The Grenville Terrain, Canada
Field Guide

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1 Description of the fieldtrip

This field trip will examine the geology of the Grenville Province along highway 62 between Madoc and Bancroft, Canada during Saturday the 7^{th} and Sunday the 8^{th} of October, with an overnight stay in Bancroft. There are excellent exposures of the progression of the metamorphic grade and deformation linked with the collision of the North America with a Continent now obliterated by the Appalachians. We will visit outcrops of marbles, metabasalts and siliciclastic/pelitic metasediments from facies Greenschist to Upper Amphibolite/ Granulite and associated intrusives (granodiorite/orthogneisses, nepheline–syenites, gabbros and norites). We will also visit the Princess Sodalite Mine, in which sodalite (an extremely rare Na–chlorine feldespatoid) occur.

2 Geographical Location

The area to be covered during this fieldtrip is located in Canada, in the southeast part of the province of Ontario (Figure 1); the town of Bancroft, is located approximately half distance between Ottawa and Toronto. In Figure (2) an extract of the official road Map of Ontario is shown (the distance between Peterborough and Bancroft is about 68 miles/110 Km on highway 28). Bancroft is the upper apex of the triangle defined by the highways 62, 28 and 7.

We will begin the trip driving from the University on Saturday morning arriving to the area about 2–3 p.m. We will have several stops

the Princess Sodalite Mine (see below), located 4 km (about 2 miles) further north following the highway 28, and during the afternoon we will visit several outcrops on the routes 62 and 7. We will return to Buffalo during the evening of the same day.

3 Geological Setting

The term Grenville terrain (*Grenvillian orogenesis*) is a major compressional event involving thrusting toward the craton Superior (Figure 3) and imbrication of the entire crust in a duplex structure, forming an imbricated fan (Figure 4). It was probably the result of the collision at *ca.* 1.1 Ga between the North american craton and a continent to the southeast, now largely obscured by the Appalachian orogen (Ordovician– Silurian ~ 440–410 Ma).

Figure 1: Map of the province of Ontario, Canada.

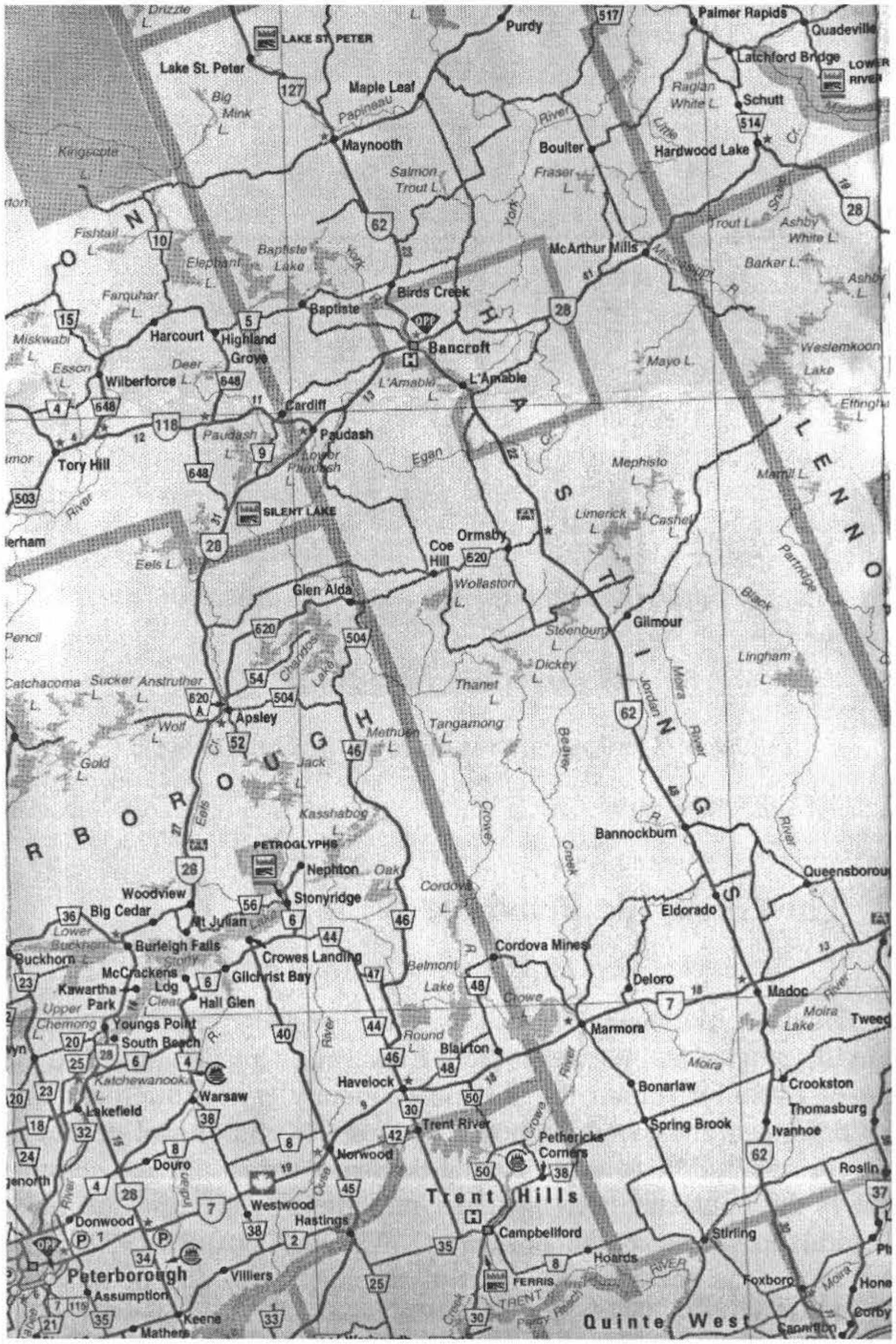

Figure 2: Road Map of the Bancroft Area.

on the highway 28 during the rest of the day to end the day in Bancroft in which we will spend the night. During Sunday morning we will visit

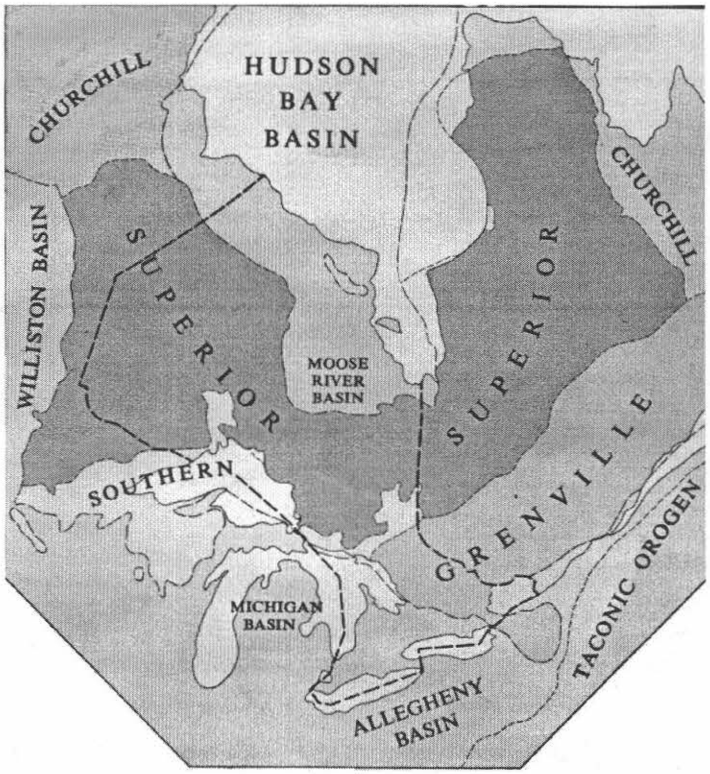

Figure 3: Geological provinces of the Ontario area.

3.1 The Grenville Province

(extracted from http://www.eps.mcgill.ca/~litho/)

The Grenville province (Figure 3) is the primary exposure of the Grenville orogen, and it extends from Lake Huron northeastward to the coast of Labrador (Figure 1). It exposes mainly crystalline rocks that were deformed and metamorphosed at lower to mid-crustal depths in the west, and middle to upper crustal depths in the east. The Grenville Front is the boundary between the Grenville province and the older structural provinces to the northwest (Wynne–Edwards, 1972). The Front marks the northwestern limit of tectonic reworking of rocks of the older provinces during the Grenville orogeny, a complex series of tectonic events generally considered to have taken place between 1300 and 1000 Ma.

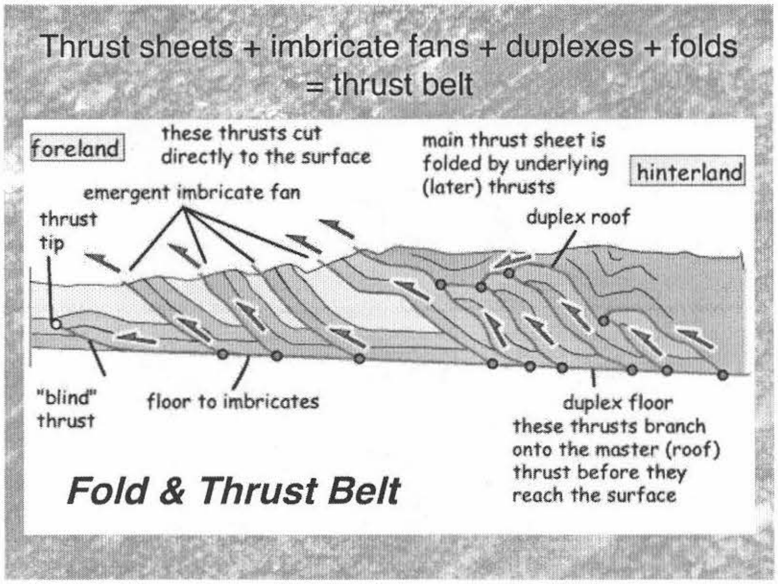

Figure 4: Structure of an orogenesis belt.

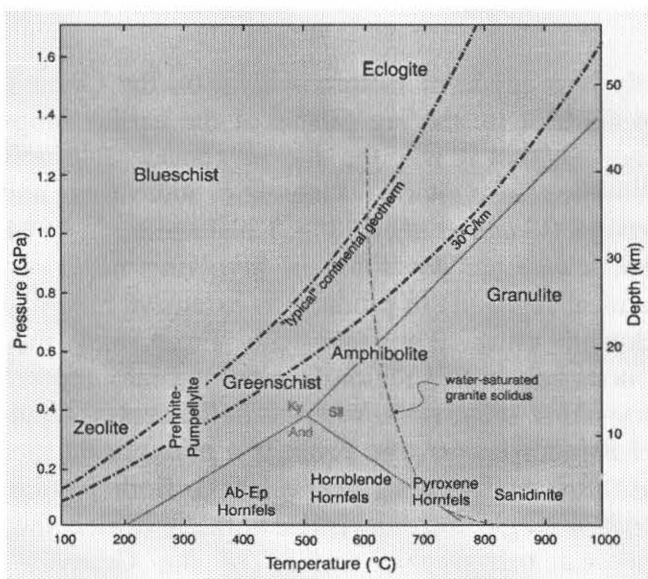

Figure 5: P–T diagram showing the metamorphic facies boundaries.

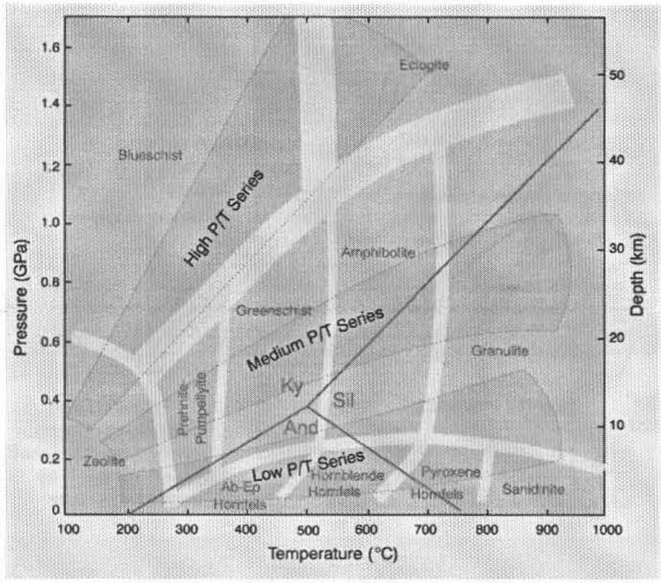

Figure 6: P–T diagram showing the metamorphic series and possible geothermal gradients.

The uniformly high grade of metamorphism on the Grenville side of the Front, in contrast to varying grades of the earlier orogens to the northwest, indicate that it was the site of considerable uplift. In the western Grenville, in Ontario, kinematic indicators and seismic reflection surveys (Green *et al.*, 1988b; Culshaw *et al.*, 1994; J. *et al.*, 1989) suggest a tectonic development involving northwest–directed stacking of crustal segments to produce an extensive mountain belt and an overthickened crust. The Grenville Front and the adjacent parautochthonous belt in this region (see below) may represent a deep crustal, reverse-sense shear zone, whereas in the central Grenville, near the Quebec–Labrador border, the Front is a mid–crustal metamorphic foreland fold/thrust belt (Rivers *et al.*, 1993). Both features may be reconciled with a single tectonic framework, in which the presently exposed east-west topographic surface of the Grenville province represents an oblique section through the crust.

The Grenville province has been subdivided into first–order belts that reflect the tectonic character of the orogen (Rivers *et al.*, 1989). The most northerly, located adjacent to the Grenville Front, is known as the parautochthonous Belt, and consists of units that can be traced into the foreland north of the Front. The more southerly Allochthonous Belt, comprising thrust slices of both monocyclic rocks and older polycyclic pre-Grenvillian units, tectonically overlies the parautochthonous Belt.

It contains most of the relics of recognizable supracrustal rocks and associated plutonic units. In the eastern Grenville province, the Allochthonous Belt can be subdivided into a thrust belt in the north and a syn-to post-tectonic granitoid magmatic belt to the south (Gower *et al.*, 1991). A major period of magmatism late in the Grenville orogeny flooded lower and mid-crustal sections with mafic magma that differentiated into large anorthosite complexes.

Although Grenvillian metamorphism in the Archean rocks makes it clear that significant thickness of transported rocks once overlay the Archean rocks (Childe *et al.*, 1993), only a thin *klippe* of transported material now overlies them, near the Grenville Front. In eastern Quebec, Archean rocks are exposed within the Grenville orogen only in a narrow zone near the Grenville Front. Seismic data make it clear, however, that Archean rocks occur in the subsurface at depths as shallow as 10 km, more than 100 km SE of the Grenville Front, corroborating the thin-skinned model for the geometry of the thrust belt in western Labrador proposed by (Rivers *et al.*, 1993).

3.2 Structure

Based in seismic profiles Green *et al.* (1988a) interpreted the structure of the Grenville province in terms of a simple tectonic model of an imbricated fan–duplex relating with thrust geometry.

For the Grenville front the lower crustal layer was interpreted as Archean crust, extended and thinned during the rupturing of the souther Superior craton and associated development of a south–facing continental margin at 2.4–2.5 Ga. On the basis of this interpretation, the upper crustal layer is either a thick wedge of highly deformed Huronian strata and displaced Archean basement or, more likely, the allocthonous mass.

During the initial stages of the Grenvillian orogeny, perhaps coeval with 1.25–1.30 Ga island–arc magmatism, there was a progressive stacking of microterranes against the Superior craton, depressing the rocks along the margin. Transport of microterranes would have occurred from southeast to northwest along ductile shear zones. The seismic profiles reveals the geometry at depth of at least two thrust planes (zones; Figure 9), that might be active at the time.

During a later phase of Grenvillian tectonism (1.15 Ga), intense deformation occurred near the stable craton. Thrusting cut deep into the crust and possibly the upper mantle, causing ductile imbrication of a wide band of rocks under high pressure (800–1000 MPa) and high temperature (600–800 °C) conditions; rocks buried deeply by the earlier stacking epizode were thrust back up to shallow depths. At this time much of the southeast–dipping fabric, clearly seen in surface outcrop was imposed. Although rocks would have deformed and metamorphosed by burial conditions it was proposed by Green *et al.* (1988a) that this thrusting under ductile conditions that created most of the mylonitic zones. In this region of the Grenville orogen the major component of reverse displacement was concentrated at the Grenville front, where abrupt increases in metamorphic grade occurred. Within the Grenville province, thrusting was largely responsible for progressive uplifting deeper level (higher metamorphic grade) rocks. The sharp increase in deformation of Superior and Southern province rocks at the Grenville front suggest that the thick lithosphere underlying most part of the craton and its southern margin acted as a rigid buttress throughout Grenvillian tectonism.

The thick crust now observed under the Grenville zone might have resulted from initial stacking of microterranes, or it might have been created during the later stages of ductile thrusting. If this is correct, the combining current 50 km crustal thickness with the 20 km of the material that must have been removed to exposed the lower crust (amphibolite–granulite facies rocks) yields a thickness of 70 km crust, comparable with the actual Himalayas.

3.3 Metamorphism in the Grenville province

Based in the maximum metamorphic conditions described in the previous section (800–1000 MPa and 600–800 $^{\infty}$C), it can be shown (Figure 5) that the maximum metamorphic conditions reached the boundary between the Upper Amphibolite –Granulite facies. Considering the high geothermal gradient consistent with a thick crust equivalent to the actual Himalayas the progressive metamorphism should have followed the path of medium P/T series (Barrovian) from Green Schists to Granulite facies (Kyanite ∅ Sillimanite transition). The subsequent thermal event due to intrussion of gabbro and norite are the causes of punctual areas of contact metamorphisms over–imposed on the regional metamorphism rocks. The interchange of fluids allowed the developing of restricted skarn zones.

3.4 Mineral resources

(extracted from: http://www.bancroftontario.com)

Due to the unique nature of the rocks exposed in the area of Bancroft, and the particular metamorphic processes that occurred during the Grenvillian orogenesis, a group of unique minerals can be found in the area.

Bancroft itself is regarded as the "Mineral Capital of Canada" because of the well known variety and quality of mineral species which occur here. A list of minerals that have been mined in the Bancroft area include: corundum, feldspar, uranium, graphite, iron, mica, lead, gold, molybdenite, apatite, beryl, fluorite, talc and sodalite. Additionally, nepheline syenite, marble, granite were also mined. Mining in most cases was carried out on a limited scale, between 1880 and 1935, and was largely confined to open cuts and quarries.

The Princess Sodalite Mine is an example of this kind of production. It is a quarry style mine with a century long history, which is still being worked at present. The Figure (7) shows the main seam of blue Sodalite ($Na_4(Al_3Si_3)O_{12}Cl$), surrounded by the grey Nepheline Syenite in which it has formed.

Figure 7: A view of the main quarry.

During her visit to the 1901 World's Fair in Buffalo, New York, the Edward VII, then the Princess of Wales was captivated by the beauty of a gift of Bancroft sodalite. Because of this, arrangements were made to quarry enough to decorate her London residence, Marlborough House. In 1906, these hillsides were worked by the owners of the property for this mineral and shortly after, 130 tonnes of the rock were shipped to England to be used as a decorative stone in the Princess' royal home. And that is from where the name "Princess Sodalite Mine" comes. Today, sodalite is commonly used in the creation of jewelry and as an ornamental stone. It is also the mineral most people associate with the uniqueness of the Bancroft region's mineral heritage.

The pieces of sodalite you will find in the rock farm vary in the intensity of blue. Look for pieces that are a deep blue colour. Surrounding the mineral you will usually find a grayish–white mineral called nepheline. Nepheline syenite gneiss is the main rock which surrounds you (Figure 8).

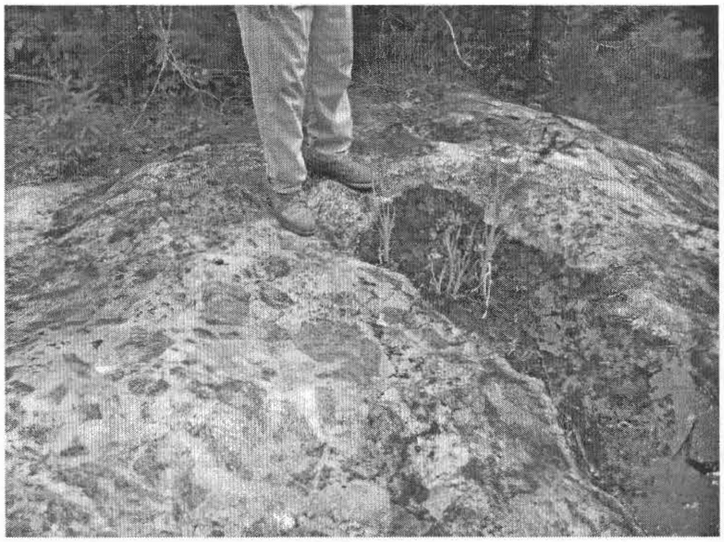

Figure 8: An outcrop of the Nepheline–Syenite in the Princess Sodalite Mine.

Since 1961, when the site was first opened to collectors, visitors have been made welcome. Andy Christie, the current owner, will do his best to make your visit a worthwhile experience. Good collecting!

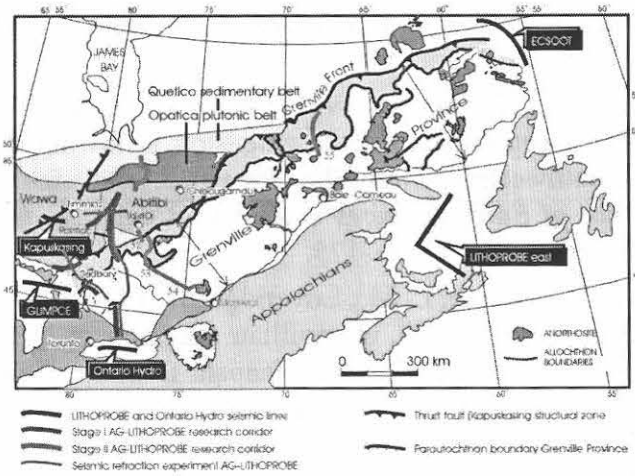

Figure 9: Tectonic Settings of the Grenville province

Sources of the Figures:

Figure 1: © 2000. Her majesty the Queen in right of Canada.Natural Resources. Canada.

Figure 2: The Official Road Map of Ontario. Canada.

Figure 3: From the Geological Map of Ontario. Ontario Geological Survey.

Figure 4: Taken from http://earth.leeds.ac.uk/learnstructure/index.htm

Figures 5, 6 : From Winter, J. D., 2001. An Introduction to Igneous and Metamorphic Petrology. Prentice Hall, 697 p.

Photographs 7, 8: Taken from Alan Goldstein's Site Photo Gallery, http://www.mindat.org/sitegallery.php?u=2749

Figure 9: Taken from: http://www.eps.mcgill.ca/~litho/structure.html

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