Journal of Asian Earth Sciences 80 (2014) 101–118

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Stratigraphy and facies development of the marine Late Devonian near the Boulongour Reservoir, northwest Xinjiang, China

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ARTICLE INFO

Article history:
Received 14 May 2013
Received in revised form 1 October 2013
Accepted 2 November 2013
Available online 14 November 2013

Keywords:
Late Devonian
Stratigraphy
Facies
Biodiversity
Geochemistry
Biotic events

ABSTRACT

Late Devonian to Early Carboniferous stratigraphic units within the 'Zhulumute' Formation, Hongguleleng Formation (stratotype), 'Hebukehe' Formation and the Heishantou Formation near the Boulongour Reservoir in northwestern Xinjiang are fossil-rich. The Hongguleleng and 'Hebukehe' formations are biostratigraphically well constrained by microfossils from the latest Frasnian *linguiformis* to mid-Famennian *trachytera* conodont biozones. The Hongguleleng Formation (96.8 m) is characterized by bioclastic argillaceous limestones and marls (the dominant facies) intercalated with green spiculitic calcareous shales. It yields abundant and highly diverse faunas of bryozoans, brachiopods and crinoids with subordinate solitary rugose corals, ostracods, trilobites, conodonts and other fish teeth. The succeeding 'Hebukehe' Formation (95.7 m) consists of siltstones, mudstones, arenites and intervals of bioclastic limestone (e.g. 'Blastoid Hill') and cherts with radiolarians. A diverse ichnofauna, phacopid trilobites, echinoderms (crinoids and blastoids) together with brachiopods, ostracods, bryozoans and rare cephalopods have been collected from this interval. Analysis of geochemical data, microfacies and especially the distribution of marine organisms, which are not described in detail here, but used for facies analysis, indicate a deepening of the depositional environment at the Boulongour Reservoir section. Results presented here concern mainly the sedimentological and stratigraphical context of the investigated section. Additionally, one Late Devonian palaeo-oceanic and biotic event, the Upper Kellwasser Event is recognized near the section base.

1. Introduction

The Late Devonian sequence near the Boulongour Reservoir (Junggar area, Northwest Xinjiang) is characterized by an abundant and diversified fossil flora and fauna consisting of acritarchs, spores, radiolarians, sponges, corals, trilobites, ostracods, gastropods, cephalopods, brachiopods, bryozoans, echinoderms (blastoids and crinoids), conodonts and fish teeth. Most of the fossil groups listed above were collected from the Hongguleleng Formation. The Hongguleleng Formation was introduced in 1973 for the Famennian deposits of the West Junggar area during an expedition organized by the Chinese Academy of Geological Sciences and the Research Group on Stratigraphy of Regional Geological Reconnaissance Brigade of Xinjiang. Fossils from the Hongguleleng Formation were first published in the Atlas of Paleontology of Northwest China (1983).

Major overviews of the stratigraphy of northern Xinjiang have been given by the Compiling Group for Regional Stratigraphic Scheme of Xinjiang Uygur Autonomous Region (1981), Zeng and Xiao (1991) for Devonian and Wu (1982) for Carboniferous units, but much information has been presented in smaller papers since these syntheses of 20 and 30 years ago. We draw attention to contributions on sedimentology by Gong and Liu (1993) and Wei et al. (2009), on microfauna (bryozoans, ostracods and microvertebrate remains) by Xia (1997a), and important papers on conodonts by Zhao (1986). Taxonomic papers on Devonian and presumed Early Carboniferous (Mississippian) faunas and floras have been contributed by nearly 70 palaeontologists. Their contributions can be summarized (in approximate chronologic sequence for each major

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http://dx.doi.org/10.1016/j.jseaes.2013.11.001

group) as follows: macroflora (Sze, 1960; Dou, 1983; Cai and Qin, 1986; Cai, 1989; Cai and Wang, 1995; Cai and Chen, 1996; Wang et al., 2004; Wang and Xu, 2005; Fu, 2006; Xu, 2006; Wang, 2008; Xu and Wang, 2008; Xu et al., 2008, 2011; Fu et al., 2011), microflora (Lu and Wicander, 1988), corals (Wang and Zhao, 1987; Liao and Cai, 1987; Liao, 1987; Cai, 1988, 1996; Soto and Lin, 1997, 2000; Liao, 2001; Soto and Liao, 2002; Wang et al., 2004), bryozoans (Xia, 1997a), brachiopods (Zhang and Zhang, 1983; Zhang et al., 1983; Zhang, 1985, 1987; Sartenaer and Xu, 1989; Xu et al., 1990; Xu, 1999; Zhao et al., 2000; Chen et al., 2002; Chen and Liao, 2006; Chen and Yang, 2011; Zong and Ma, 2012; Zong et al., 2012); cephalopods (Wang, 1983; Liang and Wang, 1991; Ruan, 1995), trilobites (Zhang, 1983), echinoderms (Waters et al., 1991, 1995, 2003, 2008; Hou et al., 1993; Lane et al., 1995, 1997; Waters and Webster, 2009; Webster and Waters, 2009), conodonts (Zhao, 1986; Xia, 1996, 1997a, 1997b; Zhao et al., 2000), and microvertebrates (Xia, 1997a).

Observations relating the Hongguleleng Formation with strata above and below as well as its lateral extent and correlation have produced differing interpretations. A high-resolution stratigraphy and biostratigraphy remains lacking. During the fieldwork from 2000 on, our research group measured several bed-by-bed stratigraphic sections of the Hongguleleng Formation, especially the type section near the Boulongour Reservoir; other sections at Yidimaodaongbo, Genaren, Qiligoa, Emuha and Aoroa have been bed-by-bed sampled for conodonts.

Here we present the results of our study on bio- and chemostratigraphy and facies of the sequence near the Boulongour Reservoir ranging from the base of the Hongguleleng Formation to the base of the Heishantou Formation.

2. Regional geology

2.1. Tectonic setting of the West Junggar area

The West Junggar area of northwest Xinjiang-Uygur Autonomous Region belongs to the Central Asian Orogenic Belt (CAOB), bordered on the north by the Siberian Craton and on the south by the North China–Tarim Craton (Jahn et al., 2000; Chen and Arakawa, 2005; Cocks and Torsvik, 2007; Windley et al., 2007). Buckman and Aitchison (2004) hypothesize a complex amalgamation-history of intra-oceanic island arcs and continental fragments to become part of the CAOB prior to the end of the latest Carboniferous. The tectonics and ophiolite belts of northern Xinjiang and especially the Hoxtolgay area and how these may relate to the Central Asian Orogenic Belt have not been foci of our research. Such matters can be approached through contributions made by Li et al. (1991), Huang et al. (1995), Buckman and Aitchison (2001, 2004), Xiao et al. (2008) and de Jong et al. (2009).

Reconstructions hypothesized for the Central Asian Orogenic Belt (Windley et al., 2007; Xiao et al., 2010) would locate the Hongguleleng Formation at approximately 25 to 30 degrees north, a more tropical setting than the previous palaeogeographic reconstructions reported by Waters et al. (2003). The diversity of the marine faunas of the Hongguleleng Formation is consistent with a tropical setting.

2.2. Previous investigations

The stratotype of the Hongguleleng Formation, first studied by the Chinese expedition in 1973, is located north of Hoxtolgay, about 1.5 km northwest of the Boulongour Reservoir (Fig. 1). The oldest beds of the sequence consist of tuffaceous sandstones and conglomerates succeeded by limestones, including bioclastic limestones, variegated siliceous, tuffaceous siltstones and fine-grained sandstones. Hou and Wang (1988) re-defined the lithological units. Non-calcareous clastic rocks, for example, tuffaceous sandstones and conglomerates forming part of what was interpreted as the basal sequence of the Hongguleleng Formation, were excluded from the Hongguleleng Formation and assigned to the Zhulumute Formation. The name Zhulumute Formation has been used in lithostratigraphic schemes since then, although Xiao et al. (1992, p. 32), Xu (1999), and Cai (2000) indicated that this, being based on facies, fossil content and suggested correlation of the sequences, could be assigned to the underlying Hujiersite Formation. This idea is supported by Wang Yi and Xu Honghe (pers. comm. 2012), based on fieldwork and study of plants including megaspores from this interval. They have suggested (pers. comm. 2012) that the Hujiersite Formation includes an interval of Frasnian age previously referred to as Zhulumute Formation in some publications (compare Fig. 2). Because the latter has priority and may be best construed as including this interval, we refer to it provisionally and informally as the 'Zhulumute' Formation, deferring a definite conclusion as to appropriate nomenclature until more information comes available.

The 'Zhulumute' Formation is widespread in western Junggar and yields abundant plant fossils such as *Leptophloeum rhombicum* and *Sublepidodendron*, consistent with a Frasnian age (Hou et al., 1993; Cai, 2000; Ma et al., 2009). Ma et al. (2011) suggested a parallel unconformity at its boundary with the Hongguleleng Formation (Fig. 2), a conclusion that does not find support from our excavation of the boundary interval (see below). Hou et al. (1993, p. 2), Xia (1996, p. 101) and Wang Yi and Xu Honghe (pers. comm. 2012) considered the 'Zhulumute' Formation to be conformably overlain by the Hongguleleng Formation.

Xiao et al. (1992, cf. our Fig. 2) divided the Hongguleleng Formation into two parts. Xu et al. (1990) and Hou et al. (1993) suggested recognition of three members (Lower, Middle and Upper). Subsequent authors suggested the lithologic character of the 'Unnamed Formation' of Hou et al. (1993) equates with the basal part of the Heishantou Formation *sensu* Xiao et al. (1992). The previously suggested Carboniferous age of the 'Unnamed Formation' (or 'Heishantou Formation') is based on the occurrence of the brachiopod genus *Syringothyris* and rugose corals by Hou et al. (1993). Division of the Hongguleleng Formation into seven or eight lithostratigraphic units was suggested by Hou et al. (1993; cf. Ma et al., 2011). Another subdivision into five lithostratigraphic units was proposed by Xia (1996). Xu's profile of the Hongguleleng Formation (Xu et al., 1990) implies more than 800 m (cf. Fig. 2), far more than observed by others. Xia (1997a,b) suggested the upper part of the Hongguleleng Formation may correspond to the lower part of the Hebukehe Formation, a unit which, according to conodonts was thought to range from the *crepida* to Early *expansa* Biozone at its type locality near the Hebukehe River (c. 8 km NW of Hoxtolgay).

It seems that ever since the Second Team of the Regional Geological Reconnaissance Brigade of Xinjiang proposed the Hebukehe Formation in 1979, most subsequent authors have suggested modifications of the time-interval it represents, mostly without firm grounds for so doing (cf. Wu, 1982; Wu and Wang, 1983; Zhang, 1985; Zhao, 1986; Wang and Zhao, 1987; Zhang, 1987; Cai, 1988; Xiao et al., 1992; Zhao et al., 2000; Zhao, 2009). Because its lithology is rather distinctive we have been inclined to follow Xia (1997a,b) though indicating our uncertainty by single inverted commas, i.e. 'Hebukehe' Formation.

Conodonts from Hongguleleng Formation near the Boulongour Reservoir were said (Zhao and Wang, 1990) to range from *crepida* to *marginifera* biozones. Hou et al. (1993), following them, suggested the Hongguleleng Formation was early to middle Famennian (Fig. 2). Later, Xia (1997a), on the basis of conodont collections from the stratotype section, suggested a span of late Frasnian to early Famennian (Late *rhenana* Biozone through the