Investigation of physical, chemical and microbiological processes in the development of forest rings in Ontario

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ABSTRACT: Forest rings are large circular features distinctive of Ontario's boreal forest. They are centred on areas of negative redox charge and characterized by a slight depression in the mineral soil around the edge of the ring. A field and laboratory investigation of forest rings is investigating the complex relationship between physical, chemical and microbiological processes occurring at the edge of these features. Physical changes that are known to occur include a slight positive electrical field anomaly over the centre of the ring, a negative thermal and hydraulic-conductivity anomaly. Chemical changes are profound and most exemplified by a very sharp redox gradient at the edge of the ring between the chemically reduced interior and the oxidized exterior. Microbiological processes are also occurring and although cause-and-effect relationships are still unproven, they may be crucial in the formation of the rings. A 4 week laboratory experiment involves the *in vitro* creation of the redox gradients of the two end-member types of rings: one centred on a hydrogen sulphide source and another on a methane source. Test-tubes are being inoculated with bacteria from the highest-gradient ring parts of the respective ring edges. Measurements will provide insight on the role of micro-organisms in ring formation.

KEYWORDS: *forest ring, thermal conductivity, redox, microbiology*

INTRODUCTION

Forest rings are large circular features commonly observed in the boreal forests of Ontario (fig. 1). Over 2000 forest rings, ranging from 15m to 1.5km in diameter, have been identified on aerial photographs thus far. The circular impression reflects a slight topographic depression (Giroux et al. 2001) that forms around centres of negative charge enclosed in the overburden or bedrock. Large accumulations of shallow, biogenic methane are estimated to account for 85% of northern Ontario's forest rings (Hamilton et al., 2004). Forest rings have also been reported to form over accumulations of bitumen, coal and dissolved hydrogen sulphide (Hamilton & Hattori, 2008). The reducing source imparts electrochemically reducing conditions in overlying and surrounding materials generating numerous physical and chemical changes at the ring edges. Most notably, subtle positive spontaneous potential (SP) anomalies can be noted in association with strong, negative-inward, redox gradients (Hamilton & Hattori, 2008). The goal of our work is to understand the role of micro-organisms in the oxidation process and in the generation of electrical fields.

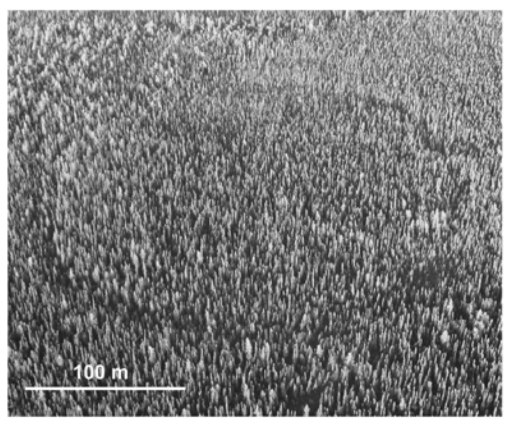

Fig. 1. Aerial view of a forest ring near Hearst, Ontario.

The current investigations monitor changes in groundwater temperature across an H_2S-centered forest ring. The rationale behind the temperature measurements was that microbiological activity and intense oxidation is known to occur at the ring edges and it was thought that temperature data might pinpoint the exact location of the associated exothermic reactions and help with energy and mass budget calculations. However, to our surprise, the results were the opposite of what had been expected; they show a significant *negative* thermal anomaly. Subsequent investigations have (1) confirmed the results, (2) shown them to occur at other rings and (3) narrowed the location of the temperature anomaly to precisely that of the physical, chemical and microbiological changes that occur at the ring edge. The purpose of this study is to understand these changes and how they are interrelated and to investigate the role of micro-organisms in the oxidation process and generation of electrical fields at the ring edge.

METHODOLOGY

Groundwater temperatures and water levels were monitored for a period of 10 months across the edge of an H_2S-centered forest ring ("Thorn-North") located 45 km northwest of Timmins, Ontario. Measurements were made using down-hole data loggers installed in existing monitoring wells at a depth of approximately 6.5 m. In addition, the ring edges of two methane-centred forest rings ("Road ring" and "Bean") were sampled for soil and peat. High-density sampling was done at several depths on transects across the ring edges. Time-sensitive parameters such as pH and oxidation-reduction potential (ORP) were measured at the time of collection.

Clay samples were collected at areas of high-redox gradient at the edge of the Thorn-north ring and the Bean ring, which are H_2S sourced and methane sourced, respectively. These samples were preserved under anoxic conditions and are now being used for the test-tube experiments.

Clay from the ring edges was suspended in agar and served as the inoculant and the carbon source for the in-vitro growth of forest ring micro-flora. A redox gradient was established by the steady supply of oxygen at one end and a source of CH_4 or H_2S at the other end of the test tube. Changes in pH, ORP and SP were monitored over a period of four weeks.

SELECTED RESULTS

A detectable drop in groundwater temperature can be measured over the ring edge at Thorn North. Peat-waters collected during the month of July, at 1.5m depth show a minimum of 2°C within the ring edge while outside values peak at 10°C. Although the sampling site is located 200km south of the southernmost limit of discontinuous permafrost, temperatures have remained low enough to allow the preservation of ice within the peat. The temperature anomaly is propagated to depth, with a 0.35°C anomaly occurring at the same place in groundwater from underlying clay (fig.2).

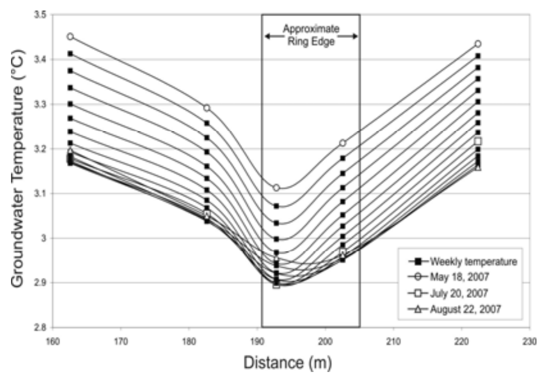

Fig. 2. Changes in mean weekly groundwater temperature of groundwaters (6.5 m depth) across the northern ring edge of Thorn-North from May to August 2007. (Brauneder et al.,2008).

In addition, the response of groundwater temperature to seasonal changes in air temperature is higher at the ring edge than in adjacent areas. At 6.5m depth, the coldest month of the year is August, due to a lag in summer warming. Groundwaters in the ring edge reach their coldest temperature on July 20, whereas groundwaters in adjacent areas reach their coldest state one month later. Similarly, data collected from November to December shows that groundwaters within the ring edge reach their warmest temperature one month earlier than in adjacent areas.

The most likely reason for the thermal anomaly at the ring edge is that it coincides with an area of increased thermal conductivity in the clays. This area also coincides with an area of decreased hydraulic conductivity (fig. 3).

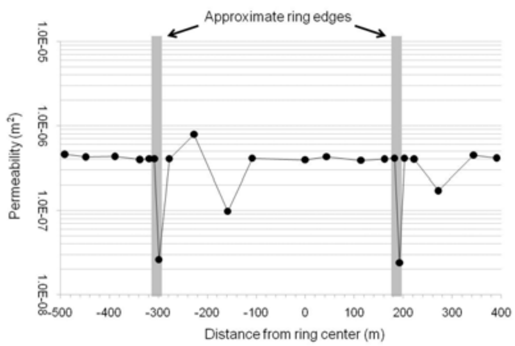

Fig. 3. Changes in permeability along a 900m long transect crossing Thorn-North from south to north.

These physical changes are accompanied by chemical changes. Most notably, a sudden and strong redox gradient, pH gradient and oxygen depletion occur on all investigated ring edges. Similar responses have been noted at other rings. Fig. 4 shows an ORP change of 200mV occurring over a distance of only 3 m at the edge of the Road ring and known to be associated with a pH increase of 0.5 units.

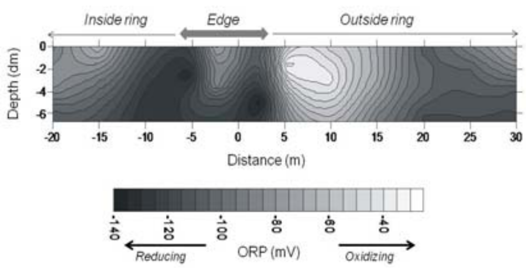

Fig. 4. ORP profiling of the top first meter of clay across the northern edge of the Road ring.

MICROBIOLOGICAL INVOLVEMENT

Redox gradients as strong as those observed at the ring edges are potential sources of energy for autotrophic bacteria. Evidence for microbial involvement includes H_2S consumption, SO_4^{2-} enrichment, oxygen depletion in the headspace of wells and minor to major biogenic methane production. Additional evidence is given by the generation of hydrocarbons at a number of rings.

The ongoing microbiological experimentation attempts to re-create *in vitro*, the redox conditions at the edge of two types of forest rings: those centred on methane and H_2S. A redox gradient is being established between each of these reducing agents and oxygen. Test-tubes will be inoculated with bacteria collected from the highest redox-gradient areas on each ring type. Measurements over the course of the 4 week experiment will help to determine the complex cause-and-effect relationships that exist between the physical, chemical and microbiological processes occurring at the ring edge.

CONCLUSIONS

A large number of physical and chemical changes occur in overburden and groundwater at the edges of forest rings. Physical changes include an apparent increase in thermal conductivity and a decrease in hydraulic conductivity. Chemical changes are dominated by a very strong and sudden change from reducing to oxidizing conditions at the ring edge. These changes are all spatially related. Broadly speaking the changes follow the model of Hamilton and Hattori (2008) but unexpected developments, including the thermal anomaly, have been uncovered. Furthermore that model does not consider the involvement of micro-flora, which may be an important or even crucial factor in the development of forest rings.

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