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Sharpe, D R; Russell, H A J

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Basin Analysis Applied to Modelling Buried Valleys in the Great Lakes Basin

Sharpe, D.R. and H.A.J. Russell
Geological Survey of Canada, 601 Booth St., Ottawa, ON, K1A 0E8; E-Mail: Dave Sharpe at dsharpe@nrcan.gc.ca

Basin analysis and regional hydrogeology. Basin analysis involves the examination of geological attributes throughout a basin that then permits interpretations of the architecture, fill, formation, and evolution of a sedimentary basin. Understanding the geological history of a basin improves where data collection, synthesis and analysis occurs at local and regional scales. Basin analysis thus provides a foundation to develop an accurate basin model. The model can be used to improve the extrapolation of knowledge from data-rich to data-poor areas in order to predict the nature of the basin fill. The value of this approach has been thoroughly demonstrated in the exploration for and the assessment of energy and mineral resources. Broader application of basin analysis to problems of aquifer delineation and characterization could likely improve the ability to understand groundwater systems.

One element of the basin model, the stratigraphic framework, may be expressed, for example, in terms of rock type (lithostratigraphy), rock architecture (event-sequence stratigraphy), age (chronostratigraphy), or rock properties such as seismic velocity (seismic stratigraphy). This information may then be expressed in map form, an example of which is the traditional geological map. Depending on the goals of the study, a basin model may also be expressed in terms of fluid properties such as hydrochemistry and hydraulic fluxes.

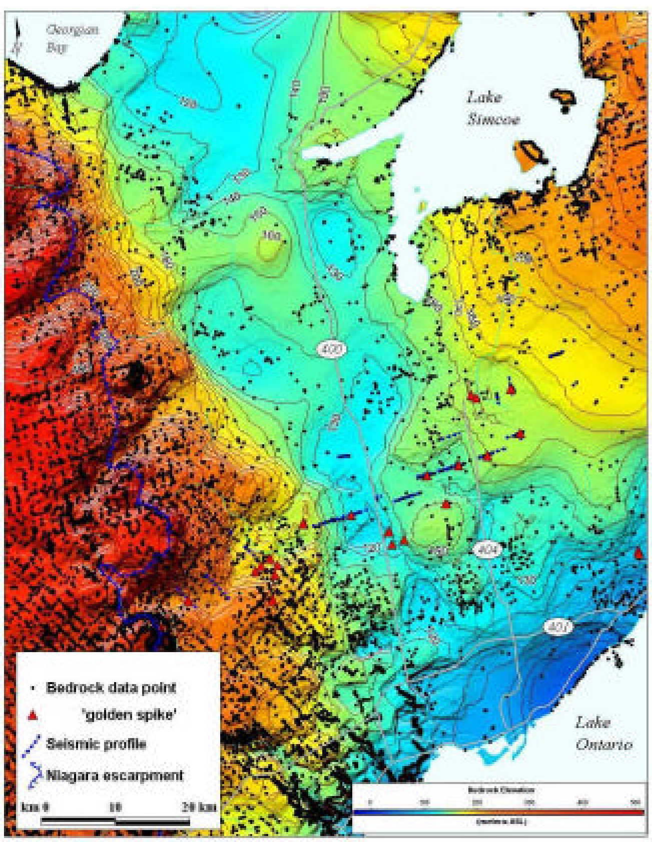


Figure 1. Topographic interpretation of the Laurentian valley based on available outcrop, borehole and reflection seismic data (modified from Logan et al., 2004). Note sparse data support in main valley trends. Surface interpolated using Inverse Distance Weighting (IDW).

Applying basin analysis to regional hydrogeology studies enhances the understanding of flow systems at local, regional, and basin scales. In larger basins, such as the Great Lakes basin, data support may be insufficient to adequately render a 3-D stratigraphic model of the basin or key elements of the basin architecture (buried valleys, Figure 1). One way to offset poor data suppport is to improve our knowledge and use of conceptual models, particularly process models that guide understanding of the geological history of a basin. For example, the rendering of both bedrock and sediment hosted buried valleys for regional groundwater modelling has demonstrated the benefit of integrating conceptual information. Integration of synthetic input may be used to define a more plausible valley architecture that then permits improved continuity of hydraulic fluxes in the flow system (e.g. Kassenaar this vol.). In this paper, we focus on a concepual framework for buried valleys in southern Ontario and the role of basin analysis in data collection, model development, and improving assessment of the regional hydrogeological significance.

Buried valley conceptual models. More than a 100 years after Spencer (~1890) inferred that a Tertiary Laurentian river network played a key formative role in shaping the Great Lakes basin, no clear idea of the geometry, extent, and the sedimentary fill in any buried valley in southern Ontario has been established. For example the Laurentian bedrock valley (Figure 1), connecting Georgian Bay to Lake Ontario, continues to be characterized from water well records with little new data contributing to systematic studies of its origin and architecture. The Laurentian valley is more than 25 km wide and 80 km long, >100 m deep, and covers an area of > 3500 km^2. A conservative estimate of the sediment fill volume is ~350 km^3. It is likely to play a key hydrogeological role in both regional and watershed-scale flow systems.

A variety of mechanisms and hypotheses for the formation and fill of bedrock valleys are suggested by recent studies in southern Ontario (e.g., Scheidegger, 1980). Erosional mechanisms likely acted in combination and were influenced by structural, lithologic, and topographic controls. Crustal geophysical data and lineament analysis suggest a relationship may occur between structural elements

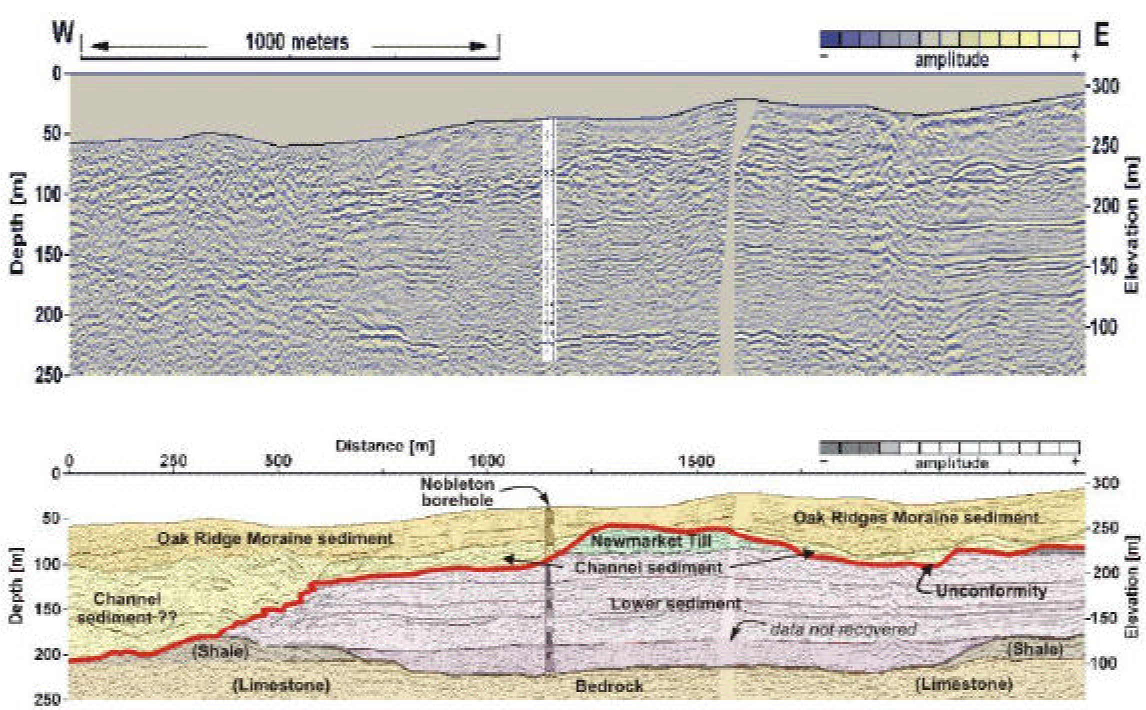
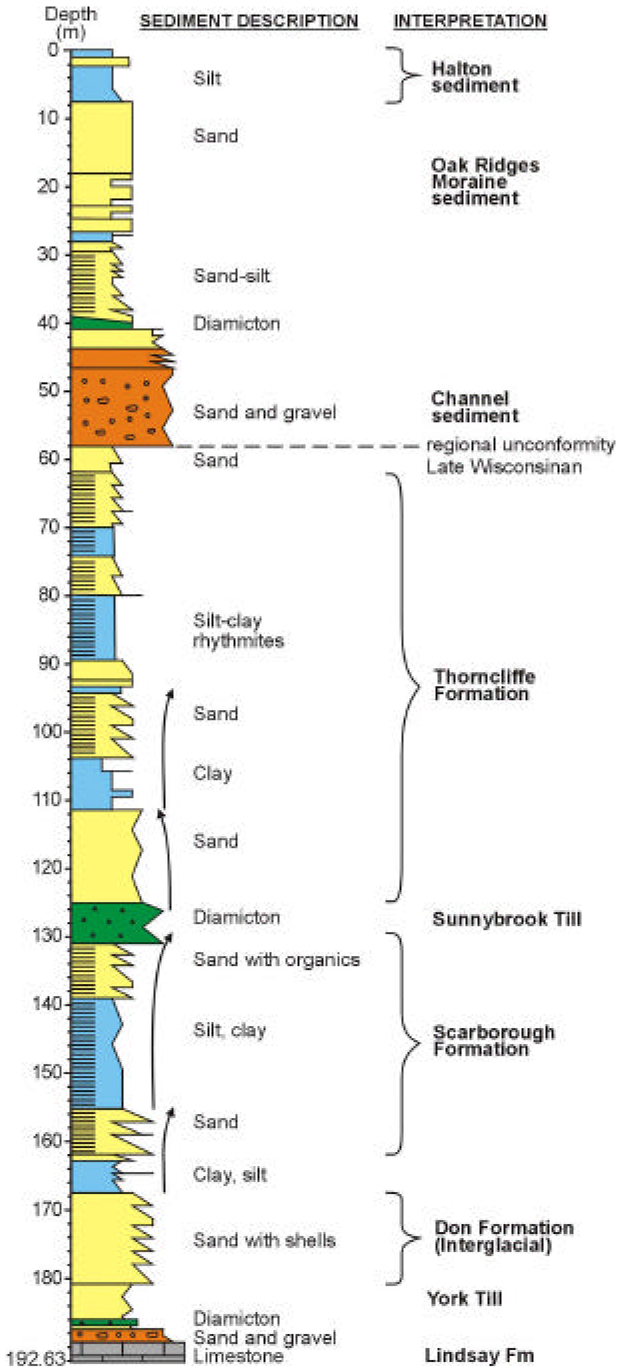


Figure 2. Seismic profile (A) and interpretation (B) in the Nobelton area of the buried Laurentian valley, indicating a bedrock-sediment unconformity where the bedrock valley cuts through shale to limestone bedrock (modified from Pugin et al., 1999). Unconsolidated sediment hosts a series of nested valley scales that locally truncate the horizontal seismic reflectors and erodes to bedrock. Note position of the seismic velocity profile (A) and sediment log (B; Figure 3).

(e.g., fractures) and the location of buried valleys (e.g., Eyles and Scheideger, 1995). Lithology and topography may also have affected the erosional action of pre-glacial, sub-aerial fluvial (e.g. Spencer, 1890), glacial (e.g,. Straw, 1968), or subglacial fluvial systems (e.g., Kor and Cowell, 1998) with each process producing different valley morphologies and erosional forms (e.g., Gilbert and Shaw, 1994). Subsequent fill of eroded valleys may have occurred during multiple cycles of sedimentation, erosion, and re-sedimentation. Nested, sediment-hosted tunnel valleys of the current Laurentian valley document (Figure 2) this process of cyclic erosion and fill (Pugin et al., 1999).



It is apparent that valley origin, orientation, geometry, and fill characteristics have developed in response to a complex set of processes that require an integrated basin approach to advance understanding of their geological origin. Furthermore, improved conceptual models of buried valleys help guide enhanced strategies for the exploration, delineation, and characterization of buried-valley aquifers. However, the processes that formed such valleys and deposited their thick sedimentary fills are poorly known and few critical data have been gathered to test basin models with respect to the valley origin as an ancestral drainage system or other origins.

Figure 3. Continuously-cored ~192 m borehole along the Nobleton seismic line (Figure 2). The borehole shows ~70% of sediment fill in the buried Laurentian valley is interglacial (Don Fm) to middle Wisconsinan (Thorncliffe Fm) age (58-190 m depth). These units correspond to the horizontal seismic reflectors in Figure 2. This succession is truncated by a Late Wisconsinan unconformity that is overlain by a fining upward succession of gravel and sand that is interpreted to be subglacial flood deposits. Note that 1 km to the west (Figure 2), the Late Wisconsinan unconformity is incised to bedrock and the Laurentian valley fill is predominantly massive sand deposited by rapid sedimentation.

High-resolution reflection seismic, borehole, and core-logging data are necessary to develop conceptual models and analysis of the buried Laurentian valley (Figures 2 and 3). These data provide the first architectural information on portions of the Laurentian valley system, as well as insights into the complex history of the thick overlying sediment infill of the valley. For instance, depositional and erosional episodes have produced a complex sediment facies arrangement in nested bedrock and ediment-hosted valleys.

The nested stratigraphic architecture of buried valleys may significantly affect both horizontal and vertical aquifer connectivity and continuity. Furthermore, the complexities of compound valley fills (Figures 2 and 3) illustrate the need for integrated geological and hydrogeological studies that foster the collection and analysis of data to develop evolving conceptual models. These improved conceptual models should allow hydrogeologist to more confidently link model areas with sound control data to those that are poorly-constrained. Ideally, such realizations can quantitatively describe this extrapolation using the support of spatial geostatistics derived from sedimentological data and knowledge of the basin.

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