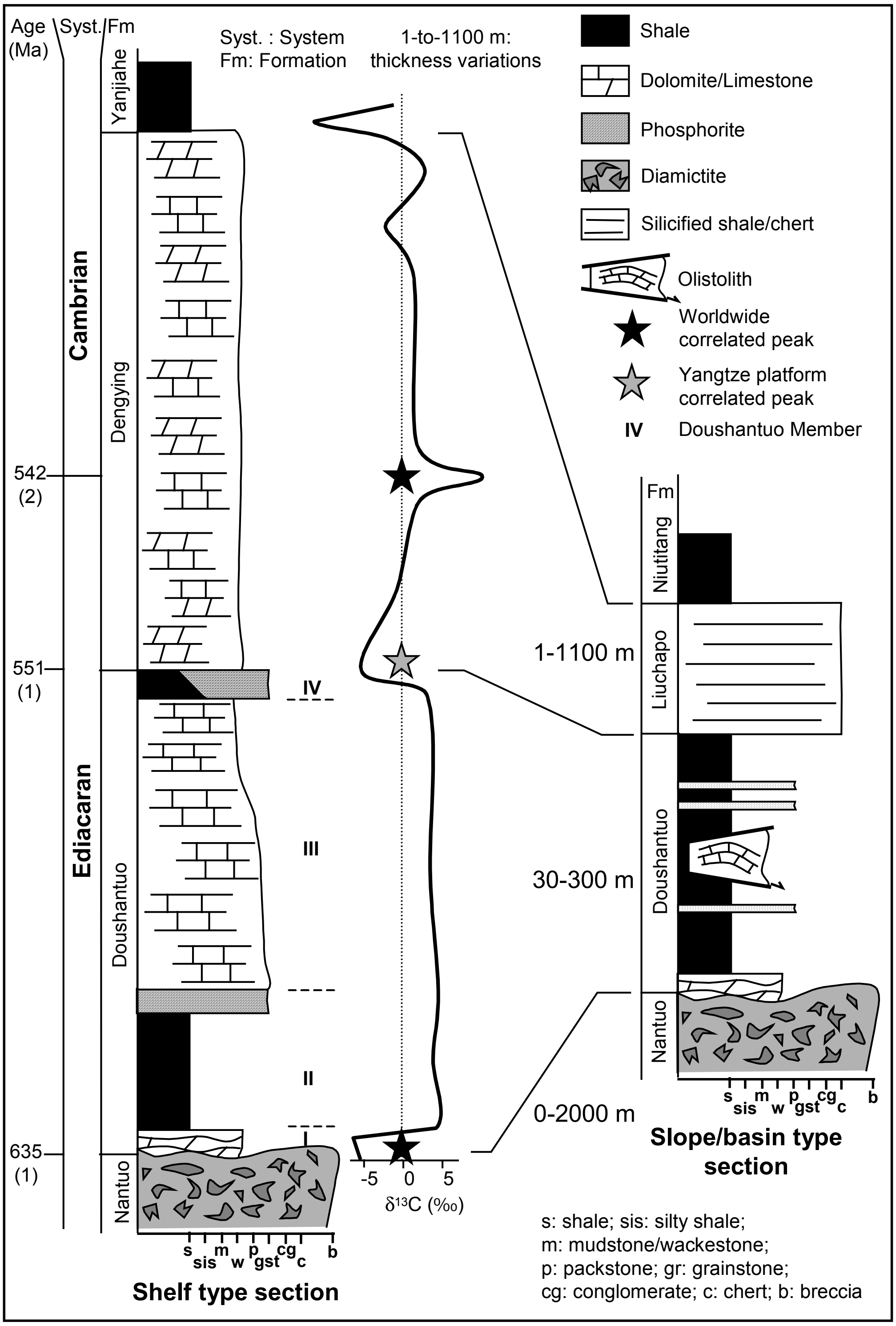

Fig. 3. Correlation of the stratigraphic columns in shallow- and deep-water environment of the Yangtze craton. The carbon isotope curve allows a regional and worldwide correlation. (Compiled from Erdtmann and Steiner, 2001; Jiang et al., 2003b; Zhang et al, 2003; Zhu et al., 2003; Goldberg et al., 2005 ; Ages: (1) Condon et al., 2005 ; (2) Brasier et al., 1994).

The Nantuo Formation has not been dated directly; however, the underlying Datanpo Formation has yielded an age of 758+/-23 Ma (Yin et al., 2003) and Condon et al. (2005) dated the top of the Nantuo Formation (base of Doushantuo Formation) at 635+/-1.3 Ma. Therefore, the Nantuo Formation is time-equivalent to the Marinoan glaciation. The Nantuo Formation principally consists of matrix-supported diamictites with dm-to-cm-sized pebbles of different origin and age. The clasts can show deep, decimetre-long grooves, induced by the movement of ice and the contact between clasts. The thickness of this formation ranges between 2000 m and 0 m (Wang and Li, 2003; Zhang et al., 2003; Dobrzinski et al., 2004; Dobrzinski and Bahlburg, submitted). These diamictites were largely interpreted as tillites; however, the glaciogenic character of the diamictites is locally doubtful (Bahlburg, 2004; Eyles and Januszczak, 2004). Deposition of the Nantuo Formation took place at the end of Rodinia rifting and at the beginning of the thermal passive-margin subsidence (Wang and Li, 2003).

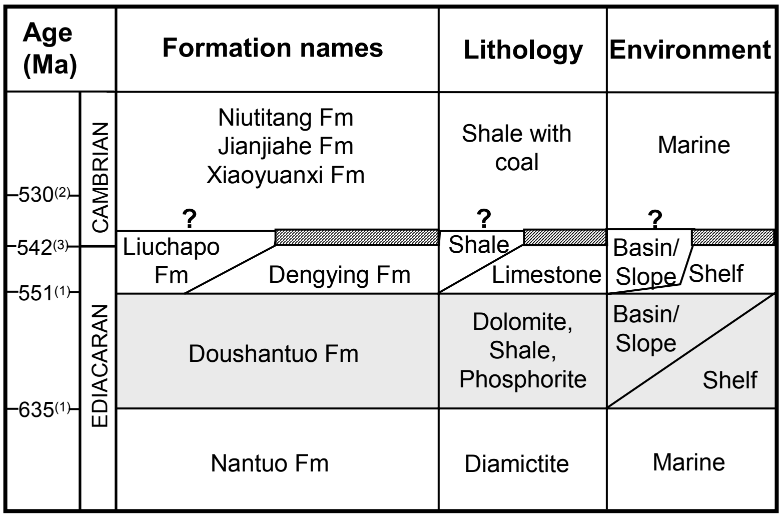

Fig. 4. Stratigraphic column of the southern margin of the Ediacaran Yangtze platform. The Doushantuo Formation is sandwiched by the Nantuo Formation diamictites at the base and by the Liuchapo Formation silicified shales or Dengying Formation dolomitized limestones at the top. Ages: (1) Condon et al. (2005); (2) Erdtmann and Steiner (2001); (3) Brasier et al. (1994). Locally, Liuchapo Fm. shows Small Shelly Fossils. Thus, the stratigraphy position of Liuchapo Fm is still debated.

- The age of the Doushantuo Formation reaches from 635 Ma to 551 Ma (U/Pb on zircons; Condon et al., 2005). The thickness of Doushantuo Formation varies from several hundred meters on the shelf to tens-of-m in the basin. According to classical regional stratigraphy, the Doushantuo Formation has four members. Its lowermost member is the famous three-to-six-m-thick “cap carbonate”. These carbonates are reported worldwide for having a major negative peak of the carbon isotope curve (Fig. 3). According to the “Snowball Earth” theory (Kirschvink, 1992; Hoffman et al., 1998; Hoffman and Schrag, 2000; 2002), this anomaly represents rapid chemical precipitation of calcite/dolomite following the melting of the ice. “Cap carbonates” also show unusual sedimentary structures such as low-angle hummocky crossbedding, large “tepee” structures, and soft-sediment deformations (James et al., 2001; Nogueira et al., 2003; Allen and Hoffman, 2005). Black shales ranging from 1 m to several m thick overlie the „cap carbonate“ and represent the second member of Doushantuo Formation. These shales are usually interpreted as a Highstand System Tract induced by deglaciation and the concomitant rise of sea level (Wang et al., 1998; Jiang et al, 2003a; Allen and Hoffman, 2005). The third member consists of interbedded black shales and limestones. The fourth member consists of black shales or phosphorites. Unfortunately, few visited sections extend over the entire Doushantuo Formation and the 4th member is often covered. In central Hunan, Liuchapo Formation slide sheets in slope environment erode the top of the Doushantuo Formation (Chapters 4 and 5). On the shelf, an erosional surface (e.g. Songlin section, Guizhou province, Appendix 3) or bentonites (e.g. Maoping and Wuhe sections, Hubei province) locally mark the transition between Doushantuo Formation and the overlying Dengying Formation. This segmentation of the Doushantuo Formation in four members is applicable only for the shelf environment of the Yangtze platform; indeed, if carbonate intervals are present in the slope/basin environment, they may represent slide sheets such as described in Chapter 4. Thus, the carbonates in slope environment may not be time-equivalent to the Member III of Doushantuo Formation on the shelf.

- The Dengying and Liuchapo Formations (551 Ma - 530 Ma) are considered as time-equivalent (Erdtmann and Steiner, 2001; Zhu et al., 2003). These two formations differ from each other by depositional environment and, then, by their sedimentary record. The Dengying Formation consists of dolomitized limestones and includes a large spectrum of structures and textures characterising the shallow-water shelf environment, such as oolith grainstones, storm-induced breccias, and stromatolitic laminations (e.g. Maoping and Wuhe sections, Hubei province, Chapter 3). Despite of its apparently short period of deposition (~20 Ma), the Dengying Formation reaches several hundred meters in thickness. Basinward, the Dengying Formation grades in the Liuchapo Formation, which consists of several tens-of-m-thick silicified black shales. Turbidites and several tuffaceous beds are interbedded with the black shales. Slump folds and large-scale limestone olistostromes affect locally the Liuchapo Formation.

A detailed facies interpretation of the Doushantuo and Dengying sedimentary record is hindered by widespread dolomitization, silicification, and local hydrothermal alteration.

1.3. Tectonic setting

The Ediacaran Yangtze platform represents the present-day central part of China and covers over 800,000 km^2 between the Qin-Lin fault to the north and the Cathaysia suture to the south. These major structures result from the Yangtze craton collision with the North China craton during the early Triassic and with the Cathaysia volcanic arc during the Silurian (Wang and Mo, 1995; Kenneth and Chen, 1999) (Fig. 5). However, these collisions deformed only moderately the sedimentary cover of the Yangtze platform. Later, Cretaceous extension created large, fault-bounded basins, such as the Jianghe basin in Hubei and Hunan provinces, filled with continental facies (Fig. 6). Thus, Proterozoic-Paleozoic strata on the Yangtze platform are preserved in a thickness of several kilometres and are moderately and large-scale folded. Two major fault directions trending ENE (1 on Fig. 6) and N-to-NNE (2 on Fig. 6) constrain the Proterozoic and Cambrian stratigraphic architecture of the southern Yangtze platform. According to Ma et al. (1984), these faults result from continental accretion during the end of Mesoproterozoic and early

Neoproterozoic. Wang and Li (2003) describe rifts developed during the Neoproterozoic, which appear to have the same trend as the Meso- and early Neoproterozoic faults documented by Ma et al. (1984) (Fig. 6).

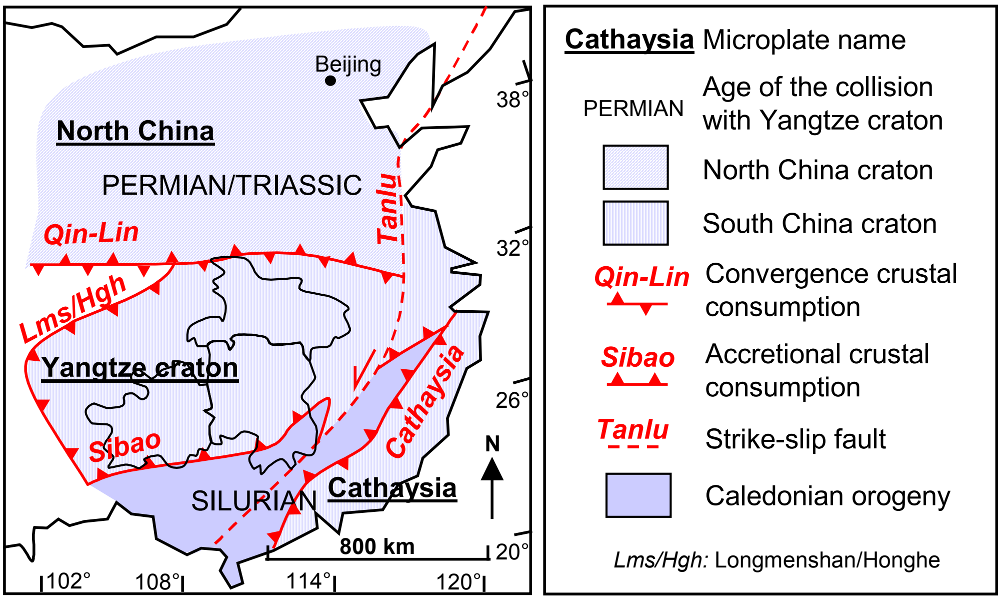

Fig. 5. Tectonic blocks of present-day eastern China. The North China craton collided with the Yangtze craton during the Permian/Triassic, while the Cathaysia arc collided with Yangtze platform during the Silurian. The Yangtze craton added the Cathaysia arc to form the South China platform (After Wang and Mo, 1995).

Paleomagnetic studies allow estimating the location of the south China craton during the Rodinia accretion (approx. 1070 Ma; Li et al., 1995) and during its breakup (approx. 600 Ma- 580 Ma) (Fig. 7). The South China craton moved from 60°-N latitude in the Rodinia supercontinent to an equatorial location during the beginning of the Doushantuo Formation (Li et al., 1995; Evans et al. 2000; Hartz and Torsvik, 2002; Powell and Pisarevsky, 2002; Condie, 2003; Macouin et al., 2004). During the Ediacaran Doushantuo Formation, the southern margin of the Yangtze platform evolved as a passive margin (Wang and Li, 2003); however, inherited faults may have controlled the development of some facies. Indeed, the Ediacaran Yangtze platform slope in Hunan province follows the line of the major fault trend No.1 (Fig. 6), which extends from Zhenyuan (Guizhou province) to Nanchang (Jiangxi province), via Zhijiang and Xupu (Hunan province). The Yangtze platform slope in Guizhou province corresponds to the orientation of the fault trend No.2 (Fig. 6). The geometry and size of intrashelf basins in Maoping area may also be constrained by inherited early Neoproterozoic faults, as postulated in Chapters 2 and 3.

1.4. The fossil record

The Ediacaran/Cambrian transition was a period of important biologic changes. The Ediacaran records the first Metazoan bioradiation, marked by the first occurrence followed by the decline in the abundance, size, and diversity, and finally, by the extinction of this Ediacaran fauna (Brasier, 1996). The extinction of the Ediacaran fauna at the end of the Neoproterozoic seems, nonetheless, partial (Crimes and McIlroy, 1999; Amthor et al. 2003; Grey et al., 2003). Some Ediacaran specimens were found in Cambrian sediments (Jensen et al., 1998; Runnegar, 2000; Clapham and Narbonne, 2002; Narbonne and Gehling, 2003). The Early Cambrian is also a period of bioradiation with a rapid increase in faunal diversity (during this period, almost all of the actually known phyla appeared, Fig. 8), in abundance of shell secretors (S.S.F.: Small Shelly Fossils) and in complexity of faunal behavior (so-called “agronomic revolution”; Seilacher, 1999; Bottjer et al., 2000) (Fig. 9).

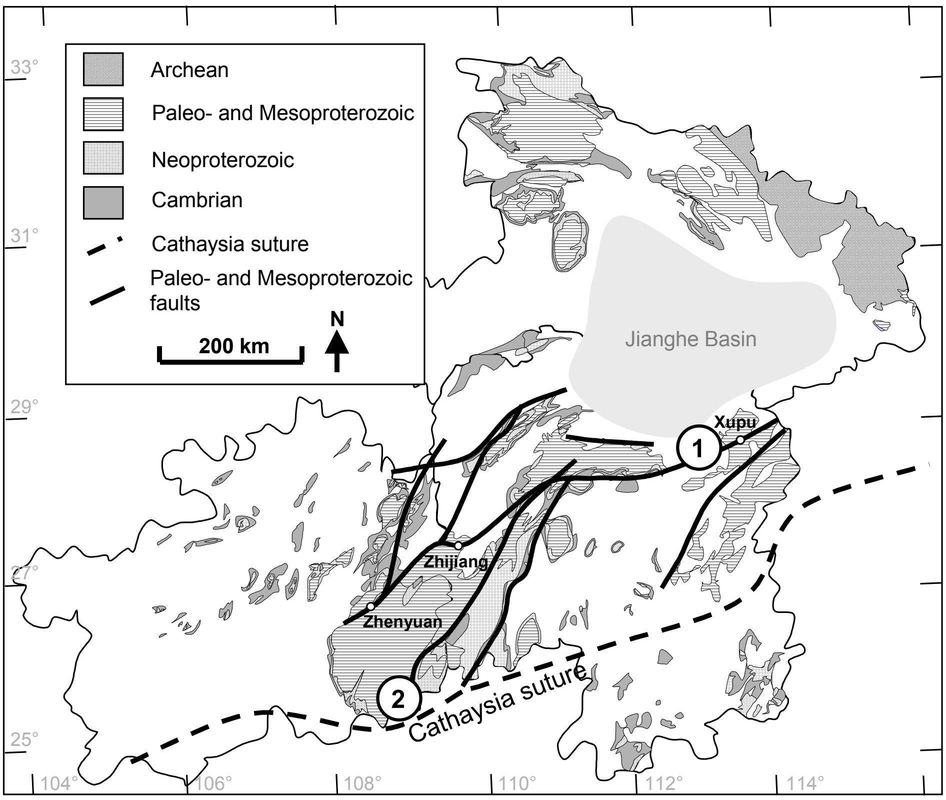

Fig. 6. Geological map of Hunan, Hubei and Guizhou provinces showing the Meso- and Neoproterozoic fault systems and terranes (after Ma et al., 1984; Wang and Mo, 1995). (1) and (2) are Mesoproterozoic and early Neoproterozoic faults, which may have constrained the geometry and location of the Ediacaran Yangtze platform slope.

The Ediacara biota (575 Ma (?) – 542 Ma (?), named after the Ediacara Hills, southern Australia, where these biota have first been described), characterized by its absence of hard parts (soft body), gave its name to the Ediacaran system. The most famous localities of Ediacaran fauna are scattered in southern Namibia (Germs, 1995; Saylor et al., 1995; Wood et al., 2002), in the Flinders Range in Australia (Christie-Blick et al., 1995; Jenkins, 1995; Walter et al., 1995; Gehling, 2000), at Mistaken Point in southeastern Newfoundland (Myrow, 1995; Narbonne and Gehling, 2003), at the Weng’an phosphorite mine in central China (Embryos of Ediacaran fauna (?)) (Yin et al., 2001; Chen et al., 2004; Yin et al., 2004), in the Lesser Himalaya (Shanker et al., 2004), and on the White Sea coast of northern Russia (Fedonkin, 1990; Vidal and Moczydlowska, 1995; Martin et al., 2000).

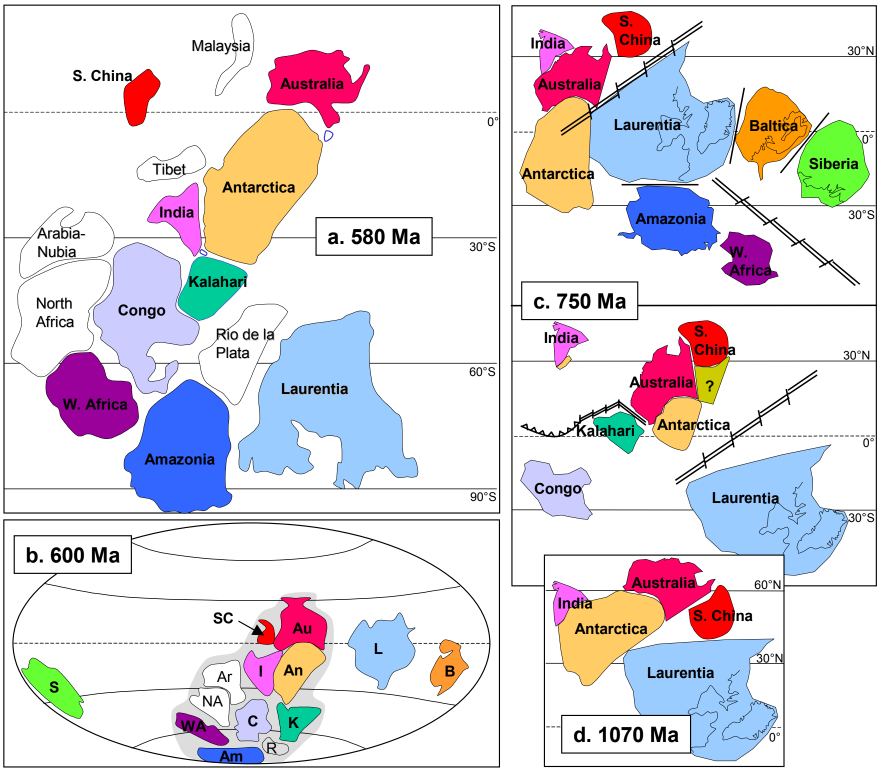

Fig. 7. Location of the South China block in Rodinia (1070 Ma) and during the beginning (750 Ma) and the end (600-580 Ma) of supercontinent breakup (compiled from Li et al., 1995; Hartz and Torsvik, 2002; Powell and Pisarevski, 2002; Condie, 2003; Macouin et al., 2004). S: Siberia, Au: Australia, SC: South China, L: Laurentia, B: Baltica, I: India, An: Antarctica, K: Kalahari, C: Congo, WA: West Africa, Am: Amazonia, Ar: Arabia, NA: North Africa, R: Rio de la Plata.

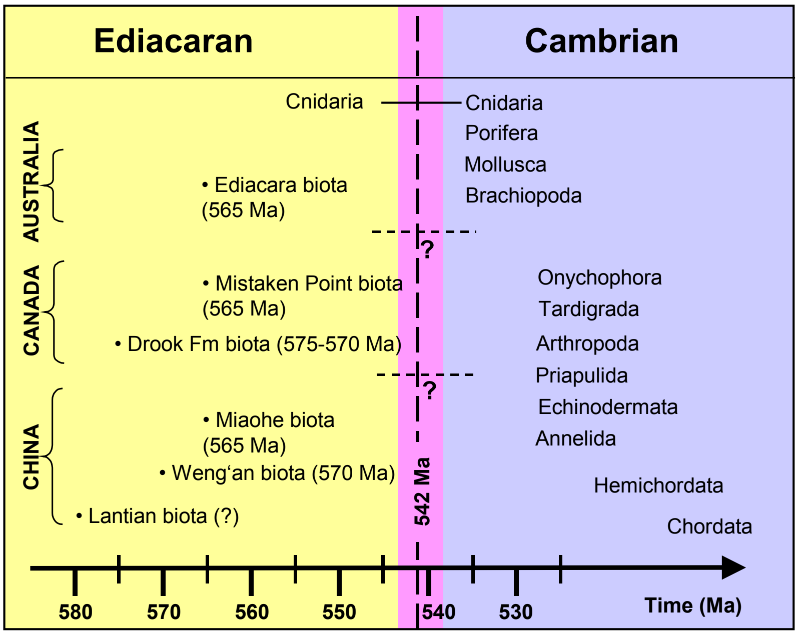

Fig. 8. The Cambrian bioradiation. The Precambrian/Cambrian transition records the first occurrence of the actual phyla (compiled from Valentine, 1995; Martin et al., 2000; Narbonne and Gehling, 2003; Zhu et al., 2003).

To explain the causes of the Ediacaran radiation, Harland (1989) and Hoffman and Schrag (2002) propose that global glaciations (see section "Ediacaran climate changes") created severe ecologic stress, forcing organisms to adapt through rapid and significant genetic changes. The late Ediacaran is also the period of major biological and ecological innovations such as mobility (> 555 Ma), calcification (550 Ma) and predation (< 549 Ma) (Narbonne, 2005).

The dramatic increase of diversity during the early Cambrian induced the occupation of new ecological niches and the appearance of new behavioral strategies. The animal activities (protection, predation, displacement) mixed sediments deeply. Material was exchanged between sediments and water (Fedonkin, 1994; Bottjer et al., 2000; Droser and Li, 2001; Altermann, 2002; Buatois and Mangano, 2003; Dornbos et al., 2004), inducing changes of the chemical composition of both (Seilacher, 1999). This so-called "agronomic revolution" indicates the activity of anatomically complex animals with complex behaviour (Fig. 9). Increase in trace fossil and small burrow quantity during the late Ediacaran (Weber, pers. comm.) predated the Cambrian "agronomic revolution".

Cloudina, a tiny worm, which built calcium carbonate skeletons, is the precursor of the abundant early Cambrian secretor organisms: Small Shelly Fossils (SSF) (Bengtson, 1994; Landing, 1994; Germs, 1995; Steiner et al., 2003). The Small Shelly Fossils belong to diverse animal groups. They range in size from 1 mm to 5 mm and include tubes, spines, cones, and platy shapes, some of which are not clearly related to modern groups yet. The most common skeletal materials are calcium carbonate (aragonite or calcite) and calcium phosphate. Protection against predation is proposed to explain the appearance of the first exoskeletons (Bengtson and Zhao, 1992; Maas et al., 2004).

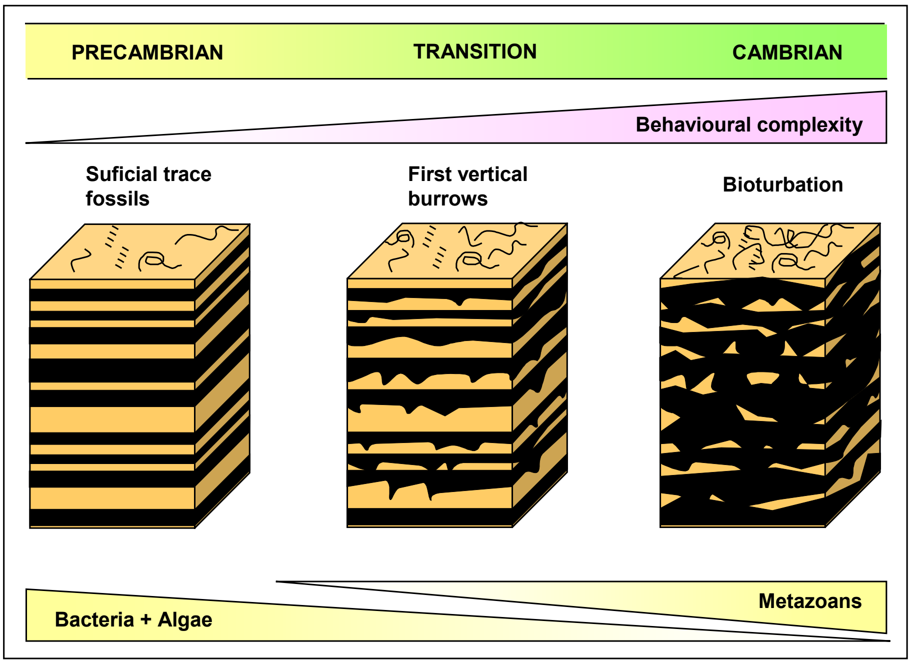

Fig. 9. Schema illustrating the agronomic revolution (or "substrate revolution"). Ediacaran (and following) complex organisms with complex behaviour mix the sediments to hunt, eat, or hide. The oldest burrows may be found in Ediacaran sediments. However, only after the Cambrian bioradiation bioturbation became effective to allow the exchange of components between sediment and the water column (modified after Seilacher, 1999; Bottjer et al., 2000).

Because of the exceptional nature of the fossil record showing a remarkable diversity with some specimens specific to China, Ediacaran and early Cambrian strata of the Yangtze platform have drawn scientific attention (Steiner, 1994; Xiao et al., 1998; Babcock et al., 2001; Babcock and Zhang, 2001; Steiner, 2001; Steiner and Reitner, 2001; Yin et al., 2001; Xiao et al., 2002; Braun et al., 2003; Steiner et al., 2003; Weber and Zhu, 2003; Li et al., 2004; Maas et al., 2004; Yin et al., 2004; Erdtmann et al., 2005). The Ediacaran organisms are well represented in China, among other; by the "Lantian biota" in Anhui province and "Weng'an biota" in Guizhou province (Yin et al., 2001; Chen et al., 2004; Yin et al., 2004). Weng'an biota, famous for the exceptionally well-preserved metazoan embryos (Xiao et al., 1998; Chen et al., 2004) and dated at 570 Ma, pushed back by 5 Ma (Martin et al., 2000; 2003) the metazoan occurrence with respect to the Ediacara biota in Newfoundland (565 Ma) (Fig. 8). The exceptional preservation of fragile embryos may be due to the early phosphoritisation (Briggs and Kear, 1993). A time-equivalent to the oldest Ediacara biota assemblage is represented on the southern margin of the Yangtze platform by the "Miaohe biota" in Hubei province (Xiao et al., 2002). If the worldwide correlation of Cambrian sections is facilitated by using SSF-based zonation, the worldwide correlation between Ediacaran sections is much more problematic. Indeed, the Ediacaran preserved fossils show such important diversity (certainly due to a preservational artifact, Erdtmann, pers. comm.) that the correlation of different biotas on the Yangtze platform and in the world is difficult.

1.5. Ediacaran climate changes

The Ediacaran recorded rapid climatic changes from icehouse to greenhouse conditions. Two (Harland, 1989), three (Germs, 1995) or four (Hoffman and Schrag, 2000) climate reversals between 750 Ma and 580 Ma have been postulated. Authors generally agree on the Sturtian (~748 +/- 12 Ma, Frimmel et al., 2002) and Marinoan (~663 +/- 4 Ma, Zhou et al., 2004) glaciations. The nearly worldwide observation of chemically precipitated dolomite (socalled "cap carbonate") immediately and with sharp contact above thick, largely glaciogenic diamictites lead to numerous investigations. The diamictite/dolomite succession suggests a high-temperature period ("greenhouse event") shortly after a low-temperature period ("icehouse event"). Diamictites attributed to glacial deposits are present on nearly all Ediacaran low-latitude cratons (Kilner et al., 2005). By extension, ice is likely to have covered a large part of the Earth. Glaciation induced a biosphere collapse, which, by the related ^{12}C-content decrease, biased the ^{13}C isotope atmosphere content to the ^{13}C isotope content of volcanic emission. Thus, the "cap carbonate" shows a negative δ^{13}C isotope anomaly. Moreover, unusual sedimentary structures (Nogueira et al., 2003; Allen et al., 2005) have been observed in these carbonates. Kirschvink (1992), then Hoffman et al. (1998), Hoffman and Schrag (2000; 2002), developed earlier ideas of Hambrey and Harland (1985) in postulating the "Snowball Earth" theory to explain field observations of a sudden climate change around 600 Ma.

Figure 10 illustrates the "Snowball Earth" theory postulated by Hoffman et al. (1998), in the five following phases:

1. The equatorial location of continents increased the average albedo of the Earth, which became colder.

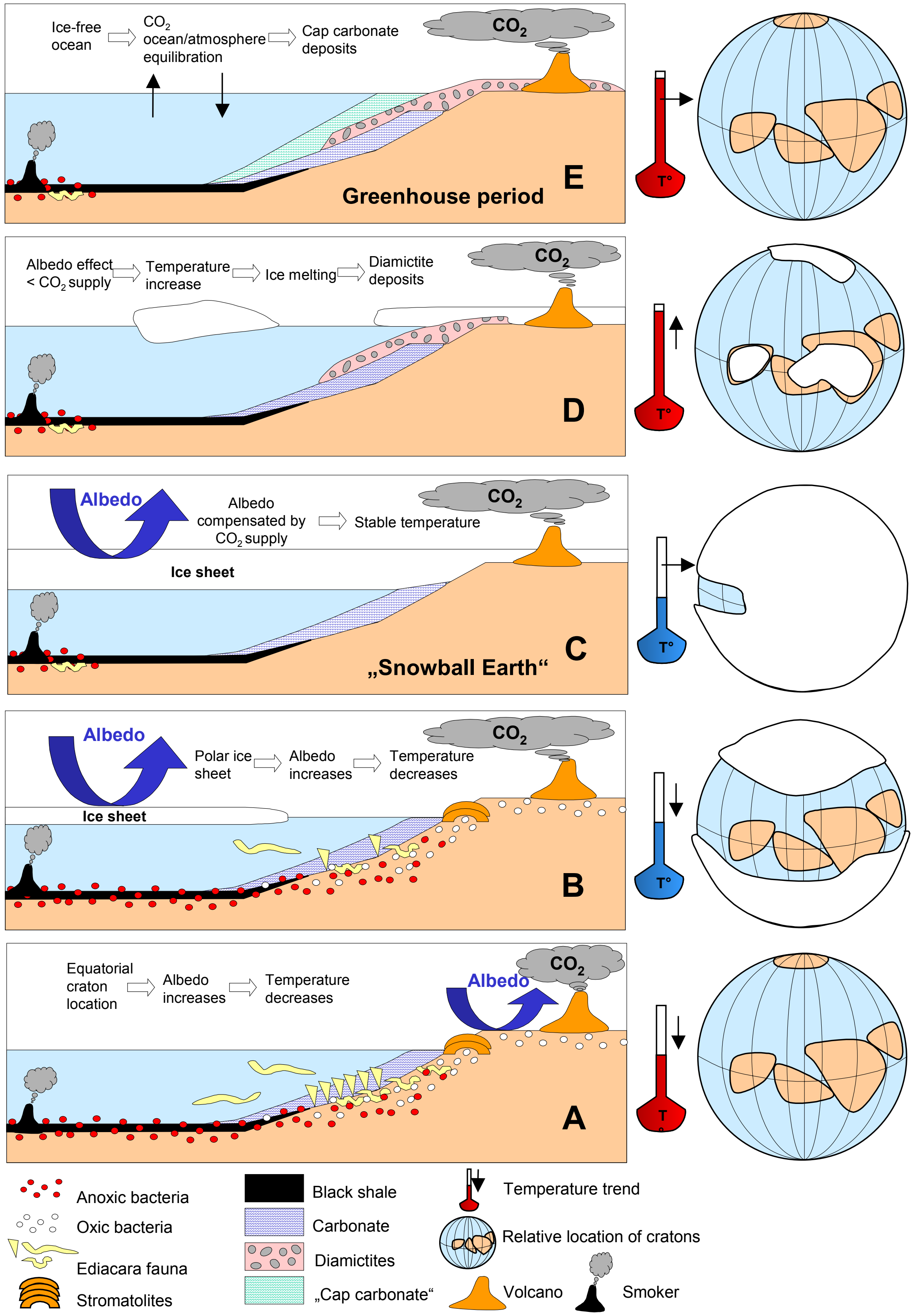

Fig. 10. Five phases of the “Snowball Earth” theory (after Hoffman et al., 1998)

2. Ice caps, nucleated at polar latitudes, started growing until they covered the entire globe. Thus, albedo increased and began a positive feedback loop.
3. Ice sheets shut down the chemical exchange between lithosphere, hydrosphere, and atmosphere. In the absence of C recycling, the atmospheric CO_2 content due to volcanic activity increased may have reached up to 0,12 bar over ~10 Ma (Hoffman et al., 1998).
4. The CO_2-related greenhouse effect increased the average temperature until it compensated the high albedo. Then, the ice sheets catastrophically melted, marked by the sedimentation of tillites and diamictites.
5. The melting of ice induced a resumption of the ocean/atmosphere exchange. “Cap carbonate” geochemical composition reflects the re-equilibration between the CO_2-rich atmosphere and ocean. The return to a “normal” ^{13}C isotope composition occurred at the end of the greenhouse period (top of “cap carbonate”) and recorded the recovery of photosynthesis and life (Hoffman and Schrag, 2000).

Recent studies indicated that the climatic conditions were not extreme and a “Slushball Earth” theory softened the “Snowball Earth” theory. Numerical models have shown that the equatorial ocean may have been free of ice, facilitating a return to “normal” climate (Hyde et al., 2000). Studies of Leather et al. (2002) or Allen and Hoffman (2005) shook more deeply the theory of Hoffman et al. (1998): the description in Oman (Leather et al., 2002; Allen and Hoffman, 2005; Kilner et al., 2005) of “interglacial” deposits during the suspected “snowball” period implicates only local glacial conditions. The “*destabilization of gas hydrate in terrestrial permafrost following rapid postglacial warming and flooding of widely exposed continental shelves and interior basins”* (Kennedy et al., 2001b) may also explain the “cap carbonate” isotopic anomaly, and reduce the need for drastic climatic changes (Kennedy et al., 2001a; Jiang et al., 2003b). The glacial origin of some diamictites, to date interpreted as tillites, is doubtful (Eyles and Januszczak, 2004).

2. The Doushantuo Formation

This study is focused on the Ediacaran Doushantuo Formation (except the “Cap carbonate”, the complexity of which requires a separate treatment), sandwiched between the Marinoan glaciation and the Cambrian bioradiation. This formation is particularly interesting because it includes the worldwide first occurrence of complex organisms (Weng’an biota) and the Ediacara-type Miaohe biota (Hubei Province). The organic-matter-rich black sediments of the Doushantuo Formation are underlain by diamictites of the Nantuo Formation and are overlain by dolomitized limestones of the Dengying Formation (shelf facies) or by the first occurrence of thin-bedded silicified (laminated) black shales of the Liuchapo Formation (slope facies) (Fig. 3).

Because Ediacaran biostratigraphic correlation is impossible (see section 1.4.), other correlation techniques have been applied to correlate the sedimentary record on the Yangtze platform.

The $\delta^{13}C$, $\delta^{18}O$ or $\delta^{14}S$ variation method has been proposed for regional and global correlation of Ediacaran sections (Knoll et al., 1995; Bartley et al., 1998; Kennedy et al., 1998; Myrow and Kaufman, 1999; Corsetti and Kaufman, 2003; de Alvarenga et al., 2004; Goldberg et al., 2003; Halverson et al., 2004; Goldberg et al., 2005; Guo et al., submitted). This method correlates peaks of isotopic variation curves, which is equivalent to correlate chemical variations of the environment. In the Doushantuo Formation, the negative $\delta^{13}C$ peak of the "Cap carbonate" and the positive peak near the Ediacaran/Cambrian boundary (Fig. 3) (Li et al., 1999; Zhu et al., 2003, Chen et al., 2004; Goldberg et al., 2003; Zhang et al., 2004; Guo et al., submitted) are characteristic of this period and are reported in many places in the world (e.g. Siberia: Knoll et al., 1995; Bartley et al., 1998; Scandinavia: Halverson et al., 2004; Brazil: de Alvarenga et al., 2004; California: Corsetti and Kaufman, 2003; Canada: Myrow and Kaufman, 1999; Congo: Kennedy et al., 1998…). However, the negative peak of the carbon isotope curve between the Doushantuo and Dengying Formations may be only regionally correlatable and may indicate another glaciation period around 555,2 +/- 6,1Ma (Zhang et al., 2005). However, no glaciogenic diamictites have been found. Even if isotopic analysis allows a global and regional correlation, the method lacks precision and the correlation of different biota remains difficult. Moreover, this method does not yield information on the dynamics of the depositional environment. The best way to correlate the Doushantuo Formation sedimentary record is geochronology. Numerous tuffaceous beds have been identified in the Doushantuo and Liuchapo Formations (Zhang et al., 2004; Condon et al., 2005). Unfortunately, beds are often highly weathered and few are available for dating. Until recently, the absolute age of the Doushantuo Formation remained problematic. Knoll and Xiao (1999), by comparing the $\delta^{13}C$ curve of the Doushantuo Formation with the worldwide-documented evolution, estimate the age of the Doushantuo Formation at between 600 Ma and 550 Ma. Condon et al. (2005), by using U/Pb dating on zircons, constrained the Doushantuo Formation between 635,51 +/- 0,54 Ma (ash bed interbedded in the "cap carbonate") and 551,1 +/- 0,7 Ma (ash bed at the contact between Doushantuo and Dengying Formations). This study confirmed the upper age limit of the Doushantuo Formation proposed by Knoll and Xiao (1999), but moved the lower age limit by 35 Ma. Zhang et al. (2005), using U/Pb on zircons, constrained the Doushantuo Formation between 621 +/- 7 Ma (tuffaceous bed in black shale ca. 2,5 m above the "cap carbonate") and 555,2 +/- 6,1 Ma (tuffaceous bed near the Doushantuo/Dengying Formations boundary), which correspond to the ages proposed by Condon et al. (2005). However, a detailed correlation of Ediacaran biota needs a tight absolute age network of the Doushantuo Formation sedimentary record. Such a geochronologic network may facilitate the correlation between sections, indicate the sedimentation rate, and the rate of fauna evolution. Lithological correlation has been abundantly used for correlating the Doushantuo Formation. This method failed to yield an evolution of the platform geometry through time because it did not consider lateral facies variations (Zhu et al., 2003). Only phosphorites no. 1 (middle Doushantuo Formation) and no. 2 (upper Doushantuo Formation) (Goldberg et al., 2005), because possibly related to global events (Cook and Shergold, 1986; Gubanov, 2002), may represent synchronous deposits and, therefore, may allow lithological correlation. This aspect is briefly developed in Appendix 1.

3. DEVELOPMENTS IN THIS WORK

Because none of the previously described methods allow a precise sedimentary correlation of the Yangtze platform sedimentary record, my work focuses on sequence-stratigraphic correlation, which yields a sedimentary evolution of the platform in time and space. Based on low-frequency sea level variations, this correlation technique is usable at regional scale (Miall, 1997; Wang et al., 1998; Einsele, 2000). This method demands good field observations and good-quality outcrops.

In a first step, I collected literature data that I compiled with my own data to obtain an overview of the Yangtze platform geometry (Chapter 2). The facies, isopachs, and interpretative maps of the southern margin of the Doushantuo Formation on the Yangtze platform confirm and refine previous paleoenvironmental reconstructions proposed by Steiner (1994, 2001) (Fig. 2). This approach highlights the relationship between the “facies patchwork” observed on the shelf and the previous rifting period of the platform. It appeared that local facies changes are constrained by relief on Meso- and early Neoproterozoic faults. This estimate of Yangtze platform geometry and sedimentary evolution introduces a more detailed sedimentary study of the shelf (transect no. 1, Fig. 1, Chapter 3) and of the slope (transect no. 2, Fig. 1, Chapters 4 and 5).

In a second step, I extracted the sequence-stratigraphic signal of the shelf sedimentary record. Thus, the facies analysis in Chapter 3 identified ten facies related to five depositional environments (Table 1). Two depositional environment models, an epeiric rimmed shelf and a wave-dominated open shelf, correspond to the observed facies associations. The evolution in time and space of these depositional environments is organized in two-and-a-half 2nd-order parasequences, which facilitated the correlation between shelf sections.

In a third step, and to meet the purpose of this project, I tried to apply sequence stratigraphy to the slope environment in order to relate it more closely to the shelf sedimentary evolution. However, the shallow-water limestone intervals are allochthonous slide sheets and do not represent a sea level drop and platform progradation. This aspect is developed in Chapter 4.

The correlation of the allochthonous limestone facies with shelf sections shows that the sliding occurred during regression at the end of parasequence II (Chapter 5). The depositional environments deduced from the facies analysis of slide sheets are all the more important because very few parts of the former shelf edge are actually accessible.

4. Summary

The absence of major tectonic deformations, the continuity of the sedimentary record from the Marinoan glaciation to the middle Cambrian, and the exceptionality of the fossil record explain the interest that the Ediacaran Yangtze platform has caused in the scientific community. The Yangtze platform appears to be an excellent place to identify the drivers of the Ediacaran and Cambrian bioradiations. The correlation of Ediacaran sections and biota worldwide and on the Yangtze platform forms an important challenge for Precambrian paleontologists. Biostratigraphy and lithostratigraphy remained inefficient for the Ediacaran correlation. Correlation using stable isotope anomalies allows a worldwide and regional correlation but lacks precision to correlate Doushantuo Formation biota. More absolute dating may be published in the immediate future and may provide a useful age network for correlation. My work provides a detailed sedimentary analysis of the shelf and slope environments of the Ediacaran Yangtze platform that should help to calibrate isotopic variation curves and to identify the main tuffaceous beds used for absolute age dating. Moreover, this work proposes a regional correlation framework using sequence stratigraphy.

Facies association	Facies	Description	Components	Grain descriptions	Bedding type	Sedimentary structures	Vertical sequence	Interpretation	Sections	Chapters 4 and 5
Shelf environment										
Lagoonal	Facies 1	Laminated shales/mudstones /wackestones interbedded with grainstones/packstones	(Calcareous) shales, medium sand-sized packstones/grainstones	mm-sized intraclasts, dolomite and opaque minerals	Thin-bedded, laterally continuous, non-cyclic	Thin parallel laminations due to biomats	5,7	Lagoon with clastic input	Songling, Xinglong (Guizhou), Zhancumping (Hubei)	X
Peritidal	Facies 2	Biolaminated phosphorites, dolomicrite and/or patchy chert. Locally, interbedded with fine-sized grainstones	Silica, Phosphorite, Evaporites	mm-sized dolo- or phos-intraclasts. Stromatolitic clasts.	~10-cm thick, laterally continuous, non-cyclic. Lenticular bedding for the grainstones	Bio-laminations, desiccation structures as mudcracks and "tepees"	7	Edge of lagoon with emergence periods	Zhancumping (Hubei), Luoyixi, Yanwutan (Hunan)	Facies 1
	Facies 3	Phosmicrites with evaporitic dolomicrites. Collapse and micro breccias.	Apatite cement, dolomite micrites, evaporites	cm-to-dm-sized phos-intraclasts	Laterally discontinuous, lenticular bedding	Collapse breccias, evaporite-induced convolutes	2	Peritidal, shallow-water lagoon edge, evaporitic conditions, eolian influences	Xixi (Hunan); Zhancumping (Hubei)	Facies 2
	Facies 4	Phosgrainstones with lenticular dolomicrites	Phos- intraclasts, biolaminations, dolomicrite, apatite cement	mm-sized, very well-sorted phosintraclasts	Laterally discontinuous, cm-thick lenticular bedding	Common convolute bedding in the dolomicrites	1,3	Peritidal lagoon edge. Evaporitic conditions	Zhancumping (Hubei), Zhongling (Hunan)	X
Shoal	Facies 5	Breccias, debrites and conglomerates	Dolomite micrite, (phos-) intraclasts, phosooliths, calcitic cement	cm-sized, phos- or dolo-intraclasts. mm-sized phosooliths and oncoliths coated by phosphorite around relic crystals, intraclasts or ooliths.	5cm-to-3m thick, limited lateral extent	Mass deposit, sometimes erosive base	6	Storm-induced instabilities	Zhongling, Yangjiaping (Hunan)	X
	Facies 6	Grainstones with trough or planar crossbedding	Dolo- and phos- intraclasts, calcitic cement	mm- to cm-sized phos- and dolo-intraclasts and/or phosooliths	5-to-20cm thick, limited lateral extent	dm-scale trough and planar crossbedding	5	Wave-influenced environment and tidal channel	Zhongling, Yangjiaping (Hunan)	X
Shallow subtidal	Facies 7	Medium sand-sized wackestones / packstones with horizontal laminations or trough crossbedding. Locally, thin-bedded breccia	Intraclasts, carbonate micrite matrix, evaporite (?).	Medium sand-sized dolo-intraclasts. Cm-sized phos-intraclasts in breccia	cm-to-dm-thick bedding, laterally continuous	Winnowing-induced horizontal laminations, cm-scale trough crossbedding	1, 4, 8	Above fairweather wave base (~30 m water depth)	Xixi, Yanwutan, Luoyixi (Hunan); Zhancumping, Xiaofenghe, Tianjianyuanzi, Wuhe (Hubei)	Facies 3
	Facies 8	Cross-stratified grainstones/medium-sand-sized grainstones/packstones	Intraclasts, recrystallized dolomites, micrite	Medium sand-sized dolo-intraclasts	dm-thick bedding,cross-strated, laterally discontinuous	Trough crossbedding	7	Sand banks (5 to 60 m water depth)	Yanwutan (Hunan); Zhancumping, Xiaofenghe (Hubei)	Facies 3
Basin/slope environment										
Basin or slope	Facies 9	Shales, shales interbedded with phosphorites and/or siltstones.	(Calcareous) shales, apatite cement, (calcareous) siltstones		Thin-bedded, laterally continuous, non-cyclic	Thin parallel laminations due to discrete changes in grain size	1, 4, 7	Basin and slope with turbidite deposits	All sections	Facies 4
	Facies 10	Shales, mudstones, wackestones/packstones, slump folds, olistoliths	(Calcareous) shales, fine-grained sand wackestones/ packstones. Varying in olistoliths		Thin-bedded, laterally discontinuous, non-cyclic	Thin, plan-parallel laminations, slump folds, varying in olistoliths	9	Slope with turbidite deposits and olistostromes	Maoping, Wuhe (Hubei); Luoyixi, Longbizui, Xixi, Yanwutan, Sangshuping, Liujata, Jinjiadong, Liuchapo, Yunmaxi (Hunan)	Facies 4

Table 1. Summary table of facies for the southern margin of the Doushantuo Formation Yangtze platform. Numbers in the column "Vertical sequence" refer to facies in column 2.