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Flood zone biogeochemistry of the Ob River middle course

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ABSTRACT

The flood zone of the Ob River, the largest (in watershed area) river of the Arctic Ocean basin, is tens of km wide and, after the Amazon's Varzea, is the world's second largest flooding territory. To better understand the biogeochemistry of the Ob River and adjacent surface waters, we studied, in May and July 2014, the dissolved and colloidal organic carbon and trace metals in small rivers, lakes, and flooded water bodies connected and disconnected with the mainstream as well as the Ob River itself. All major and trace elements were distributed among two major categories depending on their pattern of dependence on the dissolved organic carbon (DOC) concentration. Dissolved inorganic carbon (DIC), Na, Mg, Ca, sulfate, Sr, Mo, Sb and U exhibited a general decrease in concentration with the increase of the [DOC]. The lowest concentration of these elements was observed in DOC-rich humic, acidic ($4.9 \le pH \le 6.1$) upland lakes fed by surrounding bogs. These elements marked the influence of underground feeding in July during summer baseflow, which was most visible in flood lakes in the Ob riparian zone and the Ob River itself. In May, the flood lakes were statistically similar to the Ob River. The elevated concentration of DOC (up to 60 mg/L) in the upland lakes was not correlated with groundwater-related elements, suggesting a lack of significant groundwater feeding in these lakes. In contrast, insoluble, usually low mobile elements (Al, Fe, other trivalent hydrolysates, Ti, Zr, Hf) and some metals (Cr, Zn, Ni, Pb) demonstrated a steady increase in concentration with increasing DOC, with the lowest values observed in the Ob River and the highest values observed in small tributaries and organic-rich upland lakes in July. It follows that these elements are limited by their main carriers – organic and organo-ferric colloids, rather than by the availability of the source, peat and mineral soil or plant litter. While for the majority of non-colloidal, groundwater-fed elements with high mobility (DIC, Na, Mg, Ca, K, Sr…) the small tributaries can be used as representatives of the Ob main stream, this is not the case for low mobility “insoluble” elements, such as Fe, Al, trivalent and tetravalent hydrolysates, and metal micronutrients (Cu, Zn, and Mn). The low soluble elements and divalent metals exhibited a much lower concentration in the river mainstream compared to that in the flood lakes, upland lakes and small rivers. This difference is significantly more pronounced in the baseflow in July compared to the spring flood in May. Presumably, autochthonous processes, such as the photo-oxidation and bio-oxidation of organo-ferric colloids and phytoplankton uptake are capable decreasing the concentration of these elements in the river mainstream.

1. Introduction

Despite the importance of the Ob River, the largest river discharging to the Arctic Ocean in terms of watershed area, systematic seasonally resolved studies of this river's dissolved load (carbon and metals) are limited compared to those of the Lena, Yenisei and Mackenzie Rivers. A possible reason for this understudy could be the weak coverage of the Ob watershed by permafrost (only 30% of the basin compared to 75%, 90%, and 100% of the Mackenzie, Yenisei, and Lena watersheds, respectively, Environment Canada, 2015; McClelland et al., 2004), which is the object of attention of most “arctic” researchers. However, ongoing climate change in the boreal and subarctic region will likely cause not only permafrost degradation and a respective river flux change but will also affect

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the precipitation regime and, in particular, the relative contribution of the spring flood versus summer and winter baseflow (Peterson et al., 2002; McClelland et al., 2006; Shiklomanov and Lammers, 2009; Rennermalm and Wood, 2010). Here, the importance of the Ob River is triple. First, the Ob River, exhibiting the second largest (after the Amazon's Varzea, Viers et al., 2005) flooding area, may become the largest contributor of dissolved carbon and related element transport from the land to the Arctic Ocean. Second, the majority of the Ob's watershed lies within the highly productive boreal taiga zone. The productivity of the terrestrial boreal biome is at its highest at the riparian zone and river banks, especially in the permafrost-free region (Huston and Wolverton, 2009). Because the degradation of plant litter is one of the major factors regulating the overall export of DOC and chemical elements from the boreal watersheds (Laudon et al., 2012; Pokrovsky et al., 2012) and because plant litter leaching is very fast (Aerts and Chapin, 1999), the spring flood period on the Ob River is especially important for the biogeochemistry of the western Siberia plain. Third, the Ob River watershed is likely to be most vulnerable to on-going climate change and permafrost thaw because the major part of its permafrost coverage is intermittent and sporadic permafrost (0–2 °C), rather than the continuous and discontinuous permafrost that is observed in other Arctic rivers (McClelland et al., 2004). The former is known to be most vulnerable to the ground temperature rise (Romanosvky et al., 2010).

The further importance of the Ob River and its watershed for the Arctic and subarctic region function stems from the very high dissolved Fe concentration in this river; the mean value for the period 1990–1996 is a factor of 5 higher than that of the Yenisey and the Lena rivers (Alexeeva et al., 2001). As a result, the Ob River provides almost 40% of the total flux of this important, potentially limiting micronutrient (i.e., Harrison and Cota, 1991; Schroth et al., 2014) and essential vector of metal transfer in surface waters (Hassellov and Von Der Kammer, 2008) from the land to the whole Arctic basin (Alexeeva et al., 2001). In the Western Siberia Lowland (WSL) rivers in general and in the Ob River watershed in particular, the elevated concentration of dissolved organic matter (DOM) linked to the abundance of peat bogs and wetlands is the main hydrochemical feature rendering this territory an important source of dissolved organic carbon (DOC) to the Arctic Ocean (cf., Lobbes et al., 2000; Frey and Smith, 2005; Dickens et al., 2011; Amon et al., 2012). The majority of divalent metals, trivalent and tetravalent hydrolysates are likely to be transported in the form of organic and organo-mineral colloids whose migration capacity and bioavailability depends on the nature of DOM. The DOM of terrestrial (peat and forest floor) or aquatic (phytoplankton and water plants exometabolites) origin may be subjected to photo- and biodestruction as it is fairly known for the boreal zone (Von Wachenfeldt et al., 2008; Hanson et al., 2011; Koehler et al., 2012; Ilina et al., 2014). These processes produce large variety of TE-bearing colloids in western Siberia lakes and ponds of the permafrost-subjected zone (Pokrovsky et al., 2011; Shirokova et al., 2013). However, the degree of transformation of these organic colloids in small and large rivers, permanent and ephemeral lakes receiving different inputs from bogs, forests and flooded meadows of the Ob River floodplain, remains fairly unknown. Note that, while the effect of water discharge from the flood plain lakes is addressed in numerous hydrological studies of Western Siberia (Nikitin and Zemtsov, 1986; Yang et al., 2004; Zakharova et al., 2014) the effects of the flood zone of the main river hydrochemistry are totally unknown since no transect-like study on the Ob River watershed has been performed so far.

To better understand the mechanisms regulating the contemporary fluxes of carbon, trace metals and major nutrients at the Ob watershed and to predict possible future changes, the use of the time series only at the terminal gauging station (i.e., Cooper et al., 2008; Holmes et al., 2012) is not sufficient. Rather, detailed, seasonal studies of the different components of the watershed, such as the small tributaries, flooded water bodies and adjacent lakes, are necessary to reveal the variation of chemical composition, along a transversal flooding gradient.

To achieve this goal, we sampled small first order tributaries as well as upland and flooded zone lakes and the Ob River's middle course in the boreal taiga zone during the spring flood (May) and the summer baseflow (July). The chosen site is highly representative for the Ob River middle course (approx. 1000 km length) located within the permafrost-free zone. We addressed the following specific questions:

(i) How variable is chemical composition of the main river, permanent and ephemeral lakes, secondary channels and small tributaries along a transversal flooding gradient?
(ii) Can we distinguish the control of the groundwater versus surface runoff on the river and lake hydrochemistry during two contrasting seasons?
(iii) How important is the control of the dissolved organic carbon on the TE concentration and colloidal forms in various surface water bodies?

We anticipate that understanding the main features of the dissolved load transformation between the feeding water bodies and the main rivers may help to predict the magnitude and direction of future changes of the Ob River's middle course hydrochemistry in response to the water flooding, river discharge regime and water temperature rise.

2. Study sites and methods

The middle course of the Ob River, located within the boreal taiga biome (Fig. 1A), includes (*i*) isolated and interconnected water bodies that are flooded during the spring period but are persistent during baseflow (called herein "flood lakes"); (*ii*) the flooded area of the river valley and first terrace that is covered by the river during high flow in May and extends, via a system of interconnected shallow ephemeral lakes and primary and secondary water channels, over 5–10 km from the main water channel (called "flood zone"); (*iii*) permanent lakes located at the upper terraces of the river that are not flooded during the spring ("upland lakes"); and (*iv*) small, first order tributaries of the Ob River that have a watershed area of 10–100 km^2 and drain both the terraces and the flood zone ("small rivers"). Here, we operationally define an "upland" as the territory of the 1st to 3rd river terraces that are not subjected to flooding. The upland is at a higher elevation than the alluvial plain, which is considered to be "lowland" (see profile Fig. 1B). Note that upland lakes, typical water objects of the middle taiga zone of the WSL, serve as first source of DOC, metals and other solutes to the rivers and small streams reaching the Ob' River and can be considered as end-members subjected to maximal influence of bog feeding having minimal degree of groundwater discharge. To some degree, the normal transect of the Ob River middle course and its flooding zone is similar to that of the Mackenzie Delta lakes, comprising a significant flooding gradient (i.e., Squires et al., 2002; Tank et al., 2009).

The water residence time (WRT) in studied water bodies was evaluated based on the hydrological balance of the flood zone comprising the daily water flux at the nearest hydrological gauging station at Nikolskoe following the procedure recommended for western Siberia rivers (Nikitin and Zemtsov, 1986), the water volume of the lakes and in-field measurements of their inlet and outlet, or in the case of closed upland lake, the evaporation/