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GS-30 Quaternary mapping progress in southern Manitoba Phanerozoic terrane: 2-D and 3-D

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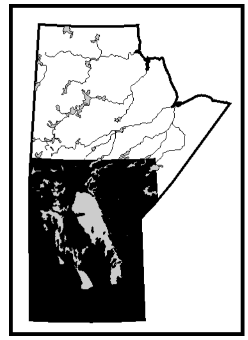

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Summary

Quaternary mapping has progressed on two fronts. Firstly, progress was made on a digital seamless compilation of 1:250 000-scale surficial geology for all of Manitoba from published paper and digital maps, and secondly, three-dimensional mapping of the southern Phanerozoic terrane of Manitoba which uses the surficial geology as a key input.

The digital seamless surficial geology compilation is set to be the long overdue replacement for the original *Surficial Geology Map of Manitoba* (Nielsen et al., 1981). To achieve this goal all the most current and most detailed paper maps required for the 1:250 000-scale compilation have been digitized. Edge matching and polygon conflicts are being resolved with the aid of a digital elevation model (DEM) derived from the recently released shuttle radar topography mission (SRTM) data (United States Geological Survey, 2002). Original mapping of several previously unmapped areas was also carried out with the aid of the SRTM DEM and limited ground truthing.

Progress has also been made in 3-D mapping. Three-dimensional geological mapping of the Phanerozoic succession in southern Manitoba, south of 55°N and west of 95°W, is being completed as a successor activity to the Prairie component of the National Geoscience Mapping Program (NATMAP). Modelling is being done in manageably sized tiles; the Lake Winnipeg basin is nearing completion, and in combination with the already completed southern Prairie NATMAP area of southeastern Manitoba, will enhance our understanding of the eastern edge of Phanerozoic rocks. Inputs to the 3-D model, in addition to surficial geological maps, are large lake bathymetry based on 31,607 soundings from 22 hydrographic charts, offshore geology of Lake Winnipeg interpreted from geophysical and coring data collected from a Coast Guard ship, Quaternary stratigraphy which is defined by cored holes logged by geologists and geophysical surveys, and then extrapolated laterally using water-well data, and several drillhole databases which contain Phanerozoic bedrock strata data. The 3-D mapping is taking advantage of current developments in computer technology and is designed to support activity related to land-use planning and, hydrocarbon, groundwater and industrial mineral development.

Introduction

The NATMAP of the 1990s was established as a collaborative effort between Canada's federal and provincial governments, industry and academic geoscience community to promote multidisciplinary, cooperative, geological mapping. Under the Prairie NATMAP project, new surficial geological mapping and Quaternary stratigraphic investigations were carried out in the Virden area of southwestern Manitoba and southeastern Saskatchewan (Blais-Stevens et al., 1999; Schreiner and Millard, 1995), as well as in the Winnipeg region of southeastern Manitoba. The Winnipeg project began in the early 1990s with mapping of an area south of 50°N and east of 97°W, equivalent in extent to one NTS 1:250 000 map sheet. Four preliminary surficial geology maps were produced for this area at a scale of 1:100 000. In the late 1990s, the Winnipeg study area was expanded to encompass the area south of 51°N and east of 98°W, the 200 km wide area south of Hecla Island and east of Portage la Prairie. The expanded study area was mapped as 12 surficial geology maps at a scale of 1:100 000, including the four maps from the first phase. These maps are in the final stages of production.

The main objective of the Winnipeg-area NATMAP was to generate new computer-based geological maps in order to better understand the geological features of the area. The mapping was designed to facilitate mineral exploration, support construction and other engineering activity, support groundwater management, provide a better understanding of Lake Winnipeg shoreline erosion, as well as support environmental and land-use management.

Following completion of the Winnipeg-area NATMAP, a project to develop a 3-D stratigraphic model for the entire Phanerozoic terrane of southern Manitoba was launched (Matile et al., 2000, 2001). This study area encompasses most of the area south of 55°N and east of 102°W, a region over 400 km west to east and 600 km north to south. The

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project is designed to incorporate and expand on the data infrastructure developed within the Winnipeg-area NATMAP.

This paper is a review of the methodology and an update on the progress of 1) the 3-D geological model of the southern Manitoba Phanerozoic terrane and 2) the digital surficial geology 1:250 000 compilation for the entire province. The surficial digital 1:250 000 compilation will be discussed as a 3-D model input. For more information on 3-D modelling methodology see Matile et al. (2002). Progress is being benchmarked with that of other Canadian, American and European geological survey organizations through international workshops co-sponsored by the Illinois State Geological Survey. These workshops took place in Bloomington in 2001 and in Denver in October 2002. This work is also being presented at the Geological Society of America workshop in Seattle in November 2003. Key activities during 2002–2003 have been the compilation of surficial map data, 3-D modelling of the Lake Winnipeg basin and collaboration with the Virtual Reality laboratories in Sudbury and Winnipeg.

Inputs to the 3-D model

Assembly of the data and partially processed portions of the model that will be required for the southern Manitoba Phanerozoic model is nearing completion. These inputs include the following:

Topography

Until March of this year, a 100 m grid cell digital elevation model (DEM) was being used as a datum for all data input to the model, including the vertical positioning of drillholes and the upper surface of the model. It has also been used for landform analysis and has drawn attention to previously unrecognized geological features. This DEM was compiled from rectification data for provincial digital orthophotography, federal 1:50 000 and 1:250 000 topographic maps, and DEM data from neighbouring jurisdictions and was updated yearly as new orthophoto data became available (*see* http://www.gov.mb.ca/itm/mrd/geo/demsm/introduction.html). In March, SRTM data was acquired to replace the provincial DEM. The SRTM DEM has a 90 m cell size and, unlike the provincial DEM, is without tile faults and covers the entire province.

Bathymetry

To incorporate large lakes, including Lake Winnipeg, Lake Manitoba, Lake Winnipegosis, Playgreen Lake and Lake of the Woods in the 3-D model, 31,607 soundings on 22 Canadian Hydrographic Survey (CHS) charts were digitized and their locations were corrected relative to shorelines as depicted on NTS 1:250 000 topographic maps. The data were modelled at 100 m resolution after adjustment of the soundings from the varying CHS low-water datum to a consistent value for long-term mean lake level, and following addition of shorelines and shoals to the database.

Offshore geology

During two cruises of the Canadian Coast Guard Ship *Namao* in 1994 and 1996 (Todd et al., 1998), low frequency and high frequency seismic data were acquired for over 1000 km of survey lines. The seismostratigraphy was interpreted for the Quaternary sediments and the Paleozoic bedrock was differentiated from the Precambrian on the basis of geometry and elevation. Where seismic velocities could be inferred, it was sometimes possible to distinguish till from Paleozoic bedrock. The offshore Quaternary and Paleozoic geology is now being modelled, guided by geology on land, bathymetry and seismic data digitized in the form of line-traces captured as profiles at intervals of five seconds of ship travel time.

Soil mapping

Digital soil maps produced by agricultural agencies provide information on the texture and composition of sediment in the uppermost 0.5 m of the Quaternary sequence. The digital soils data was made available by the Land Resource Group and covers most of agro-Manitoba (Agriculture and Agri-Food Canada, 2003). This data has been incorporated into the 1:250 000-scale seamless surficial geology compilation where surficial mapping polygons were unavailable.

Surficial geology

A digital version of the surficial geology of southern Manitoba is being compiled at a scale of 1:250 000. A large part of this task is the conversion of data from paper maps to digital vector coverage. Map legends have been standardized and map polygon boundary discrepancies are being corrected. With the acquisition of the SRTM data, these polygon discrepancies are being corrected with the aid of high-resolution shaded relief topography. In addition, the SRTM DEM made surficial mapping of several previously unmapped areas possible. These unmapped areas have limited road access and without the SRTM data, detailed mapping would have been time consuming and expensive. Map legends will define map units on the basis of factors such as texture, mineralogy, morphology and genesis of the sediments at depths between about 0.5 to 1.5 m and the digital maps will be queriable on these characteristics. These maps will guide the 3-D modelling by indicating where stratigraphic units visible in drillholes should be terminated at surface. Progress on the surficial map compilation is progressing south to north. Sixteen 1:250 000-scale surficial geology compilation maps are nearing completion. Geology polygons will be draped over the shaded relief SRTM DEM. These maps will cover the southern portion of Manitoba up to 53°N and will be available as digital files and hardcopy. These areas will also be compiled at a scale of 1:500 000 and eventually 1:1 000 000 to replace the original *Surficial Geological Map of Manitoba* (Nielsen et al., 1981).

Quaternary stratigraphy

The 3-D stratigraphic model of the Quaternary sediments in the Winnipeg pilot area was guided by NATMAP project coring (Thorleifson and Matile, 1993) and an existing lithostratigraphic model for the region which was based on previous research (Teller and Fenton, 1980). The stratigraphic correlations available in logged drillholes were extrapolated laterally with the aid of geophysical surveys, other miscellaneous drillhole data, topography and surficial geology mapping. A key source of data was the 80,000 site water-well database (GWDrill) of the Manitoba Conservation Water Branch. Much effort was required to parse the 75,000 unique lithological descriptions in this database into geologically meaningful terms suitable for database operations. Additionally, it was necessary to assign locations at quarter section or river lot centroids, as well as elevations from the DEM, to locate the water wells in the database. For the NATMAP pilot, the 200 by 230 km area was divided into 46 transects each 5 km wide, and a large colour cross-section chart was printed for each transect, showing all drillhole data, surficial geology and surface elevation. The drillhole data, colour-coded for lithology, were interpreted as a series of vertical maps using established techniques for lithostratigraphic correlation (e.g., Miall, 2000). Although the water-well data is variable in resolution and reliability, and rarely permitted the distinction of the units recognized at the stratigraphic reference sites, it did guide interpolation between already correlated units, and allowed the recognition of stark lithological breaks, such as large sand lenses. To facilitate groundwater modelling, for example, it was necessary to include in the model predictions for the sediments in areas of no data. The resulting west-east cross-sections were hand drawn as an overlay on the drillhole data, and the interpretation was captured as predicted stratigraphy points at 5 km intervals. The hand-drawn section approach, in which correlations were not linked to specific drillhole intersections, permitted the geologist to apply judgement by occasionally ignoring data based on suspect lithological descriptions or locations apparently in error. It is anticipated that the same methods will be used for the current study area, although plans are in place to experiment with an alternative approach in which the polygons drawn on the sections are digitized and linked to their lateral equivalents.

Bedrock surface

The bedrock surface is being interpreted on all transects and therefore a new bedrock elevation model will be produced as the new Quaternary model is compiled. As will be further discussed, one approach to incorporating information from previously published bedrock maps will require the new model for the bedrock surface to be completed prior to the modelling of the bedrock units.

Bedrock geology

Model construction to date has been guided by Manitoba Geological Survey 1:1 000 000 bedrock geology map polygons, following linkage and reconciliation of conflicting versions of the polygons depicting outcrop and subcrop. A major effort was required to produce stacked polygons, in which each stratum is not truncated at the limits of overlying strata. Conversion of the model to reliance on 1:250 000 polygons is currently being assessed, as is revision of this mapping based on the drillhole compilation completed for the project. This compilation includes all available drillhole data, including Manitoba Stratigraphic Database (MSD), Manitoba Oil and Gas Well Information System (MOGWIS), Geological Atlas of the Western Canada Sedimentary Basin database (WCSB), as well as newly digitized data previously stored on historical index cards.

Phanerozoic stratigraphy

Stratigraphic maps with structure contours and isopachs of the Phanerozoic strata were previously compiled by the Manitoba Geological Survey (Bezys and Conley, 1999). The digital versions of these stratigraphic maps were obtained and supplemented where necessary with information from the Geological Atlas of the Western Canada Sedimentary Basin (Mossop and Shetsen, 1994). A point dataset derived from the structural contours for each unit was gridded and trimmed to their extent as defined by the 1:1 000 000 mapping. The model has more units than were depicted in the Atlas, although less than are recognized in the Manitoba Stratigraphic Database, which includes many units that are only recognizable in limited areas. Modifications were required for pairs of previously modelled surfaces for which interpolations in data-poor areas were found to intersect. Whereas the current Phanerozoic model was derived directly from previously published stratigraphic maps, construction of a revised model is being contemplated, based on the drillhole compilation previously described. The water-well database also provides lithological data that can constrain the mapping. The drillhole data are now being plotted using methods similar to those previously described for the Quaternary. Traditionally, geological maps depict the extent of the uppermost stratum in the range of strata being mapped, while the legend, structural symbols and cross-sections convey superposition. Structural maps have shown the geometry of multiple strata by providing structure contours for the top of each stratum, which can be expressed as an isopach when one is subtracted from another. Structural charts typically have not, however, shown the elevation of the eroded edge of a stratum, the outcrop and subcrop, as this elevation is not relevant to interpreting the structural geology of the unit. This lack of elevation information for the eroded portion of a stratum is a limitation that requires correction before full 3-D modelling can proceed. An adequate definition of a stratum will require the extent of the uneroded portion, elevation of its top, extent of its edge and elevation of its edge (Fig. GS-30-1). The current version of the 3-D model is available on the web (http://www.gov.mb.ca/itm/mrd/geo/index.html). The site permits users to query the model through a cross-section–based interface (Fig. GS-30-2) and display the full extent of the corresponding stratigraphic unit in map view. Through the use of video files, users can see a rotating 3-D block diagram for the expanded Winnipeg-area NATMAP and see the geological model by the progressive removal of strata from the 3-D block model.

Sub-Phanerozoic Precambrian geology

A preliminary Precambrian geology map for all of southern Manitoba Phanerozoic terrane was prepared in order to complete the model down to the basement rocks. This map was compiled from aeromagnetic maps, compilation maps, Project Cormorant data and subsurface correlation of drilled Precambrian intervals.

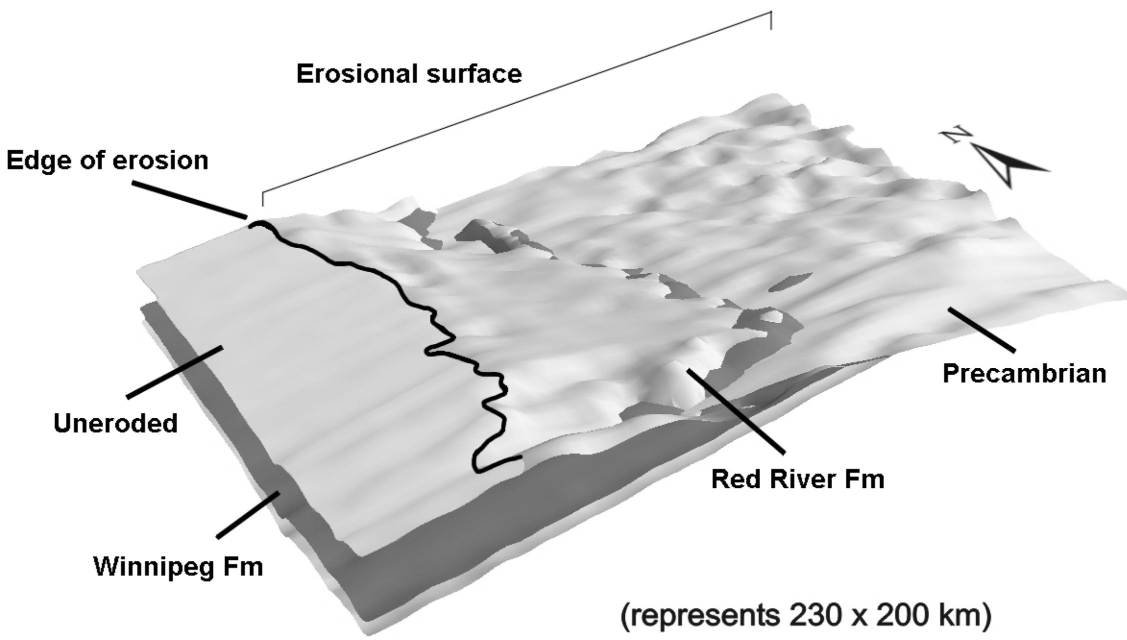

Figure GS-30-1: Each stratum is being defined by its full extent, the elevation of its uneroded top, as well as the extent and elevation of the edge that has been subject to erosion. The digital version also requires a surface defining the area of zero thickness that must coincide with the next lower surface that is present. In this example, the thickness of the Ordovician Winnipeg Formation in the area of exposed Precambrian is zero, so the top of Ordovician Winnipeg Formation must equal the top of Precambrian in this area.

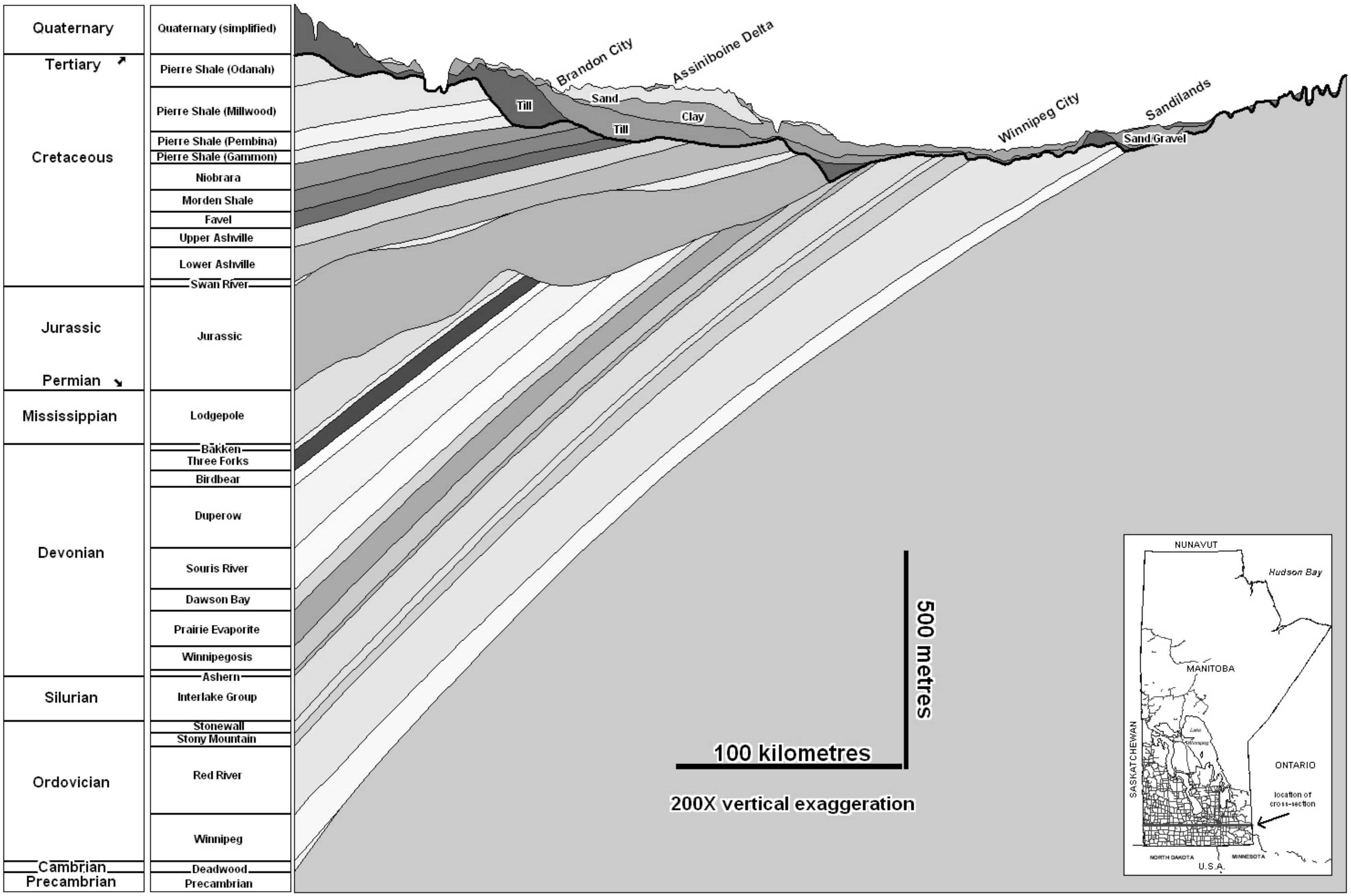

Figure GS-30-2: West-east provincial cross-section through Winnipeg and Brandon depicting modelled Phanerozoic stratigraphy. Quaternary units have been simplified due to the limits of the vertical exaggeration.

Workshops

Implementation of the 3-D program has required choices to be made regarding hardware, software and protocols for construction, verification and communication of the 3-D model. In order to share ideas and benefit from experience recently gained by other agencies, the authors have participated in regular meetings sponsored by the Central Great Lakes Geological Mapping Coalition. After presenting posters and learning from the experience of others at Coalition-sponsored sessions in Illinois (Matile et al., 1999) and Denver (Thorleifson et al., 1999), the authors collaborated with the Illinois State Geological Survey to co-sponsor two workshops on 3-D mapping and model development, one in Illinois in 2001 (Berg and Thorleifson, 2001) and the other in Denver in October 2002. Organization of and participation in the workshops have guided selection of options and has indicated that, although approaches differ, the work being done in southern Manitoba is at a stage of development at least similar to corresponding activity elsewhere in North America and Europe.

Economic considerations

Surficial and 3-D geological mapping is required for effective land-use planning, and hydrocarbon, groundwater and industrial mineral development. Datasets coming from this project have a significant impact on our ability to manage our resources. The SRTM DEM recently acquired provides the user with a detailed look at, for example, glacial ice-flow direction and, in areas of thin drift cover, rock structure, both invaluable to mineral exploration. Polygons from the 1:250 000-scale surficial geology compilation are already being used as a direct input to programs that assess groundwater vulnerability to surface and subsurface contaminants. A standardized methodology for evaluating soils, landscapes and geology (MESLG), which has been developed (Eilers and Buckley, 2002) by using standardized geological, hydrogeological and pedological characteristics to facilitate nutrient management planning in the prairie landscape, is one user of these polygons. This methodology is one of several programs supported by the Hog Environmental Management Strategy (HEMS), a federal-provincial initiative to protect groundwater resources from the potentially negative influences of livestock development. The MESLG involves a systematic approach to land-based decision making with standardized resource databases, digital map information, manure management research and farm practices guidelines. The procedure uses a geographic information system to integrate soil, landscape and surface and subsurface geological information to define environmental sensitivities and thus highlight management requirements for good stewardship of soil and water resources.

The value of 3-D geological mapping to groundwater research has already been proven. The 3-D model for the Winnipeg-area NATMAP has been used to model groundwater flow across the Winnipeg region and to assess climate-change scenarios with respect to impacts on groundwater systems (Kennedy, 2002). In addition, the value of the 3-D model has attracted participation in a $550,000 proposal to *Canada's Climate Change Impacts & Adaptation* program entitled 'Vulnerability of the Assiniboine Delta Aquifer (ADA) under Climate Change'. The ADA has been selected for this study because of its economic importance to Manitoba and the availability of the extensive data required to characterize the region. The ADA is centred on the community of Carberry, which has a large and expanding potato industry. This relatively new industry owes its existence to the sandy soils of the ADA, required for potato growth, and to the availability of abundant groundwater resources needed for irrigation and food processing. Of the groundwater-resource consumers, the potato industry is the largest and uses approximately half of the current aquifer allocation limit (Frost and Render, 2003). The estimated value of the potato crop in 1996 was $60 million, most of which came from exports (Manitoba Agriculture, 2003). Projections indicate that Manitoba may soon surpass Prince Edward Island as Canada's leader in potato production (Schroedter, 2003). As a result, much attention has been paid to supporting this resource and the value-added industries it has spawned.

Commitment to sound management of this resource has been shown by governments and stakeholders through the establishment of the ADA Round Table (Forbes, 2003), whose primary purpose is to develop an aquifer management plan that will present guidelines for managing, protecting and using the groundwater in the aquifer. This planning process will use local input on aquifer issues, assess future opportunities and apply Manitoba-based water policies. To date, however, no allowance has been made for climate-change impacts. This has been due primarily to the lack of information and tools necessary to incorporate these future changes. The above-mentioned research proposal will provide sound, climate-based adaptive strategies that will utilize 3-D geological modelling and be suited to the ADA Round Table process.

Future plans

A major issue for this project that is progressively being dealt with is the requirement to reconcile the model with corresponding activity in Saskatchewan, North Dakota, Minnesota and Ontario. Applications such as hydrocarbon and groundwater analyses in cross-border settings will fail if the respective models are not compatible. Achieving compatibility will require consultations, data sharing and compromise. To this end, a new Targeted Geoscientific Initiative II project, the Williston Basin Architecture and Hydrocarbon Potential Project, has been initiated with Saskatchewan Industry and Resources and the Geological Survey of Canada, which will resolve potential cross-border stratigraphic issues.

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