# 4.0 REGIONAL TECTONICS

The CRRRC Site lies in a structurally complex geological setting resulting from a number of regional-scale tectonic events spanning more than one billion years. Structurally, the CRRRC Site is located near the southeast end of the Ottawa-Bonnechere graben. The Ottawa-Bonnechere graben extends for approximately 700 kilometres into the Canadian Shield from the Sutton Mountains salient of the central Appalachian orogeny. The graben extends eastward beneath the Appalachian thrust sheets for approximately 30 kilometres. Rimando and Benn (2005) argue that the Ottawa-Bonnechere graben is a failed arm along the triple junction of the St. Lawrence rift.

## 4.1 Seismicity

The Ottawa-Bonnechere graben is within the larger Western Quebec Seismic Zone (WQSZ) that extends from the Timiskaming region of Quebec to the Adirondack Highlands of upstate New York. The CRRRC Site is located at the southeastern end of the WQSZ – one of five seismic zones in southeastern Canada. These seismic zones have an historic record of relatively frequent small to moderate-magnitude earthquakes over about the last 250 years (Lamontagne et al. 2007). The WQSZ can be divided into two regions. One region extends along the Ottawa River from Timiskaming to Ottawa with earthquakes associated with a zone of normal faulting along the Ottawa River. Another region extends from Montreal to Baskatong Reservoir about 200 kilometres north of Ottawa. Adam and Basham (1989) suggest that earthquakes occur on crustal fractures that formed as North America rode over a mantle hotspot between about 140 and 120 million year ago. These two seismic zones merge near the St. Lawrence River.

Circumstantial evidence of large regional earthquakes in the Holocene Epoch (last 11,000 years) has been inferred from the clustering of ages of landslides in the Ottawa Valley by Aylsworth et al. (2000). Interpretation of information east of Ottawa suggests that large pre-historic earthquakes may have occurred about 4,550 and 7,060 radiocarbon years before present (years BP). About 45 kilometres northwest of Ottawa, in southwestern Quebec, a large earthquake event about 1,000 years BP is interpreted to also have caused a large landslide along the Quyon River channel; dating is similar for a number of other landsides along the Quyon River and the north side of the Ottawa River channel northwest of Ottawa (Brooks, 2013).

Shaking from these earthquakes and probably some historic earthquakes is inferred to have deformed bedding within near-surface sediments, generated differential settlement and resulted in the formation of irregular topography within the surficial deposits. While the widespread occurrence of large landslides in eastern Ontario/western Quebec on at least three occasions in the Holocene Epoch suggests widespread earthquake-related shaking, no evidence for fault movement / rupture at the ground surface has been found to be associated with these prehistoric earthquakes and more recent local large earthquakes.

The historical record of earthquake occurrence in the region has been evaluated from pre-instrumental and instrumental records extending from the late 17th century to the present day. For this analysis, the records were compiled from the following earthquake catalogs:

- National earthquake database (NEDB) maintained by the Department of Natural Resources of Canada (NRCAN), which contains instrumental data from 1987 to 2009;
- Composite Canadian Seismicity Catalog (CCSC) spanning from late 1534 to 2010;
- Global Centroid Moment Tensor catalog (CMT), which contains records of events from 1977 to present day;

- US Comprehensive Catalog (ComCat), currently containing records from 1973 to present;
- Advanced National Seismic System (ANSS); and,
- National Oceanic and Atmospheric Administration (NOAA) and the National Geophysical Data Center (NGDC).

These records reveal that at least 289 earthquakes (duplicates removed) of moment magnitude (M) ≥ 3.0 have epicenters located within about 200 kilometres of the CRRRC Site (Figure 4-1). Ten of these earthquakes were of M≥ 6.0, 29 have recorded M≥5.0, and the remaining 250 were of M≤ 4.0. Approximately 72% of the recorded earthquakes occurred at distances greater than 100 kilometres from the CRRRC Site. Table 4-1 lists major historical earthquakes with M ≥ 5.0 within about 200 kilometres of the CRRRC Site.

The largest earthquake recorded close to the CRRRC Site was the 1944 Cornwall-Massena earthquake that occurred on September 5, 1944 (Table 4-1). The epicenter of the M 5.8 Cornwall-Massena earthquake was located on the Saint Lawrence rift system between Massena, New York and Cornwall, Ontario about 66 kilometres from the Site.

**Table 4-1: Major Historical Earthquakes (M ≥ 5.0) with Epicentres located within about 200 kilometres of the CRRRC Site**

| Year | Month | Day | Latitude ($^{O}$N) | Longitude ($^{O}$W) | Depth (km) | Moment magnitude (M) | Distance to the CRRRC Site (km) |
|---|---|---|---|---|---|---|---|
| 1944 | 9 | 5 | 44.96 | 74.77 | 18 | 5.8 | 66 |
| 1732 | 9 | 16 | 45.50 | 73.60 | - - | 5.4 | 144 |
| 1661 | 2 | 10 | 45.50 | 73.00 | - - | 5.4 | 190 |
| 1914 | 2 | 10 | 46.00 | 75.00 | - - | 5.1 | 81 |
| 1893 | 11 | 27 | 45.50 | 73.30 | - - | 5.1 | 167 |
| 2010 | 6 | 23 | 45.88 | 75.48 | 22 | 5.0 | 60 |
| 2002 | 4 | 20 | 44.53 | 73.73 | 12 | 5.0 | 161 |
| 1983 | 10 | 7 | 43.94 | 74.25 | 9 | 5.0 | 181 |

**Notes:**
- - depth information not available
km – kilometres
M – moment magnitude

The occurrence of historical earthquakes and numerous micro-seismic events and adjoining areas suggests that some of the faults in the Ottawa-Bonnechere graben and other fractures may be seismically active. Although some earthquake activity appears to be localized along the Ottawa-Bonnechere graben, the irregular pattern of earthquake locations suggests that the main mapped geological structures of the graben probably do not control the seismicity distribution. Rather, the well-developed regional fracture pattern of northwest faults and fractures and a less well developed northeast-striking set of faults may exercise the major control on the distribution of instrumental earthquakes (Kumarapeli, 1987).

## 4.2 Present Day State of Stress

Studies of the present-day regional stress field by Hurd and Zoback (2012) suggest that the horizontal stresses become increasingly compressive with respect to the vertical stress moving from the south-central to the northeast United States and southeastern Canada (Figure 4-2). Hurd and Zoback speculate that the stress field may have developed from: 1) the superposition of stresses from the unloading of the massive Pleistocene ice sheet over about the last 15,000 years; 2) negative buoyancy effects associated with the relatively high density in the mantle lithosphere that pulls down on the crust and increases compressional forces; or 3) the orientation of paleotectonic rift structures with respect to modern day stress fields.

Figure 4-3 shows the orientation of the present day stress field near the CRRRC Site. The stress field orientation was developed from the variety of data sources included in the World Stress Map database. In Eastern Canada, and the Northeastern United States, these are primarily borehole breakouts and earthquake focal mechanisms (Baird et al. 2009).

Interpretation of stresses was made by Adams and Fenton (1994) from horizontal offsets of up to 25 millimetres of closely-spaced drillholes in and around the Ottawa area. They observed drillhole offsets of up to 25 millimetres at three locations: Baskatong, Quebec, Hull, Quebec and Carling Avenue, Ottawa. However, other excavation sites showed no evidence of borehole or other reference feature offset. The offsets were relatively small, not associated with known earthquakes and were interpreted by Adams and Fenton (1994) to have a probable cause related to near-surface stress relief rather than major seismogenic tectonic stresses.