EARTH SCIENCES SECTOR
GENERAL INFORMATION PRODUCT 39

Regional 3D geological modeling of the Oak Ridges Moraine, southern Ontario

Logan, C; Russell, H A J; Sharpe, D R

2000

Originally released as: Regional 3D geological modeling of the Oak Ridges Moraine, southern Ontario, Logan, C; Russell, H A J; Sharpe, D R; 2000; 6 pages

Regional 3D geological modeling of the Oak Ridges Moraine area, southern Ontario

C. Logan, H.A.J. Russell, and D.R. Sharpe
Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8.

Contact Information: Dr. David Sharpe, Terrain Sciences Division, Geological Survey of Canada, 601 Booth St. Ottawa, Ontario, K1A 0E8, ph: (613) 992-3059, fax: (613) 992-0190, e-mail: dsharpe@nrcan.gc.ca

Abstract: Geological and hydrogeological investigations of the Oak Ridges Moraine (ORM) and Greater Toronto Area (GTA) have been used to develop a regional hydrostratigraphic framework that consists of five principal units: i) bedrock, ii) lower deposits, iii) Newmarket Till, iv) Oak Ridges Moraine sediment, and v) Halton Till. This conceptual model is now being used to develop a data-driven hydrostratigraphic model by integrating field data with archival data in a relational database and GIS. A multi-step approach is used that involves: i) manually coding field data; ii) manually coding geotechnical and hydrogeological borehole data; iii) generation of individual stratigraphic surfaces that integrate geological map boundaries; iv) interpretation and integration of Ministry of Environment and Energy (MOE) waterwell data to refine the spatial elevation variability of these surfaces. The structural elevation surfaces can be used to produce sediment thickness maps as well as to constrain hydrogeological modeling.

Municipalities, conservation authorities and other agencies can use this hydrostratigraphic model to provide a regional context and to improve the hydrogeological understanding of site-specific investigations. For example, current groundwater modeling efforts that only rely on a small number of waterwell records for geological and hydrostratigraphic control can be significantly improved by using this model to develop a regional context.

Introduction

In order to quantify potential groundwater resources, and to produce flow models necessary for water resource management, accurate 3D hydrostratigraphic models are required. The Geological Survey of Canada (GSC) and its partners are developing a regional 3D stratigraphic model of the Oak Ridges Moraine and GTA for this purpose. A series of structural, stratigraphic unit elevation surfaces are generated that can then be used to produce accurate sediment thickness (isopach) maps by subtracting one from another in a GIS overlay operation. Stratigraphic mapping is based on the surficial geology of the GTA (Sharpe et al. 1997; Sharpe et al. 1999) and a regional stratigraphic framework (e.g. Sharpe et al. 1996). Four stratigraphic surfaces were produced: i) Lower deposits, ii) Newmarket Till, iii) Oak Ridges Moraine and iv) Halton Till (Fig. 1). This report is a summary of the approach used.

Data Sources

A diverse suite of field and archival geological data were integrated in a GIS (Fig. 2a. e.g. Russell et al. 1996). New field data include shallow roadside, river and lake bluff sections, boreholes, and seismic reflection data. Archival data include borehole data collected for hydrogeological and geotechnical studies, and MOE waterwell data. Sediment descriptions from these datasets differ considerably in their level of detail, ranging from thorough lithological descriptions of continuously cored material by geologists (e.g. GSC drillcore, Russell et al. 1998b) to one or two-word descriptions of wash borings by well drillers (e.g. MOE, Russell et al. 1998a). Seismic data were integrated (e.g. Hubbard, et al., 1999) by generating seismic borehole logs positioned at 200-500 m intervals along the seismic profile. Depth coverage of datasets range from shallow, predominantly < 5 m deep mapping sites to complete sediment penetration down to bedrock. MOE waterwells are the most extensive dataset with ~55,000 wells in the area, however, only ~ 40 % of the complete sedimentary basin is intercepted. A topographic DEM

(Kenny et al. 1999) provides a reference datum and 1:50 000 scale surficial geology mapping provides additional stratigraphic control (e.g. Sharpe et al. 1997).

Method

The modeling procedure consists of: i) data pre-processing, ii) manual and automated borehole log interpretation and iii) interpolation to produce stratigraphic surfaces. Data analysis and processing was completed using Microsoft Access (1997) and Visual Basic for Applications. GIS interpolation from point to areal coverage was completed using Triangular Irregular Networks (TIN) in MapInfo (1998) and Vertical Mapper (1998).

Data Pre-Processing

Integration of diverse datasets required recoding to a standard lithological classification. A ten-unit classification was developed to integrate the range of material descriptions found in the aforementioned data sources (Russell et al. 1998b). Coding was completed manually for field and archival geotechnical data. A rule-based system was developed that enabled automatic classification in a relational database of MOE waterwell data (Russell et al., 1998b). Location errors in the waterwell data are a known limitation of this dataset (Hunter and Associates and Raven / Beck, 1996). Consequently, the location accuracy was verified using the OBM cadastral fabric and the surface topographic DEM (Kenny et al. 1997). The analysis identified that ~30 % of the data was likely incorrectly located. Furthermore, waterwells tend to be clustered due to human settlement patterns. Data redundancy as well as shallow and poor-quality waterwell data were identified and removed thereby reducing the dataset by ~ 55% to 18 161, or < 2 wells km^2. The surficial geology polygons were recoded to the four regional stratigraphic units and appended to the first unit in each well. The absence of any stratigraphic unit in a borehole was accounted for by the addition of zero-thickness records in the database. All stratigraphic intervals were flagged as: 1 - positive thickness, known bottom; 2 - positive thickness, unknown bottom; 3 - zero thickness, known elevation; 4 - zero thickness, unknown elevation.

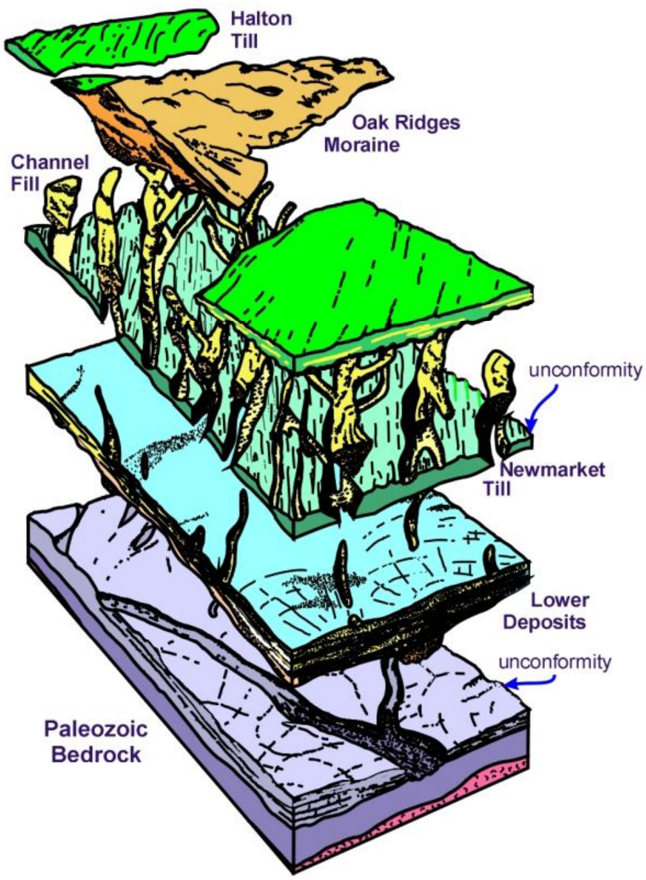

Fig. 1: *Conceptual model of the stratigraphic framework of the Greater Toronto Area.*

Modeling

The stratigraphic modeling procedure consisted of database analysis, GIS interpolation, and overlay operations completed in two stages. Stage I used manually coded data to generate preliminary surfaces used for interpreting the waterwell records in Stage II. Stage II involved stratigraphically coding waterwells and merging the two datasets to produce final surfaces and isopachs.

Stage I: anchor points and preliminary surfaces

All manually coded records flagged as types 1, 2 or 3 for a specific stratigraphic unit were selected and combined with corresponding points from map polygon boundaries (Fig. 2.b). The data were then interpolated to produce a continuous stratigraphic elevation surface (Fig. 2c The surface was checked using data flagged as type 2 for the overlying stratigraphic unit and for incomplete penetration of a stratigraphic unit. This ensures that the surface honours all of the data (Fig. 2d,e). The surface was then interpolated a second time using the appropriate ‘push-down’ data. The process was then repeated for the remaining stratigraphic units. Each surface is continuous across the study area. In areas where a stratigraphic unit is not present, its top elevation surface

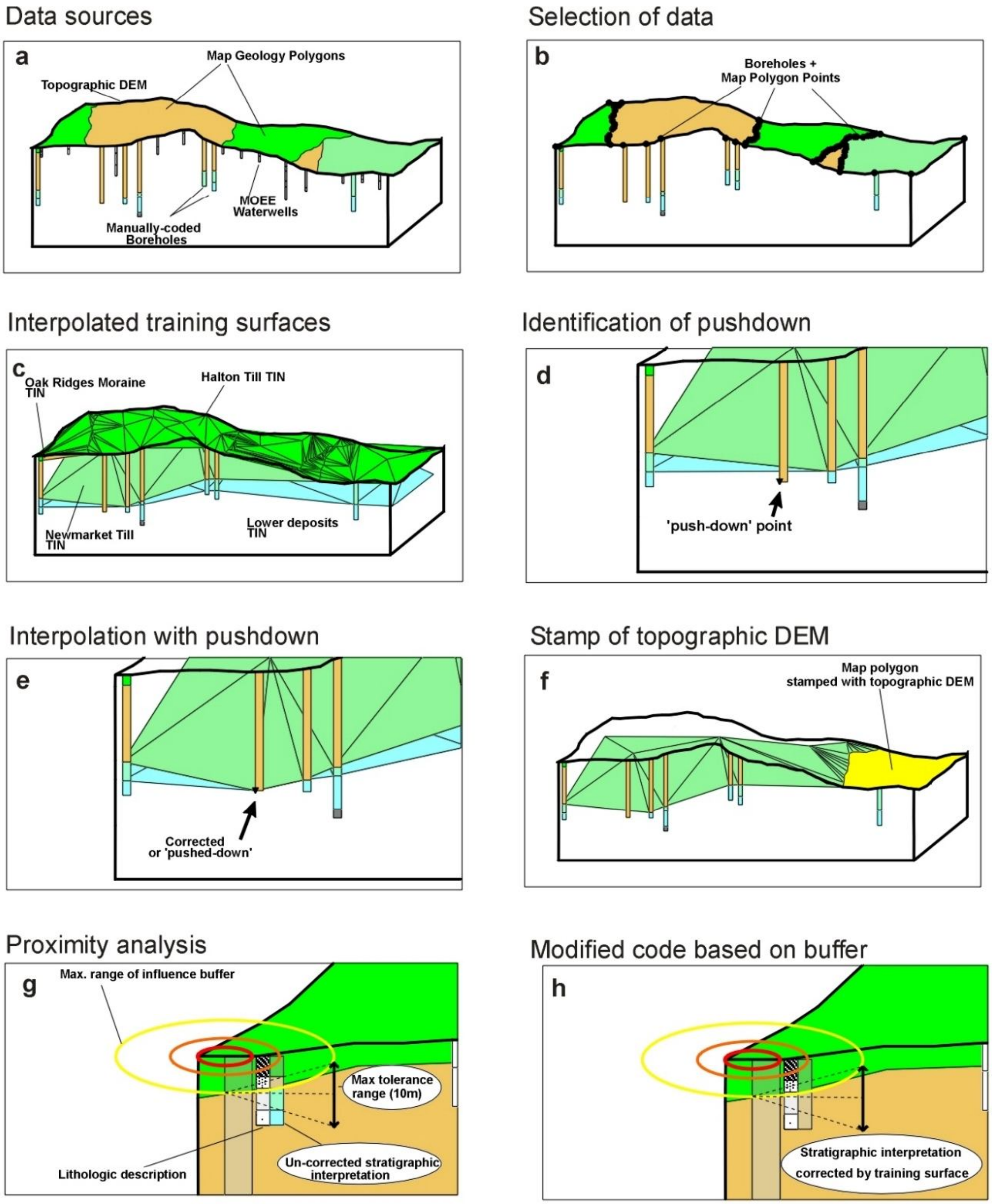

Fig. 2: *Schematic illustration of process used in generation of the stratigraphic surfaces.*

will be coincident with that of the next lower stratigraphic unit. Slight differences in the interpolated triangular facets can produce overlap in elevations. Surface mismatches were resolved by forcing the lower surface to be coincident with the overlying surface. Finally, areas of the surface that correspond with mapped geology polygons are stamped with the topographic surface DEM (Fig. 2f).

Stage II: automated waterwell interpretation and coding

To integrate regional geological knowledge into the automatic stratigraphic coding, data on depth to top of each preliminary surface (Stage I) and distance buffer value were appended to each waterwell record. A proximity analysis was completed to determine the degree of influence that manually coded data had on the automated stratigraphic coding process (Fig. 2g,h). This buffer distance was different for each stratigraphic unit and involved a linear decay away from anchor sites. Starting from the surface unit of each waterwell, four steps were followed to code the stratigraphy: i) use initial stratigraphic code assigned to unit one, ii) check material code rules, iii) check thickness and elevation rules, iv) verify stratigraphic coding with stage I surface. Following stratigraphic coding, the waterwells were integrated with manually coded data into one dataset. The sequence of steps outlined in Stage I was then repeated with the combined dataset (see above).

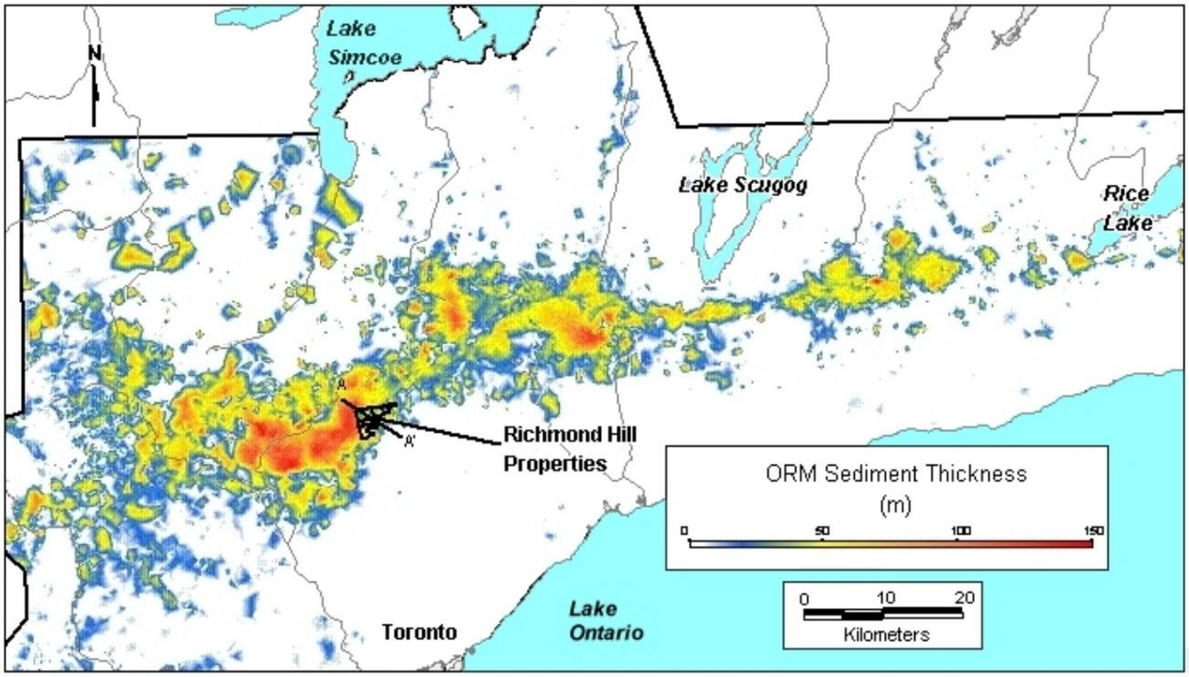

Fig. 3a: *Oak Ridges Moraine sediment thickness map.*
Note variation of sediment thickness across the Richmond Hill sites.

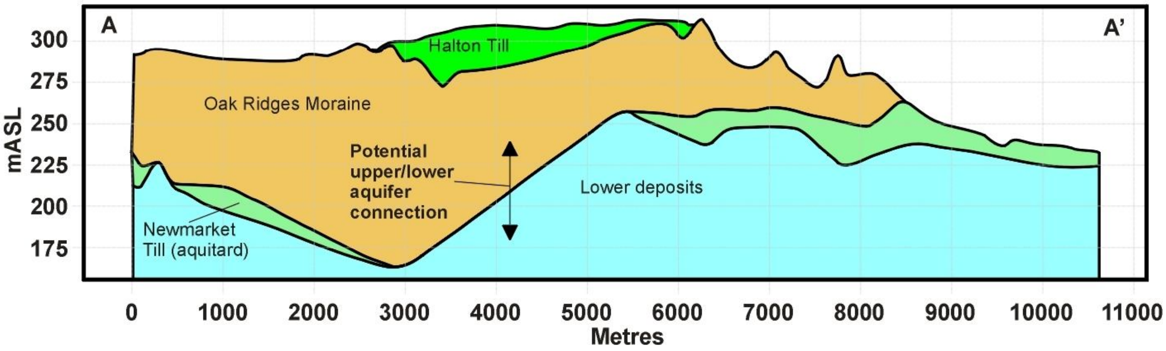

Fig. 3b: *Cross section through all stratigraphic surfaces.*

Example: mapping the thickness of the ORM

Stratigraphic surfaces derived from geological data allow watershed and site specific studies to be carried out using the most consistent and reliable 3-D sub-surface information available. Current site development studies in Richmond Hill can be used as an example to illustrate the utility of a regional stratigraphic model. The regional thickness map of the Oak Ridges Moraine and related sediment indicates thick aquifer material beneath the proposed development sites (Fig. 3a). It shows that the site is situated on very thick, permeable sediment at a topographic high. A corresponding depression in the Newmarket Till surface and a thin to absent Newmarket Till suggests the presence of a channel as seen in cross section (Fig. 3b). Hence, aquifers of lower deposits (Scarborough or Thorncliffe formations) may be hydraulically connected via more permeable sands of the Oak Ridges Moraine and channel fills to surface aquifers. Consequently, site investigations may need to verify the potential absence of aquitard material by drilling to an adequate depth to establish the site stratigraphy and confirm the thickness of channel aquifer sediments. Local waterwells and geotechnical borings alone are not deep enough to show this architecture.

Summary

The stratigraphic surfaces (Fig. 3) provide a regional model for the GTA using a well-documented procedure that integrates regional geological knowledge. This model can be used for reconnaissance in regional planning, for establishing the hydrostratigraphic setting in site-specific studies, and for improved groundwater flow modeling. As recently noted (LeGrand and Rosen 1998), the integration of this type of regional information into the preliminary stages of site-specific studies should help to improve their cost-effectiveness. In addition, groundwater modeling that only relies on waterwell records for geological and hydrostratigraphic control can be significantly improved by the use of these techniques.

References

Beckers J. 1998. Modeling the Oro Moraine Multi-Aquifer System: Role of Geology, Numerical Model, Parameter Estimation and Uncertainty. Phd thesis presented to the University of Waterloo, Waterloo, Ontario, Canada.

De Kemp, E.A., 2000, 3-D visualization of structural field data: examples from the Archean Caopatina Formation, Abitibi greenstone belt, Québec, Canada: Computers and Geoscience, v. 26, p. 509-530.

Hunter and Associates and Raven / Beck, 1996, Hydrogeological evaluation of the Oak Ridges Moraine area: technical report: *Prepared for* the Oak Ridges Moraine Technical Working Committee.

Hubbard, S. S. Rubin, Y., and Majer, E., 1999, Spatial correlation structure estimation using geophysical and hydrogeological data: in Water Resources Research, vol. 35, no. 6, p. 1809-1825.

Kenny, F.M., Chan, P., and Hunter, G., 1997, Quality control of the Positional Accuracy of Records in Ontario's Waterwell database using automated GIS techniques: Conference Proceedings Geomatics in the Era of RADARSAT GER 97, Ottawa, May 24-30, 1997.

Kenny, F.M., Paquette, J., Russell, H.A.J., Moore, A.M., and Hinton, M.J., 1999, A Digital Elevation Model of the Greater Toronto Area, Southern Ontario and Lake Ontario Bathymetry: Ottawa, Ontario, Geological Survey of Canada, Ontario Ministry of Natural Resources, and Canadian Hydrographic Service; Geological Survey of Canada.

LeGrand, H.E., and Rosen, L., 1998, Putting hydrogeological site studies on trace: Ground Water, v. 36, p. 193-194.

Martin, P.J., and Frind, E.O., 1998, Modeling a Complex Multi-Aquifer System: the Waterloo Moraine: Groundwater, v. 36(4), p. 679-690.

Russell, H.A.J., Brennand, T.A., Logan, C., and Sharpe, D.R., 1998a, Standardization and assessment of geological descriptions from waterwell records: Greater Toronto and Oak Ridges Moraine Areas, southern Ontario: Ottawa, Current Research 1998-E; Geological Survey of Canada, p. 89-102.

Russell, H.A.J., Logan, C., Brennand, T.A., Hinton, M., and Sharpe, D.R., 1996, A regional geoscience database: An example from the Oak Ridges Moraine NATMAP / Hydrogeology Project: Current Research, 1996-E, p. 191-200. Geological Survey of Canada.

Russell, H.A.J., Sharpe, D.R., and Arnott, R.W.C., 1998b, Sedimentology of the Oak Ridges Moraine, Humber River watershed, southern Ontario: a preliminary report: Ottawa, Ontario: Geological Survey of Canada Current Research 1998-C; Geological Survey of Canada, p. 155-166.

Sharpe, D.R., Barnett, P.J., Brennand, T.A., Finley, D., Gorrell, G., Russell, H.A., and Stacey, P., 1997, Surficial geology of the Greater Toronto and Oak Ridges Moraine area, southern Ontario: , Geological Survey of Canada, Open File 3062.

Sharpe, D.R., Barnett, P.J., Russell, H.A.J., Brennand, T.A., and Gorrell, G., 1999, Regional geological mapping of the Oak Ridges Moraine, Greater Toronto Area, southern Ontario, Current Research 1999-E: Ottawa, Geological Survey of Canada, p. 123–136.

Sharpe, D.R., Dyke, L.D., Hinton, M.J., Pullan, S.E., Russell, H.A.J., Brennand, T.A., Barnett, P.J., and Pugin, A., 1996, Groundwater prospects in the Oak Ridges Moraine area, southern Ontario: application of regional geological models, Current Research 1996-E: Geological Survey of Canada, p. 181-190.

Srivastava, R.M., 1997, Describing spatial variability using geostatistical analysis: in Geostatistics for Environmental and Geotechnical Applications, ASTM STP 1283, R.M. Srivastava, S. Rouhani, M.V. Cromer, A.J. Desbarats, A.I. Johnson, Eds., American Society for Testing and Materials, p. 13-19.

Weissmann, G.S., Carle, S.F., Fogg, G.E., 1999, Three-dimensional hydrofacies modeling based on soil surveys and transition probability geostatistics: Water Resources Research, v. 35, n. 6, p. 1761-1770.