Global and Planetary Change 63 (2008) 40–56

Contents lists available at ScienceDirect

Global and Planetary Change

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

Evaluation of palaeo-oxygenation of the ocean bottom across the Permian–Triassic boundary

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ARTICLE INFO

Article history:
Received 12 November 2007
Accepted 14 May 2008
Available online 27 May 2008

Keywords:
Palaeo-oxygenation
Permian–Triassic boundary
Mass extinction
Anoxia
Radiolarian chert
Trace fossil

ABSTRACT

The 'long-lasted anoxia' of a deep ocean bottom which may be related to the Permian–Triassic (PT) mass extinction event has been accepted without critical evidence. The degree of bioturbation is examined for radiolarian chert successions in central Japan with the reassessment of geochemical proxies to evaluate the degree of palaeo-oxygenation of a pelagic oceanic bottom. No evidence for anoxia is found from Wuchiapingian and lower Changhsingian chert by the reassessment of geochemical proxies. Anoxia started from the late Changhsingian stage that was interrupted by an oxygenation event at the supposed PT boundary. Griesbachian to the earliest Smithian, being characterised by the occurrence of black carbonaceous claystone, is an anoxic interval with rare bioturbation in the early part and is oxygenated in the later part. Succeeding grey siliceous claystone of early Smithian represents largely an anoxic interval, but it is oxygenated in the later part of this stage. Grey siliceous claystone with black carbonaceous claystone interbeds of Spathian was suboxic to oxic, and temporal anoxia being caused mainly by high productivity intermittently was established within a short time interval. Red chert is rather common in Anisian, but unusual sedimentation of organic matter still continued until the latest Anisian.

1. Introduction

The Permian–Triassic boundary (PTB) event is well known as the severest mass extinction in the Phanerozoic (Raup and Sepkoski, 1984; Erwin, 1993). An oceanic anoxic event is thought to be one of the causes of decimation of marine organisms, most of which inhabited shallow seas, and is verified by geochemical and sedimentological methods including the degree of bioturbation (Wignall and Twitchett, 1996b; Hallam and Wignall, 1997; Wignall and Twitchett, 2002; Kakuwa and Matsumoto, 2006). On the other hand, a long-lasted anoxic condition of the oceanic bottom as long as 20 million years from Wuchiapingian to early Anisian and 10 million years superanoxia ranging from Changhsingian to the early half of Spathian are suggested. This is based on the change in colour of radiolarian chert and the appearance of pyrite-bearing black carbonaceous rocks deposited on the bottom of the Panthalassa Ocean (Isozaki, 1997). Geochemistry is one way of clarifying the hypothesis, and several works have been published on the rocks of radiolarian chert successions. Kajiwara et al. (1993a, 1993b, 1994) applied the sulphur isotopic analysis to the pelagic radiolarian chert in Japan, and concluded that a largely anoxic condition prevailed from the Late Permian to the Early Triassic, but the pyrite-bearing black carbonaceous rocks of the basal Triassic was interpreted to be oxic, contrary to Isozaki's working hypothesis. Nakao and Isozaki (1994) and Kubo et al. (1996) concluded the change of environment from reducing to oxidising in the Middle Triassic by the identification of iron minerals species contained in chert using XRF and Mössbauer spectrometry, respectively. Mineral species of iron are although overprinted by the redox condition during the diagenetic process, and do not necessarily indicate the oxygenation level of bottom water itself. Sugitani and Mimura (1998) also supported the redox change in the Middle Triassic based mainly on the concentrations of transition metals such as Ni, Cu and Zn. Kato et al. (2002) approved the 20 Ma deep-sea anoxia of Panthalassa Ocean based on the change in Fe and Mn concentrations and cerium anomaly from Middle Permian to Early Triassic, but those major elements such as Fe and Mn give poor constraint in identifying the redox condition of sedimentary rocks.

A much more direct way to monitor the palaeo-oxygenation of the oceanic bottom than geochemistry is to study bioturbation found in rocks. The study of the palaeo-oxygenation across the PTB by the bioturbation is listed in the following: Wignall and Hallam (1993), Wignall et al. (1995), Wignall and Hallam (1996a) in South China and Pakistan, Twitchett and Wignall (1996), Twitchett (1999) in Italy and Austria, and Schubert and Bottjer (1995) and Woods et al. (1999) in western USA. All of those works concentrated on carbonate or siliciclastic rocks deposited on either shallow platforms or shelves. Wignall et al. (1998) examined siliceous rocks in Spitzbergen, but the rocks had been deposited on a shelf environment. Reports of the bioturbation of radiolarian chert deposited on a pelagic oceanic bottom are limited to a series of studies by Kakuwa (1991, 1996, 1998, 2004). Kakuwa (1991) suggested that the earliest Triassic is anoxic

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doi:10.1016/j.gloplacha.2008.05.002

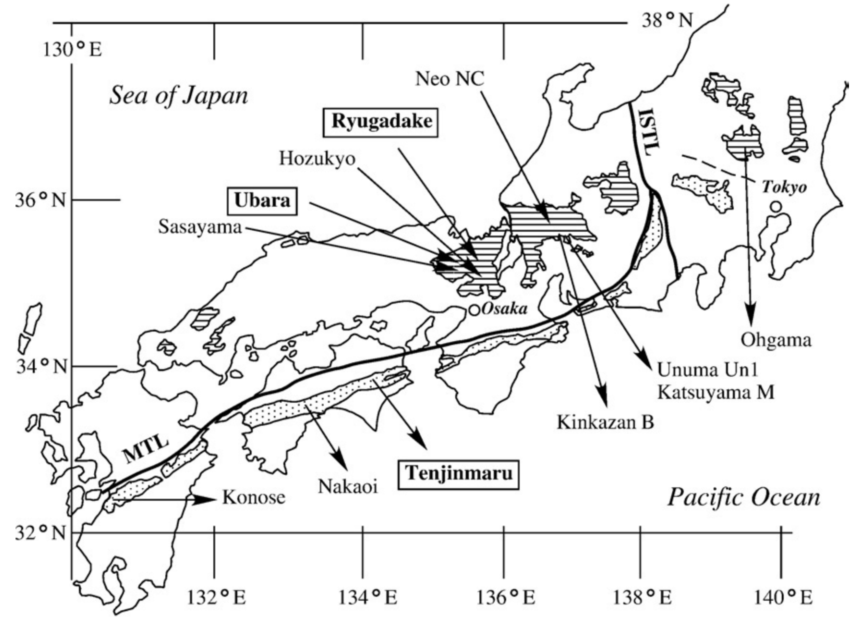

Fig. 1. Index map. Ruled: Mino–Tamba Belt. Dotted: Northern and Southern Chichibu belts. ISTL: Itoigawa–Shizuoka Tectonic Line. MTL: Median Tectonic Line.

because well-laminated rocks occur in the basal Triassic. Kakuwa (1996) found bioturbation in the PTB rock and the Lower Triassic siliceous claystone, and cast doubts on the anoxia as long as 20 Ma. Kakuwa (1998) proposed that suboxic and oxic conditions repeatedly occurred during Early Triassic based on the preliminary study of bioturbation found in radiolarian chert successions, and also Kakuwa (2004) described some trace fossils in the Lower Triassic siliceous claystone.

The objective of this paper is to assess the secular change of palaeo-oxygenation of the bottom of a pelagic ocean from Middle Permian to Middle Triassic based on the degree of bioturbation of the rocks belonging to pelagic radiolarian chert successions, as well as to reassess published geochemical data.

2. Study sections

Radiolarian bedded chert of Late Carboniferous to Early Jurassic is distributed in the Mino–Tamba Belt, Ashio Belt, Northern and Southern Chichibu belts in central Japan. Three sections are selected for detailed examination in which samples are collected bed by bed.

2.1. Ubara section

The Ubara section belongs to the Mino–Tamba Belt, and is situated in Ayabe City, Hyogo Prefecture (Fig. 1). Grey radiolarian chert gradually changes to grey siliceous claystone and then to black carbonaceous claystone (Kuwahara et al., 1991; Kakuwa and Toyoda, 1996; Fig. 2). Kuwahara et al. (1991) described the occurrence of Late Permian radiolarians. Yamakita et al. (1999) reported the diagnostic Changhsingian conodont, *Neogondolella changxingensis* from the uppermost part of the siliceous claystone, and Griesbachian conodont, *Hindeodus parvus* from the basal part of the black carbonaceous claystone. A 3 cm-thick grey siliceous claystone bed occurs in the basal part of the black carbonaceous claystone, and two alternatives of the PTB is placed on lithologic boundaries; the lower boundary of the first occurrence of the black carbonaceous claystone or the upper boundary of the 3 cm-thick grey claystone bed (Fig. 2). A fault in the basal part of the carbonaceous claystone is not significant and judged as conformable. The black carbonaceous claystone is exposed to a thickness of a few metres in this section, but the upper portion is not useful for ichnofabric analysis due to tectonic disturbance.

2.2. Tenjinmaru section

The Tenjinmaru section belongs to the Northern Chichibu Belt, and is situated in Kisawa Village, Tokushima Prefecture (Fig. 1). This section is composed of dark grey radiolarian bedded chert with thick shale partings, black carbonaceous claystone and grey siliceous claystone, in ascending order (Yamakita, 1993; Kakuwa, 1996; Kakuwa and Toyoda, 1996; Fig. 3). The chert is dated as late Late Permian by the occurrence of Radiolaria *Neoalbaillella triangularis* and *N. levis* (Kuwahara and Yamakita, 2001), and Changhsingian age by the

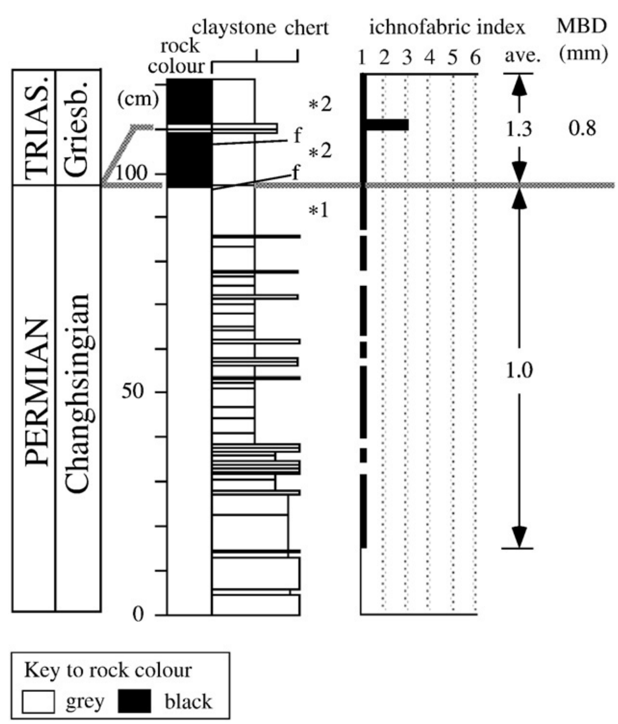

Fig. 2. Lithologic column and stratigraphic variations of ichnofabric indices of the Ubara section.