Understanding the Regional Hydrodynamics in the Normal and Sub-hydrostatic Regimes of the Canadian Rockies Foreland Basin, Alberta

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Summary

A regional-scale study of the groundwater flow dynamics is being undertaken in the Canadian Rockies foreland basin, comprising parts of Alberta, Saskatchewan and British Columbia. The groundwater flow is being analytically and numerically studied within post-Colorado group aquifers, composed of late Cretaceous to Recent sediments, attaining thickness of >2600 m. In addition to the tectonically influenced complex hydrostatigraphic architecture, the presence of sub-hydrostatic conditions at various depths within the study area complicates the nature of groundwater flow. Initial results suggest that the depth to the transition zone between hydrostatic to sub-hydrostatic regimes is laterally variable, being shallowest in southwestern parts of the study area. Groundwater generally flows towards the east-northeast in the normally pressured areas, however understanding of flow paths in areas with discernible sub-hydrostatic zones has yet to be developed.

Introduction

The foreland basin of the Canadian Rockies, encompassing major parts of Alberta and some parts of Saskatchewan and British Columbia, was developed during the late Mesozoic-early Cenozoic Laramide orogeny. Tectonic loading and flexure led to deposition of clastic wedges and terrane accretion at the edge of the North American plate (Cant and Stockmal, 1989), resulting in deposition of sediments of considerable thickness, increasing towards the west. Because of this substantial sediment thickness, tectonic complexities, and intricate geologic-geomorphic evolutionary history, the basin provides an unique setting for study of basin-scale fluid flow mechanisms. Several previous attempts have been made to understand the regional groundwater dynamics in parts of the basin (e.g. Hitchon, 1969a and b; Tóth, 1978; Bachu and Undershultz, 1995, Parks and Tóth, 1995, Michael and Bachu, 2001). Many of these studies recognized that in addition to the normal topography controlled conditions, a large part of the basin demonstrates sub-hydrostatic regimes with observed pressure of pore fluids being much lower than the theoretical pressure at a given depth (e.g. Pendergast, 1969; Tóth, 1978). The objective of the present study is to 1) decipher the patterns of regional groundwater flow within the sediments deposited in the basin since the late-Cretaceous, 2) delineate the regional extent of the sub-hydrostatic domain, and 3) understand the possible interactions between the flow fields within the normal and sub-hydrostatic pressure domains.

Study area and methods

The present study area encompasses about 10^6 km^2 of southern and central Alberta, parts of southwestern Saskatchewan and northeastern British Columbia. The western boundary of the area is marked by the Brazeau-Wapiti thrust belt of the Canadian Rockies deformation zone. It is bounded in the north and east by the sub-crop of the top of the thick Cretaceous-aged Colorado group aquitard, identified as the Lea Park Formation. The formation also forms the base of the study area, thus defining a contained system for the purpose of groundwater interaction across the boundary. The southern boundary was chosen along a line 20 km south of Oldman-South Saskatchewan river system (Figure 1a). The major surface water bodies within the area are the fluvial systems of Peace, Athabasca, North and Oldman-South Saskatchewan Rivers. The topographic elevation varies from >1700 m in the west to <600 m in the plains of Saskatchewan in the east, with geomorphology varying from rugged mountains in the west, piedmont deposits centrally, to alluvial plains in the east. The hydrostratigraphic units identified within the study area include the major lithostratigraphic units and their equivalents (Figure 1b). From surface to depth, the bedrock aquifers are the Paskapoo Formation, Scollard Formation, Horseshoe Canyon Formation, and Belly River Formation. The aquitards are the Battle-Whitemud Formation and the Bear Paw Formation. The surficial, unconsolidated sediments include the glacial tills, intra and inter-till sands and buried valley deposits, thus having variable hydraulic properties.

For purposes of analytic interpretation and numerical simulation, the hydrostratigraphic layers were mapped and discretized in a 3-D finite difference grid cumulatively using $>10^6$ data points (Figure 1a, b). Data for groundwater head (n = 70600) and drill-stem tests for liquids (n = 2435) have been obtained from existing water and hydrocarbon wells in the area, and were used for mapping pressure heads at regular depth intervals and in individual formations. These data are also used to delineate the 3-D extent of the top of the zone that marks the transition from normal to sub-hydrostatic pressure regimes. Surface water and hydrologic data have been obtained and used to calculate the effective recharge and surface water-groundwater interactions. Hydraulic properties have been estimated from aquifer tests and measurements done within the area during this study. The block-centric, finite difference groundwater code MODFLOW (McDonald and Harbaugh, 1988) is being used for numerical analyses.

Interim results and discussion

Estimation of potential recharge based on meteorological and stream flow data suggests that groundwater is recharged at a rate of five to seven times higher in the mountain front than in the central and eastern plains. Within normally pressured areas, the recharged water flows along topographically-driven local to medium-scale flow paths, discharging towards the northeast. Distinct sub-hydrostatic pressure domains exist in the south-central parts of the study area (Figure 1c), with stronger under-pressuring towards the southwest. The phenomenon is most conspicuous in areas south of Red Deer. Initial analyses suggest that transition from normal to sub-hydrostatic conditions can occur within 150 m depth in some areas close to Drumheller (east-northeast of Calgary), whereas in areas close to Edmonton such a transition has not been observed even within 700 m of ground surface. Topography doesn’t seem to be an influencing factor. The transition zone does not reside in any particular geologic formation, but rather exist from the shallowest (i.e. Paskapoo formation) to the deepest (i.e. Belly River formation) bed rock aquifer unit within the study area. The vertical gradient of hydraulic heads across this transition zone suggests strong downward flow. However, this is yet to be confirmed by detailed numerical analyses. Tomographic mapping of hydraulic heads also indicate that the sub-hydrostatic domains could have internal upward or downward flow paths which are disconnected from the larger-scale flow across the transition zone. Further study is being undertaken to conclusively delineate the nature and direction of flows and groundwater flux across the transition zone between the two pressure regimes.

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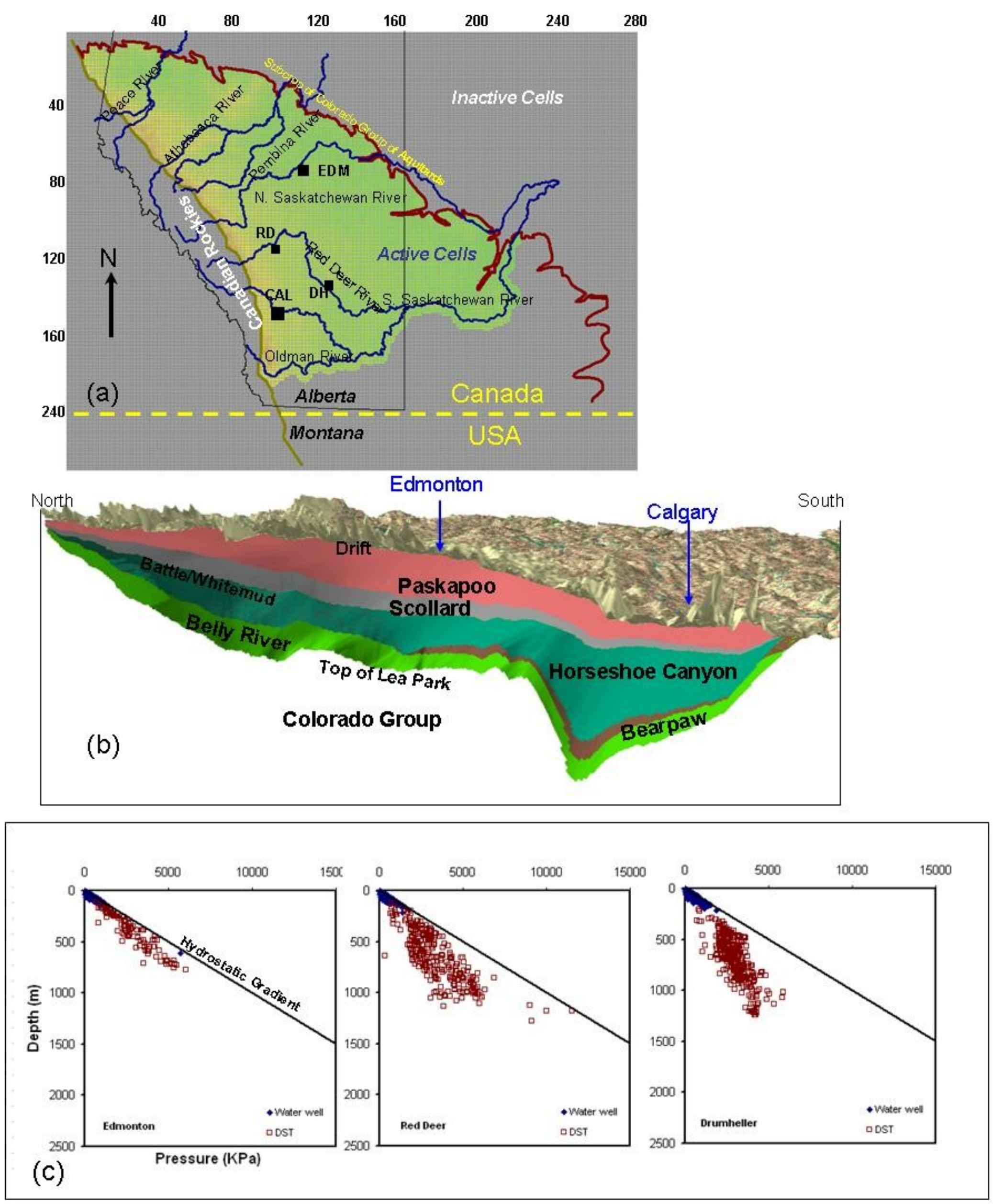

Figure 1a: A map view of the study area showing the numerical grids and major boundary conditions (EDM: Edmonton, RD: Red Deer, CAL: Calgary, DH: Drumheller); 1b: a 3-D view (looking from southwest, vertical exaggeration 300×) showing the hydrostratigraphic architecture used in the study; 1c) Pressure-depth plots of measurements obtained from water wells and drill-stem tests (DST) in and around Edmonton, Red Deer, and Drumheller