GeoConvention 2014 FOCUS | adapt refine sustain

Aquifer Systems in Southern Ontario: Hydrogeological Considerations for Well Drilling and Plugging

Terry R. Carter, Petroleum Operations, Ministry of Natural Resources, London, ON
Lee Fortner, Petroleum Operations, Ministry of Natural Resources, London, ON
Mitchell E. Skuce, The University of Western Ontario, London, ON
Fred J. Longstaffe, The University of Western Ontario, London, ON

Summary

Three groundwater regimes have been identified in the Paleozoic bedrock terrain of southern Ontario based on geological and geochemical criteria: a shallow fresh water regime, an intermediate depth brackish sulphur water (dissolved H_2S) regime and a deep brine regime.

The shallow fresh water regime is an active, topography-driven flow system. Fresh water is encountered in petroleum and water wells up to 250 metres below the surface. Fresh water occurs in unconsolidated glacial and post-glacial sediments overlying Paleozoic bedrock, as a regional contact aquifer at the interface between the sediments and the bedrock, and in karstic Paleozoic limestones and dolostones in areas of thin drift. Individual aquifers in glacial drift are generally unconfined to partly confined, forming complex, local systems with limited lateral extent. The contact aquifer extends beneath most of southern Ontario and is the source of potable water for a large proportion of domestic water wells in southern Ontario. It has only recently been possible to map the geographic extent of the karst aquifer system and detailed studies have yet to be initiated.

Aquifers in the intermediate to deep regimes are contained in several discrete regional paleokarst horizons developed in limestones and dolostones at regional unconformities. Aquifers are generally thin, and are confined between thick aquitards of shale, evaporites and non-karstic limestone and dolostone. All of these confined aquifers display downdip geochemical zonation from fresh water at the subcrop edge to brines in the deep subsurface, separated by an intermediate zone of brackish sulphur water. Buoyancy effects related to the presence of deep subsurface brines probably prevent deep penetration of fresh water. At least one active flow system has been documented in the sulphur water system, confirmed by meteoric water signatures in oxygen and hydrogen isotopic compositions.

Unique isotopic signatures have been identified for the deep brines in each confined aquifer, indicating very long residence times and no active flow in the deep brine regime.

Introduction

All petroleum wells in Ontario encounter groundwater during drilling, including shallow aquifers that supply potable water to domestic, municipal and commercial water wells. Petroleum well operators are required to design their drilling and well construction programs to permanently isolate and protect these aquifers from contamination and prevent the migration of oil, gas or water between geological formations along the well bore. Wells that are no longer productive must be plugged to accomplish the same goals. The ability for industry to meet these

requirements depends directly on the availability of accurate geological and hydrogeological data and knowledge.

In 2006 the Ministry of Natural Resources (MNR) initiated its Abandoned Works Program to locate and plug, on a priority basis, petroleum wells that were left unplugged by now-defunct operators. A gap in our understanding of the hydrogeology of southern Ontario relevant to plugging these wells became apparent and in 2008 the MNR initiated a program of hydrogeological and hydrogeochemical mapping and research to provide the required data and knowledge to guide our well plugging projects and provide a scientific basis for improved regulatory oversight.

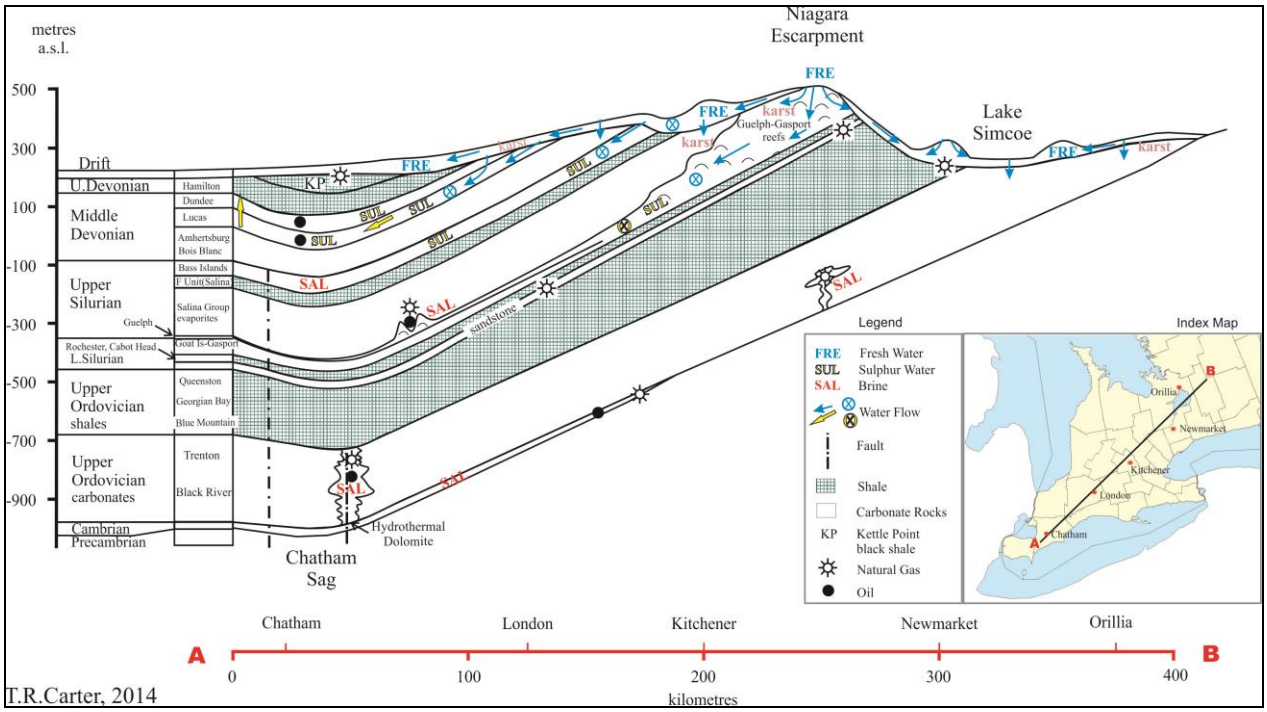
Method

The geological setting and Paleozoic stratigraphy of southern Ontario has been documented by Armstrong and Carter (2010) and others. Sources of information for aquifer and aquitard mapping include: (i) field observations in outcrops, quarries and road-cuts, (ii) petroleum well digital records for 27,000 wells in MNR's Ontario Petroleum Data System, (iii) digital water well records for over 400,000 wells in the Water Well Information System of the Ontario Ministry of Environment, (iv) hydrogeochemical analyses (by SGS Canada Inc.) and oxygen, hydrogen, sulphur and carbon isotopic ratios (by Skuce) of 130 formation water samples from petroleum wells, springs, quarries and orphan wells,(v) recent hydrogeochemical data published by the Ontario Geological Survey (Hamilton, 2011, and (vi) a thorough literature review.

As part of this study a quality assurance review of the water records in the MNR petroleum well database has been completed. The edited data has been used to map the regional occurrence of aquifers and aquitards in the Paleozoic bedrock of southern Ontario, utilizing MNR's customized PetroGIS application, and to document and map the depth zonation of water types (fresh, sulphur, brine) in the bedrock formations of southern Ontario. GIS analysis of water well data from the MOE database was used to identify and map the geographic distribution of the karst and contact aquifers in the fresh water regime.

Examples

This scaled geological cross section shows regional southwesterly dip of bedrock formations and occurrence of water, oil, and natural gas in these layered marine sedimentary rocks (modified from Carter, 2012 and Sharpe et al., 2013). Fresh water (blue-FRE) is confined to a relatively thin veneer (<250 m) of glacial sediment and shallow bedrock. Saline water containing dissolved H_2S (yellow—SUL) occurs at intermediate depths from 30 – 500 m, and the deepest rocks (>150 m) contain brine with no dissolved H2S (orange—SAL). Interpreted flow in the shallow bedrock is down-gradient from topographic highs and down regional dip of confining geological formations and/or along strike of the formations (circles with × symbols). There is no water movement in the deep confined brine aquifers.



Conclusions

Improvements in the petroleum well database of the Ministry of Natural Resources have made it possible to map the regional occurrence of aquifers and aquitards in the Paleozoic sedimentary rocks of the Michigan and Appalachian basins in southern Ontario.

A system of thick regional aquitards and thin confined aquifers within the deep bedrock setting of southern Ontario has been identified. Aquitards are formed by shale strata, most notably the Upper Ordovician Queenston, Georgian Bay and Blue Mountain formations, which exceed 300 m in combined thickness, and by thick evaporites of the Salina Group. In the deep subsurface, carbonate rocks also generally form thick aquitards. Where these same rocks occur near the surface they form fractured or karstic aquifers.

Regional paleokarst horizons are the principal geological control on development of aquifers in the deep Paleozoic bedrock. Regional confined aquifers occur within the Middle Devonian Lucas and Dundee formations, the Upper Silurian Bass Islands and Bois Blanc formations, the Upper Silurian Guelph Formation, within fault-related hydrothermal dolomite zones in the Upper Ordovician limestones of the Trenton and Black River groups and in Cambrian limestones and sandstones.

This new understanding provides a scientific basis for exploration for potable water supplies, design of petroleum well drilling programs to protect potable water supplies, for mitigation of drilling hazards such as artesian flow conditions, loss of circulation, and corrosive sulphur water, and for other potential subsurface uses.

Acknowledgements

Geological and hydrogeological studies were completed by the Ministry of Natural Resources as part of its commitment to utilizing the best available scientific knowledge as a basis for its regulatory and resource management activities. The isotopic geochemistry studies are a joint project of the MNR and the University of Western Ontario, with funding for MSc studies by Mitchell Skuce provided by the University of Western Ontario and a NSERC Discovery Grant (FJL). As always, this work builds on the work of previous researchers (Dollar et al., 1991, Sharpe et al., 2013, Carter, 2012, Carter and Fortner, 2012, Brunton, 2008, Weaver, 1994, Husein, 1998, 2004, and others). The authors gratefully acknowledge useful discussions with many colleagues, including; Frank Brunton, Derek Armstrong, Theo Beukeboom, Jeff Markle, Scott MacRitchie, Dave Sharpe, Candace Freckelton, Chris Smart, Jonathon Sykes, Joanne Potter, and Dick Jackson.

References

Armstrong, D.K., and Carter, T.R. 2010. The subsurface Paleozoic stratigraphy of southern Ontario. Ontario Geological Survey, Special Volume 7, 301 p.

Brunton, F.R., and Dodge, J.E.P., 2008. Karst of southern Ontario and Manitoulin Island; Ontario Geological Survey, Groundwater Resources Study 5.

Carter, T.R. 2012. Regional groundwater systems in southern Ontario; in Ontario Oil & Gas 2012, Ontario Petroleum Institute, p.44-48.

Carter, T.R., and Fortner, L. 2012. Regional bedrock aquifers and a geological groundwater model for southern Ontario. International Association of Hydrogeologists, 39th International Congress, Session TH1-G, Abstract 369, p.238.

Dollar, P.S., Frape, S.K., and McNutt, R.H., 1991. Geochemistry of formation waters, southwestern Ontario, Canada and southern Michigan, USA: Implications for origin and evolution; Ontario Geological Survey, Open File Report 5743.

Hamilton, S. M., 2011. Ambient groundwater geochemistry data for southwestern Ontario 2007–2010. Ontario Geological survey, Miscellaneous Release Data 283.

Sharpe, D.R., Piggott, A., Carter, T.R., Gerber, R.E., MacRitchie, S.M., de Loe, R., Strynatka, S. and Zwiers, G. 2013. Southern Ontario hydrogeological region, p.464-519, in Rivera, A. (editor), Canada's Groundwater Resources, Fitzhenry and Whiteside, Canada, 824 p.

Weaver, T.R., 1994. Groundwater flow and solute transport in shallow Devonian bedrock formations and overlying Pleistocene units, Lambton County, southwestern Ontario; unpublished PhD thesis, University of Waterloo, Canada.