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The Ponto-Caspian basin as a final trap for southeastern Scandinavian Ice-Sheet meltwater

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ABSTRACT

This paper provides new data on the evolution of the Caspian Sea and Black Sea from the Last Glacial Maximum until ca. 12 cal kyr BP. We present new analyses (clay mineralogy, grain-size, Nd isotopes and pollen) applied to sediments from the river terraces in the lower Volga, from the middle Caspian Sea and from the western part of the Black Sea. The results show that during the last deglaciation, the Ponto-Caspian basin collected meltwater and fine-grained sediment from the southern margin of the Scandinavian Ice Sheet (SIS) via the Dniepr and Volga Rivers. It induced the deposition of characteristic red-brownish/chocolate-coloured illite-rich sediments (Red Layers in the Black Sea and Chocolate Clays in the Caspian Sea) that originated from the Baltic Shield area according to Nd data. This general evolution, common to both seas was nevertheless differentiated over time due to the specificities of their catchment areas and due to the movement of the southern margin of the SIS. Our results indicate that in the eastern part of the East European Plain, the meltwater from the SIS margin supplied the Caspian Sea during the deglaciation until ~13.8 cal kyr BP, and possibly from the LGM. That led to the Early Khvalynian transgressive stage(s) and Chocolate Clays deposition in the now-emerged northern flat part of the Caspian Sea (river terraces in the modern lower Volga) and in its middle basin. In the western part of the East European Plain, our results confirm the release of meltwater from the SIS margin into the Black Sea that occurred between 17.2 and 15.7 cal kyr BP, as previously proposed. Indeed, recent findings concerning the evolution of the southern margin of the SIS and the Black Sea, show that during the last deglaciation, occurred a westward release of meltwater into the North Atlantic (between ca. 20 and 16.7 cal kyr BP), and a southward one into the Black Sea (between 17.2 and 15.7 cal kyr BP). After the Red Layers/Chocolate Clays deposition in both seas and until 12 cal kyr BP, smectite became the dominant clay mineral. The East European Plain is clearly identified as the source for smectite in the Caspian Sea sediments. In the Black Sea, smectite originated either from the East European Plain or from the Danube River catchment. Previous studies consider smectite as being only of Anatolian origin. However, our results highlight both, the European source for smectite and the impact of this source on the depositional environment of the Black Sea during considered period.

1. Introduction

Climate change in Europe during the Last Glacial Maximum (LGM; ca. 26–19 kyr BP) and the subsequent deglaciation have been intensively investigated through various archives leading to recently published compilations that focus on both the extent and timing of the last European Ice Sheet (EIS) (Hughes et al., 2015; Stroeven et al., 2015; Toucanne et al., 2015). During the LGM and until the complete melting of the ice sheet after 9.7 cal kyr BP (Stroeven et al., 2015), the EIS affected environmental conditions not only locally but also on a much wider scale. As a prominent example of this, glacigenic sediments were deposited as far away as the Eastern North Altantic and the Bay of Biscay through meltwater

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pulses originating at the southern margin of the Scandinavian Ice Sheet (SIS, itself part of the EIS system). The meltwater was funneled from Baltic lowlands by ice-marginal valleys and by the so-called Channel River (Toucanne et al., 2009, 2010). Part of the meltwater from the southeastern side of the SIS could have been evacuated into the Caspian and Black Seas via the Volga and Dniepr Rivers respectively, as it has been postulated by many authors (e.g. Mangerud et al., 2004; Soulet et al., 2013). Indeed, both rivers drain the East European Plain that constitutes partly their catchment area, and their northern extent is close to, or on the limit of the southeastern SIS margin during the LGM and the deglaciation.

In the Western Black Sea, the so-called Red Layers form part of the Late Quaternary sedimentary sequence (Major et al., 2002; Strechie-Sliwinski, 2007; Soulet et al., 2013). Their formation has been attributed to the transport of sediments into the Black Sea by meltwaters from the southern SIS margin during the last deglaciation (Soulet et al., 2011a). On the river terraces in the lower Volga, the so-called Chocolate Clays are present. They constitute part of sediments deposited during the Early Khvalynian transgression of the Caspian Sea in the Late Pleistocene (e.g. Varuschenko et al., 1987). Nevertheless the precise timing of this transgression, as well as the origin of Chocolate Clays (even if considered as being deposited in cold climatic conditions) and time of their deposition are not clearly established, and still debated (e.g. Leonov et al., 2002; Badyukova, 2010; Yanina, 2012; Tudryn et al., 2013a; Sorokin et al., 2014; Arslanov et al., 2015; Bezrodnykh et al., 2015; Makshaev and Svitoch, 2015 and papers cited therein). As Kroonenberg et al. (1997) pointed out, accurate dating of the Early Khvalynian transgression, and determination of the origin of the Chocolate Clays, would aid in clarifying the relationship between global climate (the primary driving mechanism), Caspian Sea level and the evolution of hydrological systems on the East European Plain, and provide major arguments for causal mechanisms.

In this context we propose a detailed sedimentological, palynological and geochemical study based on sediments from the western part of the Black Sea, from the river terraces in the lower Volga and from the middle basin of the Caspian Sea. Based on our results and on recent findings concerning the Caspian and Black Seas as well as SIS evolution, the aim of this study is to ascertain the source areas of clay minerals deposited in the Ponto-Caspian basin during the last deglaciation. Further to this, we intend to identify the origin of Chocolate Clays deposited in the Caspian Sea during the Early Khvalynian transgression to improve the chronological framework for this transgression and to establish its causal mechanisms.

2. Setting

2.1. SIS southern margin at the LGM

Studies of sediments along to the southern and eastern SIS margin reveal the complexity of the spatiotemporal evolution of the SIS. The ice margin was marked by end moraines and hummocky landscapes with frequent ice-dammed lakes spanning from Lake Onega in Russia to northern Germany (Svendsen et al., 2004; Stroeven et al., 2015).

The precise timing for SIS fluctuations is still debated; nevertheless the timing for westward meltwater routing via ice-marginal valleys from the Baltic lowlands is quite well known. Indeed, based on glacigenic sediments from the southern SIS margin deposited in the Bay of Biscay, Toucanne et al. (2015) proposed a revised chronology for the LGM and post-glacial ice sheet evolution in this area. According to these authors, the main Channel River meltwater releases occurred before the LGM and during the deglaciation. They were produced by five phases of the large-scale ice-margin retreats: (i) during Heinrich Stadial 3 (HS3: between ~31 and 29 cal kyr BP), (ii) during HS2 (between ~26 and 23 cal kyr BP), (iii) at ~22.5–21.3 cal kyr BP, (iv) at ~20.3–18.7 cal kyr BP and finally (v) from ~18.2 to 16.7 cal kyr BP (first part of HS1; between 18 and 15 cal kyr BP). At around 17 cal kyr BP, the Channel River stopped its activity; according to Toucanne et al. (2010), meltwater then flowed towards the Nordic Seas.

In the southern part of the SIS (i.e. Baltic lowlands of Poland and Germany), a succession of three moraine belts, the Brandenburg-Leszno, Frankfurt-Poznań and Pomeranian (Pomorska), was identified from the LGM and dated (Rinterknecht et al., 2006, 2008; 2012, 2013; Dzierżek and Zreda, 2007; Marks, 2015). The new chronology proposed by Toucanne et al. (2015) identifies the Brandenburg-Leszno ice advance between ~23.4 and ~20.3 cal kyr BP. The Brandenburg-Leszno phase ended with a significant ice retreat dated at ~20.3–18.7 cal kyr BP. The Frankfurt-Poznań ice advance occurred between ~18.7 and ~18.2 cal kyr BP, while the Pomeranian one was between ~16.7 and ~15.7 cal kyr BP.

In the southeastern part of the SIS, recent reconstructions of its deglaciation that include the recalibration of previously published dates (Rinterknecht et al., 2008), indicate that the south Baltic coast was already ice free at 15–14 kyr (Stroeven et al., 2015; Hughes et al., 2015). Stroeven et al. (2015) proposed that the local LGM was reached at ~19 cal kyr BP in Belarus (Orsha phase), Lithuania (Gruda phase), Latvia and Estonia. This local LGM has been correlated with the Frankfurt-Poznan phase to the west, while in the northeastern sector in Russia, it was reached at 17 cal kyr BP, and broadly correlates with Pomeranian ice advance. According to Svendsen et al. (2004) and Hughes et al. (2015), the maximum position of the ice sheet advance was reached there at ~20–18 kyr. The outermost ice sheet limit during its maximum formed three major lobes in the Russian sector (Hughes et al., 2015; Stroeven et al., 2015). But the exact extent in the area of the Rybinsk basin is still not clearly established. As pointed out by Marks (2015), the deglaciation steps in the Russian sector are not well known; nevertheless, at least the Vepsian (probably corresponding to the Pomeranian phase in central Europe), Sebezha, Luga and Neva phases of ice sheet advance have been identified. The Luga phase was derived from the last ice sheet margin that extended to the south of Lake Onega, and it was considered as having occurred at ~14.2 cal kyr BP. Afterwards, the Neva phase was dated at ~13 cal kyr BP (Marks, 2015). This is in good agreement with data from the eastern shore of Lake Onega, which indicate that this area was deglaciated between 14.4 and 12.0 kyr BP (Saarnisto and Saarinen, 2001), and with recent compilation of Hughes et al. (2015).

During the LGM, the East European Plain belonged to the zone of continuous permafrost including the middle basins of Dniestr, Dniepr and Don (Bogutskiy et al., 1975; Velichko et al., 1996) as well as the Volga catchment area and the northern shoreline of the Caspian Sea from that time (Yanina, 2012). According to Vandenberghe et al. (2014), permafrost degradation started as early as 17–15 kyr BP.

2.2. The Ponto-Caspian basin - study area

The Black and Caspian Seas (Fig. 1) belong to the Ponto-Caspian region. They are relicts of the East Paratethys, and became individualized during the Pliocene (Varuschenko et al., 1987; Forte and Cowgill, 2013; Yanina, 2014; Van Baak, 2015). Caspian and Black Seas are intracontinental, effectively closed and semi-closed reservoirs of waters and thus very sensitive to climatic changes. They have important part of their catchment areas in the East European Plain and, during the Quaternary, were subjected to large amplitude water-level fluctuations (more than 100 m) (e.g. Serebryanny, 1982; Varuschenko et al., 1987).