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Ichnological constraints of palaeoenvironmental and palaeoclimatological features of the middle Palaeozoic Palaeo-Asian Ocean, evidence from the western Junggar, NW China

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ABSTRACT

Late Devonian to Early Carboniferous deep-sea deposits of the western Junggar, NW China contain 21 ichnotaxa: *Arenituba verso* (Chamberlain), *Chondrites* cf. *intricatus* (Brongniart), *Chondrites targionii* (Brongniart), ?*Chondrites* isp., *Gordia marina* Emmons, *Halopoa imbricata* Torell, *Helminthoidichnites* isp., *Helminthopsis* cf. *hieroglyphica* Wetzel and Bromley, *Laevicyclus* isp., *Lophoctenium comosum* Richter, ?*Multina* isp., *Nereites missouriensis* (Weller), *Phycodes* cf. *bilix* (Książkiewicz), *Phycosiphon incertum* Fischer-Ooster, ?*Phycosiphon* isp., *Planolites* isp., cf. *Taenidium*, *Thalassinoides* isp., *Zoophycos* isp., undetermined short ridges, and undetermined tubular structures. They form three typical ichnoassemblages, i.e. the *Helminthopsis–Helminthoidichnites–Arenituba* ichnoassemblage characteristic of upper-bathyal, probably hyperpycnal-flow-influenced deposits, *Zoophycos–Nereites–Phycosiphon* ichnoassemblage in typical slope deposits, and the *Phycosiphon–Nereites* ichnoassemblage featuring bottom-current-influenced, lower slope or basin floor muddy deposits. They can be ascribed to the *Cruziana*, *Zoophycos*, and the *Nereites* ichnosubfacies respectively. Comparison with contemporaneous deep-water facies (foremost the Kulm facies in Western and Central Europe) reveals significant loss in the western Junggar of otherwise common element *Dictyodora liebeana* (Geinitz). Combining the global Palaeozoic tectonic evolution, we propose that *Dictyodora* was probably originated from peri-Gondwana terranes and the larvae/juveniles of *Dictyodora* producers hadn't migrated to the northern palaeolatitudes (open ocean Kazakhstan "archipelago") in the Early Carboniferous. The relatively global distribution of the *Phycosiphon–Nereites* association indicates efficient larval dispersal of their producers. Intensive bioturbation in deposits dominated by the *Phycosiphon–Nereites* ichnoassemblage implies a high level of food supply at certain stratigraphic levels, most likely related to surface blooms and enhanced plant detritus input. The monsoonal palaeoclimatic model is integrated with the archipelagic palaeogeography to account for the deep-sea ichnofauna in the western Junggar during the Late Devonian to Early Carboniferous. The most important factors include seasonal climatic perturbations, such as monsoon-derived upwelling events and enhanced primary production, and efficient food/nutrients transport in the dotted island scenario.

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1. Introduction

Studies on trace fossils in deep-water deposits have gained much progress in systematics, palaeoenvironmental interpretations, as well as macro-evolutionary trends since earlier works (e.g., Książkiewicz, 1977; Seilacher, 1974, 1977; Uchman, 1999, 2001, 2004; Uchman and Wetzel, 2011 and references therein). Deep-sea neoichnological studies in the recent decade allow a more rational interpretation of fossil examples based on the uniformitarian approach (e.g., Wetzel, 2002, 2008, 2010). However, the ichnology of deep-water formations of certain geological periods is still poorly known, foremost the upper Cambrian, Middle–Upper Devonian, and the Permian–Jurassic (Uchman, 2004). Although the Early Carboniferous deep-sea facies witness a boom in certain ichnotaxa, e.g. *Dictyodora liebeana* (Geinitz, 1867), most of the studied formations are restricted to the southern palaeolatitudes (e.g. the Kulm facies). The Kazakhstan Block was relatively isolated from major continents and experienced extensive accretion of arcs and microcontinental terranes in the middle Palaeozoic (Windley et al., 2007). The western Junggar is an important part of the Kazakhstan Block, constituting the northeastern part of the Kazakhstan Orocline (Fig. 1). Preliminary ichnological studies of the western Junggar focus on description and interpretation of trace fossils at the ichnogeneric level (Jin and Li, 1991; Jin et al., 2003; Li and Jin, 1989). The deep-water deposits in the western Junggar suggest a seemingly barren seafloor, given the almost absence of in-situ body fossils, with locally relatively abundant radiolarians and plant debris. Trace fossils are also sporadically distributed, although with high density in certain outcrops.

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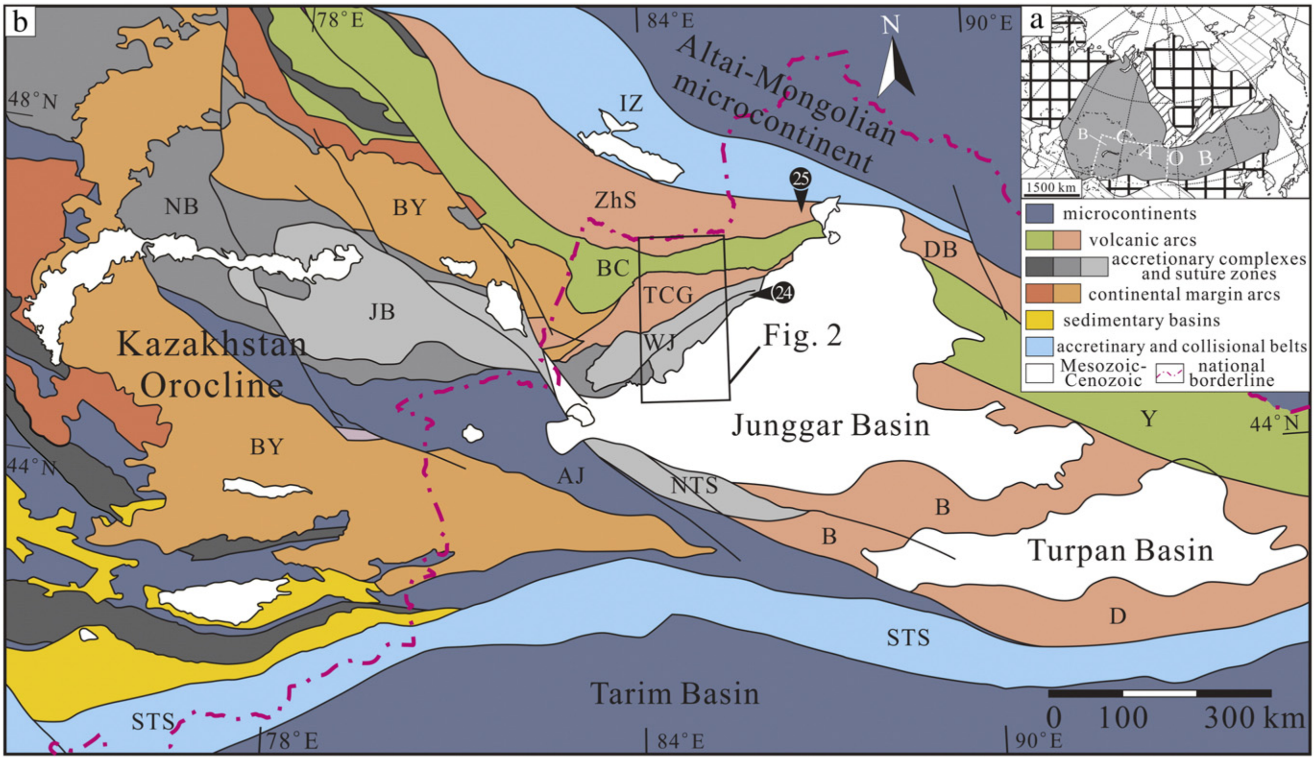

Fig. 1. Global and regional tectonic background of the study area (compiled from Han et al., 2010; Wilhem et al., 2012; Windley et al., 2007; Xiao et al., 2008 and our recent regional geological survey of the study area). A. General map of the Central Asian Orogenic Belt bounded by major continents Baltica, Siberia, and smaller Tarim, North China, with the area of figure B indicated. B. Tectonic units of the study area in the western Junggar and the adjacent eastern Junggar, southern Xinjiang, and the eastern Kazakhstan. Abbreviations of major tectonic units (in alphabetical order), AJ: Aktau-Junggar microcontinent; B: N. Tien Shan-Bogdo Shan arc (D–C); BC: Boshchekul-Chingiz arc (Cm_2–S); BY: Balkhash-Yili continental margin arc (D_3–P); D: Dananhu arc (O–D/C); DB: Dulate-Baytag arc (S–D_1); JB: Junggar-Balkhash accretionary complex (D_3–C); NB: N. Balkhash accretionary complex (O–D_3); NTS: North Tien Shan accretionary complex (D–C); STS: South Tien Shan accretionary and collisional belt (PZ_3); TCG: Tiechanggou arc (D_{1-2}); WJ: West Junggar accretionary complex (C_{1-2}); Y: Yemaquan arc (D–C_1); ZhS: Zharma-Saur arc (D–C); abbreviations in parentheses: Cm, Cambrian; O, Ordovician; S, Silurian; D, Devonian; C, Carboniferous.

Detailed stratigraphic logging is possible only in some well-outcropped localities, since the middle Palaeozoic deep-water deposits in the western Junggar have endured multi-stage tectonic deformation and disintegration (see Choulet et al., 2012; Li et al., 2006). This paper is an attempt to: 1) systematically describe the trace fossils of the middle Palaeozoic deep-water deposits in the western Junggar; 2) compare them with contemporaneous deep-water ichnoassemblages; and 3) interpret the palaeoclimatic and palaeogeographic background of the deep-sea ichnoassemblages in the western Junggar during the middle Palaeozoic using the uniformitarian approach.

2. Geological setting and stratigraphy

2.1. Western Junggar and adjacent areas

The Xinjiang Province in NW China is characterised by widespread orogens. Nowadays it is geographically represented as a collage of basins separated by mountain ranges. The Junggar Basin is situated between the Altai and Tianshan mountains. The area to the northwest of the Junggar Basin is referred to the western Junggar (Fig. 1).

The Junggar Basin is about 700 km long latitudinally and attains maximum width of 450 km meridionally, with the Guerbantonggute Desert at the core. Large part of the basement of the Junggar Basin is probably a collage of arcs, accretionary complexes, and trapped oceanic crust in the Palaeozoic (Xiao et al., 2008). The Karamay oil and gas field is located in the northwest margin of the Junggar Basin, whose reservoir is mainly in the Mesozoic continental rocks. The Carboniferous and Devonian deep-water deposits in these areas have been considered possible source rocks (e.g., Gong and Liu, 1993; Jin et al., 2003).

Most of the tectonic units in the western Junggar well connect with the eastern Junggar and the eastern Kazakhstan (Shen et al., 2012; Zhao and He, 2013; Fig. 1). The western Junggar can be subdivided into two tectonic regimes, roughly along the E-W trending Xiemisitai Fault on the southern margin of the Xiemisitai Mts (Fig. 1). The southern part is generally attributed to the West Junggar accretionary complex, which, along with the Junggar-Balkhash accretionary complex, was formed by the northward subduction of the Junggar-Balkhash Ocean under the Kazakhstan continent during the Devonian to Carboniferous (Geng et al., 2009; Windley et al., 2007; Xiao et al., 2008). The deep-water sedimentary rocks in the south western Junggar record a gradual basin-filling sequence during the Early Carboniferous based on lithofacies analysis (Zong et al., 2014c). The northern part corresponds to two volcanic arcs, i.e. the Cambrian–Silurian Boshchekul-Chingiz arc and the Devonian–Carboniferous Zharma-Saur arc, which were produced by the southward subduction of the Irtysh-Zaysan Ocean under the Kazakhstan Block (Windley et al., 2007; Xiao et al., 2008). The Kazakhstan Block was formed during the Late Ordovician and is a collage of Precambrian and Early Palaeozoic microcontinents and island arcs, surrounded by Carboniferous–Permian collisional fold belts (Bykadorov et al., 2003). In the northern younger Zharma-Saur arc, there are widespread subduction-related plutons, which are of Early Carboniferous age (Chen et al., 2010). Extensive arc-related volcanism is also indicated by the Early Carboniferous Eastern Sawur caldera complex (Shen et al., 2008). The deep-water sedimentary rocks of the south western Junggar are dated to the Early Carboniferous by redeposited

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