Applied Geochemistry 98 (2018) 172–190

Contents lists available at ScienceDirect

Applied Geochemistry

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

Origin and hydrogeological setting of saline groundwater discharges to the Athabasca River: Geochemical and isotopic characterization of the hyporheic zone

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ARTICLE INFO

Editorial handling by J. Mirecki

Keywords:
Saline groundwater
Athabasca oil sands
Groundwater-surface
Water interactions
Hyporheic zone
Glaciogenic
Stable isotopes
Athabasca river

ABSTRACT

Identifying impacts of oil sands development on aquatic ecosystems requires understanding of the natural background water quality. In the Athabasca Oil Sands Region of Alberta this is challenging because the Athabasca River is incised directly into bitumen saturated sands of the McMurray Formation, and other saline Cretaceous and Devonian formations. This study compares the geochemical and isotopic composition of porewater sampled from the alluvial sediment beneath the Athabasca River with regional groundwater data to identify the geological origin of these saline groundwaters, and improve characterization of natural background sources of solutes entering the Athabasca River. Terrain conductivity surveys conducted along the Athabasca River were used to identify areas with evidence of saline groundwater discharge. Porewater samples were obtained from the alluvial sediment using drive point piezometers installed between 1 and 3 m below the water-sediment interface and were analyzed for $\delta^{18}O$, $\delta^{2}H$, $\delta^{34}S{-}SO_4$, $\delta^{18}O{-}SO_4$, $^{87}Sr/^{86}Sr$, $\delta^{13}C$-DIC, $\delta^{13}C$-DOC, ^{3}H, and ^{14}C. The porewater in the alluvial sediment showed variable degrees of mixing with the overlying Athabasca River water, but the geochemical and isotopic composition in zones 1, 3 and 5 are consistent with discharge of saline groundwater from Cretaceous or Devonian units. The low percentages of modern carbon, and $\delta^{18}O$, $\delta^{2}H$, $\delta^{34}S{-}SO_4$, $\delta^{18}O{-}SO_4$, and $^{87}Sr/^{86}Sr$ signatures in the deepest porewater samples from Zones 1, 3 and 5 indicate glaciogenic water with high total dissolved solids originating from Devonian sourced solutes. Theses saline groundwater discharge zones occur where higher horizontal hydraulic gradients coincide with areas of higher salinity in the adjacent Cretaceous and Devonian aquifers, and areas with vertical connectivity with underlying Devonian aquifers. The results of this study demonstrate the influence of groundwater-surface water interactions and saline bedrock formation water discharge to water quality along some reaches of the Athabasca River which need to be considered in monitoring and water management strategies.

1. Introduction

The Athabasca Oil Sands Region (AOSR) of Northeastern Alberta represents an important energy reserve for Canada and the world. Identifying potential impacts of oil sands development on aquatic ecosystems requires understanding of the natural background water quality. The Athabasca River and its tributaries are incised directly into bitumen saturated sands of the McMurray Formation, as well as other saline Cretaceous and Devonian formations so there are many natural background sources and pathways for organics and salinity to reach rivers in the region. The input of saline groundwater from these formations has been attributed as the cause for increases in chloride along this reach of the river (Jasechko et al., 2012; Gue et al., 2017), but better understanding of the composition, sources and spatial distribution of natural saline groundwater inputs are needed to improve our ability to identify anthropogenic impacts to water quality. Saline groundwater has been observed discharging near the Athabasca River as springs (Hitchon et al., 1969; Ozoray et al., 1980; Grasby and Chen, 2005; Gue et al., 2015), in saline fens adjacent to the river (Stewart and Lemay, 2011; Wells and Price, 2015), and more directly as riverbed seepage in alluvial sediment beneath the river (Gibson et al., 2011, 2013). Electromagnetic surveys along the Athabasca River between

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https://doi.org/10.1016/j.apgeochem.2018.09.005
Received 21 November 2017; Received in revised form 5 September 2018; Accepted 5 September 2018
Available online 20 September 2018

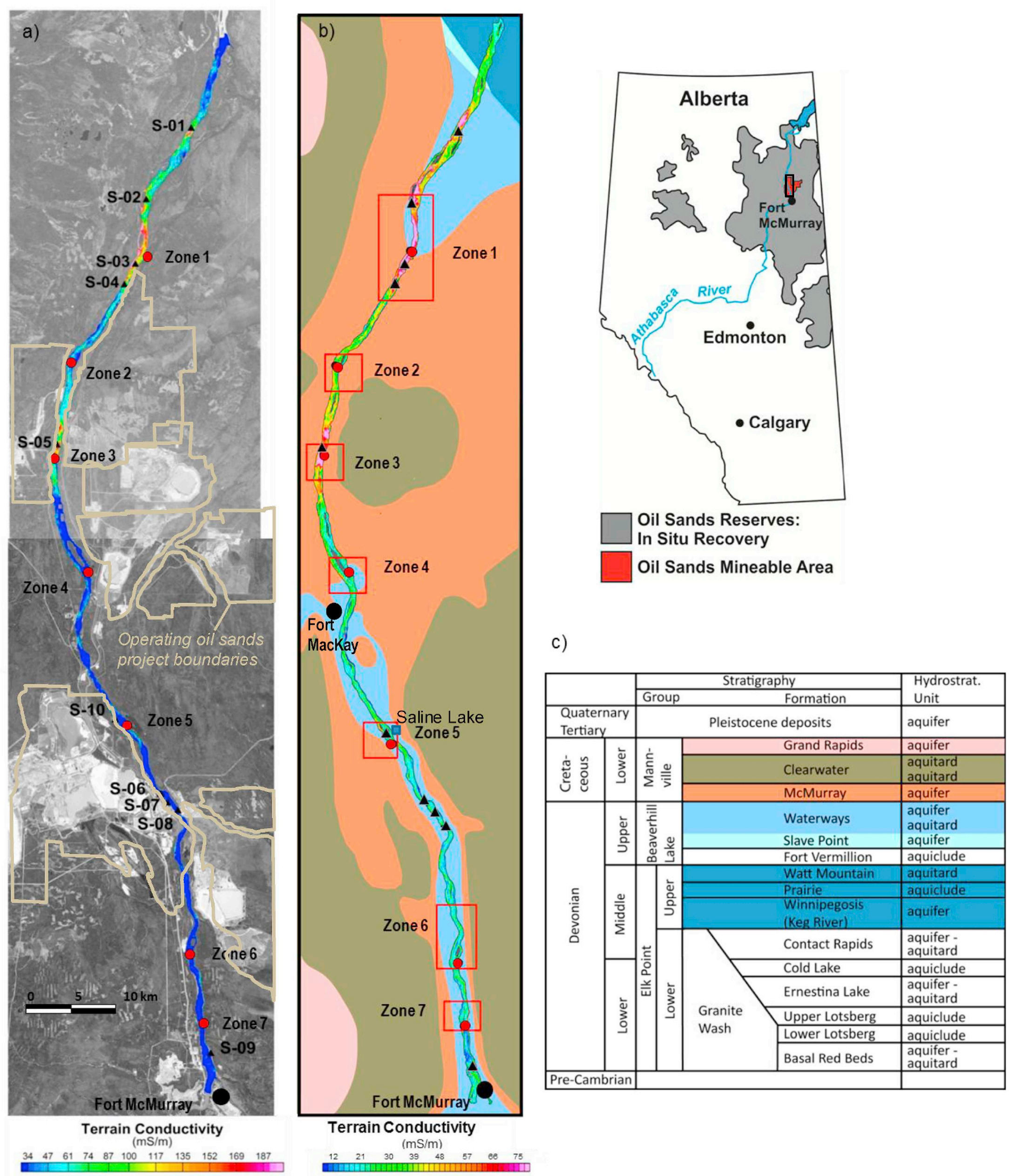

Fig. 1. The results of the low resolution terrain conductivity survey (a) and high resolution survey shown with bedrock geology (b) and the location of the porewater sampling locations (black triangles, 2009 samples, red circles October 2010 samples) and zones discussed in the text. The shading within the Athabasca River show the terrain conductivity with different resolutions (note different scales, low resolution left, higher resolution right). The lease boundaries for oil sands mining operations active as of 2018 are shown in beige. Inset shows the location of the Athabasca River and c) shows the legend with shading corresponding to the geological units shown in (b). Geology is modified from Prior et al. (2013). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fort McMurray and the confluence with the Firebag River were used to identify areas with elevated terrain conductivity to evaluate if these areas show evidence of saline groundwater discharge (Gibson et al., 2013). Previous work on porewater sampled from alluvial sediments in areas with elevated terrain conductivity, found that these saline porewaters had major ion compositions and $\delta^{18}O$ and $\delta^{2}H$ signatures similar to Cretaceous and Devonian saline groundwater suggesting that groundwater discharge from these units as a likely source of saline groundwater discharging to the Athabasca River (Gibson et al., 2013). Here we present an expanded suite of geochemical and isotopic data for the same porewater samples previously described in Gibson et al. (2013) and compare them with regional groundwater and river water datasets to better understand the distribution, sources and hydrogeological controls on these saline groundwater inputs.

1.1. Geological setting and hydrostratigraphy

The study area includes the 125 km reach of the Athabasca River from Fort McMurray north to the Firebag River (Fig. 1a) in an area with extensive surface mining developments. Over the study area the river incises Cretaceous (McMurray) and Devonian (Waterways, Slave Point and Keg River) formations (Fig. 1b). The complete stratigraphic