Geothermics 43 (2012) 25–36

Contents lists available at SciVerse ScienceDirect

Geothermics

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

Geothermal energy potential in the St-Lawrence River area, Québec

Jacek Majorowicz[a,b], Vasile Minea[c,*]

[a] Northern Geothermal Consult., Edmonton, AB, T6R 2J8, Canada
[b] Department of Physics, University of Alberta, AB, T6G 2E1, Canada
[c] Hydro-Québec Research Institut, Laboratoire des technologies de l'énergie (LTE), Shawinigan, G9N 7N5 Canada

ARTICLE INFO

Article history:
Received 5 March 2011
Accepted 19 March 2012
Available online 13 April 2012

Keywords:
Quebec geothermal
Geothermal energy
Geothermal resource base
Enhanced geothermal systems
Heat flow density
Temperature-at-depth

ABSTRACT

Previous estimates of geothermal energy potential in Canada give an indication of available heat to be 'farmed' at depth with focus on Western Canadian Cordillera and Western Canadian Sedimentary basin as prime targets. This paper examines in more detail temperature–depth realtionships near large population centres in Québec, in order to provide a first order assesment of enhanced geothermal systems (EGS) potential for electrical and heat generation. Results show areas with significant EGS potential in the St-Lawrence River valley related to high heat flow density and thermal blanketing of thick sedimentary cover. At >120 °C found to be a prospect for several areas in Québec (drilled to depths of over 4.5 km in Trois-Rivières area, near 4.5 km in the Eastern St-Lawrence River (Rimouski, Gaspé and Golf, including Anticosti Island) and just 4 km in Quebec area) the potentially available geothermal power from EGS hydrothermal systems in deep sediments can be of significance.

1. Introduction

Previous study of geothermal potential across Canada (see Jessop et al., 1991; Majorowicz et al., 2009; Majorowicz and Grasby, 2010; Majorowicz and Moore, 2008) has focused mainly on the Canadian Sedimentary Basin (Western Canada), Cordillera (British Columbia) and mines of Nova Scotia in Eastern Canada. The potential of Québec has not been studied in detail.

The existing Heat Flow Map of North America (Blackwell and Richards, 2004a) provides an initial overview of the geothermal resources of Québec and surrounding areas. However, this map has too few data points in Québec. Therefore, additional industrial drilling temperature data, provided by Hydro-Québec, were used to update the heat flow map of the study area data. Examination of the geothermal energy potential for Québec was the goal of this study.

Hydrothermal systems commonly used across the world (Barbieri, 2002; Rybach, 2008) require high temperature easily accessible geothermal water resources, limiting its nationwide use. On the other hand, the enhanced geothermal systems (EGS) require introduction of water into the rock of limited permeability (either tight sediment or basement) in a controlled fracture setting so that this water can be withdrawn in other wells for heat extraction (e.g., MIT-Led Report, 2006; Blackwell et al., 2007; Soultz-sous-Forêts project result summary in: Gerard et al., 2006; Genter et al., 2009). If rock with temperatures of 150 °C, and preferably higher, are available at depths less than 6–7 km and water can be circulated through them at high rates, one can expect economically viable electrical energy production with the use of a power cycle. The target production temperature needs to reflect the economics and the state of conversion technology in the Organic Rankine Cycle (ORC) (lower limit around 85 °C) and of Kalina technology (lower limit around 100 °C) (MIT-Led Report, 2006; Baujard et al., 2008).

Fracturing of sedimentary rock reservoirs is well proven technique and has been used in thousands of wells in the Western Canada Sedimentary basin for enhancing flow of hydrocarbons. Geothermal reservoir stimulation in crystalline rocks differs from the conventional oil and gas industry practice as shown by projects such as Soultz, France (Gerard et al., 2006). However, conventional practices can be used in setting similar to that of the deep sedimentary formation like in Gross Schönebeck, Germany (Huenges, 2008).

In this paper, we present new detailed heat flow density and deep temperature maps as a first step in determination of geothermal resource base in Québec's conduction dominated systems (sedimentary rock systems and, at larger depth granitic and methamorphic rocks, building basement below with primary and secondary porosity or a potential for fracturing in a system with no natural convection). We aim at areas with thick sedimentary rock platform such as exists in southern Québec. It is shown that this setting, potentially, will provide temperatures greater than 120 °C within sedimentary aquifers, which temperature, according to Baujard et al. (2008), is an acceptable minimum requirement

* Corresponding author.
E-mail address: minea.vasile@lte.ireq.ca (V. Minea).

0375-6505/$ – see front matter. Crown Copyright © 2012 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.geothermics.2012.03.002

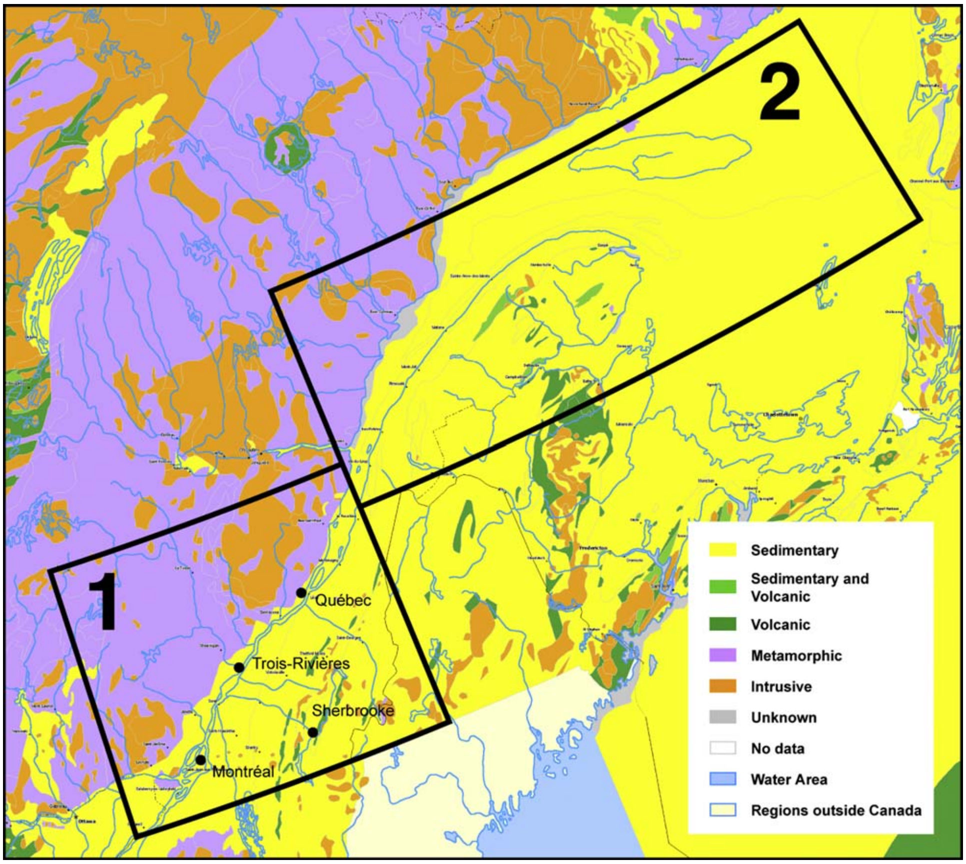

Fig. 1. Major rock types of the geological basement in Southern Québec. *Note*: geothermal areas 1 and 2 are shown.
Source: Geothermal Survey of Canada, 2007.

for >10% efficient ORC and/or Kalina thermal to electrical energy conversion cycles (Marcuccilli and Zouaghi, 2007).

2. Structure and stratigraphy

Most of the large population centers in Québec like Montréal, Trois-Rivières, Québec City and Sherbrooke are underlined by sedimentary rocks of the Saint-Lawrence platform just south of the metamorphic and intrusive rock complexes of Precambrian shield (Fig. 1). Less populated Gaspé area also has large areas of sedimentary rocks. The St-Lawrence rift system trends northeast–southwest and forms a half-graben that extends more than 1000 km along the St-Lawrence valley. Major rock categories common in the study area are shown in Fig. 1.

The basin within Saint-Lawrence platform can be delimited by three zones a shallow basin (<750 m of sediments on top of crystalline basement) is in the area north-west of the lineament called *Yamaska Fault*; an intermediate depth basin (1250–2500 m is between the *Yamaska Fault* and major lineament to the south-east called *Logan lineament*; a deep basin in the area south-east of the Logan lineament where sediments are thicker than 2500 m.

The sediments in the deep part of basin consist of mainly Ordovician and Cambrian sedimentary rocks (see stratigraphy chart in Fig. 2 and cross-section in Fig. 3) overlying the Precambrian crystalline rocks which are intrusive, or metamorphic. These contain some good aquifers such as Ordovician Trenton Group, Black River Formation (Fm), Beauchamonis Fm and fair aquifers like Ordovician Theresa Fm and Cambrian Potsdam Group (Geological Survey of Canada, 2007; Dietrich et al., 2011). The bottom formations of sedimentary overburden are of the Cambrian Potsdam group where the highest temperatures for potential EGS are expected. The Potsdam Group has formations which are classified as fair reservoirs. EGS techniques can be used to enhance permeability and flow rates (fracturing). Intrusive and metamorphic complexes below sediments form a mosaic of the Precambrian.

According to the geological map of Canada, several orogenic events affected the Archean craton, which is a major component of the Shield. The Superior Province (4–2.5 Ga) (1 Ga represents 1000 million years ago) forms a large portion of the North American continent, and covers a third of Québec's landmass, i.e. a surface area of 600,000 km^2. This geological province forms the central part of the Canadian Shield. It is world-renowned for its numerous metal deposits and diamond occurrences. The Superior is subdivided into numerous sub-provinces, half of which are located in Québec. These are: Abitibi Sub-province (large extent Archean volcano-sedimentary belt with many gold and copper deposits. Rocks of the Superior Province are bounded to the east by the Churchill Province and to the southeast by the Grenville Province. The Grenville Province (1.2 Ga–950 Ma) (Ma – million of years) is of very large surface area of 600,000 km^2. It forms the southeastern margin of the Superior Province. Grenville consists of three large size belts rich in iron and ilmeite. The St. Lawrence Lowlands (700–350 Ma) developed at the end of the Proterozoic and during the Paleozoic, with the formation of the St. Lawrence graben. The Lowlands consist of the St. Lawrence Platform and the Anticosti Platform. They overlie rocks of the Precambrian Grenville Province. The platform sediments have large quantities of limestone. The Paleozoic Appalachian Orogen (650–350 Ma) developed along the margin of the Canadian Shield. The Appalachian Orogen is divided into three belts, and is bounded to the east by the Permo-Carboniferous Magdalen Basin. The St-Lawrence