Science in China Series D: Earth Sciences

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Devonian Frasnian-Famennian transitional event deposits of Guangxi, South China and their possible tsunami origin

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A suite of event deposits, isochronous and interrelated in origin, occurs widely near the Frasnian-Famennian boundary in Guangxi, South China. It is mainly distributed in the facies areas of the platform-margin slope and inter-platform rift-trough. The rudstone or calcirudite occur in the Liujing section of Hengxian and Luoxiu and Baqi sections of Xiangzhou in the facies area of platform-margin slope. The turbidites are observed in the sections of Yangdi and Baisha of Guilin, Du'an of Debao, Nandong and Sanli of Wuxuan, Xiangtian, Ma'anshan of Xiangzhou, Nayi of Chongzuo, Yunpan of Shanglin in the facies area of inter-platform rift-trough. The massive homogenites occur in sections of Mangchang, Luofu and Road from Nandan to Tian'e and Ma'anshan etc in the facies area of inter-platform rift-trough. Herein event deposits can be correlated in stratohorizon to the turbidite in the bottom of the Lower *triangularis* Zone in Hony railroad cut of Belgium, Devils Gate of Nevada, USA, Atrous of Morocco, South Urals and Fore-Kolyma of northeastern Siberia of Russia, and erosional discontinuities and brecciation in the Frasnian-Famennian boundary in South Polish-Moravian shelf. The event deposits could be caused by a violent tsunami related to bolide impacts into ocean.

Devonian, Frasnian-Famennian mass extinction, South China, tsunami, event deposits

The Frasnian-Famennian biotic crisis (F/F event) is one of the five greatest global mass extinctions in earth history. The F/F event embroiled almost all of stromatoporoid and tentaculite, a mass of corals, ammonites, crinoids, trilobites, ostrocods and placoderms. This event is identified between the *linguiformis* Zone and the Lower *triangularis* Zone, and was global and isochronous[1,2]. Numerous studies have been done on the F-F event, including variation in Ce anomalies[3], comparisons of C, O, Sr and S isotope patterns[4−10], paleoenvironmental and paleoecological changes[11,12], high-resolution sequence stratigraphy and cyclostratigraphy[13,14], magnetostatigraphy[15], and event-stratigraphy[16,17]. Extraterrestrial (the impact of bolides on the earth) and terrestrial geneses are the bipolar interpretations of the F-F event for a long time. Mclaren[18] first considered that biotic crisis during a short period in the Late Devonian was a mass extinction caused by the impact of bolides on earth. Leroux et al.[19] recognized the shocked quartz related to the impact event. Furthermore, Over et al.[20] suggested the impact genesis to the F-F event through Platinum group element enrichments and possible chondritic Ru/Ir across the Frasnian-Famennian boundary. Robert and Playford[21] studied the iridium anomaly at the F-F boundary. Claeys and Casier[22] distinguished

Received June 4, 2008; accepted July 11, 2008
doi: 10.1007/s11430-008-0117-1
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Supported by the National Natural Science Foundation of China (Grant No. 40621002), "111" Project (Grant No. B08030), and MOE Innovative Research Team Program (Grant No. IRT0546)

microtektite-like impact glass. Ma and Bai[23] discussed the importance of microspherule and geochemical records of the F-F boundary beds, South China. Racki[24] analyzed the relationship between bolide impacts and Frasnian-Famennian biotic crisis. Bai et al.[25] and Gong and Li.[26] investigated the event deposition around the F-F boundary, South China and ascribed the event to meteorolite impact and tsunami. Many scholars took the global anoxia for the main terrestrial cause of the F-F biotic mass extinction[5,27−30].

The F-F event of South China has been studied from the aspects of the mass extinction and biotic recovery[31,32], biostratigraphy[33,34], geochemical stratigraphy and isotope[23,25,35−39], sequence stratigraphy, cyclostratigraphy and eustatic changes[13,14] and so on. Comparatively, physical effect on the F-F event has not been sufficiently emphasized. Based on the previous biostratigraphic studies, particularly the conodont stratigraphy, this paper aims to demonstrate the types of event deposits at the F-F transition and their probable tsunami origin.

1 Geological setting

In late Caledonian, the whole region of Guangxi was folded and raised to be highland influenced by the Caledonian Movement, except the Qinzhou-Fangcheng area where the Devonian inherited the marine sedimentation of the Early Paleozoic. From the beginning of the Devonian, marine waters gradually invaded the South China from south to north. From Lochkovian to Pragian of the Early Devonian the marine terrigenous deposits expanded considerably, whereas alternation between clastic rocks and carbonates in the early Emsian occurred. From the late Emsian of the Early Devonian to Famennian of the Late Devonian, syndepositional rifts incised the marine basin, shaping a tessellate-type paleogeography characterized of the alternation of platform and inter-platform rift-trough[40]. This geographical pattern controled the distribution of sedimentary facies and formed the uniquely diverse depositional and biological assemblages of the Devonian. From the late Emsian to the Famennian, the paleogeography of Guangxi can be approximately divided into paleocontinental margin clastic facies, platform carbonate facies, platform margin facies, platform slope facies, intra-platform rift trough facies and deep water basin and basin margin facies (Figure 1). The carbonate platforms included shoreline platforms in the northern and eastern parts of Guangxi, and isolated platforms in Heshan, Litang, Bama Jingxi and Tiandong. Reef-mound associations developed along the platform margins. The area of inter-platform rift trough facies is elongated, and featured by the cherts, marlites and mudstones in which the fossils are dominantly tentaculites and pelagic ostrocods. The stratigraphical systems in different facies are different from the Frasnian to Famennian: The Gubi Formaiton or Guilin Formation (Frasnian) and the Rongxian Formation and Etoucun Formaiton/ Dongcun Formaiton (Famennian) in the facies areas of platform and platform margin slope respectively. The Liujiang Formation (Frasnian) and Wuzhishan Formation (Famennian) developed in the facies area of the inter-platform rift-trough. The Gubi Formaiton is mainly composed of wackestone with bioclasts, mudstone, nodular limestone, muddy limestone and dolomites. The Guilin Formaiton consists mostly of organism-bearing wackestone and packstone. The Dongcun Formaion is mainly constituted by the dolomitized limestone with alage lamellae, calciferous domolimite and dolomite. The Etoucun Formation consists mainly of mudstone. The Liujiang Formation is mainly constituted by shales and silicalites; The Wuzhishan Formation is mostly composed of lenticular limestone, nodular limestone and banding limestone. The Frasnian-Famenian boundary is located near the interface between the Liujiang Formaiton and Wuzhishan Formaiton, Gubi Formaiton and Rongxian Formaiton, Gulin Formaiton and Dongcun Formaiton in different facies areas respectively.

2 Event deposits in the F-F transition

A suite of event deposits widely occurs in the base of the Lower *triangularis* Zone or the top of the *linguiformis* Zone near Frasnian-Famennian boundary in Guangxi, which are isochronous and interrelated in origin. The event deposits are characterized by the rudstones of debris in the Liujing section of Hengxian, turbidites in the Yangdi section of Guilin and homogenites in Mangchang, Luofu of Nandan and the Road from Nandan to Tian'e.

2.1 Rudstone in Liujing section, Hengxian County

The Liujing section is located in platform margin slope of the Litang isolated platform (Figure 1) with the F-F boundary situated at the bottom of the Rongxina Formation (Figure 2). The upper part of the Gubi Formation is

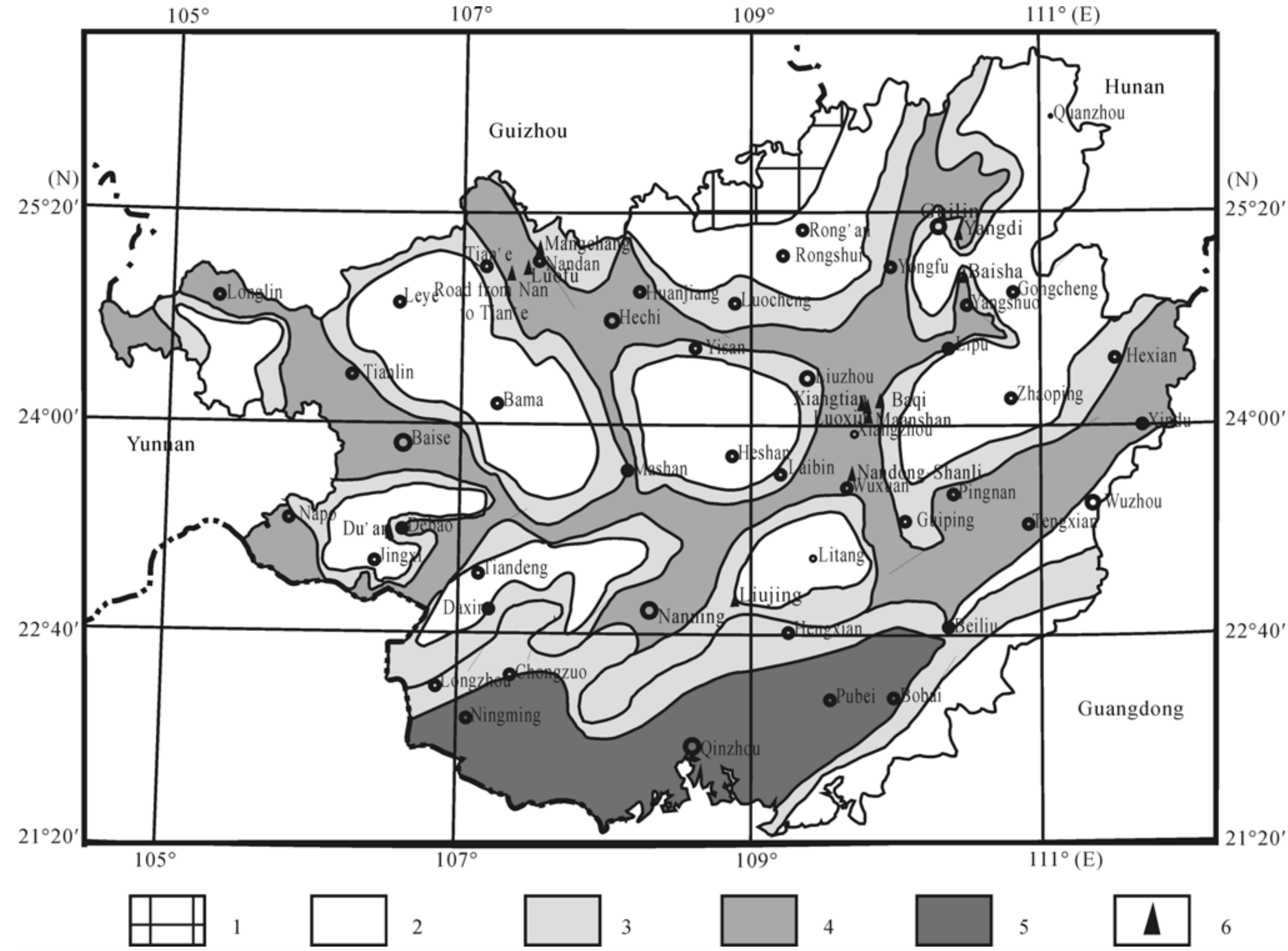

Figure 1 The Devonian Frasnian paleogeographical map and sites of event deposits of Guangxi, China (revised from Zhong et al.[40]). 1, Land; 2, shoreline platform or isolated platform; 3, slope of outer margin of platform; 4, inter-platform rift trough; 5, deep-water rift trough; 6, the studied section locality.

composed of banding, lenticular or nodular limestone (Figure 2, layers 1—4). The lower part of the Rongxian Formation consists of rudstone, nodular limestone and algal reef limestone. Two sets of rudstone are observed in the bottom of the Rongxian Formation with thickness of 1.4 m and 6.0 m respectively. The composition of the gravels is complex, including mudstone, algal packstone and wackstone, stromatolite limestone etc. The size of gravels is changed greatly, with the width from a few millimeters to more than ten centimeters and mostly in the range of 1—5 cm. Most of the gravels are angular with poorly sorting (Figure 3(b)). Radial fabric can be recognized in local areas (Figure 3(a)) and is similar to that of storm deposits. The gravels of the layers 8—13, with more complex components, are larger than those of the layer 5. Based on the results of the conodont analysis, some reworked conodonts are collected from the rudstone. The analysis of the gravel composition of the rudstone and the relationship between the rudstone and its background deposits indicate the nodular limestone neighboring the rudstone represents the shallow sea deposits. Whereas the gravels of rudstone, containing mudstone are from the shallow sea, stromatolite limestone and limestone with algal clasts or oncolite from the intertidal to restricted subtidal zone are inferred to be originated from the nearby shallow sea and the platform and platform margin, They differ from the tempestite, the gravels of which are derived from the recracked pebbles in situ.

From top of the Gubi Formation (layers 1—4) to lower part of the Rongxian Formation (layers 5—15), three conodont zones are distinguished (Figure 2):

(1) Upper *rhenana* zone. The fossils of the Upper *rhenana* zone including *Palmatolepis rotunda, Pa. simpla*, *Pa. hassi*, *Pa. gigas gigas*, *Pa. jamieae*, *Polygnathus procerus*, *Po. tenellus* occur in the top of Gubi Forma-

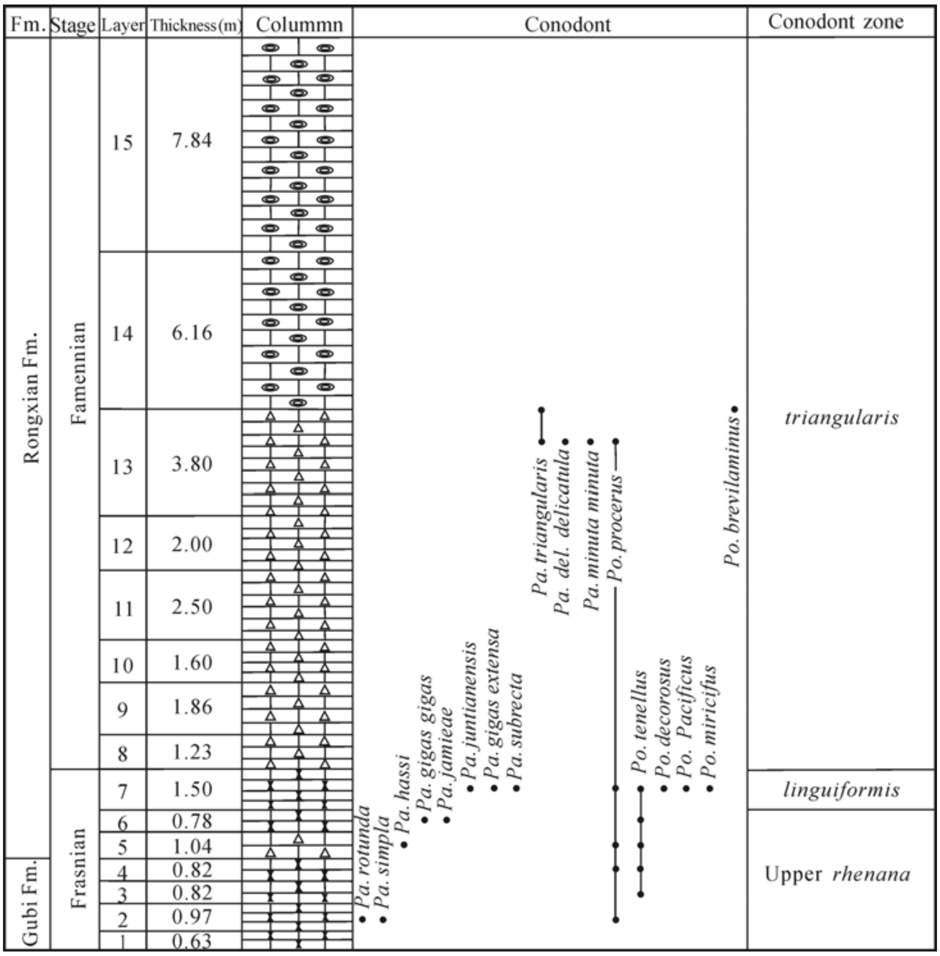

Figure 2 The sketch showing the strata succession from the upper Frasnian to the lower Famennian in the Liujing section, Hengxian.

tion (layers 1—4) and the bottom of the Rongxian Formation (layers 5—6). *Palmatolepis rotunda* occurs firstly in the bottom of the zone which is the typical conodont of the Upper *rhenana* zone. *Pa. simpla* disappear in the zone. *Pa. jamieae* and *Pa. gigas gigas* occur in the top of the zone.

(2) *linguiformis* zone. The important members of the *Linguiformis* zone including *Palmatolepis juntianensis*, *Pa. gigas extensa*, *Pa. subrecta*, *Polygnathus decorosus*, *Po. pacificus*, *Po. tenellus*, *Po. mirificus* occur in the layer 7 of Rongxian Formation. All species of the *Palmatolepis* disappear in the top of this zone.

(3) *triangularis* zone. *Palmatolepis triangularis*, *Pa. minuta minuta*, *Pa. delicatula delicatula*, *Polygnathus brevilaminus*, *Po. Procerus* occur in the layer 13. *Palmatolepis triangularis,* the zonal fossil of the *triangularis* zone, occurs in the layer 13 of Rongxian Formation *Palmatolepis triangularis* also occurs in the layers 14—15 of algal reef[41]. Because the rudstones from layer 8 to layer 13 are event deposits of a lone event, we consider that *triangularis* zone comprises of the strata from layer 8 to layer 15. Thus, the Frasnian-Famennian boundary is located between layer 7 and layer 8.

2.2 Turbidite in Yangdi section, Guilin

The Yangdi section is situated in the facies area of the Guilin inter-platform rift trough. The lower part of Wuzhishan Formation is mainly composed of ribbon-like nodular limestone with intercalated mudstone, marl and siliceous limestone. Two sets of event deposits are observed in the lower part of the Wuzhishan Formation: calcirudites of 1.6 m in thickness and graded-bedding turbidity limestone about 50 cm in thickness at 5.8 m and 17.93 m above the bottom respectively. The calcirudite mainly includes gravels of mudstone, which are sorted poorly and angularly or subroundly with size in the range of 0.5—5 cm. The turbidity limestone with graded bedding is interlayered between thin nodular mudstones (Figure 3(c)).

Palmatolepis rhenana is found in the calcirudites and

Figure 3 The photos of the rudstone in the Liujing section ((a), (b)), turbidite in the Yangdi section (c) and homogenite in the Mangchang section (d). (a) Rudstone in layer 5, showing radial fabric; (b) rudstone in layer 13, showing breccia of stromatolite; (c) turbidite; (d) homogenite of the Mangchang section.

Pa. linguiformis in the mudstone above the calcirudites. The mudstone underlying the turbidity limesotone yields *Pa. linguiformis*, whereas *Pa. triangularis* occurs in the nodular mudstone above the turbidity limestone. Consequently, the lower event deposits, calcirudites layer, represent the *rhenana* Zone, and the upper event deposits, turbidity limestone, occur in the F-F boundary between the *linguiformis* Zone and Lower *triangularis* Zone.

2.3 Homegenite in Luofu, Mangchang and Road from Nandan to Tian'e sections

Nandan is located in the facies area of Nandan-Hechi inter-platform rift trough. In sections of Luofu, Mangchang and Road from Nandan to Tian'e, the lower part of the Wuzhishan Formation is composed of thin-platy limestone with thick homegenite interbeds (Figure 3(d)). The thin-platy limestone is intercalated muddy limestone with alternation between muddy trips and calcareous bands, and the thickness of bands is about 2—5 mm. The horizontal bedding is obvious. The thin-platy limestone underlying homegenite is about 0.5 m thick, covering over the silicalite and siliceous shale of the Liujaing Formation. The thickness of homogenite is about 1 m. The homogenite consists mainly of sandy clasts, which are well-sorted and intermediately-poorly rounded and whose size is about 1 mm. This rock is characteristic of massive bedding with local wave bedding and small hommocky bedding.

The top of the Liujiang Formation in the Nandan area includes ostrocods *Entomoprimitianitina, Entomozoe pseudorichterina*, etc, and tentaculite *homoctenus* became extinction. In the bottom of the Wuzhishan Formation, conodonts are not found. In the thin-platy limestone overlying homogenite occur *Palmatolepis quadrantinodosa lobata*, *Pa minuta lobata, Pa. glabra acuta, Pa. glabara glabara*, *Pa. subprelobata, Pa. Delicatula*, etc. The temporal limitation of *Palmatolepis quadrantinodosa lobata* is in *crepida* Zone to *rhomboidea* Zone[40]. Accordingly, it is inferred that the massive homogenite occurs also at the Frasnian-Famennian boundary.

Except the sections demonstrated above, four layers of turbidite with a total thickness of 5.3 m are discovered in the lower part of the Lower *triangularis* Zone in Nandong of Wuxuan, accompanied by Ni spike and δ^{13}C drop. In the Ma'anshan section of Xiangzhou occurs 2.4 m of homogenite at the bottom of the Lower *tri-*

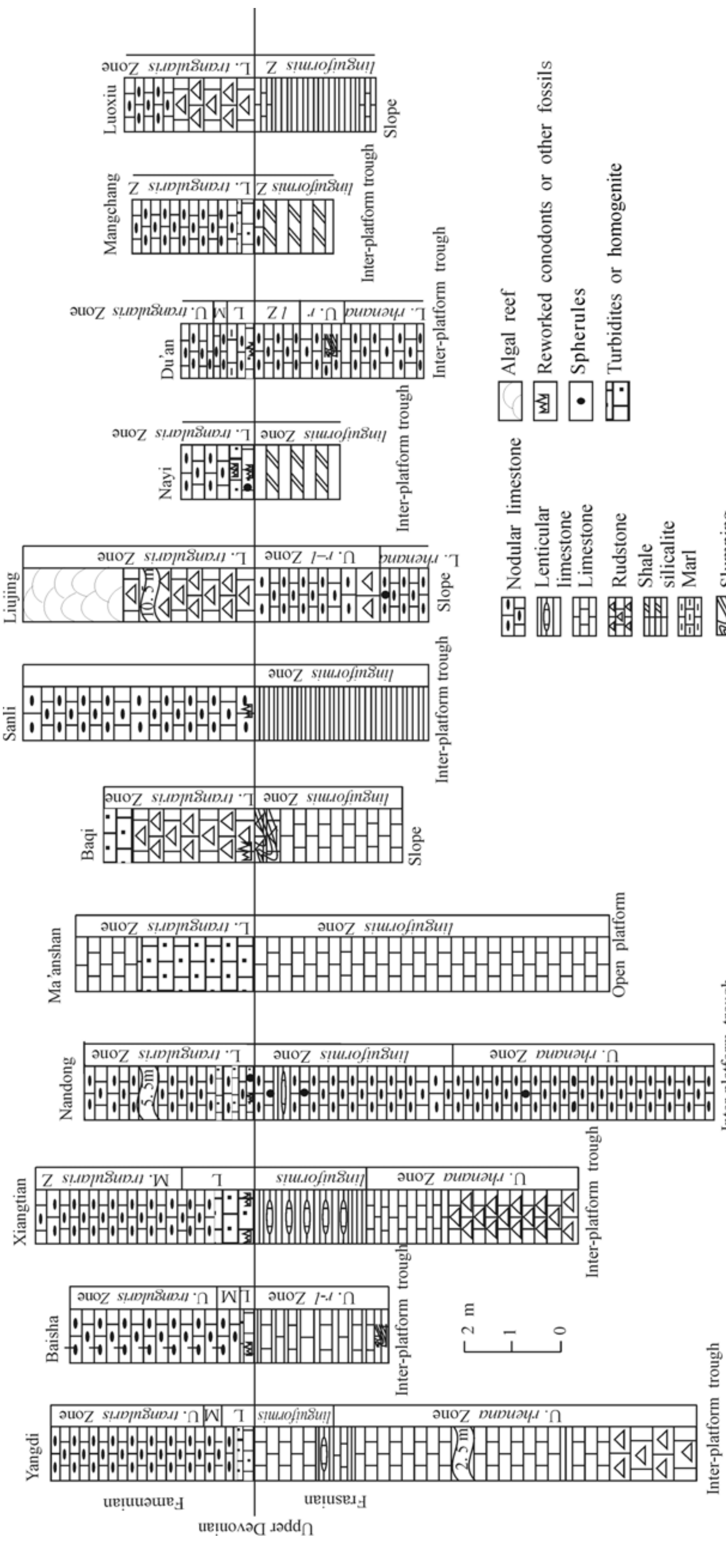

Figure 4 Event deposits and an integrated stratigraphic correlation of the Frasnian-Famennian transition of Guangxi, South China.

angularis Zone, with accompanying δ^{13}C drop. In the Baqi section of Xiangzhou, homogenite with a thickness of 0.6 m, reworked conodonts and slump block are observed at the bottom of the Lower *triangularis* Zone. A set of 0.7 m-thick turbidite appears at the bottom of the Lower *triangularis* Zone in the Xiangtian section of Xiangzhou. In the Qiaotou sections of Xiangzhou, a set of 20 m-thick rudstone is observed at the bottom of the Lower *triangularis* Zone. In the Shanli section of Wuxuan, reworked conodonts are found at the bottom of the Lower *triangularis* Zone[25]. In the Luoxiu sections of Xiangzhou, below the *Pa. triangularis* fossil zone occurs immediately a set of 6 m thick rudstone, in which reworked corals, brachiopods and tentaculites, etc, are found[40] (Figure 4). In Liantang of Guiyang, Hunan, two sets of brecciated limestone appear near the Frasnian-Famennian boundary. In Baisha of Guilin and Nayi of Chongzuo, comparable turbidites are observed at the bottom of the Lower *triangularis* Zone (Figure 4).

3 Discussion

In whole Guangxi, or even a broader region, the event deposits near the Frasnian-Famennian boundary possess the following features: (1) isochronous, (2) widely distributed, (3) interrelated in origin, (4) controlled by facies.

There are two event deposits in the Devonian Frasnian-Famennian transition in Guangxi and its adjacent areas. One is the calcirudite or rudstone in the *rhenana* Zone, and the other is turbidite, rudstone, calcarenite or homogenite near Frasnian-Famennian boundary. The former is observed in Liujing of Hengxian, Yangdi and Baisha of Guilin, Xiangtian of Xiangzhou of Guangxi and Liantang of Guiyang of Hunan, and the latter occurs in Liujing of Hengxian, Yangdi of Guilin, Luofu, Mangchang og Nandan, Road from Nandan to Tian'e counties, Nandong of Wuxuan, Ma'anshan, Baqi, Luoxiu, Xiangtian of Xiangzhou and Nayi of Chongzuo of Guangxi (Figure 1), and Liantang of Guiyang of Hunan and so on. Most of turbidite, rudstone, calcirudite or homogenite occur at the bottom of the Lower *triangularis* Zone, and some at the top of the *linguiformis* Zone. The event deposits contain reworked conodonts and other fossils. They may be caused by the same event as the event deposits at the bottom of the Lower *triangularis* Zone.

The event deposits near the Frasnian-Fanmiannian boundary are characteristic of obvious regionality. The event deposits occur mostly in the facies area of the inter-platform rift trough, such as Guilin, Wuxuan, Nandan-Hechi, Nanning and Baise-Qinjia inter-platform rift trough of Guangxi (Figure 1) and the Guiyang inter-platform rift trough of Hunan Province. Some occur in the platform margin slope areas, for instance, slope facies area between the Litang isolated platform and the Nanning inter-platforn rift trough, and between the Wuxuan inter-platform rift trough and the Eastern Guangxi shoreline platform.

The event deposits near the Devonian Frasnian-Fanmiannian boundary are interrelated in origin and most are gravity flow deposits, and debris flow deposits occur mainly in platform slope facies. The derivations of the gravels in debris flow are complicated and include the stromatolites, oncoids from carbonate platform, which is quite distinct from the neighboring lenticular and nodular limestone. The sandy or silty grains of turbidite with graded bedding are dominated in inter-platform rift trough facies area. The components of homogenite with massive bedding are different from neighboring thin-platy or nodular limestone, reflecting deposits from a far source.

The event deposits near the Devonian Frasnian-Famennian boundary are widely distributed in Guangxi and South China. In the Guilin, Wuxuan, Nandan-Hechi, Nanning, Baise-Qinjia inter-platform rift troughs of Guangxi and the Guiyang inter-platform rift trough of Hunan, event deposits are found. By all appearance, such widely-distributed isochronous event deposits are not a lone deposit event, but a series of isochronous events in different basins caused by various incidents. Viewed from a wider region, the basal Famennian turbidites are distributed at Hony railroad cut of Belgium, Devils Gate of Nevada, USA, Atrous of Morocco, South Urals and Fore-Kolyma of northeastern Siberia of Russia[25,42−45]. In South Polish-Moravian shelf (Holy Cross Mountains, Cracow and Brno areas), the Frasnian-Famennian boundary is a 'natural' stage boundary marked by erosional discontinuities, hardgrounds and brecciation or omission surfaces[17]. Such widely-distributed isochronous event deposits must have been related to the global geological events.

The F-F mass extinction event is interpreted as a result of an extraterrestrial impact by many researchers. Mclaren[18] first proposed that the Frasnian-Famennian biotic crisis may be caused by the asteroid impact on earth. Leroux et al.[19] reported the shocked quartz related to the impact event. Over et al.[20] documented Platinum group element enrichments and possible chondritic Ru/Ir across the Frasnian-Famennian boundary, confirming the impact cause for the F-F event. Girard[27] revealed iridium richness, Ni-rich spinel bearing spherules and glassy micotektites related to impact event at the F-F boundary of the standard section in southern France. Robert and Playford[21] detected the iridium anomalies of the Upper Devonian Frasnian-Famennian boundary in the Canning Basin, Western Australia. Claeys and Casier[22] found microtektite-like impact glass associated with the Frasnian-Famennian mass extinction in the Hony section in Belgium. Bai et al.[25] and Ma and Bai[23] dug out the geochemical record of the existence of microspherules, Ni spike and δ^{13}C drop, etc. Racki[24] analyzed the relationship between bolide impacts and Frasnian-Famennian biotic crisis. Bai et al.[25] suggested the possibility of tsunami-derivation for the turbidity deposits near the Devonian Frasnian-Fanmiannian boundary of South China.

Tsunami's enormous waves are created by an underwater disturbance caused by earthquake, landslide, volcanic eruption, or meteorite impact into ocean. A tsunami can move hundreds of miles per hour in the open ocean and smash into land with waves as high as 100 feet or more. The propagational velocity is in positive correlation with the depth of water through which the tsunami traverses, and the maximum velocity is up to 1000 km/h. As a tsunami travels into shallow water (across submarine ridges or a coastal zone), the tsunami velocity decreases to tens of kilometers and the great hydroenergy is converted to wave-energy. And the induced vertical run-up can reach tens of meters, forming the typical tsunami deposits. The tsunami triggered by earthquakes, volcanic eruption and submarine slide can reach a long distance, but is usually limited in a lone ocean. The global tsunami is caused by bolides impacts into ocean frequently. Of the 160 meteorite impact craters currently identified on the Earth's surface, seven are found in the modern ocean, although a further twenty craters now preserved on land were originally marine impacts. Terrestrial cratering rates, however, would indicate that over eight thousand major oceanic craters could have formed in the last 3.5 billion years, making ocean impacts from bolides (asteroids and comets) a potentially important tsunamigenic process[46].

Numerical simulations show that bolides larger than 1 km in diameter ought to penetrate to the floor of a 5 km deep ocean, instantly displacing the entire water column and generating in the first moments of the impact tsunami amplitudes equivalent to the ocean depth. Thereafter, tsunami waves of hundreds of meters high would follow as the transient air cavity collapses, while additional tsunami-like waves could be triggered by slumps and slides along the crater highs and margins[46]. It is reported that the Eltanin asteroid impact at 2.15 Ma, modeled as a 4 km impactor reaching the ocean floor, is predicted to have delivered a 200—300 m high tsunami to the Antarctic Peninsula and the southern tip of South America 1200—1500 km away[47]. Such 100 m radius bolides can be expected to impact the Earth anything between every 3000—5000 years to 10000 years[48]. With two-thirds of the Earth covered with ocean, the water landings of medium-sized asteroids and comets would appear to be an important mechanism for generating tsunamis detectable in the geological records[46]. As long as the depth to which the sea is agitated by tsunami waves is enough, more than 5 m, the past tsunami deposits can be recorded in the geological imprints. Consequently, it is evident that tsunamis large enough to have a geological imprint (i.e. wave heights >5 m) can be readily generated by these comparatively modest strikes, as tsunamite.

Since Alvarez et al.[49] described tsunami associated with the K/T impact, a considerable literature has emerged on aspects of tsunami sedimentation. Bourgeois et al.[50] described a set of coarse-grained sandstone with large clasts of mudstone, reworked carbonate nodules and wood fragments at the Brazos River section in Texas and concluded that these characteristics were consistent with a tsunamite. Masaitis[51] suggested that the Middle Devonian angular breccia deposits found in the Baltic countries and adjacent areas of northwestern Russia and Belarus may be a possible tsunamite from the Kaluga impact, which struck shallow (300—500 m deep) seas of the East European platform 380 million years ago. Hassler et al.[52] reported the small wave ripples within a spherule bed in Late Archean strata appear in the Hammersley basin of Western Australia and are interpretd as the product of abyssal scour by giant tsunami waves rippling out from an oceanic bolide impact several thousand kilometers away.

The Frasnian-Famennian event deposits in Guangxi,

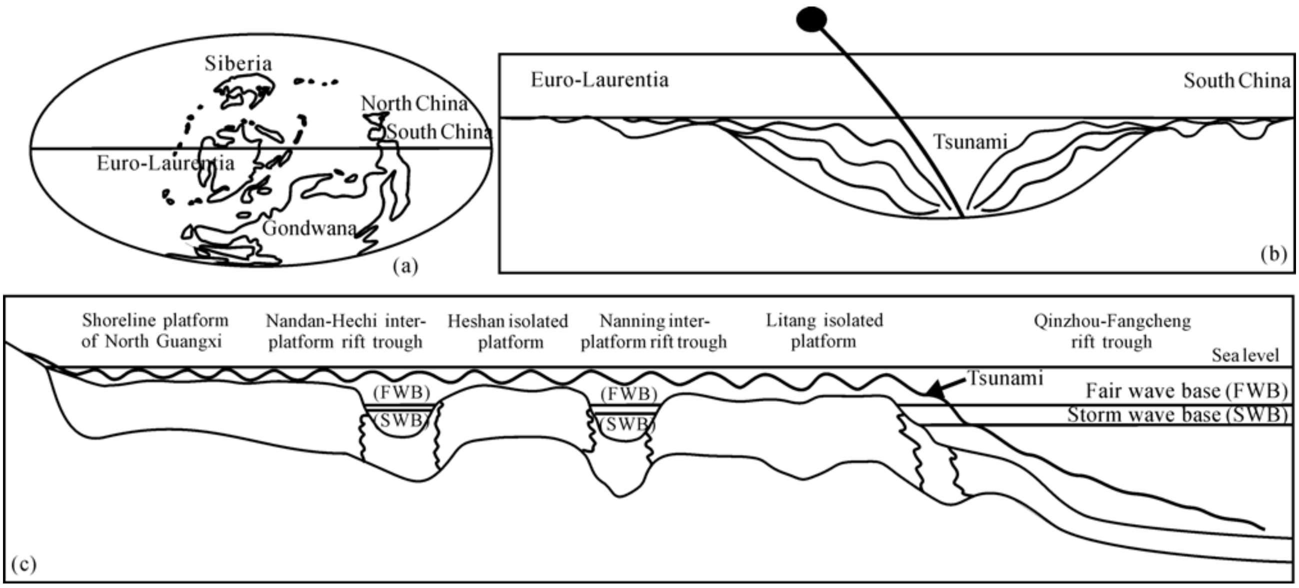

Figure 5 Sketch showing a tsunami model related to bolide impacts in the Devonian F-F transition. (a) Global reconstruction of paleocontinent and paleocean of the Devonian Frasnian; (b) tsunami caused by a bolide impact into paleo-Tethys; (c) tsunami caused by a bolide impact in South China.

South China, and even the global event deposits may be related to the tsunami triggered by bolides impact into ocean. We assume that a bolide impacted into the paleo-Tethys ocean and giant tsunami waves expanded from impact center to several thousand kilometers away (Figure 5). The sea beds including South China, Europe, Laurentia, Siberia and Gondwana etc. are scoured by giant tsunami waves. The debris flows or turbidity currents are trigged by tsunami in facies areas of slopes and deep-water basins and the debris, turbidite and tsunamite are formed. The reason for most of the event deposits developing in the Upper Devonian platform margin slope and inter-platform marine trough of South China can be interpreted by the following: (1) enough materials exist in these places, making the gravity flows happen facilely, and (2) these positions of event deposits are below the normal wave base, ensuring no destruction after the forming of tsunami-derived sedimentation. The tsunami sedimentation above the normal wave base tends to be demolished by the deuteric waves, and is hard to be preserved.

4 Conclusions

A set of turbidite, rudstone, calcarenite and homogenite of event deposits develops near the Devonian Frasnian-Famennian boundary in Guangxi. These event deposits are isochronous and all occurred at the bottom of the Lower *triangularis* Zone or the top of the *linguiformis* Zone. These event deposits are distributed broadly in the facies area of the platform foreslope and inter-platform rift trough, in Guangxi and Hunan. The event deposits are comparable with the turbidite or rudstone at the bottom of the Lower *triangularis* Zone in Hony railroad cut of Belgium, Devils Gate of Nevada, USA, Atrous of Morocco, South Urals and Fore-Kolyma of northeastern Siberia of Russia and South Polish-Moravian shelf. Turbidite, rudstone, calcarenite are gravity flow deposits, and homogenite is tsunami sediments. Such widely-distributed event deposits could be associated with the tsunami caused by bolides impacts into ocean.

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