Ottawa - Gatineau Seismic Site Classification Map From Combined Geological/Geophysical Data

Ottawa - Gatineau Seismic Site Classification Map From Combined Geological/Geophysical Data

by

Hunter, J.A., Crow, H.L., Brooks, G.R., Pyne, M., Lamontagne, M., Pugin, A.J.-M., Pullan, S.E., Cartwright, T., Douma, M., Burns, R.A., Good, R.L., Oliver, J.
Geological Survey of Canada

and

Motazedian, D., Khaheshi-Banab, K., Caron, R., Dion, K., Dixon, L., Duxbury, A., Folahan, I., Jones, A., Kolaj, M., Landriault, A., Muir, D., Plastow, K., Ter-Emmanuil, V.
Carleton University

The influence of local geological materials on seismically -induced ground motions is recognized in the 2010 National Building Code of Canada (NBCC 2010; NRC, 2010) which introduced seismic site classifications to characterize site conditions based on the average stiffness of the upper 30 m of the ground surface (Finn and Wightman, 2003). Five of the six seismic site classes defined in NBCC2010 correspond approximately to: hard rock (class A), rock (class B), soft rock or very dense soil (class C), stiff soil (class D) and soft soil (class E); the sixth site, class (F), is discussed below. The classes are defined in terms of shear wave velocity for classes A-E (Table 4.1.8.4.A in NRC, 2010; see also the map legend), though standard penetration resistance or undrained shear strength can be used instead for classes C, D and E. For building design, NBCC2010 provides amplification factors (Tables 4.1.8.4B and 4.1.8.4C in NRC, 2010) for each site class in order to compute the spectral accelerations of the design ground motion at a specific site. The amplification factors are functions of ground motion intensity, and take non-linear effects into account.

Site class F, the sixth NBCC seismic site class, defines a special case of soil conditions, including liquefiable soils, quick and highly sensitive clays, >3 m of peat, >8 m of highly plastic clays and >30 m of soft to medium stiff clays (Table 4.1.8.4.A in NRC, 2010). At a class F site, site-specific geotechnical evaluation is required to assess amplification of the firm-ground seismic hazard values.

The map of seismic site classes for the cities of Ottawa and Gatineau presented here was compiled jointly by staff of the Earth Sciences Department of Carleton University and the Geological Survey of Canada. The map depicts the spatial distribution of class A to E site conditions within the municipal boundaries of the two cities and demonstrates the application of geophysical techniques for compiling seismic classification maps. Where measurements were made in the field by the GSC, the site classes were defined by using the travel-time averaged shear wave velocity over the upper 30 m of the ground. It should be noted that it is possible that class F site conditions may be found within the areas mapped as C through E, as Vs30 alone does not allow class F conditions to be indentified. Similarly, some areas mapped as classes A and B may instead be class C if more than 3 m of soil underlies the bottom of a spread footing or mat foundation (see Commentary J, item 100 in NRC, 2006).

The map was compiled using subsurface geological data obtained from borehole records and measurements of shear wave velocities using shallow geophysical techniques. The borehole data consist of 21,800 waterwell and engineering records that were compiled from the Urban Geology of Canada's National Capital area, Geological Survey of Canada (Belanger, 1998), and from the Ontario Ministry of Environment waterwell database. Based on our interpretation of the borehole unit descriptors, the borehole records were classified into three generalized stratigraphic units which have distinct shear wave velocity (Vs) characteristics. These three units (from surface downwards) are: (1) deglacial/post-glacial deposits (consisting of glaciomarine, deltaic, and fluvial deposits); (2) glacial deposits (till, diamicton and glaciofluvial deposits); and (3) bedrock. The interpretation of the borehole stratigraphy considered the surficial geology mapped nearby, the vertical ordering of the deposits, proximally-located boreholes and/or geophysical data, and knowledge of the general stratigraphy of the Ottawa area. The resulting borehole database provides the thicknesses of deglacial/post-glacial deposits and glacial units (units 1 and 2), and the depths to the two seismic impedance boundaries (top of glacial sediments and bedrock surface). Bedrock at a given location was classified into Paleozoic and Precambrian rock types and further subdivided into lithologies using local geology maps (Carson, 1982; Belanger, 1998).

The generalized stratigraphic units of the waterwell and engineering logs, from surface down to and including bedrock, were converted into unique time-averaged Vs profiles using average observed Vs refraction velocities for glacial deposits and bedrock types and functions that relate average Vs to depth for the deglacial/post-glacial deposits (Hunter et al., 2010, see also Hunter et al., 2007; Motazedian and Hunter, 2008; Benjumea et al., 2008; Motazedian et al. 2011). These velocity-depth functions and refraction velocities are based on direct measurements of shear wave velocities at 750 surface reflection/refraction shear wave survey locations, 25 line-km of landstreamer shear wave reflection profiling (see Pugin et al., 2007), and nine downhole shear wave velocity surveys. Each of these Vs profiles was then used to determine the travel-time-averaged Vs for the upper 30 m of the ground surface (Vs30) allowing an NBCC seismic site class to be assigned to each borehole and geophysical site. To supplement the borehole data within Gatineau, fundamental site period was measured at 61 point locations using a Tromino® microseismograph and the horizontal to vertical spectral ratio method of Nakamura (1989). The fundamental site period data were converted to estimates of soft soil thickness using an empirical equation derived from reflection/refraction seismic site data collected in the greater Ottawa-Gatineau region.

The 21,800 determinations of Vs30 were contoured using a "natural neighbors" interpolation technique. The final mapped boundaries between site classes were edited to respect borehole and surface geophysics data points as well as known surficial geological boundaries. The boundaries between site classes are subject to uncertainty in position, especially where few data points occur. To reflect the uncertainty in the contouring, the variability in data density, and to show the complexity of local geology, data points are displayed on the map and keyed by a symbol for the data type and by the colour of the associated seismic site class. In some areas where data density is high, these seismic site classification boundaries are accurate to within a few hundred meters. In other areas, where data are sparse, the uncertainty in the mapped boundary might be 2 km or larger.

All five of the NBCC seismic site classes A to E are present within the cities of Ottawa and Gatineau. In particular, the map reveals that class D and E areas are present beneath the urban and suburban parts of the city, mainly due to the presence of thick deposits of 'soft' glaciomarine sediments (or Leda clay). In some places Leda clay reaches thicknesses up to 100 m, infilling buried bedrock valleys. Locally, the transitions from classes A to E can occur over distances of less than 500 m (e.g. Motazedian and Hunter, 2008), reflecting the steeply-sloped margins of the buried valleys.

Relationship between Site Class and Amplification

The 2010 NBCC provides tables of amplification factors (Tables 4.1.8.4.B and 4.1.8.4.C, NRC, 2010) which modify the firm-ground spectrum (shaking with a 1:2475 year return period) to the design ground motion spectrum. The current factors indicate that the expected level of ground shaking increases up to four times between classes A to E due to the decreasing soil stiffness, and suggest that soft soils (D and E) will experience greater shaking during an earthquake than stiffer soils or bedrock. The amplification factors, when used for building design, do take frequency content into account even though shaking frequency is not considered in the definition of site class.

It is recognized that the NBCC amplification factors have some limitations, may have considerable uncertainty (for details see Finn and Wightman, 2003), and may not take into account the complexity of local site effects (Boore, 2004; CFEM, 2006; Benjumea et al., 2008). For example, seismic shaking can be amplified or attenuated by factors that may act in combination with the geological materials immediately underlying a site. These include: shear wave velocity and/or density contrasts between rock and overlying soil layers (impedance contrast amplification); internal reflection of seismic energy within a soil layer (resonance amplification); focusing or defocusing caused by topography or by subsurface geometry (buried bedrock topography effects); basin-edge effects (e.g. Cassidy and Rogers, 2004); and generation of Rayleigh and Love waves across the surface of a sediment-filled basin (basin effects).

There is a strong need to measure seismic shaking on soils in the Ottawa and Gatineau areas in order to assess the amplification factors of the NBCC and to better understand ground motion response. To date, only limited such measurements have been conducted, as reported by Al-Khoubbi and Adams (2004), Adams (2007), and Hunter et al., (2010).

This seismic site classification map is presented as one element of a regional framework for further assessment of seismic hazards in the Ottawa-Gatineau area, and as a guide for the local geotechnical engineering community as to the general distribution of seismic site conditions across the two cities. The data on the map, however, show regional trends and are neither suitable, nor are intended, for building design. This map does not replace the need for site-specific geotechnical studies, as required by the 2010 NBCC, Ontario's 2006 Building Code, and Québec's 2008 Building Code.

Acknowledgements

The authors gratefully acknowledge financial support from the Geological Survey of Canada, Natural Resources Canada, through the Eastern Canada Geohazards Assessment Project, Reducing Risk from Natural Hazards Program, and from an NSERC Discovery Grant, the Ontario Research and Development Challenge Fund (ORDCF) awarded to D. Motazedian. As well, we would like to acknowledge and recognize technical support received from the Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity (POLARIS). Editorial review comments by Dr. John Adams and Dr. John Cassidy of GSC, as well as Dr. Gail Atkinson, University of Western Ontario and Michael Snow, P. Eng., of Golder Associates, were very helpful. The co-operation of the staff from the cities of Ottawa and Gatineau is greatly appreciated and was critical in the data collected for this map.

References

Adams, J., 2007. Soil amplification in Ottawa from urban strong ground motion records. In Proceedings of the 9th Canadian Conference on Earthquake Engineering; 2007, p. 379-389.

Al-Khoubbi, I., and Adams, J., 2004. Local site effects in Ottawa, Canada - first results from a strong motion network. In Proceedings of the 13th World Conference on Earthquake Engineering; 2004; 11 pages.

Belanger, J.R., 1998. Urban geology of Canada's National Capital Area, in Urban geology of Canadian cities; (ed.) Karrow, P.F. and White, O.W.; Geological Association of Canada, Special Paper 42, p. 365-384.

Benjumea, B., Hunter, J.A., Pullan, S.E., Brooks, G.R., Pyne, M., Aylsworth, J.M., 2008. Vs30 and fundamental site period estimates in soft sediments of the Ottawa Valley from near-surface geophysical measurements; Journal of Environmental and Engineering Geophysics, v. 13, p. 313-323.

Boore, D.M., 2004. Can site response be predicted?; Journal of Earthquake Engineering, v. 8, p. 1-41.

Cassidy, J.F., and Rogers, G.C., 2004. Variation in ground shaking on the Fraser River delta (Greater Vancouver, Canada) from analysis of moderate earthquakes. In Proceedings of the 13th World Conference on Earthquake Engineering; 2004; 7 pages.

Canadian Foundation Engineering Manual (CFEM). 2006. Fourth Edition, Canadian Geotechnical Society, 488 p.

Carson, D.M., 1982. Paleozoic Geology of the Merrickville Area, Southern Ontario; Ontario Geological Survey, Map P.2494, Geological Series – Preliminary Map, Scale 1:50 000.

Finn, W.D.L. and Wightman, A., 2003. Ground motion amplification factors for the proposed 2005 edition of the National Building Code of Canada; Canadian Journal of Civil Engineering, v. 30, p. 272-278.

Hunter, J.A., Burns, R.A., Good, R.L., Aylsworth, J.M., Pullan, S.E., Perret, D. and Douma, M., 2007. Borehole shear-wave velocity measurements of Champlain Sea sediments in the Ottawa-Montréal Region. Geological Survey of Canada, Open File Report 5345, 30 p.

Hunter, J A; Crow, H L; Brooks, G R; Pyne, M; Motazedian, D; Lamontagne, M; Pugin, A J -M; Pullan, S E; Cartwright, T; Douma, M; Burns, R A; Good, R L; Kaheshi-Banab, K; Caron, R; Kolaj, M; Folahan, I; Dixon, L; Dion, K; Duxbury, A; Landriault, A; Ter-Emmanuil, V; Jones, A; Plastow, G; Muir, D; 2010. Seismic site classification and site period mapping in the Ottawa area using geophysical methods; Geological Survey of Canada, Open File Report 6273.Geological Survey of Canada, Open File 6273, 80 p., 1 DVD.

Motazedian, D. and Hunter, J.A., 2008. Development of an NEHRP map for Orleans suburb of Ottawa, Ontario. Canadian Geotechnical Journal; Vol. 45, p. 1180-1188.

Motazedian, D., Hunter, J.A., Pugin, A. J.-M., Crow, H.L., 2011. Development of a Vs30 (NEHRP) map for the city of Ottawa, Ontario, Canada, Canadian Geotechnical Journal, Vol. 48, p. 458-472

Nakamura, Y. 1989. A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Railway Technical Research Institute (Quarterly Report) 30(1), pp. 25-30

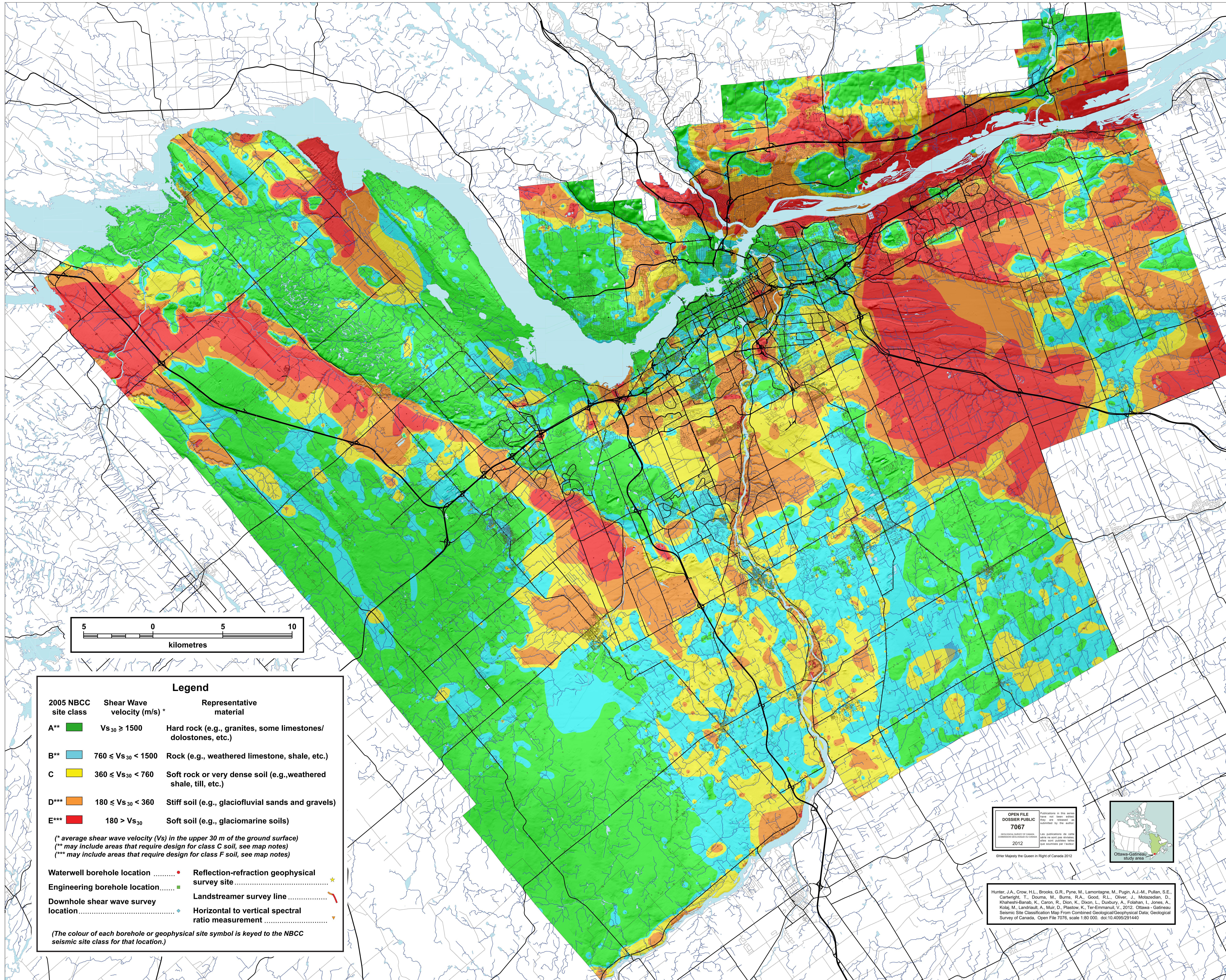
National Research Council (NRC), 2010. National Building Code of Canada 2005; Volume 1, Division B, Part 4.

National Research Council (NRC), 2006. User's Guide – NBC 2005 Structural Commentaries (Part 4 of Division B); Canadian Commission on Buildings and Fire Codes, National Research Council of Canada.

Pugin, A.J.-M.,, Hunter, J.A., Motazedian, D., Brooks, G.R., and Khaheshi-Banab, K., 2007, An application of shear wave reflection landstreamer technology to soil response evaluation of earthquake shaking in an urban area, Ottawa, Ontario, In, Proceedings SAGEEP'07 (Symposium on the Application of Geophysics to Engineering and Environmental Problems), Denver, CO, April 1-5, 2007, 11p.

doi:10.4095/291440

This publication is available from the Geological Survey of Canada Bookstore (http://gsc.nrcan.gc.ca/bookstore_e.php)
It can also be downloaded free of charge from GeoPub (http://geopub.nrcan.gc.ca/).



OPEN FILE
DOSSIER PUBLIC
7067
GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA
2012

Publications in this series have not been edited; they are released as submitted by the author.

Les publications de cette série ne sont pas révisées; elles sont publiées telles que soumises par l'auteur.

Hunter, J.A., Crow, H.L., Brooks, G.R., Pyne, M., Lamontagne, M., Pugin, A.J.-M., Pullan, S.E., Cartwright, T., Douma, M., Burns, R.A., Good, R.L., Oliver, J., Motazedian, D., Khaheshi-Banab, K., Caron, R., Dion, K., Dixon, L., Duxbury, A., Folahan, I., Jones, A., Kolaj, M., Landriault, A., Muir, D., Plastow, K., Ter-Emmanuil, V., 2012. Ottawa - Gatineau Seismic Site Classification Map From Combined Geological/Geophysical Data; Geological Survey of Canada, Open File 7076, scale 1:80 000. doi:10.4095/291440