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Middle–Upper Jurassic (Upper Callovian–Lower Kimmeridgian) stable isotope and elemental records of the Russian Platform: Indices of oceanographic and climatic changes

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ABSTRACT

New isotope ($\delta^{18}O$, $\delta^{13}C$) and elemental (Mg/Ca, Sr/Ca) data of well-preserved belemnite rostra, ammonite and gastropod shells from the Middle Oxfordian–Lower Kimmerdgian (Densiplicatum–Kitchini zones) of the Russian Platform are presented. This record is supplemented with published data from the Upper Callovian–Lower Kimmeridgian interval (Athleta–Kitchini zones). Significant differences in average temperatures calculated from $\delta^{18}O$ values of particular fossil groups (5–15 °C) show the thermal gradient and the presence of cold bottom waters in the Middle Russian Sea during the Late Callovian–Middle Oxfordian. An Upper Oxfordian–lowermost Kimmeridgian decrease in $\delta^{18}O$ values and an increase in Sr/Ca ratios of cylindroteuthid belemnite rostra likely reflect a warming of the bottom waters of ca. 3.5 °C. The gradual Late Oxfordian–earliest Kimmeridgian warming is followed by an abrupt temperature rise of 3–6 °C that occurred at the transition of the Early Kimmeridgian Bauhini and Kitchini chrons.

The occurrences of cold bottom waters and of (Sub)Mediterranean ammonites and belemnites in the Middle Russian Sea at the Middle–Late Jurassic transition are regarded as a result of the opening of seaways during a sea level highstand. The bottom waters are considered to have been formed in the cool Boreal Sea. The subsequent retreats of the cold bottom waters and of the (Sub)Mediterranean cephalopods from the Middle Russian Sea in the Late Oxfordian are explained by the restriction of water circulation during a sea-level fall. The Early Kimmeridgian rise of bottom temperatures of the sea is linked to a global climate warming. The data presented do not support a major cooling of the Arctic and a consequent glaciation in this region at the Middle–Late Jurassic transition. Since occurrences of cold water masses are diachronous in different European basins, the observed variations in sea water temperatures are interpreted as a result of changes in marine currents and water circulation.

$\delta^{13}C$ values of belemnite rostra from the Russian Platform are scattered but show the long-term Upper Callovian–Middle Oxfordian positive excursion consistent with the previously published isotope records of the Boreal Realm and terrestrial organic matter.

1. Introduction

Oxygen isotope records of biogenic carbonates from the Russian Platform and of tooth phosphates from Western Europe as well as migrations of ammonite fauna have been interpreted as an evidence of severe cooling at the Middle–Late Jurassic transition and subsequent warming (Dromart et al., 2003; Nunn et al., 2009; Price and Rogov, 2009; Donnadieu et al., 2011) or of prominent sea-level rise and changes in water circulation and salinity (Wierzbowski et al., 2009; Wierzbowski and Rogov, 2011). Major perturbations in the carbonate carbon cycle have been observed at the Middle–Late Jurassic transition, with a decline of carbonate platforms during the Late Callovian–Early Oxfordian and a recovery of carbonate sedimentation starting from the Middle Oxfordian (Bartolini et al., 1996; Morettini et al., 2002; Dromart et al., 2003; Cecca et al., 2005). The perturbations in the carbonate carbon cycle were claimed to be a source of the low atmospheric CO_2 level in the Late Callovian–Early Oxfordian period followed by a rise in the atmospheric CO_2 content in the Middle Oxfordian (Louis-Schmid et al., 2007b; Donnadieu et al., 2011). The enhanced volcanic activity of the seafloor observed during the Middle–Late Jurassic transition was in turn suggested to have been a source of the increased CO_2 degassing from the lithosphere (Wierzbowski et al., 2009, 2012).

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Despite numerous studies climatic proxy data for the Middle–Upper Jurassic are still fragmentary. The theories presented are therefore of limited relevance for the understanding of the contentious nature of environmental changes during and after the Middle–Late Jurassic transition.

The paper presents a compilation of new and old isotope and elemental data from the Subboreal Province of the Russian Platform. The new and old datasets are precisely correlated stratigraphically with the Submediterranean ammonite zonation of Central Europe. The interpretation of the environmental changes in the Middle–Late Jurassic (Late Callovian–Early Kimmeridgian) is based on thorough analysis of geochemical and faunistic proxies. The aim of the present contribution is to unravel the causes of the prominent changes that occurred in the Middle Russian Sea during and after the Middle–Late Jurassic transition and to discuss the reasons for the migrations of marine faunas.

2. Paleogeography and paleobiogeography

Most of Europe was flooded by shallow, epicontinental seas during the Late Callovian–Early Kimmeridgain (Fig. 1). Non-depositional events occurred in central-European seas during the Late Callovian–Early Oxfordian, whereas calm carbonate sedimentation prevailed in the Middle–Late Oxfordian and the Early Kimmeridgian. North-eastern European basins including the huge Middle Russian Sea and its central part — the Volga basin were connected with both the Boreal Sea and the Tethys Ocean and surrounded by land-masses. The Middle–Upper Jurassic deposits of the north-eastern Europe basins consist predominantly of siliciclastics — they are often organic rich and calcareous. The Callovian–Oxfordian boundary sections of the north-European basins are generally more complete than are those of the Tethyan and peri-Tethyan areas.

The provincialism of Jurassic ammonite and belemnite fauna caused the development of two major biochoremas: the Boreal (Arctic) and the Mediterranean (Tethyan) realms. Transitory faunistic zones, including the belemnite Boreal–Atlantic Subrealm (or Province) and the ammonite Subboreal and Submediterranean provinces, are also distinguished in Europe (Doyle, 1987; Westermann, 2000; Cecca and Westermann, 2003; Page, 2008; Page et al., 2009). Worth noting is the marked overlap of ammonite faunas observed in Europe during the latest Callovian–Early Oxfordian. This results in difficulties in the determination of province borders but has enabled common utilization of the standard Boreal ammonite zonation (Matyja and Wierzbowski, 1995; Page et al., 2009).

The Volga Basin was settled predominantly by Boreal–Subboreal ammonites (cardioceratids, kosmoceratids and aulacostephanids) and belemnites (cylindroteuthids) in the Late Callovian–Early Kimmeridgian. Other ammonites (aspidoceratids, perisphinctids and oppeliids) that usually inhabited Submediterranean and Mediterranean provinces, and Tethyan mesohibolitid ("belemnopseid") belemnites, were also present in this area (cf. Głowniak et al., 2010).

3. Geological setting

Belemnites, ammonites and a few gastropods (*Bathrotomaria* sp.) were collected from the Middle Oxfordian–Lower Kimmerdgian succession of the Makar'yev (57° 54′ 21″ N, 43° 49′ 44″ E) and Mikhalenino (57° 59′ 56″ N, 44° 0′ 23″ E) outcrops located at the Unzha river (tributary of the Volga), in the Kostroma District of Russia (Fig. 2). The sediments exposed in the Makar'yev and Mikhalenino sections consist of gray calcareous clays containing a few glauconitic and phosphoritic layers and one layer of calcareous concretions (Mesezhnikov, 1989; Hantzpergue et al., 1998; Bushnev et al., 2006; Rogov and Kiselev, 2007; Głowniak et al., 2010). Two bituminous oil shale horizons occur in the Middle–lowermost Upper Oxfordian part of the succession (TOC contents of 5–15%; Hydrogen Index of 400–500; Hantzpergue et al., 1998; Bushnev et al., 2006). The clays that outcrop in the Makar'yev and Mikhalenino sections have a total thickness of ca. 11 m and are rich in well-preserved foraminifer, ostracod, gastropod, ammonite and

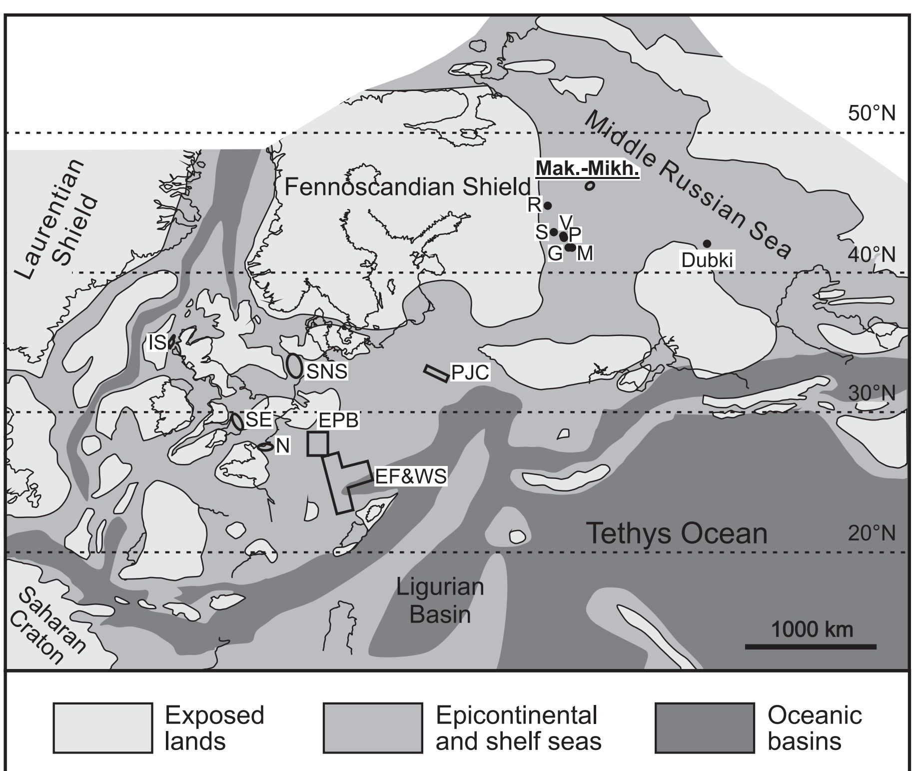

Fig. 1. Early Oxfordian paleogeography of Europe (after Wierzbowski and Rogov, 2011). Areas of paleoclimatic studies (referred in the text and figures): EPB — eastern Paris Basin; EF&WS — eastern France and western Switzerland; G — Gorenka; IS — Isle of Skye; M — Mikhaylov; Mak.-Mikh. — Makar'yev, Mikhalenino; N — Normandy; P — Peski; PJC — Polish Jura Chain; R — Rybinsk (Ioda River); S — Shchelkovo; SE — southern England; SNS — southern North Sea; V — Voskresensk.