Quaternary Science Reviews 86 (2014) 13–23

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Architecture of buried valleys in glaciated Canadian Prairie regions based on high resolution geophysical data

André J.-M. Pugin [a,*], Greg. A. Oldenborger [a], Don I. Cummings [b], Hazen A.J. Russell [a], David R. Sharpe [a]

[a] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada
[b] Gatineau, Québec J9H 2M3, Canada

ARTICLE INFO

Article history:
Received 26 June 2013
Received in revised form
28 November 2013
Accepted 6 December 2013
Available online 19 January 2014

Keywords:
High resolution airborne electromagnetic
Seismic reflection
Buried valleys
Glacial valleys
Valleys morphology
Sedimentary architecture of valley

ABSTRACT

Airborne electromagnetic and high resolution seismic geophysical data provide insight into complex buried valley geometry and internal sedimentary architecture of buried valleys in the Canadian Prairies. Buried valleys with an extent in excess of 20,000 km beneath the Canadian prairie landscape have been previously interpolated using borehole data; however, they provide only limited insight into the geometry and spatial relationships of these valleys. The collected high-quality geophysical datasets, a three-dimensional airborne electromagnetic survey and high resolution seismic profile data provide much greater resolution of buried valley geometry and internal sedimentary architecture of buried valleys. Several generations of valleys at different scales are identified. We interpret multiple erosion surfaces bounding thick diamicton sequences that fill the largest valleys; the youngest valleys are filled with variable sediment types. Three valley morphologies are identified and process origins inferred: 1) regional-scale, extensive, subaerial and pre/interglacial named α-type valley, 2) regional-scale, narrow and mainly proglacial, β-type valley and 3) local-scale, apparently discontinuous, subglacial, γ-type valley. Within the glacial sediment stratigraphy filling α-type valleys are thick diamicton sequences bounded by erosional surfaces. The β-type and γ-type valleys are filled with variable sediment types. The proglacial β valleys erode bedrock and also occur within the α-type valley fill. Conversely, the γ subglacial valleys are observed to crosscut other valleys and may be shallow and wide, or deep and narrow. The reported geophysical datasets supported by borehole data are able to map buried valleys in three-dimensions and hence identify the morphologic and stratigraphic relationships that permit improved constraints on process and erosional origin and fill of buried valleys. Results provide insight into the relationship between valleys formed as part of Tertiary fluvial erosion, multiple glaciations, and glaciofluvial events. These data provide significant insights on the distribution and character of potential groundwater reservoirs in Prairie regions.

1. Introduction

The Canadian Prairie landscape has been shaped by two continental-scale events during the past 50 million years. First, Tertiary uplift of the Canadian Rockies caused strata in its foreland basin to become truncated by large drainage systems that shed sediment north-eastward from the continent to the Labrador Sea (Cummings et al., 2012). Second, over the Quaternary, continental glaciers traversed the Prairies and eroded and deposited a succession of sedimentary deposits up to 300 m thick (Cummings et al., 2012). Buried valleys are a product of these two continental events and have been mapped across the Canadian Prairies from the foothills to the eastern edge of the Western Canadian Sedimentary Basin (Fig. 1; e.g., Atkinson and Lyster, 2010a,b; Betcher et al., 2005; Maathuis et al., 2011). An improved understanding of buried valleys in the Prairies, and other glaciated terrains, can aid groundwater management for multiple potentially conflicting uses (e.g., potable, agriculture, resource extraction). To advance conceptual geological models requires collection and analysis of high quality multi-dimensional (2D and 3D) datasets capable of testing and refining interpretative models of the geometry and sedimentary heterogeneity of buried valley aquifers.

Knowledge of the paleo-prairie landscape is based largely on sparse outcrops and a regional borehole database compiled from water-well and some resource development drilling (oil and gas,

* Corresponding author. Tel.: +1 613 943 6513.
E-mail address: Andre.Pugin@NRCan.gc.ca (A.J.-M. Pugin).

0277-3791/$ – see front matter
http://dx.doi.org/10.1016/j.quascirev.2013.12.007

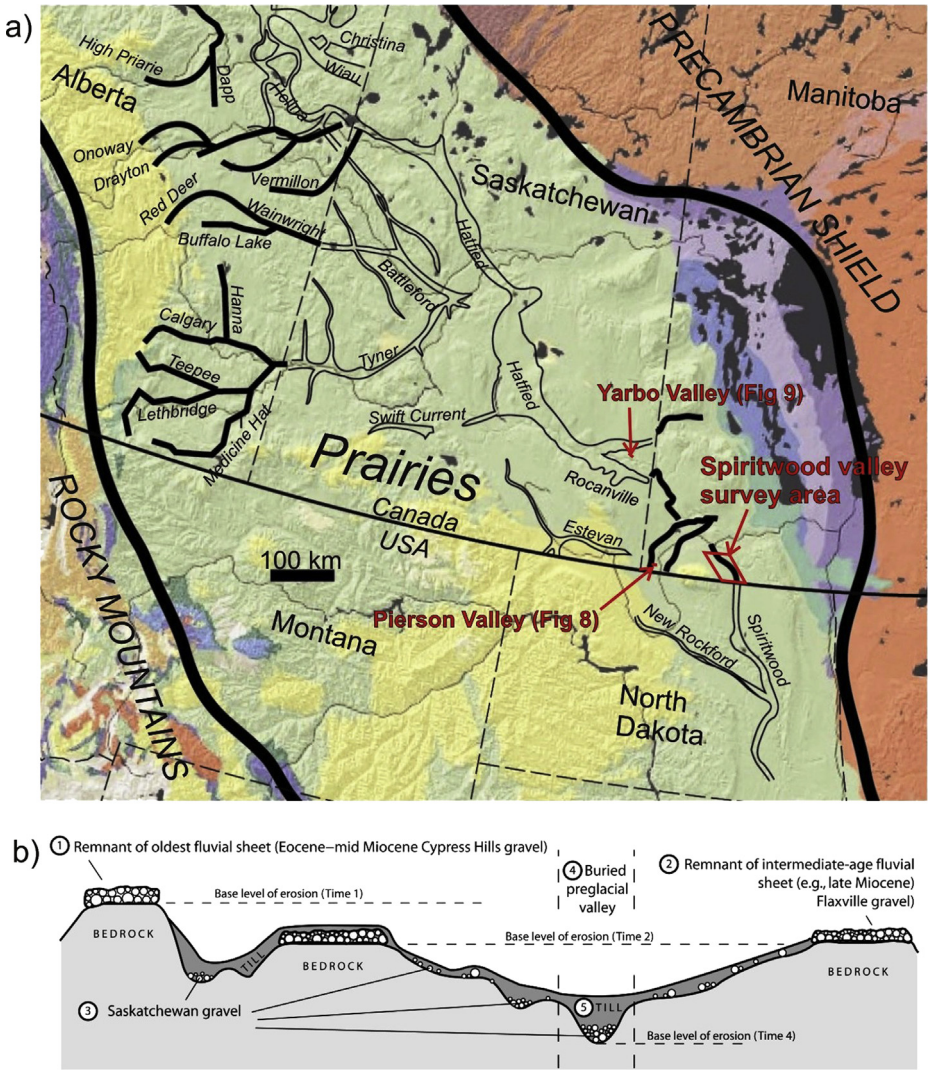

Fig. 1. a) Regional network of Canadian Prairie buried valleys superimposed on bedrock geology (modified from Cummings et al. (2012)). Dark lines are thalwegs, light lines define approximate valley extents. All valleys are mapped based on sparse borehole and outcrop data. b) Prairie cross-section carton illustrates the stratigraphic position, elevation, and relative age of Rocky Mountain-derived, quartzite-rich fluvial gravel deposited during Tertiary erosion of the Canadian Prairies. Overlying glacial sediment (dark grey) has a predominant eastern source with Canadian Shield Pre-Cambrian lithology. The Spiritwood and Hatfield buried valleys are represented as a topographically and stratigraphically low, preglacial valley (4); Modified from Cummings et al. (2012).

potash) (e.g., Cummings et al., 2012). Based on the analysis of boreholes and bedrock elevation surface digital elevation models (DEM) over 20,000 km of buried valleys have been identified beneath the Prairie landscape (Fig. 1). Borehole and outcrop datasets alone do not have the density, resolution and continuity required to map Prairie buried valley geometry, hierarchy, depth, and internal architecture given: 1) the range of scales of formative fluvial, glacial, and glaciofluvial events, 2) the potentially complex valley network geometries, 3) the longitudinal and cross-sectional variability, and 4) the lack of surface expression. The interpretation of the origin of Prairie buried valleys include a range of processes related to subaerial fluvial, glacial and glacial fluvial processes (Baker, 2001; Gibling, 2006). These conceptual models are first-order, regional in scale and related with general notions of pre-glacial, proglacial and subglacial origins. Integration of high-quality, high-resolution, continuous geophysical data can enhance the buried valley conceptual framework, add to knowledge on the origin of buried valleys, and provide characterization of individual aquifers (e.g., Gabriel et al., 2003; Ahmad et al., 2009; Jørgensen and Sandersen, 2009; Siemon et al., 2009; Hoyer et al., 2011; Jørgensen et al., 2012).

We present a characterization of parts of the Spiritwood, Pierson and Hatfield buried valleys in Manitoba and Saskatchewan based on interpretation of airborne electromagnetic and high-resolution seismic reflection data along with water well data. We interpret the data in terms of seismic stratigraphy and electromagnetic properties to define a morpho-stratigraphic structure of buried valleys with well-defined 3D geometry, valley continuity, complexity of valley hierarchy, and characteristics of valley fill. Integration of multiple, high-quality datasets reduces ambiguity of our interpretation. Sedimentary architecture and interpreted form-stratigraphic relationships are used to constrain interpretation of valley formation within the context of the continental-scale events of Tertiary fluvial erosion, and, glacial and glaciofluvial action.

2. Geological setting

Poorly consolidated Cretaceous shale and minor sandstone of the Western Canadian Sedimentary Basin (WCSB) form the main bedrock substrate of Prairie buried valleys (Maathuis and Thorleifson, 2000). WCSB strata dip gently southwest toward the