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GEOLOGY

Evidence for Anoxia in Deep Environments of Northeast Asia at the Permian–Triassic Transition

A. S. Biakov and I. L. Vedernikov

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It is well known that the Permian–Triassic transition was marked by significant changes in the biota and sedimentation settings. Evidence for the development of anoxic environments in various world areas during events at the Permian–Triassic transition in both shallow- and deep-water settings are reported in [1–8 and others]. Such data have been unavailable thus far for the Russian territory. The study of Permian–Triassic boundary deepwater sediments in Northeast Asia provided the first evidence for H_2S contamination of bottom waters in this region.

Both shallow- and deep-sea basins existed in Northeast Asia during the Permian Period [9]: Ayan-Yuryakh, Balygychan, Sugoi, and Gizhiga. They were characterized by avalanche sedimentation, which was responsible for accumulation of thick (up to 7 km) sandy–clayey and volcanogenic (frequently, turbidite) sediments with impoverished fossil assemblages. The fossils are represented by Inoceramus-like bivalves and subordinate ctenodont bivalves and gastropods (*Straparolus*).

In the terminal Permian, the system of sea basins in Northeast Asia experienced some shoaling. In deep marginal sea basins, bathyal settings recorded by the accumulation of turbidite sequences gave way to shallower conditions comparable with deep shelf settings, which differed, however, from typical shelf environments. They reflected substantial shoaling of marginal basins in response to the global regression in the terminal Permian [10]. The rocks are characterized by abundant structural distortions and traces of intense bioturbation (distinctly or vaguely patchy structures). Benthic fossils are more common as compared with the underlying strata.

The sea basins became deeper during the Permian–Triassic transition. This is evident from the change in the sedimentation pattern in the section: the complete disappearance of distorted bedding, spotty structures, and any other signs of vital activity of benthic organisms, as well as their remains. Instead, thin horizontal and, less commonly, oblique lamination appears. The rocks become fine-grained. All these features imply intense activity of contour currents and lack of benthic life. Such a lithological change in deep-water settings is characteristic of spacious areas of Northeast Asia extending from the Verkhoyansk region to the Taigonos Peninsula. Lower Triassic sediments (up to the *Tompophiceras pascoei* Zone) lack benthic fossils and bioturbation.

The Orotukan segment of the Balygychan basin is one of the most promising areas for the study of the Permian–Triassic boundary sediments (Fig. 1). The upper part of the Permian section (200 m) is represented here by foliated silty argillites of the Pautovaya Formation, while the lower part of the Triassic sequence is composed of silty argillites with thin siltstone laminae of the Gerba Formation [10]. The Late Permian (late Changhsingian) age of the upper Pautovaya Formation is substantiated by a finding of an impression of the bivalve *Claraioides* aff. *primitivus* (Yin) [11]. The Early Triassic age of the Gerba Formation is confirmed by ammonoid *Tompophiceras pascoei* (Spath) remains found several kilometers northwest of the study section 70–80 m above the Permian–Triassic boundary.

The rocks are characterized by an elevated C_{org} content (0.91–0.95% on average, up to 4.92% in some samples), which makes them similar to carbonaceous black shales [12]. Organic matter is finely dispersed. Its origination is most likely related to zoo- and phytoplankton [13].

The above-mentioned lithological features of rocks and lack of benthic fossils indicate that the sediments accumulated in anoxic settings. Kholodov and Nedumov, who studied Quaternary and Tertiary sediments of the Black Sea region [14] and Cretaceous organic-rich clayey rocks of the Atlantic [15], suggested using the Mo/Mn ratio as an indicator of anoxic environments. They established that Mo/Mn values ranging from 0.0*n* to 0.*n* correspond to H_2S-contaminated environments in

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Northeast Interdisciplinary Research Institute, Far East Division, Russian Academy of Sciences, ul. Portovaya 16, Magadan, 685000 Russia; e-mail: abiakov@mail.ru

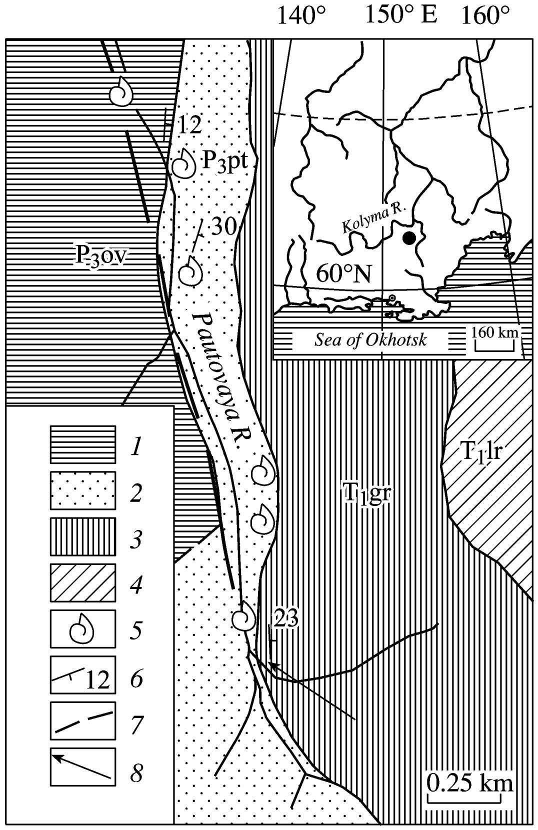

Fig. 1. Schematic geological map of the study area and its position in Northeast Asia. (*1*) Ovod Formation; (*2*) Pautovaya Formation; (*3*) Gerba Formation; (*4*) Larukov Formation; (*5*) finds of fossils; (*6*) attitude elements; (*7*) assumed fractures; (*8*) location of the studied Permian–Triassic boundary section. The dot in the inset indicates the position of the study area.

paleobasins. We also used this parameter for reconstructing anoxic settings.

In 2003, we sampled thoroughly the Permian–Triassic boundary section in the watershed between the Pautovaya and Gerba rivers that was studied preliminarily in 2000. The samples (approximately 100 g each) were taken from the least altered rocks with an interval of 6–40 cm. The total thickness of the sampled interval was approximately 7 m (6 samples from the 3-m-thick Upper Permian sediments and 36 samples from the 4.2-m-thick Lower Triassic section). The samples were studied in the Analytical Center of the Northeastern Complex Research Institute. Mo and Mn were determined by the express quantitative spectral method (T.P. Kozyreva, analyst) and the X-ray spectral silicate method (V.I. Manuilova, analyst), respectively. The lower detection limits for Mo and Mn were 0.125 and 20 ppm, respectively.

Nineteen samples taken immediately above the Permian–Triassic boundary (Fig. 2) demonstrated Mo/Mn values an order of magnitude higher (up to 0.048 against the background values of 0.002–0.008 in the study basin). Lower layers of the Triassic layers (samples 7–17) are characterized by a drastic increase in the concentration of the following elements (ppm): Mo (from 1 to 5–25), Sn (from 2 to 12), Pb (from 5 to 40), As (from 5 to 95), and Sb (from 2 to 10 ppm).

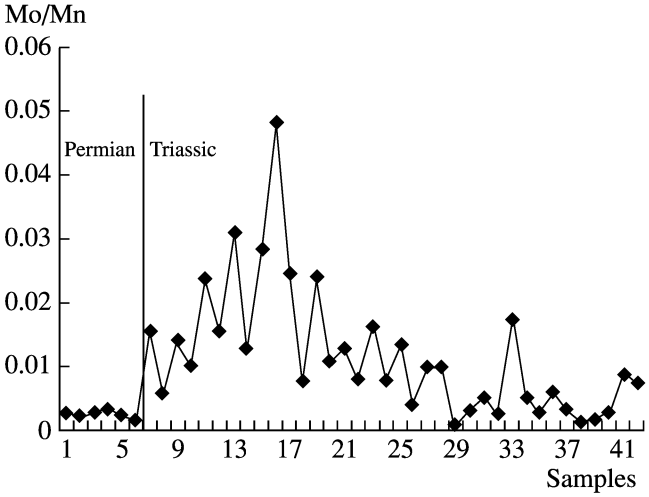

Fig. 2. Plot demonstrating variations in Mo/Mn values in the Permian–Triassic boundary sediments.

The data obtained evidence clearly anoxic environments in deep basins of Northeast Asia during the Permian–Triassic transition.

Judging from data obtained for some samples from the underlying sediments of other sections of the Balygychan basin, anoxic environments appeared repeatedly in earlier periods as well (at least since the beginning of the Wuchiapingian Age of the Late Permian), but they were most prolonged and widespread at the Permian–Triassic transition, which likely resulted in the death of the entire deep-water benthic biota.

Thus, our studies of the Permian–Triassic deep-water boundary sediments revealed for the first time features indicating H_2S contamination of bottom waters in the eastern part of the Boreal realm, which includes the studied sedimentation basins of Northeast Asia. This fact confirms similar inferences of some authors concerning the global development of anoxic settings in the Permian–Triassic transition in various basins of Panthalassa [1, 3], Tethys [2, 5–7], Australia [4], and the western Boreal realm [8].

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