

Groundwater prospects in the Oak Ridges Moraine area, southern Ontario: application of regional geological models¹

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Abstract:

A geological model is presented for the glacial deposits of the Oak Ridges Moraine area of southern Ontario. The model contains four units as well as incised channels dissecting the strata. Channels eroded through the Newmarket Till, a regional aquitard, provide hydraulic connection between the aquifers of the overlying Oak Ridges Moraine and those of the underlying lower drift. Buried channels filled with silt, sand, and gravel, and preferentially oriented north-northeast-south-southwest, are indicated by drill core and seismic reflection profiles. The model, with two successful case studies, has significant implications for groundwater resource development in the Greater Toronto Area. Groundwater flow to the lower drift may occur through channels so that groundwater resources in the lower drift may be more productive than previously suggested. Gravel sequences within channels may be targets for high yield wells. Further investigations are required to examine buried channel locations, distribution, and sediment fill.

Résumé :

Un modèle géologique montrant comment s'organisent les dépôts glaciaires de la région de la moraine d'Oak Ridges (partie sud de l'Ontario) est présenté dans le présent article. Le modèle tient compte de quatre unités de même que des chenaux découpant les couches. Les chenaux érodés traversant le till de Newmarket, un aquitard régional (couche semi-perméable), servent de connexion hydraulique entre les aquifères de la moraine d'Oak Ridges et ceux des sédiments glaciaires inférieurs. Les chenaux enfouis sont remplis de silt, de sable et de gravier et leur orientation préférentielle est NNE-SSW. Les carottes de forage et les profils de sismique réflexion corroborent l'existence de ces chenaux. Le modèle, selon lequel deux aquifères ont été identifiés, a des répercussions importantes sur la mise en valeur des eaux souterraines régionales dans le Toronto métropolitain. Il se peut que l'écoulement des eaux souterraines vers les sédiments glaciaires inférieurs emprunte les chenaux; ainsi, les ressources en eaux souterraines dans les sédiments glaciaires inférieurs pourraient être plus abondantes que prévu. Les séquences de gravier dans les chenaux pourraient être des cibles pour des puits à débit élevé. Des travaux supplémentaires sont nécessaires pour étudier l'emplacement des chenaux enfouis, la répartition des unités et la nature des sédiments de remplissage.

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INTRODUCTION

The Oak Ridges Moraine (Fig. 1) and underlying sediments form an aquifer complex which supplies large amounts of potable water within the Greater Toronto Area. In 1993, the Geological Survey of Canada (GSC) began a three year regional hydrogeological study of the Oak Ridges Moraine to understand the extent of, and the geological controls on, the groundwater resource. The complex geology of the Oak Ridges Moraine area requires use of innovative subsurface investigations, including geophysical surveys and database syntheses. The study has relied heavily on co-operation from provincial government ministries, planning and engineering departments of all the Greater Toronto Area regional municipalities, consulting firms, and universities.

This paper presents a geological model for the Oak Ridges Moraine area. The stratigraphic model presented is used to define the major hydrostratigraphic elements and their influence on regional hydrogeology (Fig. 2). A case history involving the development of a high-yield municipal well is also presented, along with strategies for conducting future searches for similar high-yield water supplies.

WATER RESOURCE ISSUES IN THE GREATER TORONTO AND OAK RIDGES MORAINES AREAS

Adequate water supplies are essential and are an important consideration in planning from the residential to the national scale. On a regional scale, the Greater Toronto Area has to date had sufficient water supplies to enable large population growth without suffering major water shortages, although short-term water supply problems have been experienced in smaller communities.

In the Regional Municipality of York, for example, water is supplied from three major sources: Lake Ontario (76% of total supply in 1991) in the south, groundwater (21%) in the central and northwestern region, and Lake Simcoe (3%) in the northeastern region (Regional Municipality of York, 1993). Even with water conservation measures, long-term projections indicate that water demand will continue to grow. Groundwater has proven to be a reliable and economical resource, but the size of the resource is not well known. Stream baseflow into Lake Simcoe is not adequate to meet water supply needs for the region. Various options for supplying water by pipeline from Lake Ontario or from Georgian Bay are presently being considered. However, pipeline infrastructure is expensive and is estimated to cost approximately \$550 million (Regional Municipality of York, 1993) without considering the high operational and maintenance costs of water transport.

Groundwater is a renewable resource that should be thoroughly evaluated. As groundwater is available closer to the water demand location and at a higher elevation than lake water, it can cost significantly less to supply than surface water. Even if groundwater resources prove to be insufficient to supply all future water needs, they could be used to supplement surface water supplies. Such a system is presently operating in Durham Region where Skinner's Spring has supplied 1.5 million litres per day to Bowmanville at low cost since 1914. In many small communities with more modest water demands, pipelines will be uneconomical and continued reliance on groundwater supplies is expected.

Similar considerations regarding the sources of future water supply have been discussed in several areas of the country where complex geology controls the water resource

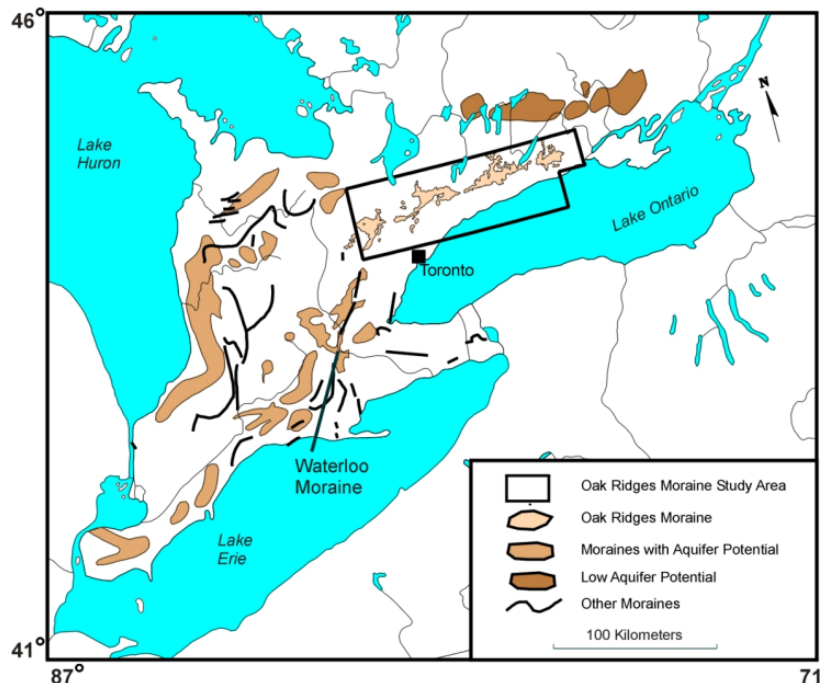
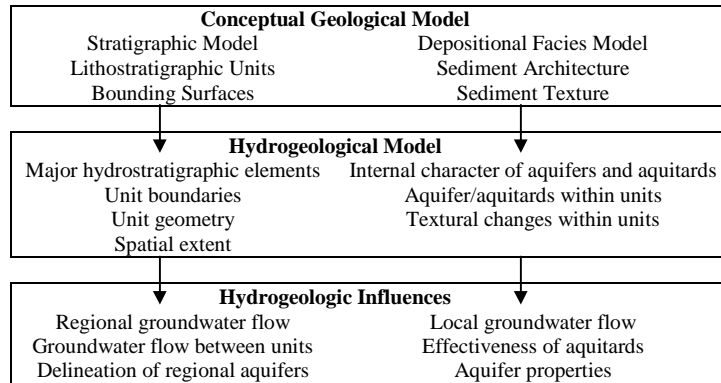


Figure 1. Moraines of southern Ontario. (Digital file modified from Fulton, 1995)

(e.g. Waterloo Moraine, Fig. 1). Better understanding of the geological controls on groundwater flow and the development of improved methods of groundwater investigation in the Oak Ridges Moraine may also be beneficial in addressing water supply issues in other areas.

Figure 2. Components of the geological and resulting hydrogeological model.



INVESTIGATIONS BY THE GEOLOGICAL SURVEY OF CANADA

The principal objective of the Oak Ridges Moraine Hydrogeology project has been aquifer delineation. Work has focused on surface and subsurface investigations to map geological and hydrogeological features, with the aim of developing a regional geological model. The working geological model comprises two components: a) stratigraphic, and b) depositional facies, both of which are important to hydrogeological studies although only the stratigraphic component of the model will be discussed (Fig. 2). The development of the model relies on past geological mapping and on the interpretation of new high quality data collected by detailed geological mapping, geophysical surveys, and stratigraphic drilling. In parallel with this working model, a large quantity of archival surface and subsurface data has been collected (Table 1) to form a geological and hydrogeological database (T.A. Brennand, D.R.

Table 1. Investigative techniques used by the Oak Ridges Moraine project for aquifer delineation.

		Investigative Techniques		Application
Surface	Remote Sensing & GIS	Thematic Mapper Spot ERS-1 RADARSAT Themography Digital Elevation Model	Soil Moisture, Land Cover, Image enhancement Soil Moisture Soil Moisture Spring Locations Landscape / basin modelling / datum	
	Mapping	Field Sites Stream Gauging Stream Chemistry	Detailed sediment characterization Discharge Hydrogeology	
Subsurface	Drilling	Sediment Description Piezometer Installations	Geology Hydrogeology	
	Geophysics	Reflection Seismic Ground-Penetrating Radar EM-34, 47 Gravity Borehole	Stratigraphy / architecture Water Table, Structures Stratigraphy Depth to Bedrock Physical Properties	
	Archival Boreholes	MOEE Water Wells Geotechnical Interim Waste Authority	Geology, Water Levels Geology, Water levels Geology, Hydrogeology	

Sharpe, H.A.J. Russell, and C. Logan, 1994: poster H9 presented at 1994 Ontario Mines and Mineral Symposium, Toronto, Ontario; Russell et al., 1996; Brennand, in press a). Data integration, viewing, and analysis is being completed in a Geographic Information System (GIS) environment to advance geological and hydrogeological understanding.

Surface mapping is being completed by means of detailed field observations, remote sensing techniques, and hydrological surveys (Table 1). Geological mapping is the cornerstone for Oak Ridges Moraine model development, data integration, and field verification of remotely sensed data. Remotely sensed data are being combined with a digital elevation model (Kenny et al., 1996) to permit landform and land cover analysis, and materials mapping.

Subsurface investigations comprise archival borehole data, surface and downhole geophysical surveys, and analysis of new drilling (Table 1). The project has drilled four new stratigraphic boreholes and used existing Ontario Geological Survey (OGS) boreholes in the area. Geophysical surveys (including seismic reflection profiling, ground penetrating radar, and a regional gravity survey; e.g. Pullan et al., 1994) provide lateral extensions of point data, enhancing the stratigraphic and structural understanding of the study area. Analysis incorporates an upgraded (locations improved by ~15%) Ontario Ministry of Environment and Energy (MOEE) waterwell database (Hunter, 1996), with other archival data to provide regional information on sediment distribution and therefore aquifer/aquitard distribution.

GEOLOGICAL MODEL

The geological model (Fig. 3) of the Oak Ridges Moraine has been constructed (Sharpe et al., 1994a, b) using detailed mapping (e.g. Barnett, 1992, 1993, 1994, 1995; Barnett and Henderson, 1995), published data (e.g. Sibul et al., 1977), recent borehole data (Barnett, 1993), logging of sediment exposures, and shallow seismic reflection profiles (Pullan et al., 1994; see Fig. 6). These high-quality data are most abundant in the moraine corridor between Uxbridge in the east and Nobleton in the west, and thus the model best applies to this area, the Uxbridge wedge. Nevertheless, it appears that some of the key strata comprising the model extend to the east or west of the Uxbridge wedge (e.g. mapping and recent borehole data from the Interim Waste Authority (IWA), 1994a, b).

From the youngest units downwards, four major units and two erosional surfaces are identified (Fig. 3):

1. Halton/Kettleby drifts
2. Oak Ridges Moraine
3. Channellized erosional surface on the Newmarket Till
4. Newmarket Till
5. Lower drift
6. Erosional bedrock surface

1. Halton/Kettleby drifts

Halton and Kettleby drifts form the highest stratigraphic units, and occur as surface tills and lake sediments south (Halton) and north (Kettleby) of Oak Ridges Moraine (Fig. 4). These different drifts are dominantly clayey silt to silt till with interbedded sand and silt. The Halton Till is thickest in the Humber River area (20-30 m) and thins towards the north and east. Along the southern flank of the Oak Ridges Moraine the Halton overlaps the moraine where it is characterized by a zone of hummocky terrain (e.g. Barnett and Henderson, 1995).

2. Oak Ridges Moraine

The Oak Ridges Moraine forms an extensive surface deposit 160 km long and 2 to 11 km wide. Its surface form can be divided into four sediment bodies or wedges, each widening westward. The Oak Ridges Moraine may be more extensive in the subsurface, particularly beneath the Halton drift. Rhythmically interbedded fine sands and silts are the dominant sediments, but coarse sands and gravels are prominent locally. Core logging indicates that areas of the moraine are composed of two to four fining upward packages. Regional landform relations and textural trends indicate paleoflow from the northeast. The lower contact of the moraine is an irregular channelled Newmarket Till surface (Fig. 5). Where this underlying till sheet has been completely eroded, Oak Ridges Moraine sediments may reach thicknesses of 150 m, and rest either on the lower drift or bedrock.

3. Channellized erosional surface on the Newmarket Till

A network of channels mapped north of the Oak Ridges Moraine, and oriented north-northeast to south-southwest (Fig. 5), is cut on the Newmarket Till (Barnett, 1990; Brennand and Shaw, 1994). The surface expression of the channels disappears beneath the moraine. Mapping (e.g. Barnett, 1992), seismic reflection profiling (Fig. 6; Pugin et al., in press), and drilling (e.g. Barnett, 1993) have shown that channels continue beneath the Oak Ridges Moraine. The channels may be confined within, or have eroded through, the Newmarket Till into the lower drift. The channel geometry at surface indicates features 1-4 km wide and tens of meters deep; subsurface geometry reveals features 1-2 km wide and tens of meters deep. The channels contain mainly sandy sediments related to the Oak Ridges Moraine complex; however, at least some channels contain thick (10-15 m) gravels.

GEOLOGIC MODEL

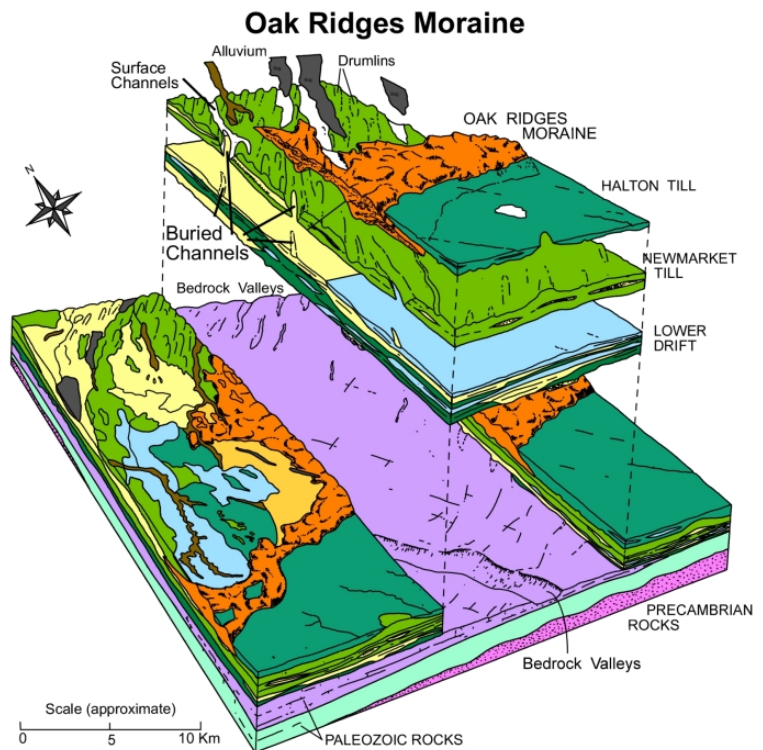


Figure 3. Geological model of major strata in the Oak Ridges Moraine area. (Kettleby not shown)(Drawing by J.Glew; computer rendering by D.Finley, March 1994)

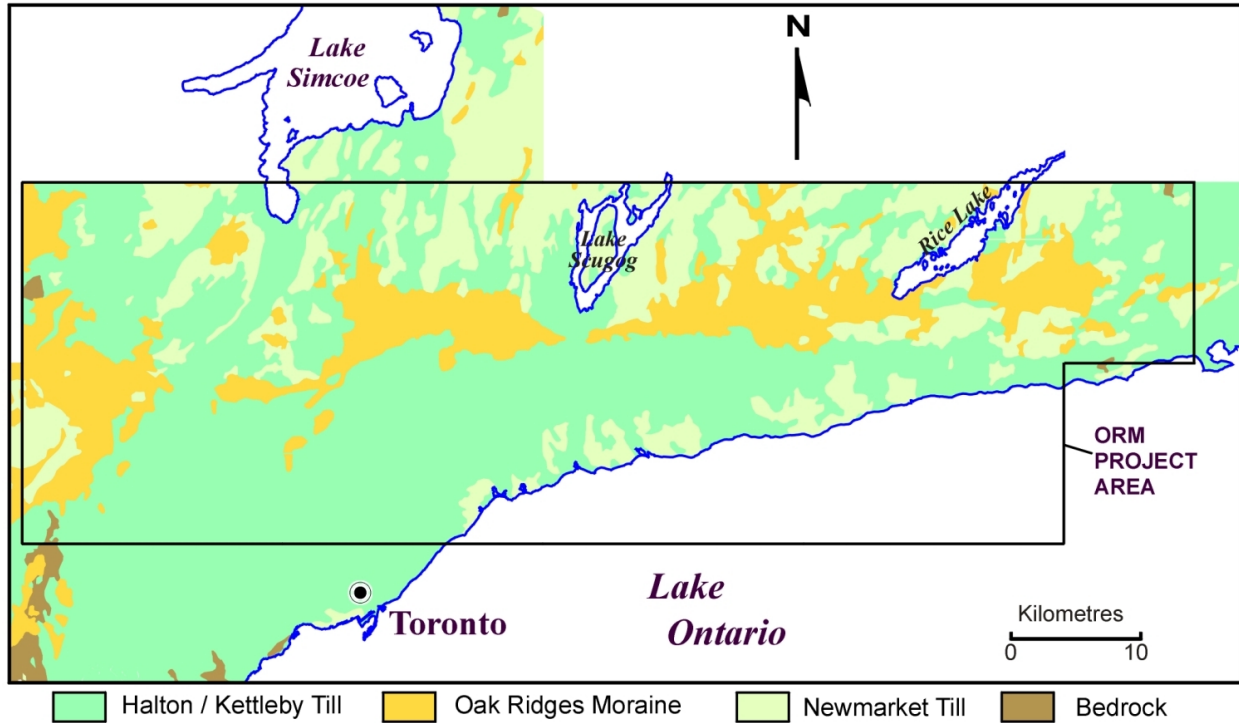


Figure 4. Surficial geology of the Oak Ridges Moraine area (from Barnett et al., 1991).

4. Newmarket Till

Newmarket Till occurs at the surface north of Oak Ridges Moraine (Gwyn and DiLabio, 1973), and has both streamlined (drumlins) and erosional (channels) elements. It is less extensively exposed south of the moraine but has been mapped in the subsurface at Musselman Lake (see Barnett et al., 1991; Sharpe, in press), Sutton, and Newcastle, and at the surface near Kleinburg (Russell, in press) and Port Hope (Brennand, in press b). This sediment is a dense, stony, silty sand till, observed to be 5-30 m thick in surface outcrop. Newmarket Till is characterized by high seismic velocities in downhole seismic logs obtained over widespread areas, and the contrast in velocities between it and overlying sediments make it a prominent reflection on seismic profiles (Pullan et al., 1994; Boyce et al., 1995). The base of the unit typically occurs between 200 and 220 m a.s.l. within the Uxbridge wedge (see also Hunter, 1996).

5. Lower drift

Lower drift units defined as Don and Scarborough formations and Sunnybrook Till at Scarborough Bluffs (Karrow, 1967), may extend north of the Oak Ridges Moraine (Eyles et al., 1985). These units are exposed north of the Lake Ontario shoreline along some river banks and at Woodbridge (White, 1975). The sandy Don Formation has been identified as a prominent seismic unit in the Nobleton area (A. Pugin, unpub. report to Geological Survey of Canada, 1996) and confirmed by drillcore data (Sado et al., 1983). Overlying Scarborough Formation sands have been confirmed as far north as the GSC borehole in Vandorf. These sands have regional extent as a unit tens of metres thick and are well displayed on seismic profiles (Pugin et al., in press). The Sunnybrook diamicton, a fine grained unit, may occur in a GSC borehole east of Newmarket and thus appears to form a regional aquitard within the lower drift sequence. Where the Newmarket Till is completely eroded, lower drift sediments may also have been eroded.

6. Bedrock surface

Attempts to define the bedrock topography in the Oak Ridges Moraine area have been made using unedited water well records (e.g. Eyles et al., 1985). However, beneath the moraine and in the Laurentian channel, a buried valley extending from Georgian Bay to Lake Ontario; the precise definition of the bedrock surface is poorly constrained as few water wells intersect bedrock. Investigations west of Bolton indicate that several tributary channels may descend toward the Laurentian Channel (Hunter, 1996). Regional gravity surveys are providing a means of better delineating buried bedrock valleys including the Laurentian Channel (e.g. Belisle, 1995).

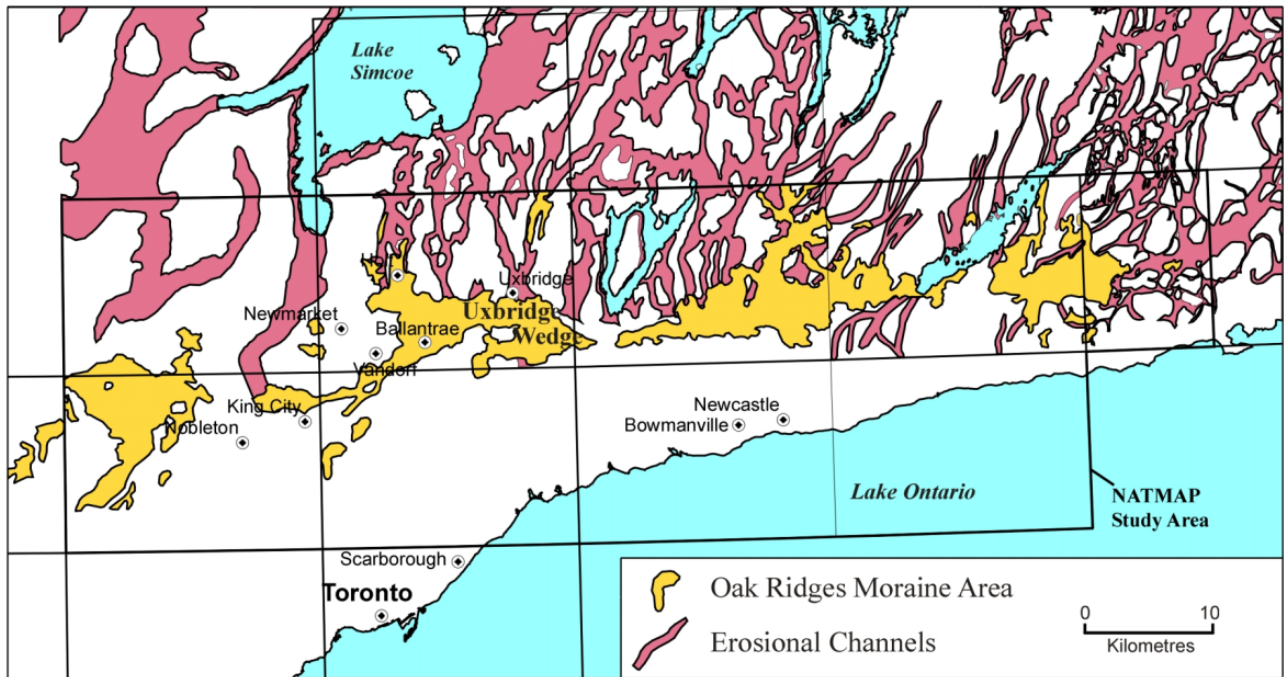


Figure 5. Channels eroded in the Newmarket Till (preliminary map). Data from Barnett, 1990; Shaw and Gorrell, 1991; Gorrell and Sharpe, 1994; Brennand and Shaw, 1994.

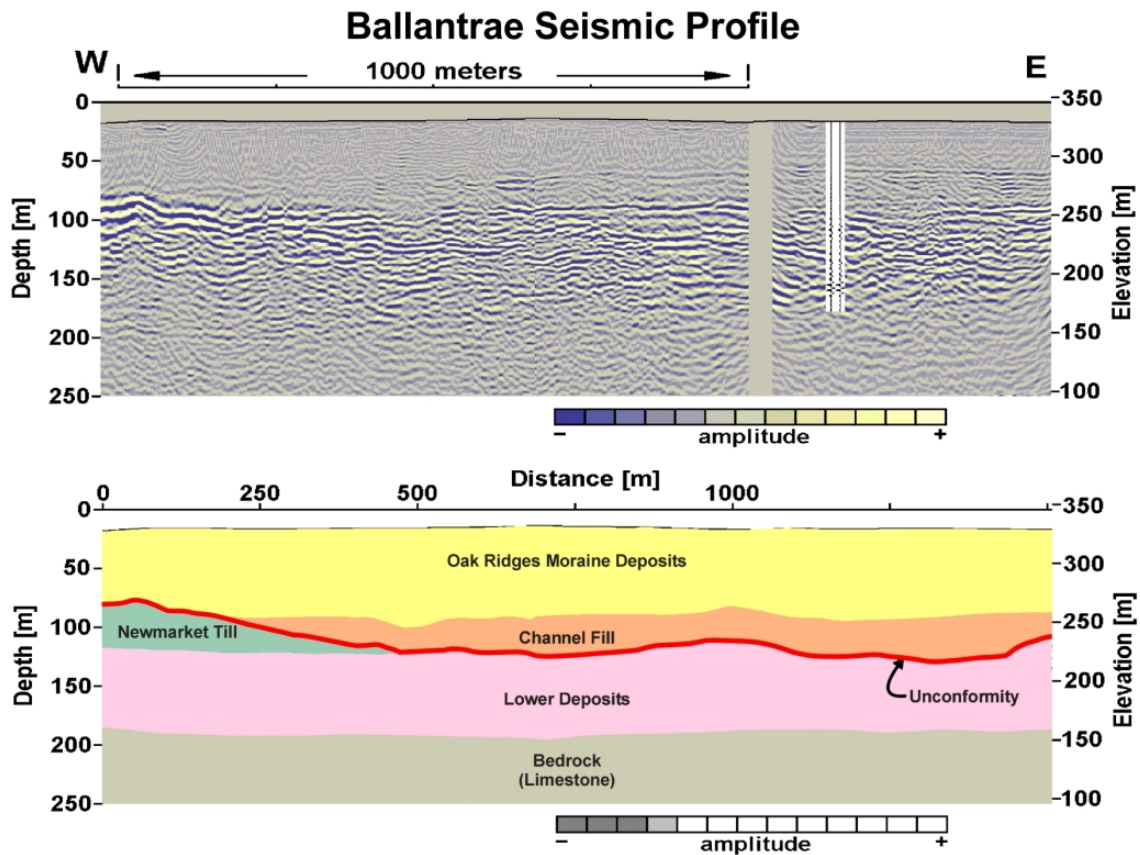


Figure 6. Seismic reflection profile from Ballantrae area, showing the geometry of broad subsurface channels and channel fill confirmed by core logging.

HYDROGEOLOGICAL SIGNIFICANCE OF THE GEOLOGICAL MODEL AND PROSPECTS FOR WATER SUPPLY

The geological model indicates that at least four geological units or subsurface structures are potential aquifer targets and at least two units that are aquitards. The Halton and Kettleby drifts are mainly surficial aquitards that reduce local groundwater recharge and that may serve to reduce the exposure of underlying aquifers to contamination (hydraulic conductivities from 10^{-8} to 10^{-4} cm/s; Interim Waste Authority, 1994a). Where the Newmarket Till is present, it is a regional aquitard that overlies the lower drift and may limit groundwater recharge from the ground surface or groundwater flow from the Oak Ridges Moraine sediments. Newmarket Till is an aquitard that may reduce groundwater recharge and contaminant migration. Core samples have low hydraulic conductivities (10^{-9} to 10^{-8} cm/s), but those calculated from piezometer or pump tests have a wider range (10^{-9} to 10^{-4} cm/s). It has been reported that larger-scale fractures could serve as pathways for groundwater flow through the till (Interim Waste Authority, 1994b).

The four main aquifer targets are:

1. extensive Oak Ridges Moraine sediments exposed at the surface;
2. channel structures cut into or through the Newmarket Till and filled by Oak Ridges Moraine sediments;
3. extensive sands within the lower drift sequence; and
4. lower drift sands filling valleys on the bedrock surface.

The Oak Ridges Moraine sediments form near surface aquifers across most of the moraine. These aquifers supply sufficient water for individual residential water demand, so wells have simply been drilled where water is required. Coarse sand and gravel beds within the moraine sediments offer good prospects for larger capacity wells. The location of these beds depends primarily on the type and distribution of depositional facies (e.g. gravel). Therefore, facies changes within the moraine are more important than the generalized stratigraphy as a guide for productive aquifers.

The high topographic position and predominantly sandy texture of the Oak Ridges Moraine implies that it plays a significant role in regional groundwater flow and groundwater resources in terms of its high recharge potential and subsequent flow to other down gradient aquifers. Thus, the long term integrity of groundwater supplies in the region depends, in part, on the recharge of groundwater within the Oak Ridges Moraine and on protecting these groundwaters from contamination.

Mapping, geophysical surveys, and drilling carried out for the Oak Ridges Moraine project have identified channel structures below the moraine that are eroded into or through the regionally extensive Newmarket Till. Infilled channels may extend to elevations comparable to those of the lower drift sediments, so that productive 'lower' aquifers in some areas may be composed of moraine sediments. The high density of channels in the Newmarket Till north of the moraine suggests that these channels could significantly influence groundwater flow on a regional scale (Fig. 5). These channels are hydrogeologically significant for two reasons: 1) they can form significant hydraulic connections between the Oak Ridge Moraine sediments and the lower drift, and 2) gravel deposits within the channels may form high yield aquifers.

Since these channels are filled with silt, sand, and gravel, they are probably more permeable ($\approx 10^{-7}$ to $>10^{-3}$ cm/s) than the Newmarket Till and are potential pathways for groundwater flow (and potential contaminants) to the lower drift. Estimates of groundwater recharge to the lower drift (30 and 250 mm per year) are based on calculations which assume that groundwater flows through a continuous aquitard (Regional Municipality of York, 1993; Smart, 1994). Channels cut to lower drift likely provide greater recharge to portions of the lower drift than previously estimated.

Some channels contain gravel sequences which are potential targets for municipal water supplies. The extent and prevalence of these gravel deposits within channel structures will require further mapping. Since these channel aquifers are hydraulically connected to the Oak Ridge Moraine sediments, groundwater flow to the gravel could be high and aquifers may capture recharge from a broad surface area. The channels have little or no surface expression where they are covered by the moraine, so it is difficult to effectively predict the locations of channels without geophysical mapping.

The lower drift is composed of several geological and hydrostratigraphic units. South of the Oak Ridges Moraine, at least two confined aquifer units have been identified within the lower drift by logging sections (Sibul et al., 1977), but their regional extent and interconnectedness are not well known. Where the Oak Ridges Moraine is not present, sands within the lower drift are the primary aquifers. If vertical flow through the channels is significant, recharge through the moraine could

also supply much of the regional groundwater flow to lower drift aquifers. Since lower drift may be supplying a significant portion of the groundwater supply in York Region and in parts of Peel Region, it is important to evaluate whether the geological model is appropriate in these areas. The lower drift is also a good groundwater supply target for small communities on the north side of the moraine in York and Durham regions, where continued reliance on groundwater is anticipated. Groundwater within the lower drift may be less susceptible to contamination than groundwater from the surficial units.

Finally, it is suggested that there could be productive aquifers in buried bedrock valleys. Recent GSC and Interim Waste Authority drillholes in bedrock valleys identified a thin gravel zone near the bedrock surface. Several municipal wells in the vicinity of the Laurentian Channel obtain their water from productive zones in the lowermost aquifers (Regional Municipality of York, 1993); some of these wells may be located within the fill of bedrock valleys. At present, the stratigraphy within the Laurentian Channel is poorly known, and therefore it is difficult to assess the potential for recharge to these aquifers.

CASE STUDIES IN WATER SUPPLY LOCATION

In the course of the field investigations carried out as part of this project, two potential high-yield water supplies have been identified; one of which is now under development as a municipal water well.

The Regional Municipality of York has recently completed aquifer testing and supply well installation for the community of Ballantrae (Fig. 5). Although the location of the well was partly determined by the availability of municipal lands and earlier exploratory drilling, GSC (Fig. 6) and OGS work in the area provided geological support for the decision to proceed with supply well installation. The municipal well is close to a GSC borehole interpreted to have intersected a channel cut through the Newmarket Till. One hundred meters of Oak Ridges Moraine sediments were logged in the borehole above a prominent 15 m thick (north-northeast-south-southwest) sand and gravel horizon (240 m a.s.l.). The association of the gravel with a channel supported the prospects for finding an aquifer in the same channel. A producing gravel horizon was found at the same depth in the Regional Municipality of York borehole located one-half kilometre to the north. Pumping tests demonstrate direct hydraulic connection between the gravels at the two locations and indicate that this well will meet the municipal water requirements.

The second example, near Nobleton, is untested as yet in terms of water production, but drill core combined with seismic reflection profiles suggest that it could also be a high yield water supply. Geological Survey of Canada, supported by both Peel and York regions, completed the continuously cored Nobleton borehole to bedrock at ~192 m depth. This borehole intersects a 12 m sand, and coarse gravel unit at a depth of 50 m (210 m a.s.l.). A shallow seismic reflection profile which runs by the borehole clearly shows this gravel sequence as a complex reflection package that can be traced westward for a distance of approximately 500 m. Detailed logging of the core is required to determine whether this gravel unit is part of the Oak Ridges Moraine sediments, or is another example of gravel within an erosional channel beneath the moraine. In either case, this gravel intersection and its significant lateral extent imply the possibility of groundwater reserves on a production well scale.

PROSPECTS FOR GROUNDWATER SUPPLIES IN THE OAK RIDGES MORaine AREA

Historically, municipal production wells have been drilled close to consumption areas or located according to previous drilling experience with little geophysical profiling. Although a concept of the distribution of water-bearing zones does emerge as wells are added to a system, this approach will ultimately fail to define groundwater potential because of the complexity of the geology and the lack of a geological basis for extending searches for additional water. The geological model developed during this study provides a local and regional strategy for locating new groundwater supplies as well as subsequent aquifer protection strategies. The two case studies demonstrate the application of this model to successful groundwater searches.

The geological model includes four potential stratigraphic targets for groundwater searches 1) channels in drift; 2) Oak Ridges Moraine sediments; 3) lower drift; and 4) bedrock channels. The prime stratigraphic drilling targets identified in the model are buried channels which may host gravel deposits and are at moderate depths. While channels are relatively narrow targets, the model provides some guidance by defining the dominant channel orientations and size, and mapping out the surface occurrences north of the moraine. Exploration strategies should focus on east-west surveys that are most likely to intersect buried channels. The recognition that the base of the Newmarket Till commonly occurs around 200 m a.s.l. (in the

Uxbridge wedge) provides a stratigraphic marker to help identify whether drilling has encountered the lower drift or a buried channel. However, at the present time, the model is not sufficiently detailed, or requires supplemental depositional facies information to be fully effective as a prospecting tool for high-yield water supplies in the Oak Ridges Moraine sediments, lower drift units, or bedrock channels.

Groundwater flow through channels may be high enough to permit sustainable groundwater extraction from the lower drift in the vicinity of channels. Regional groundwater flow in the lower drift could also provide a sustainable groundwater supply to many areas both north and south of the moraine.

The geological model of the Oak Ridges Moraine area presented in this paper should be updated and revised as more information becomes available. Municipal water supplies should be assessed in terms of the current working geological model to better understand the geological controls on the groundwater resources being tapped. Exploration for new water supplies should include subsurface investigations such as geophysical surveys and stratigraphic drilling as reconnaissance tools. As well as aiding particular water searches, such surveys constitute invaluable investments because of the geological and hydrogeological information made available for refining the understanding and promoting wise resource management within the Oak Ridges Moraine area.

CONCLUSIONS

A regional geological model and its possible hydrogeological significance have been presented for the central portion of the Oak Ridges Moraine. The model emphasizes the importance of channel structures eroded into or through the Newmarket Till, a regional aquitard. New mapping, seismic reflection profiles, and drilling support this stratigraphic model.

Gravel sequences within channels have been identified as potentially productive aquifers. Application of the model suggests that groundwater flow through channels to aquifers within the lower drift may be higher than implied by current estimates. Consequently, channels could influence how groundwater resources are assessed and managed on a regional scale. Further research is needed to delineate buried channels and the infilled sediments. Hydrogeological work is also required to assess vertical groundwater flow through these channels to the lower drift. The development of depositional facies models will improve our understanding of the internal structure of the geological units and assist in the development of improved strategies to locate productive aquifers.

A valid geological model is a critical tool in hydrogeological assessments and exploration. The regional model influences perceptions of the prospects for groundwater resources in the Oak Ridges Moraine area and provides a stratigraphic context in which geological and hydrogeological data can be examined. More work remains to be done in refining and validating the model in the central portion of the Oak Ridges Moraine, and in verifying and adapting the model for other areas. However, the tools and methods required for this work have been tested and proven, and can now be put to effective use in searching for and evaluating the potential of groundwater resources in the Oak Ridges Moraine area.

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