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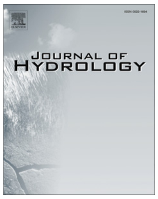

Research papers

The stable isotopes of site wide waters at an oil sands mine in northern Alberta, Canada

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ABSTRACT

Oil sands mines have large disturbance footprints and contain a range of new landforms constructed from mine waste such as shale overburden and the byproducts of bitumen extraction such as sand and fluid fine tailings. Each of these landforms are a potential source of water and chemical release to adjacent surface and groundwater, and consequently, the development of methods to track water migration through these landforms is of importance.

The stable isotopes of water (i.e. ^{2}H and ^{18}O) have been widely used in hydrology and hydrogeology to characterize surface water/groundwater interactions but have not been extensively applied in mining applications, or specifically to oil sands mining in northern Alberta. A prerequisite for applying these techniques is the establishment of a Local Meteoric Water Line (LMWL) to characterize precipitation at the mine sites as well as the development of a 'catalogue' of the stable water isotope signatures of various mine site waters.

This study was undertaken at the Mildred Lake Mine Site, owned and operated by Syncrude Canada Ltd. The LMWL developed from 2 years (2009/2012) of sample collection is shown to be consistent with other LMWLs in western Canada. The results of the study highlight the unique stable water isotope signatures associated with hydraulically placed tailings (sand or fluid fine tailings) and overburden shale dumps relative to natural surface water and groundwater. The signature associated with the snow melt water on reclaimed landscapes was found to be similar to ground water recharge in the region. The isotopic composition of the shale overburden deposits are also distinct and consistent with observations made by other researchers in western Canada on undisturbed shales. The process water associated with the fine and coarse tailings streams has highly enriched ^{2}H and ^{18}O signatures. These signatures are developed through the non-equilibrium fractionation of imported fresh river water during evaporation from cooling towers used within the raw water process circuit. This highly fractionated surface water eventually becomes part of the recycled tailings water circuit, and as a consequence it undergoes further non-equilibrium fractionation as a result of surface evaporation, leading to additional enrichment along local evaporation lines.

1. Introduction

The oil reserves in northern Alberta are estimated to be in the order of 1.7×10^{12} barrels of oil (McLinden et al., 2012), 20% of which may be extracted through surface mining with a final disturbance footprint of approximately 4800 km^{2} (Government of Alberta, 2008). Oil sands mining involves stripping and salvaging surface organic and underlying mineral soils, such as glacial till or alluvium, for future use in reclamation. This is followed by the removal and stockpiling of the bedrock overburden within mined out pits or on surface in overburden dumps. The oil sands are crushed and hydraulically transported to a mill/upgrader for extraction using a combination of hot water and diluent extraction. The waste streams from extraction are comprised of coarser sand tailings and fluid fine tailings (FFT) which contain a mixture of finer particles (silts, clays) as well as residual bitumen. These tailings are hydraulically transported back to disposal areas using recycled process water also known as oil sands process water

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(OSPW). The transport of mined ore, processing, and tailings transport requires large volumes of water. The Mildred Lake Mine, operated by Syncrude Canada Ltd., recycles approximately 1.5×10^8 m^3 of OSPW through the extraction/upgrading plant annually. This volume represents about 80% of the total water requirement for production (Zubot, 2010). The remainder of the water requirement is provided by freshwater imported from the Athabasca River. Approximately 2.5 m^3 of freshwater import is required for every 1 m^3 of bitumen produced. The main use of this freshwater is for steam generation (RSC, 2011) associated with extraction and bitumen upgrading.

Oil sands mines are designed to operate as 'zero release' facilities, meaning that the sites retain all water associated with dewatering, mining and extraction on site during operations. As the mine site moves towards closure, there will need to be release of site waters back to the Athabasca River. An evaluation of the magnitude and quality of these site waters will require that the rates, pathway and volume of water moving through the various closure landforms such as overburden and tailings be characterized.

There are relatively few cases in which stable isotopes of water have been measured for mining waste. Sracek et al. (2004) collected a limited number of water samples from a full scale waste rock pile (30–35 m) using suction lysimeters and a well in the underlying saturated zone. They were able to show that there was an equal contribution of snow melt water and spring rainfall to the stored water within the waste rock. Allen and Lepitre (2004) and Allen and Voormeij (2002) also utilized stable isotopes of water in a relatively small number of samples (n = 32) to characterize meteoric water as well as sources and mixing of mine site waters at the Sullivan mine in British Columbia, building on some similar work undertaken by Ghomshei and Allen (2000) at the Nickel Plate mine, British Columbia. Gibson et al. (1998) and Gibson and Reid (2010, 2014) used isotopes to estimate the water balance of tailings ponds and natural lakes over a 20-year period at sites in Yellowknife and in the central Arctic. Hydrogeological studies at mine sites using stable isotopes have been more numerous (e.g., Douglas et al., 2000; Fracflow Consultants Inc., 1998). A recent study by Barbour et al. (2016) undertook high resolution profiling of stable isotopes of water through waste rock piles associated with coal mining in southern British Columbia and were able to identify seasonal cycles of winter and summer recharge over depths of up to 85 m.

Gibson et al. (2011) undertook a broad survey of isotopic and geochemical tracers for natural waters (river and groundwater; n = 31) and tailings pond waters (n = 8) for sites along the Athabasca River in the oil sands mining region of northern Alberta. The tailings pond water appeared to fall along a local evaporation line (LEL) with a slope of approximately 4.5 when compared to the LMWL for Edmonton. The stable isotope of water composition of the process affected water in the tailings ponds also appeared to be strongly enriched relative to mean precipitation. The study by Jasechko et al. (2012) was focused on deeper groundwater in the same area associated with the discharge of deep saline waters into the Athabasca River. They report that freshwater lakes in the region appear to be recharged by water with an average isotopic composition of $\delta^{18}O$ of −19.8‰ and $\delta^{2}H$ of −148.2‰.

This study attempts to build on these earlier studies but with a particular focus on a single operating oil sands mine: Syncrude's Mildred Lake Mine. The objectives of the study are to establish a preliminary LMWL for the mine site; characterize the stable isotope of water signature of all mine site waters; and identify key processes responsible for the various isotopic signatures associated with mine site waters.

2. Study area

The Mildred Lake Mine operated by Syncrude Canada Ltd. (SCL) is located about 35 km north of Fort McMurray, AB within the North Athabasca Oil Sands Region (Fig. 1a). The bitumen rich ore at the site is primarily present in the Lower Cretaceous Wabiskaw-McMurray Formation and is overlain by shale from the Cretaceous Clearwater formation (Hein and Cotterill, 2006). The Mildred Lake Mine site covers approximately 200 km^2 and contains a variety of landforms including active mining areas, tailings sand structures, overburden dumps, above ground and in-pit tailings areas and freshwater reservoirs. An aerial image of the mine site is shown in Fig. 1b with the principle areas accessed for this study highlighted. These areas include: a reclaimed overburden dump comprised primarily of shale referred to as South Bison Hills (SBH); an above ground sand tailings area, Southwest Sands Storage (SWSS); a fluid fine tailings (FFT) and process water containment structure, the Mildred Lake Settling Basin (MLSB); an in-pit tailings basin containing mature fine tailings (MFT), West in-pit (WIP); and in-pit tailings basins containing composite tailings (e.g. mixtures of MFT and sand tailings), East in-pit (EIP); and Southwest in-pit (SWIP); as well as a freshwater reservoir which contains water pumped from the Athabasca River, the Mildred Lake (ML) reservoir.

The oil sands region of northern Alberta, Canada is located in the sub-humid region of the boreal forest and is marked by long, cold winters with approximately 450 mm of annual precipitation, of which 1/3 is snow, and with 500 mm of potential evapotranspiration (Huang et al., 2015a). The mean monthly air temperature within the region ranges from −19 °C during January to 17 °C for July, with a mean annual temperature near 1 °C. Daily relative humidity also varies seasonally from 77% during the winter months of November to March to 65% during the evaporation months of April to October (RAMP, 2015).

3. Materials and methods

Field sampling programs were undertaken from 2012 through 2014 at sampling locations distributed across the various landforms at the site as described in Section 2. The sampling program included meteoric water (rain and snow pack samples), tailings pond water samples, and soil samples taken from the tailings (sand and FFT) as well as shale overburden.

3.1. Field sample collection

Rainfall was collected at three rainfall gauge stations located across the mine site including rainfall stations at the north-east end of SWSS (Cell 32), SBH (30 Top), and the south-west side of the MLSB (U-Cell) as shown in Fig. 1b. These samples were generally collected during non-freezing months (April through September) using collection samplers constructed with a funnel connected to a long tube which transferred the water to a 1 L collection bottle. These collection devices were based on a design similar to those described by IAEA (2014). The long tubing minimizes evaporative loss from the collected water between collection times. The rainfall collectors were sampled after significant rain events or were checked on a bi-weekly basis.

Snow surveys over a number of the closure landforms are performed each spring by SCL personnel or their field consultants. During the surveys undertaken in March 2012, January/February 2013, March 2013 and 2014, snow pits were dug or cored to ground surface and a composite depth snow sample was placed into large Ziploc® freezer bags (26.8 cm × 27.3 cm). These samples were then allowed to fully melt at room temperature and the melt