Vingtièmes journées techniques du Comité Français d'Hydrogéologie
de l'Association Internationale des Hydrogéologues.
« Aquifères de socle : le point sur les concepts et les applications opérationnelles » La Roche-sur-Yon, juin 2015

An overview of the hydrogeology of the Canadian Shield with emphasis on the Saguenay-Lac-Saint-Jean area (Une synthèse de l'hydrogéologie du Bouclier canadien avec un accent sur la région du Saguenay-Lac-Saint-Jean)

Alain Rouleau[(1)], Julien Walter[(1)], Romain Chesnaux[(1)], Vincent Cloutier[(2)], Ian D. Clark[(3)]

(1) Université du Québec à Chicoutimi, Saguenay (Qué), Canada; arouleau@uqac.ca
(2) Université du Québec en Abitibi-Témiscamingue, Amos (Qué), Canada
(3) University of Ottawa, Ottawa (Ont), Canada

I. INTRODUCTION

The Canadian Shield covers roughly half of Canada's surface area and is composed of Precambrian igneous and metamorphic crystalline rocks. The lithologies comprise belts of stratified or banded volcano-sedimentary rocks, as well as bodies of diverse intrusive plutonic rocks which have been metamorphosed and deformed to various degrees. These rock types are typically of low porosity, but the presence of discontinuities, such as joints, dykes, faults, and fracture zones allows for groundwater flow to take place locally, at different scales and down to a depth of several kilometres. Groundwater is also present in granular aquifers, Quaternary in age, constituted of late glacial fluvial deposits, and of post-glacial deposits such as plains of deltaic systems, particularly along Shield margins.

A review of the present knowledge of the hydrogeology of the Canadian Shield is presented in Rouleau et al. (2013). Moreover, hydrogeological mapping has recently been conducted in selected areas of the Canadian Shield as part of the *Programme d'acquisition de connaissances sur les eaux souterraines* (PACES) of Quebec (MDDELCC, 2015), as reported in CERM-PACES (2013) for the Saguenay-Lac-Saint-Jean (SLSJ) region, in Cloutier et al. (2013) for the eastern Abitibi region, and in Comeau et al. (2013) for the Outaouais region. This paper presents highlights of the hydrogeological knowledge over the entire Canadian Shield, as well as a summary of recent findings over the SLSJ area, a typical region of the Shield.

II. HIGHLIGHTS OF THE HYDROGEOLOGY OF THE CANADAIN SHIELD

The Precambrian Shield region extends from the North-West Territories to Labrador, across northern Saskatchewan, and constitutes most of the surface area of the provinces of Manitoba, Ontario and Québec. The general physiography of this region is a peneplain at an elevation ranging generally from 500 to 1000m. This region has been subjected to numerous erosional cycles following the Precambrian orogenies. It is underlain almost entirely by Precambrian igneous and metamorphic bedrock and minor areas of sedimentary rocks. The bedrock is covered by generally thin layers of glacial and post-glacial sediments.

Most of the largest cities in Manitoba (Winnipeg), Ontario (Toronto and Ottawa) and Quebec (Montreal and Quebec City) are located immediately to the south of the Shield region. Population centers are located within the southern part of the Shield, such as Sault-St-Marie, Timmins, Sudbury, Rouyn-Noranda, Ottawa-Gatineau, and Saguenay. Mining and forest industries constitute important economic activities over many areas in the Shield. Hydroelectric power generation is also important in some areas, as well as industries requiring high energy input such as aluminium plants in the Saguenay region of Quebec. Tourism and resorts, as well as agriculture in lowland areas, constitute other important activities in these regions.

The Canadian Shield is subdivided into geological provinces according to deformation style and age. The two principal geological provinces south of the discontinuous permafrost line are the Superior (Archean in age) and the Grenville (Middle Proterozoic in age) Provinces (*Figure 1*). The former provides a good example of the distribution of greenstone belts within an Archean Province, while the latter, being the youngest in the Canadian Shield, may herald the present-day mountain ranges with deep crustal roots in the Earth's mantle. Subhorizontal layers of sedimentary rock, Paleozoic and Mesozoic in age, cover the Canadian Shield platform on its border, e.g. the Saint-Lawrence and Hudson Bay Lowlands, the Saguenay graben, and the Interior platform to the west.

Hydrogeological data are available at very sparsely located sites over the Shield region. These mainly include a number of mine sites, as well as research areas related to nuclear waste disposal. A general decrease in rock mass permeability with depth has been observed at many sites.

In recharge areas, groundwater in the upper hundreds of meters in the bedrock is typically fresh with TDS values of up to approximately 500 mg/L, and stable isotopes show that the groundwater originates from recent meteoric recharge. A gradual downward geochemical evolution is observed from near-surface Ca-HCO_3 type groundwaters to deeper Na-HCO_3 waters. Hypersaline brines of the (Na-Ca)-Cl type are ubiquitous at depths greater than approximately 1000 m, with TDS values up to 300 g/L.

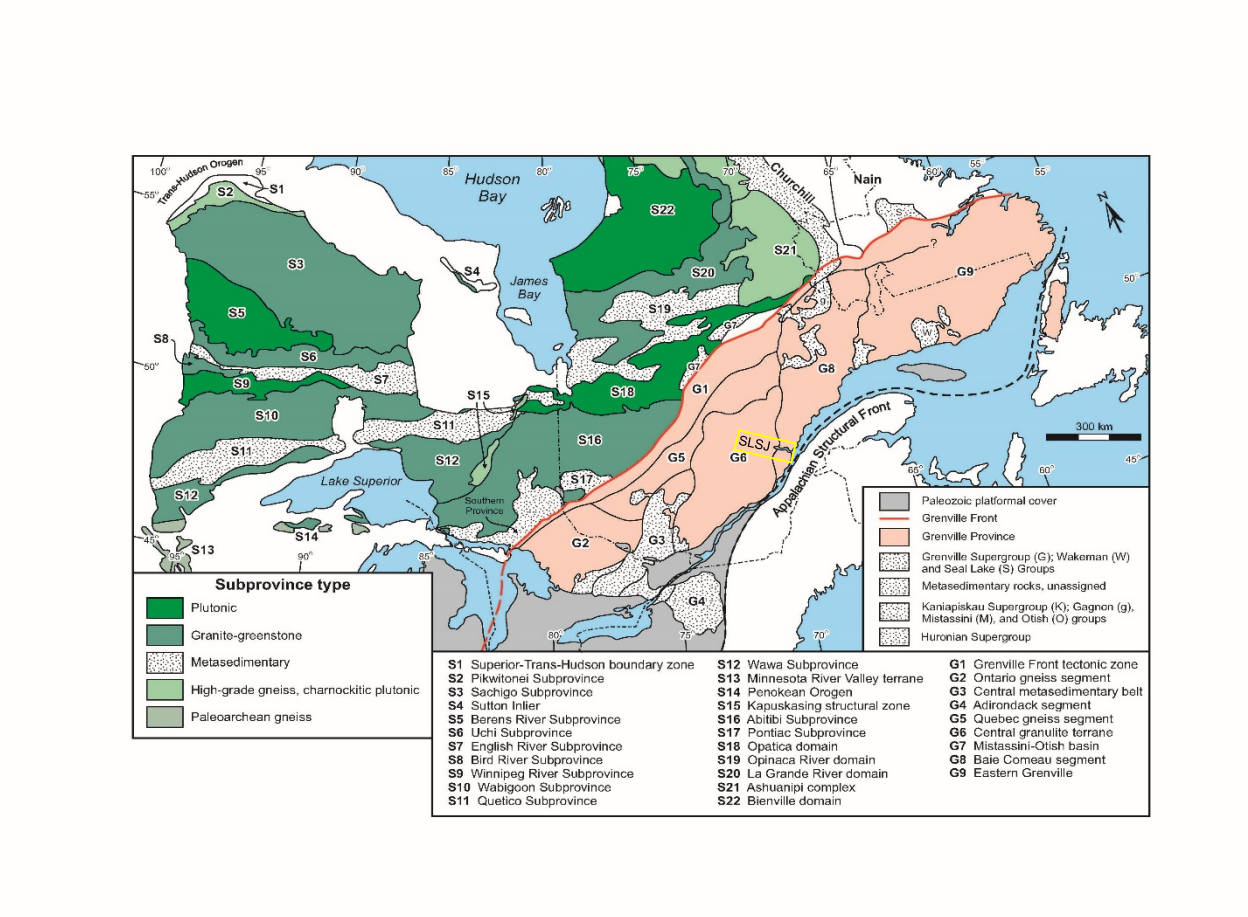

Figure 1 - The Grenville (mostly in pink) and the Superior (mostly in green) geological Provinces and their subdivisions based on structure, lithology and metamorphism. The Saguenay-Lac-Saint-Jean (SLSJ) area is indicated by a yellow rectangle (Rouleau et al. 2013; adapted from Card and Poulsen 1998, and from Rivers et al. 1989).

III. RECENT FINDINGS IN THE SAGUENAY-LAC-SAINT-JEAN AREA

In lowland areas in the Canadian Shield and at its southern border, the Quaternary sediments deposited during and after the Wisconsinian glaciation include important units of granular material that constitute important aquifer systems. Various types of Quaternary granular aquifers are illustrated schematically on *Figure 2,* showing a block diagram of the Saguenay-Lac-Saint-Jean (SLSJ) region as an example. The regional physiography, deeply affected by the Saguenay graben, has controlled the emplacement and the formation of these granular deposits in the lowland areas.

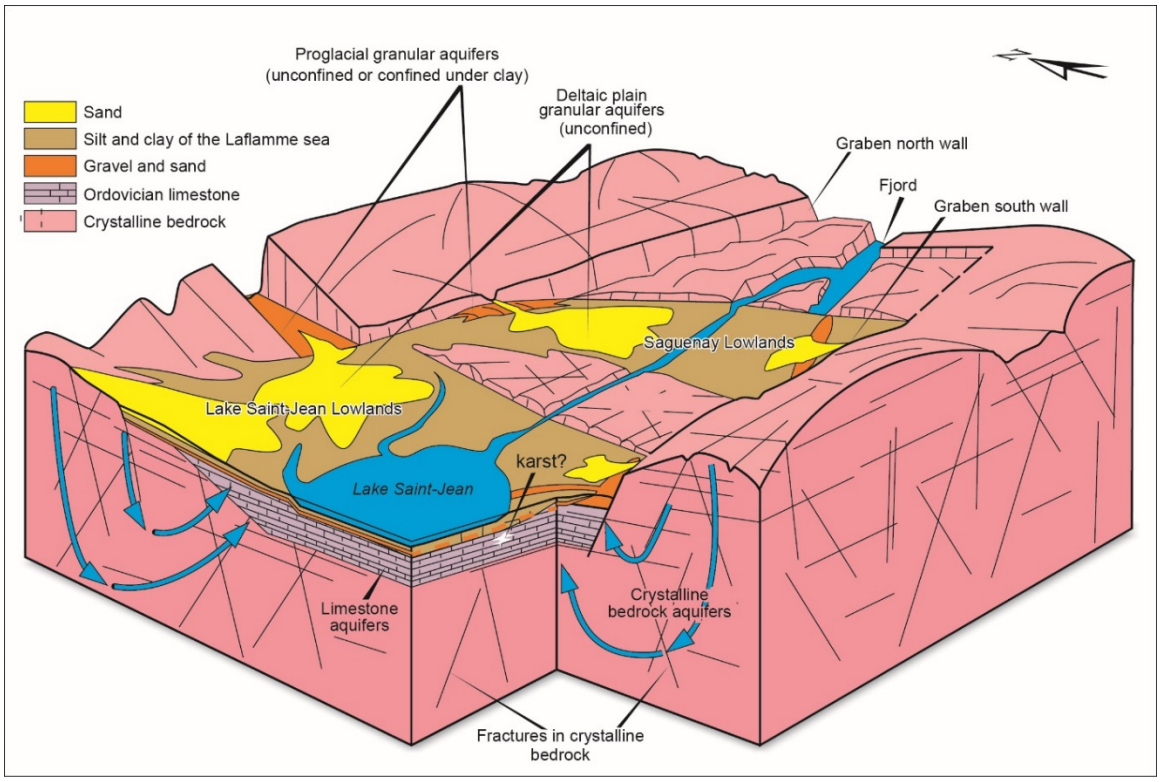

Figure 2 – Schematic block diagram of aquifer types identified in the Saguenay-Lac-Saint-Jean region (modified from CERM-PACES 2013)

The Quaternary granular aquifers include glacial and glaciofluvial deposits, post-glacial prograding alluvial sediments and delta plain sediments that were deposited in lowlands, as well as sediments deposited on bedrock uplands and plateaus. *Figure 2* illustrates important glaciofluvial aquifers (in orange) located at the border of the Saguenay lowlands, near the east-west oriented graben faults that are located to the north and to the south. In glaciofluvial deposits such as eskers and kames, fine particles were mostly washed out during the sedimentation process, resulting in permeable granular aquifers. These granular units are either unconfined in places, or they are confined by extensive units of silt or clay (in brown on *Figure 2*) deposited at the bottom of glacial lakes or seas that invaded the lowland areas at the end of the last glaciation.

A second type of Quaternary granular aquifer is constituted of post-glacial deposits such as large outwash plains and deltaic systems, particularly along Shield margins. In the SLSJ region (in yellow on *Figure 2*), rivers that were discharging from both sides of the graben into the invading Laflamme sea after the last glaciation have deposited granular sediments in their deltas or deltaic plains. These deposits now constitute relatively productive unconfined aquifers.

Recent studies in the Saguenay-Lac-Saint-Jean area (CERM-PACES 2013) have allowed a number of specific observations, including: 1) numerous occurrences of groundwater that exceed the drinking water standards for fluorides and manganese (Walter 2010); cases of interconnections, either natural or man-made, between bedrock aquifers and overlying granular aquifers (Richard 2014); and 3) limited recharge in the

crystalline bedrock (Chesnaux 2013), although higher values of recharge may be localized around fault systems.

References

Card K.D. and Poulsen K.H. (1998). Geology and mineral deposits of the Superior Province of the Canadian Shield; Chap. 2 in *Geology of the Superior and Grenville Provinces and Precambrian Fossils in North America*, Lucas S.B. and St-Onge M.R. (eds), Geology of Canada, no.7, Geol. Survey of Canada; and Geology of North America, vol. C-1, Geol. Society of America, pp.13-204.

CERM-PACES (2013). *Résultats du programme d'acquisition de connaissances sur les eaux souterraines de la région Saguenay-Lac-Saint-Jean*. Rapport remis au Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs du Québec, par le Centre d'études sur les ressources minérales, Université du Québec à Chicoutimi. http://rqes-gries.ca/fr/archives-et-documents/rapports-memoires-et-cartes/261-paces-saguenay-lac-st-jean.html

Chesnaux R (2013) Regional recharge assessment in the crystalline bedrock aquifer of the Kenogami uplands, Canada. *Hydrological Sciences Journal*, 58 (2): 421-436.

Cloutier V., Blanchette D., Dallaire P.-L., Nadeau S., Rosa E., et Roy M. (2013*). Projet d'acquisition de connaissances sur les eaux souterraines de l'Abitibi-Témiscamingue (partie 1)*. Rapport final déposé au Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs du Québec, par le Groupe de recherche sur l'eau souterraine, Institut de recherche en mines et en environnement, Université du Québec en Abitibi-Témiscamingue. http://rqes-gries.ca/fr/archives-et-documents/rapports-memoires-et-cartes/262-paces-abitibi-temiscamingue-1.html

Comeau G., Talbot Poulin M.C., Tremblay Y., Ayotte S., Molson J., Lemieux J.M., Montcoudiol N., Therrien R., Fortier R., Therrien P., Fabien-Ouellet G. (2013). *Projet d'acquisition de connaissances sur les eaux souterraines en Outaouais, Rapport final*. Remis au Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs du Québec, par le Département de géologie et de génie géologique, Université Laval. http://rqes-gries.ca/fr/archives-et-documents/rapports-memoires-et-cartes/282-paces-outaouais.html

MDDELCC 2013. *Programme d'acquisition de connaissances sur les eaux souterraines du Québec*. Ministère du Développement Durable, de l'Environnement et Lutte contre les changements climatiques. http://www.mddelcc.gouv.qc.ca/eau/souterraines/programmes/acquisition-connaissance.htm

Richard S.K, Chesnaux R., Rouleau A., Morin R., Walter J. et Rafini S. (2014). Field evidence of hydraulic connections between bedrock aquifers and overlying granular aquifers: examples from the Grenville Province of the Canadian Shield. *Hydrogeology Journal,* 22/8, p.1889-1904.

Rivers T., Martignole J., Gower C.F., and Davidson T., 1989. New Tectonic divisions for the Grenville province, southeast Canadian Shield; *Tectonics*, vol. 8, p.63-84.

Rouleau A., Clark I.D., Bottomley D.J., Roy D.W. (2013). Precambrian Shield. Chap 11 in *Canada`s Groundwater Resources*, A. Rivera, ed., Fitzhenry & Whiteside, p.415-442.

Walter J. (2010). *Les eaux souterraines à salinité élevée autour du Lac-Saint-Jean : origines et incidences.* Mémoire de Maîtrise, Université du Québec à Chicoutimi, 177p.