9.0 EVALUATION OF POTENTIAL GEOLOGICAL IMPACTS

9.1 Fault Rupture

At a number of localities in southern Ontario geologists have observed vertical offsets in glacial deposits and in some cases the underlying basement rock (e.g., Mohajer et al. 1992) associated with faults. One of the most extensively studied locations is at Rouge River east of Toronto and about 3 to 5 kilometres north of Lake Ontario (e.g., Mohajer et al., 1992; Adams et al., 1993; Wallach, 1994; Godin et al., 2002). The faults observed at Rouge River have been regarded as an example of Late Quaternary (last 130,000 years to present) co-seismic fault movements associated with major geophysical lineaments by Mohajer et al., (1992) and Wallach (1994). By contrast, Adams et al. (1993) and Godin et al. (2002) have more recently suggested that these normal faults have developed in response to localized pre-Holocene (last 11,700 years) glacial ice movements that are not associated with crustal faulting.

Godin et al. (2002) concluded from the results of their detailed analysis and re-interpretation that the deformation features preserved in glacial sediments at Rouge River were generated by glacial processes. They consider that the normal faults preserved in glacial sediments and in outcrops of the underlying Ordovician bedrock were generated by regional and local ice flow. Because borehole data show that the surficial faults do not penetrate beyond a depth of about 20 metres within the bedrock, i.e., they are relatively shallow, the faulting at Rouge River is considered by them to not be generated by deep seated tectonic stress and co-seismic faulting (Godin et al., 2002).

Review of published geologic and seismic information for the region surrounding Ottawa-Gatineau carried out as part of the CRRRC studies found no evidence that mapped bedrock faults have ruptured to the ground surface since the retreat of glacial ice and the Champlain Sea from the Ottawa valley. While there are expected to be high surface stresses at some locations (e.g., Adams and Fenton 1994), there is no clear association between surficial stress relief and the generation of large local earthquakes. Studies to date, i.e., Aylsworth et al. (2000) indicate that even when larger earthquakes have occurred in the recent past, they may not be of sufficient magnitude (energy) to generate movement or displacement within the bedrock fault to propagate rupture to the ground surface. Furthermore, where evidence of surface faults has been found in local bedrock outcrops, it can usually be explained as resulting from local ice deformation or landslides rather than by the rupture of a major through-going surface or near surface tectonic fault. This conclusion does not preclude the possibility that vertical and/or horizontal fault movements have occurred in the region but are as yet undetected. Based on available information, however, there is no indication of surface ruptures from historical earthquakes at the proposed CRRRC Site or its immediate vicinity.

Joints and faults within the Ottawa-Bonnechere Graben often contain calcite, indicating that they have been cemented after the formation and lithification of the basement rocks (Rimando and Benn 2005; Adams and Fenton 1994). Unpublished dates from near-surface (2 metres below ground surface) calcite within multiphase, joint-controlled veins in the Ordovician limestone (Pat Smith, University of Toronto, personal communication) indicate ages of about 100 million years ago and about 50 million years ago for the time of calcite cementation. These ages for episodes of calcite vein filling coincide approximately with the relative age of the youngest of the three deformation phases with the Paleozoic rocks identified by Rimando and Benn (2005), as described in Section 3.1.1. The presence of calcite within most of the fault planes and their early Paleogene (40 to 65 million years ago) and older crystallization ages suggests that there has been no Quaternary movement (including the Holocene Epoch of the past 11,700 years) along calcite-bearing faults and joints in the bedrock in the vicinity of the CRRRC Site.

9.2 Assessment of Potential for Fault Rupture at CRRRC Site

Fault rupture at the ground surface is a potential geological hazard because the surface fault rupture could cause localized differential displacements that can adversely affect engineered structures and facilities. A fault is a planar fracture in the Earth along which displacement occurs in response to stresses that accumulate in crustal rocks. Faults can have both vertical and horizontal displacements, although one type of movement is usually dominant. Faults with larger total displacements (100's of metres) have moved repeatedly along the same plane.

To identify the potential for fault rupture at the ground surface of a site, the important faults are those that are accumulating strain in the present-day tectonic strain field. Empirical studies indicate that only the larger faults generate displacements at the ground surface, and it is these larger faults that can present a significant hazard to engineered structures. For example, most surface fault ruptures occur in geologically active areas, have single-event horizontal and/or vertical surface displacements that range from about 100 millimetres to 10 metres, and are associated with moderate to large earthquakes (moment magnitude $M \geq 6$). Further, these surface rupturing faults usually show repeated displacements in the same location over thousands to millions of years.

The identification of "active" faults and/or lineaments that could intersect the footprint of the CRRRC is based in tectonic geomorphology – the interactions between tectonic and surface processes that shape the landscape. Tectonic geomorphic processes operate in regions of ongoing deformation, and at time scales ranging from days to millions of years. An understanding of the geomorphic characteristics and landforms generated by movement at active faults is critical for the evaluation of the fault rupture potential at the CRRRC Site. Fault rupture produces distinctive tectonic geomorphology and landforms such as linear valleys, aligned offset stream channels, linear scarps, aligned linear ridges, faceted ridge spurs and linear vegetation patterns. If these distinctive tectonic geomorphologic landforms can be recognized at the CRRRC Site, then the presence, location, nature, type and activity of the fault or lineament may be evaluated.

Similarly, abrupt offsets or a change in orientation of subsurface geologic layers often indicates that near-surface faults are present at a site. Thus, if tectonic geomorphic features and/or the subsurface layers at the CRRRC Site show abrupt elevation changes, then a fault may be indicated.

Golder's analysis of topography and interpretation of aerial imagery of the CRRRC Site indicate that the Site is essentially horizontal at an elevation of about 76 to 77.5 m ASL. Neither topographic interpretation nor imagery analysis revealed the existence of tectonic geomorphic features crossing the Site. While that lack of tectonic geomorphology indicates no recently active fault features, it remains possible that anthropogenic modification or localized erosion may have removed diagnostic surface fault features.

Figure 3-11 provides a generalized west-east cross-section through the CRRRC Site, and Figures 3-14 and 3-15 are more detailed west-east and north-south cross-sections, respectively. A key layer for the evaluation of the potential for past surface fault rupture at this Site is the 0.1-metre to 0.6-metre thick silty layer (Figure 3-17) at a depth of about 4 to 6 metres below ground surface. This relatively thin silty layer represents a short duration change in the sedimentary depositional environment in the Champlain Sea about 10,000 years ago, perhaps because of a minor change in water depth/sea level or sediment source. This marker bed within the upper part of the silty clay deposit is sub-horizontal; the bottom elevation of the silty layer varies between about elevation 70.5 and 71.5 m ASL, while the top surface elevation varies between about elevation 71 and 72 m ASL. Because the silty layer was encountered and identified in all 25 borehole locations advanced in a grid pattern beneath the Site, it is reasonable to interpret that the silty layer is continuous across the CRRRC Site (as illustrated on Figures 3-14, 13.5 and 3-17). The largely consistent elevation and lateral continuity indicates that this layer has not been offset in any significant way by vertical fault displacements at the CRRRC Site. It is reasonable to conclude, therefore, that there has been no surface fault rupture at the CRRRC Site since at least the deposition of the silty layer (i.e., in the past 8,000 to 10,000 years). Furthermore, the evidence from the surrounding geological structure indicates that recent fault movements are unlikely to have occurred within the bedrock underlying the Site and surrounding area.

Considering the regional, local and Site geological conditions within the CRRRC Site and surrounding area, and the nature of "active" faults as described above, it is reasonable to conclude that the probability of future fault movement resulting in large differential displacements at the surface or shallow subsurface at or in the vicinity of the CRRRC Site is negligible. For the reasons discussed in Section 11.4, even if smaller scale differential displacements were to occur, they are of no engineering significance for the development of the CRRRC Site.

9.3 Assessment of Potential Subsurface Settlement from Earthquake Ground Shaking

The GSC has studied the effects of possible prehistoric (Holocene) earthquakes on the marine clay deposits in eastern Ontario. Published information on this topic has been reviewed and integrated with Site-specific investigation of the clay deposit that underlies the CRRRC Site. The purpose of the review has been to assess if the clay deposit beneath or in the area of the Site is likely to have been disturbed by earthquake shaking in eastern Ontario. Much of the following has been taken from Aylsworth and Lawrence (2003), noting that there have been a number of related articles published on this topic.

Following the deposition of the marine clay soils in eastern Ontario about 10,000 years ago, a number of channels (called Paleo-channels) were cut into the clay deposit between about 10,000 and 8,000 years ago by flowing water prior to the development of the present-day alignment of the Ottawa River channel. As shown on Figure 9-1, four wide channels formed across eastern Ontario. Three channels were oriented northwest to southeast and one connecting these three oriented west to east. By about 8,000 years ago, the Ottawa River established itself in its current course, abandoning these deep, former channels. The western end of one the channels is presently occupied in part by the Mer Bleue to the northwest of Carlsbad Springs. The general location of the CRRRC Site relative to the location of the Paleo-channels is shown on Figure 9-1. The location of the Site is beyond (south of) the area of Paleo-channels.

Analysis of aerial photos and field observations indicate past landslide activity along the margins of the Paleo-channels as shown on Figure 9-1. Radiocarbon dating of organic materials buried by a number of landslides indicates a common date of about 4,550 years BP. Aylsworth et al (2000) and Aylsworth and Lawrence (2003) interpreted the age concordance of the large landslide to indicate that they were triggered by a large earthquake event about 4,550 years BP. They estimated the earthquake to have a M greater than 6.2, and probably at least M 6.5.

There are also three large areas of flat-lying low-relief terrain underlain by marine clay soils, located beyond the Paleo-channels that have been found to be highly disturbed. These are located at Treadwell, Wendover and Lefaivre, about 30 to 50 kilometres northeast of the Site, and are labelled A, B and C on Figure 9-1. Based on field studies, Aylsworth et al (2000) interpreted this disturbance as further evidence of a large earthquake of at least M 6.5 about 7,060 years BP.

Evidence of disturbance by earthquake shaking is indicated by an irregular, hummocky ground surface in an area that is otherwise flat and underlain by sub-horizontal sediment layers. Layering of the sand and clay soils that underlie the hummocky ground is deformed and in some cases faulted. There is also evidence of sand liquefaction and its upward flow through overlying clay layers. Subsurface investigations of these disturbed areas have included geophysical imaging, test trenching and borehole drilling and sampling programs, and description of the continuous soil cores where the presence of deformation of the subsurface materials was evident.

Key evidence cited by Aylsworth et al (2000) and Alysworth and Lawrence (2003) to explain why these three areas experienced disturbance and other areas did not are: 1) the clay deposit is very thick, greater than 100 metres; 2) uncommonly thick layers of liquefiable sand (greater than 10 metres to 20 metres thick) are present within the clay deposit; and 3) the areas are located within deep, locally steep-sided bedrock basins that could amplify earthquake ground shaking. The investigation work in the zone immediately adjacent to the disturbed area showed that where the clay deposit is only 38 metres thick and no thick sand layers were present (i.e., conditions similar to that underlying the CRRRC Site) there was no evidence of sedimentary deformation or disturbance.

The CRRRC Site is located in an area of flat-lying terrain without topographic irregularities, and the Site is not in an area inferred to have been disturbed by past earthquakes or landslides. The silty clay underlying the Site is about 30 to 35 metres thick, anomalously thick sand layers are not present within or underlying the clay deposit; and the Site is not located within a deep bedrock depression. That is, none of the factors identified by Aylsworth et al. (2000) are present at the CRRRC Site.

Although these Site-specific subsurface conditions strongly suggest the absence of amplified earthquake shaking and soft sediment deformation, the soils underlying the Site were also evaluated for any evidence of disturbance. The evaluation was completed from examination of continuous soil cores for evidence of deformed, tilted or sheared bedding patterns indicative of sand liquefaction and flow. Evidence of sediment disturbance was not observed.

As described above, subsurface investigation of the CRRRC Site identified a continuous silty layer within the upper part of the silty clay deposit. This silty layer is a marker bed throughout the subsurface (Figures 3-14 and 3-15) deposited about 10,000 years ago. The presence of a flat-lying surface topography and the lower horizontal subsurface silty layer supports the conclusion that any strong earthquake shaking during the past 10,000 to 8,000 years has not resulted in liquefaction or other disturbance of the Holocene stratigraphy beneath the Site.

In summary, based on the available regional and Site-specific information, the large pre-historic earthquakes (4,550 and 7,060 years BP) inferred by Aylsworth et al (2000) and Aylsworth and Lawrence (2003) have not resulted in large scale deformation of the silty clay deposit that underlies the Site. There is no evidence of deformation or displacement in the continuous samples recovered from the Site boreholes completed as part of the EA/EPA investigation. While it is possible that there has been smaller-scale deformation that is not apparent from the Site investigation program, differential settlement associated with strong earthquake shaking (liquefaction), is not considered to be a hazard at the CRRRC Site, nor for the reasons discussed in Section 11.4 to be of engineering significance in any event.