Mapping the Subsurface of Waterloo Region, Southwestern Ontario, Canada

Bajc, A.
Sedimentary Geoscience Section, Ontario Geological Survey, Willet Green Miller Crt., 933 Ramsey Lake Rd., Sudbury, ON P3E 6B5; E-mail: andy.bajc@ndm.gov.on.ca

Background. Pressures directed at protecting and preserving the quality and sustainability of groundwater resources within the province of Ontario have greatly increased over the past decade. The impacts of rapid urban expansion from metropolitan centres and nutrient management practices in rural areas must now be considered when assessing the long-term preservation of groundwater. Wise land-use planning is essential, especially within recharge areas where aquifers are replenished and are most susceptible to contamination. A detailed understanding of the properties and 3-dimensional architecture of Quaternary deposits is critical if well informed decisions regarding land use are made.

As a significant start to this process, the federal and provincial geological surveys have cooperatively undertaken an extensive program of Quaternary geology, hydrogeology and database management within the Oak Ridges Moraine of south-central Ontario (Sharpe et al. 2002). The Oak Ridges Moraine is a provincially significant geological feature extending for well over 100 kms north of Lake Ontario. Sensitivities over land use are paramount within this area. Details of this multidisciplinary geoscience program can be found at http://sts.gsc.nrcan.gc.ca/orm/index.asp. Future studies within other areas of the province should attempt to follow a similar approach.

The Sedimentary Geoscience Section of the Ontario Geological Survey (OGS) is embarking on a new program as part of a provincially-mandated directive referred to as “Operation Clean Water”. Several projects are being undertaken as part of this program. These include: 1) the generation of a seamless, 1:50 000 scale, attributed Quaternary geology map of southern Ontario (Bajc et al.2001); 2) the development of data model standards for 3-dimensional mapping and hydrogeological studies (van Haaften 2002); 3) the assemblage and filtering of subsurface information (mainly MOEE water well data) by selected Conservation Areas in southern Ontario following the methods employed by the Grand River Conservation area in their 3-dimensional studies (Holysh et al, 2000); and 4) the generation of a 3-dimensional model of Quaternary geology within the Regional Municipality of Waterloo. This article summarizes the current status of 3-dimensional studies within the Regional Municipality of Waterloo (RMOW). The project is being undertaken cooperatively with the RMOW and the Grand River Conservation Authority (GRCA).

The RMOW is the largest municipal user of groundwater in Canada. Its average daily production exceeds 160,000 cubic metres supplying water to about 395 000 residents (1999 Biannual Groundwater Monitoring Report, RMOW). The region is centrally located in the interlake area of southwestern Ontario and occupies an area of approximately 1400 sq. km. Lying within the region is the Waterloo Moraine, an interlobate feature composed of interbedded sand and gravel. Deposits of the Waterloo Moraine contain a significant proportion of the water extracted for municipal use within the region.

The RMOW is one of the most advanced municipal governments in Ontario in terms of its hydrogeological monitoring programs. It utilizes more than 130 dedicated observation wells to record water levels, monitor water quality and measure aquifer pressures on a regular basis (1999 Biannual Groundwater Monitoring Report, RMOW). The RMOW is also fortunate in that both the University of Waterloo Ground Water Research Institute, a world class hydrogeology department and the Quaternary Sciences Institute, are situated within the region. The GRCA is also very active in both surface and subsurface water monitoring programs. Numerous studies, dealing with Quaternary stratigraphy, sedimentology and groundwater modelling have been undertaken within the RMOW. Most of these have been undertaken by the staff and students of the University of Waterloo or consultants that obtained their training at the university. The GRCA has also produced a comprehensive technical report on the regional ground water conditions within the Grand River watershed.

Objectives and Work Plan. The main objective of this project is to generate a 3-dimensional geologic model of the Quaternary geology of the RMOW to assist with hydrogeologic modelling. Quaternary studies over the last 4 decades have already resulted in a fairly good understanding of the Late Wisconsinan stratigraphic record of the region. Most studies, however, focussed on till stratigraphy with little detail directed to the intertill stratified drift. Facies modelling of these deposits will be undertaken to bolster the geological model already in place. The record of pre-Late Wisconsinan deposits is fragmentary and requires further study as well.

The development of a 3-dimensional geologic model requires that a strong understanding of the Quaternary geology exist by the geology team. To this end, the author spent 8 weeks in the field during the summer of 2002 observing landscapes, classifying terrain, examining existing natural and man-made exposures and undertaking detailed sedimentological studies of stratified deposits exposed mainly in licensed sand and gravel pits. Several cores recently drilled for the RMOW were also logged in detail to become familiar with the deposits of the Waterloo Moraine and some of the older stratigraphic units.

The second phase of this project will involve the compilation and examination of as many datasets as possible that record subsurface geology within the region. The highest quality datasets reside at the RMOW and the University of Waterloo Earth Sciences Department. Numerous studies that required continuous coring of the overburden have been undertaken by both the region and the university. These records will be studied in detail and will form the basis of the derived 3-dimensional geological model. Abundant subsurface information is also stored within a geotechnical database created by the Geological Survey of Canada (GSC) during the early 1970's as part of its UGAIS program. This database is somewhat dated and requires updating. Geotechnical records are likely contained within the files of the region's engineering department as well as with private consulting firms. Additional information is also contained within field notes of Dr.P.F. Karrow who mapped the Quaternary geology of the Stratford-Conestogo areas for the GSC and the Cambridge and Guelph areas for the OGS. Most of this information will however, address the near-surface stratigraphy of the region. The MOEE water well database will also be used to produce derived bedrock topography and drift thickness maps.

All of these datasets will be stored within a database with a structure following that proposed by the OGS as part of its data modelling exercise (van Haaften 2002). Preliminary interpretations of these data will be undertaken using 3-dimensional viewing software such as ViewLog, Rockworks, Gocad and Surfer. Following this initial interpretation, additional geological information will be obtained to address gaps in the datasets as well as to assist with the geological modelling exercise. Geophysical surveys, including ground penetrating radar and shallow reflection seismics will be undertaken in areas of poor exposure and areas where suspected buried bedrock valleys occur. Additional continuous coring of the overburden to bedrock will be undertaken to fill-in gaps, address geological problems and target potential older records in buried bedrock valleys.

The final phase of the geological modelling exercise will involve the analysis of the existing water well database to determine whether it can be trained to yield useful information on the subsurface stratigraphy of the region. A similar exercise was undertaken by the GSC in the Oak Ridges Moraine dataset with mixed results (Russell et al. 1998). Most problems arise from the over-representation of clay in the stratigraphic sequence and the inability to distinguish between sand and gravel and coarse grained till.

Regional Geologic Setting. Bedrock outcrops are uncommon within the RMOW. The position of formational contacts is inferred from irregularly spaced boreholes that penetrate the bedrock surface. The region is underlain by southwesterly-dipping dolostones of the Guelph Formation and interbedded green to grey shales and dolostones of the Salina Formation. The approximate contact between the 2 formations passes under the cities of Kitchener-Waterloo just west of the Grand River. Thin to medium-bedded dolostones of the Bass Island Formation subcrop in the extreme northwestern corner of the region in Wellesley Township.

Drift thickness within the RMOW is highly variable. Depths frequently exceed 30 m and occasionally surpass 100 m, especially within the Waterloo Moraine. The bedrock surface slopes gently from an elevation of approximately 350 m asl in the northwest to 225 m asl in the southeast. The extension of the Dundas buried valley and its tributaries into the region likely accounts for added bedrock relief.

Although the record of Late Wisconsinan glaciation within the RMOW is relatively well understood, the record of older glacial and non-glacial events is fragmentary. Many publications summarizing the current status of knowledge of the Quaternary stratigraphy have been published over the past 4 decades. Most references pertinent to this study can be found in the citations following a paper by White and Karrow (1999) on the urban and engineering geology of the Kitchener-Waterloo area as well as within a recent paper on the origin of the Waterloo kame moraine (Karrow and Paloschi1996).

The Quaternary record preserved within the RMOW is characterized by repeated glacial advances of ice lobes originating from the Lakes Huron-Georgian Bay and the Erie-Ontario basins. Indicator lithologies assist with determining provenance. For example, till originating from the Huron-Georgian Bay lobe often contain clasts of Proterozoic-aged metasedimentary rocks, including jasper conglomerate, Gowganda Formation tillite and quartzites. Erie-Ontario lobe tills often contain mottled red and green Queenston Formation shales and red to white sandstones and siltstones. Grenville marble is occasionally encountered as well.

Pre-Late Wisconsinan drift has been encountered at numerous locations within the RMOW. It consists of a complex sequence of older, fine- and coarse-textured tills and stratified deposits. The Canning Till, a fine-textured till displaying a reddish colour is the only formally named pre-Late Wisconsinan till unit recognized within the RMOW. The reddish colour of this till is likely derived from Queenston Formation red shales that outcrop below the Niagara Escarpment to the east. An Erie-Ontario source lobe is suggested (White and Karrow 1996). Alluvial channel-fill deposits containing organic remains have been encountered at a few sites. The Waterloo interstadial site has been dated at 40 ka BP and represents the deposits of a Middle Wisconsinan non-glacial episode (Karrow and Warner 1984).

The main Late Wisconsinan glaciation is represented by the Catfish Creek Till. This silty to sandy till of northern provenance is often overconsolidated and forms an important marker horizon within the region (Karrow 1988). It occurs frequently in borings, roadcuts and sand and gravel pit and river bank exposures. Following a significant retreat of ice from southwestern Ontario (Erie Interstade), competing lobes of Huron-Georgian Bay and Erie-Ontario ice advanced into the region. Significant moraines are associated with some of the till sheets. For example, the Macton Moraine represents the outer limit of the Mornington Till and the Paris Moraine represent the outer limit of the Wentworth Till. The Waterloo Moraine was constructed during the ice advance that deposited the Maryhill Till.

The Waterloo Moraine. The Waterloo Moraine is defined as an irregular tract of gently rolling to hummocky terrain occupying an area of approximately 500 sq. km. It lies west of the Grand River from Hawkesville in the north to New Dundee in the south and extends westward to Phillipsburg. Distinct spurs of sand and gravel extend outward from the moraine to the north, west and south. The relationship of these spurs to the Waterloo Moraine is under investigation. The vast accumulations of sand and gravel comprising the Waterloo Moraine are sometimes blanketed by clayey Maryhill Till or sandy Port Stanley Till. The moraine is believed to be the product of the ice advance that deposited the Maryhill Till (Karrow and Paloschi 1996). This clay-rich till, which is often interbedded with glaciolacustrine deposits, occurs as layers at the base, within and above the morainic deposits. The layers are discontinuous in all 3 environments.

All of the sand and gravel deposits comprising the moraine are mapped as ice-contact stratified drift. This classification is likely based solely on geomorphology since there are very few exposures within the moraine proper. The stratified deposits comprising the Waterloo Moraine are an important aquifer for the RMOW. A better understanding of the depositional environments into which these sands and gravels were deposited is essential to better predict where the greatest potential for additional groundwater reserves exist.

New Findings. Several new observations were recorded as part of the field work that will assist with the development of the geological model. The Waterloo Moraine has been described as a hummocky to rolling tract of land. Some of the hummocky terrain is in fact interpreted as erosional or dissected in origin. Dissection likely occurred during and shortly following retreat of the Erie-Ontario lobe from the region and drainage as glacial lakes drained and base level fell. Surface morphology throughout the region should be classified to assist with the determination of facies models. Few exposures within the moraine actually display ice-contact features such as faults and chaotic bedding as shown on published maps. The moraine appears to be composed of a complex network of subaquatic fan, deltaic, braided stream, subglacial conduit and kame/kettle depositional environments. The youngest morainic sediments were likely deposited within a transitional basinal to shallow lacustrine environment. In fact, the glaciolacustrine environment appears to dominate most of the deposits observed in sand and gravel pit exposures. Coarsening upward sequences indicate basin filling or shallowing processes late in the development of the moraine. Most paleocurrents obtained from planar cross-beds, trough cross-beds and steeply-dipping foreset beds within the moraine indicate paleoflow towards the west to northwest. This is consistent with an Erie-Ontario source lobe for the moraine.

Aside from general statements describing coarsening upward sequences, few descriptions are available on the nature of the morainic deposits at depth. Exisitng borehole logs should be studied to determine the nature of the lower morainic deposits. Future searches for substantial groundwater resources within the morainic deposits should be focussed on depressions in the upper surface of the Catfish Creek Till where subglacial meltwaters associated with the advancing Maryhill ice would be directed. One might expect linear bodies of coarse-grained sediment with high permeability and hydraulic conductivity within these depressions.

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