

Annual review by C.O. Böhm

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In 2013, the Manitoba Geological Survey completed new bedrock mapping at Oxford Lake as part of an ongoing effort to remap select greenstone belts in the northwestern Superior province¹, in conjunction with thematic studies. In the Pikwitonei domain, new bedrock mapping at Cauchon and Partridge Crop lakes focused on identifying the protoliths of granulite-grade gneissic rocks to facilitate comparisons with lower grade, potentially equivalent rocks in adjacent domains. Bedrock mapping in the Trans-Hudson orogen continued in the Snow Lake area alongside collaborative programs by the Geological Survey of Canada (GSC) and university partners. The Manitoba Geological Survey also undertook new work to better define the settings of various mineral commodities across the province: gold in the Rice Lake belt, rare metals in the northern Trans-Hudson orogen, and magmatic base metals and platinum-group elements in the Bird River belt.

Phanerozoic investigations in southwestern Manitoba focused on the upper Cretaceous sedimentary section and included radiometric dating of bentonite beds, evaluation of rare-earth–element potential and regional stratigraphic correlations. In the Hudson Bay Lowland, lithofacies of a Silurian formation with petroleum reservoir potential were analyzed in detail.

As part of an ongoing effort to support mineral exploration in heavily drift covered areas, Quaternary sediments within a large tract of land east and northeast of Southern Indian Lake were mapped and sampled in 2013. In addition, Quaternary mapping was started in the Gillam area in preparation for a larger program planned for next year.

Collaborative programming with the Geological Survey of Canada

In August 2013, the Government of Canada announced a seven-year renewal of the Geo-mapping for Energy and Minerals (GEM) program, the first phase of which ended in the spring of 2013. The GEM program is designed to provide geoscience information on Canada's northern regions, to facilitate informed investment decisions and to foster discovery and development of new energy and mineral resources. In Manitoba, the GEM-Minerals program was used to procure a GSC-funded airborne radiometric and magnetic survey in the Seal River region, and as support for surficial mapping and geochronology in conjunction with the Manitoba

Geological Survey's 2008–2012 Far North Geomapping Initiative. A second project, focused on the hydrocarbon potential of Phanerozoic strata of the Hudson Bay and Foxe basins, was funded under the GEM-Energy program. This project used a multifaceted approach to understand and characterize the hydrocarbon potential of lower Paleozoic marine strata in the Hudson Bay Lowland of Manitoba. Both the GEM-Minerals and the GEM-Energy projects in Manitoba have been highly successful; new collaborative opportunities in Manitoba under the GEM2 program are currently being discussed.

The Targeted Geoscience Initiative (TGI) is a federally funded program that is coplanned and jointly delivered with the provinces and territories, which contribute funding for activities within their jurisdictions under the program. The TGI-4, announced in early 2010, is the fourth such initiative since 2000 and focuses on deep exploration and exploration-methods development. Projects being conducted under the TGI-4 are currently in the third year of field study and include alteration and metallogenic studies of the Lalor volcanogenic massive-sulphide (VMS) deposit near Snow Lake; a three-dimensional seismic survey and ambient-noise imaging of the Lalor deposit; and studies of mafic–ultramafic intrusions and Ni-Cu-Cr-Pt-Pd mineralization in the Bird River belt.

Precambrian Geoscience Section

Superior province

In 2013, the Manitoba Geological Survey (MGS) completed bedrock mapping of Oxford Lake, which lies at the western end of the largest contiguous greenstone belt in the northwestern Superior province (Anderson et al., GS-1, this volume). The Oxford Lake–Knee Lake belt is central to understanding the stratigraphy, tectonic evolution and economic potential of a large and geologically diverse region that includes some of the most prospective yet underexplored greenstone belts in the Superior province. Based on the combined results from the 2012 and 2013 field seasons, the supracrustal succession at Oxford Lake is divided into four tectonostratigraphic assemblages and three major structural panels bounded by ductile shear zones. Results from this program will be used to further constrain the stratigraphic and structural context of known base- and precious-metal occurrences at Oxford Lake.

¹For the sake of consistency, the Manitoba Geological Survey has opted to make a universal change from capitalized to noncapitalized for the generic part of lithostructural feature names (formal stratigraphic and biostratigraphic nomenclature being the exceptions).

Bedrock mapping in the Archean Pikwitonei domain, situated at the northwestern margin of the Superior province, continued in 2013 with projects at Cauchon and Partridge Crop lakes (Couëslan, GS-2, -3, this volume). In both areas, variably retrogressed granulite-facies rocks were remapped with emphasis on interpretation of protoliths and further understanding the polyphase tectonothermal evolution. The new mapping at Cauchon Lake reveals the presence of significant volumes of supracrustal rocks, similar to recognizable sequences in adjacent lower grade domains. High-grade metamorphic terranes have traditionally been underexplored, due in part to the challenge of recognizing supracrustal rocks, which tend to hold the greatest economic potential. The fact that some world-class mineral deposits are hosted in granulite-facies rocks, together with evidence that high-grade metamorphism can be responsible for the localized concentration of metals to form economic mineral deposits, warrants a new assessment of the mineral potential of the Pikwitonei domain. The proximity of the Partridge Crop Lake area to the Thompson nickel belt, moreover, provides opportunity to evaluate effects and extent of the Paleoproterozoic overprint and to compare rocks common to both the Thompson nickel belt and the Pikwitonei domain.

In southeastern Manitoba, the eastern extension of the Rice Lake mine trend in the Rice Lake greenstone belt was mapped in detail in 2013 (Anderson, GS-4, this volume), taking advantage of clean bedrock exposures created by a 2011 forest fire in an area that had not been mapped by MGS in more than 60 years. Many of the exposures are volcanic, volcanoclastic, epiclastic and subvolcanic intrusive rocks corresponding to the Rainy Lake Road unit of the Gem assemblage. The stratigraphy, depositional setting and structural geology of these rocks suggest good potential for orogenic lode-gold and VMS deposits. Equivalent rocks to the west host several significant gold deposits, including the Rice Lake deposit at Bissett.

Whereas most gold deposits in the Rice Lake greenstone belt are hosted by layered gabbro sills, basalt flows or volcanoclastic rocks, a University of Waterloo Ph.D. study is focused on the stratigraphic and structural setting of auriferous quartz (-carbonate) veins hosted by brittle-ductile shear zones in granitoid rocks at the southeastern margin of the Ross River pluton (Zhou et al., GS-5, this volume). New results from detailed geological mapping in the second summer of fieldwork provide a better understanding of the stratigraphic and structural setting of gold deposits in the area of the Central Manitoba mine. In particular, detailed structural analysis of shear-hosted mineralized veins provides important new information to constrain exploration models and will help draw attention to intrusion-hosted, shear-related, vein-type gold mineralization in the Rice Lake belt.

Geological mapping along the northern arm of the

Bird River greenstone belt in southeastern Manitoba progressed into the Cat Lake–Euclid Lake area (Yang et al., GS-6, this volume). This area contains several Archean layered mafic–ultramafic intrusions, some of which are associated with and have been explored for magmatic Ni-Cu-PGE sulphide and chromite deposits, and are similar to the Mayville intrusion to the west-northwest. As part of the TGI-4 program, the geological architecture and apparent stratigraphy of the Euclid Lake intrusion, a historical chrome deposit, is being re-examined with recent drillhole and historical data (Bécu et al., GS-7, this volume). In addition to magmatic mineralization associated with mafic–ultramafic intrusions, a suite of tonalite-trondhjemite-granodiorite (TTG) intrusions in the northeastern Bird River greenstone belt show evidence of potential for Cu-(Au) porphyry and skarn mineralization, and rare-metal (Li, Cs, Nb, Ta) mineralization has been documented in a late peraluminous granitoid suite and associated pegmatites. New U-Pb ages and geochemical data for the main tectonic assemblages in the Cat Lake–Euclid Lake area will facilitate exploration for a variety of commodities by providing a new geological framework for the northeastern arm of the Bird River greenstone belt.

Trans-Hudson orogen

New geological mapping of the Reed Lake area in the Flin Flon belt was initiated in 2013 with 1:20 000 scale mapping in the Rail Lake–Sewell Lake area southwest of Snow Lake (Gagné, GS-8, this volume). Bimodal volcanic rocks in the study area belong to the Fourmile Island assemblage, which hosts five known VMS deposits (Rail, Dickstone, Fourmile Island, Reed Lake, Lon) and one orogenic gold deposit (North Star). The objective of the new geological investigations is a better understanding of the distribution and economic potential of arc-related volcanic rocks by documenting along-strike continuity of prospective stratigraphy and/or alteration assemblages away from the known deposits.

A program of lithostratigraphic and structural mapping was continued within the McLeod Road–Birch Lake thrust panel in the Snow Lake area as part of a Ph.D. study at Laurentian University (Rubingh et al., GS-9, this volume). The New Britannia mine (now ‘Snow Lake mine’) is a structurally controlled gold deposit hosted by mafic and felsic volcanic and volcanoclastic rocks in the hangingwall of the McLeod Road thrust. Combined surface mapping and drillcore logging have focused on documenting the volcanic stratigraphy, structural framework and deformation history of the thrust panel, to guide ongoing gold exploration.

Reconnaissance geological investigations of granitic pegmatite at Southern Indian Lake, Partridge Breast Lake and South Bay were conducted to evaluate the potential for rare-metal mineralization in the northern part of the Trans-Hudson orogen (Martins and Kremer,

GS-10, this volume). Of particular interest is an unusual style of polymetallic Be-Au-Zn-Bi mineralization hosted by pegmatite at Southern Indian Lake. Pegmatite at Partridge Breast Lake locally shows significant B-Nb-Ta mineralization (tourmaline and columbite), and a pegmatite field at South Bay is enriched in Li-Cs-Ta (beryl and columbite), suggesting exploration potential. In addition to the investigated pegmatites, mineral studies and whole-rock geochemistry on samples collected from the Thorsteinson Lake granite will be used to evaluate its potential for Nb-Y-F mineralization. Results of the ongoing rare-metal investigations contribute to an updated rare-metal inventory of Manitoba, initiated by MGS in 2011.

Sedimentary Geoscience Section

Phanerozoic stratigraphy and resources

The Cretaceous Gammon Ferruginous Member of the Pierre Shale has been intersected in thousands of oil wells in southwestern Manitoba and locally contains elevated concentrations of rare-earth elements (REE), as indicated by outcrop samples collected in 2012. Follow-up investigations in 2013 focused on comparisons of the Gammon Ferruginous Member to other Cretaceous shale horizons (Bamburak et al., GS-11, this volume). Preliminary geochemical results from new shale samples yielded significant total REE contents (>3000 ppm), of which about 30% is represented by the more economically attractive heavy REE. These values are higher than those reported for some active REE exploration projects. Ongoing investigations, including electron-microprobe analysis of apatite and zircon, which are presumably the major REE phases in the shale, will document the REE distribution and mineralogy of the Gammon Ferruginous Member, and assess the potential for a new type of REE deposit in Manitoba.

Radiometric dating of bentonite beds in southwestern Manitoba is being conducted to provide absolute time markers for Upper Cretaceous stratigraphy (Bamburak et al., GS-12, this volume). New U-Pb zircon ages of 81.5 ± 0.5 and 78.8 ± 1.0 Ma for bentonite beds sampled immediately above and below the Gammon Ferruginous Member provide a new, precise age bracket for this member. To corroborate and complement these new ages, sanidine or biotite in duplicate bentonite samples are planned to be dated by the $^{40}\text{Ar}/^{39}\text{Ar}$ method in collaboration with the Alberta Geological Survey. The combined age results for a number of bentonite beds will facilitate correlation of stratigraphic units and creation of a simplified, standardized stratigraphic nomenclature across the Western Canada Sedimentary Basin.

Gas-bearing mudstone units of the Upper Cretaceous Favel Formation in southwestern Manitoba represent a prospective shallow shale-gas resource for Manitoba.

One of the main goals of an ongoing collaborative Ph.D. study at the University of Calgary (Nicolas et al., GS-13, this volume) is to better characterize the Favel Formation in Manitoba by correlating subsurface information from drillcore and well-log data with surface exposures. In 2013, a number of key exposures of the Favel Formation were studied in detail and compared to a reference section in drillcore to determine the stratigraphic position of the outcrops. It was found that correlation is best achieved on the basis of lithology rather than thickness and the presence or absence of bentonite beds. Due to the lack of drillcore through the Cretaceous in Manitoba, correlations to drillcore sections from Saskatchewan are in progress to provide a more regional picture of the sedimentology of the Favel Formation. Outcomes of this study will aid in the evaluation of the economic potential of the Favel Formation as a gas resource. This project is partly funded by Centra Gas Manitoba Inc., a subsidiary of Manitoba Hydro, through the Shallow Unconventional Shale Gas Project.

The Devonian Duperow Formation in southwestern Manitoba is a thick carbonate section with good hydrocarbon potential. Although this formation is oil stained in Manitoba, there is no current oil production. However, it produces oil in Saskatchewan and North Dakota, and is stratigraphically equivalent to the prolific oil producer of the Leduc Formation in Alberta. Detailed lithostratigraphy has identified good reservoir-quality lithofacies and the occurrence of organic-rich mudstone beds within the formation, making it both a conventional and unconventional oil target. This formation is underexplored in Manitoba and is the focus of a M.Sc. project in the Department of Geological Sciences at the University of Manitoba, done in collaboration with the Manitoba Geological Survey.

As part of the GEM Hudson Bay and Foxe Basins Project, detailed lithofacies analysis of the Lower Silurian Attawapiskat Formation in the Hudson Bay Lowland of northeastern Manitoba was conducted as a collaborative B.Sc. (Honours) study at the University of Manitoba (Ramdoyal et al., GS-14, this volume). The GEM Hudson Bay and Foxe Basins Project completed its fifth and final year in spring 2013. The aim of this project is to understand the hydrocarbon potential, sedimentological framework and evolution of the Hudson Bay Basin, to help promote hydrocarbon exploration. The Attawapiskat Formation, due to its highly porous and reefal character, has been identified as the best conventional hydrocarbon-reservoir candidate in the Hudson Bay Lowland of Manitoba.

Quaternary

A thorough understanding of surficial geology is essential for mineral exploration and prospecting in drift-covered terrains, including much of Manitoba's northern regions. Here, geochemical and indicator-mineral analysis

of till, combined with data on the orientation, timing and nature of ice-flow phases, can provide tools to more accurately locate exploration targets.

In the summer of 2013, Quaternary geological mapping, including sampling of till and measurements of ice-flow indicators, focused on a 3330 km² tract of land east and northeast of Southern Indian Lake (Trommelen, GS-15, this volume). Previous Quaternary geology investigations of this large area have been inadequate in scale and detail, thereby necessitating new Quaternary studies to augment understanding of the glacial geology and geomorphology. Results from the 2013 field season and ongoing analytical studies will provide new and better constraints to drift exploration in a region with potential for a variety of commodity types, including diamonds, gold, base metals and pegmatite- and carbonatite-hosted rare-element deposits.

Also in 2013, reconnaissance Quaternary mapping and sampling were conducted in the Gillam area of northeastern Manitoba. Preliminary results from the new field investigations imply that the Quaternary landscape in the Gillam area is complex, with evidence for at least three different cycles of glacial deposition, as well as later inundation by both glacial Lake Agassiz and the Tyrrell Sea (Trommelen, GS-16, this volume). The complex paleogeology of the Gillam area warrants a larger field program, which is being planned for 2014.

Three-dimensional mapping

The MGS is continuing to work toward completion of a comprehensive three-dimensional (3-D) geological model of the Phanerozoic succession in southern Manitoba. One key output from this work is a series of 2-D cross-sections based on data compiled over a decade, with inputs that include Manitoba's water-well, oil-well and stratigraphic-drillhole databases, large-lake bathymetric data, the Lake Winnipeg seismic survey, and surface datasets such as the provincial surficial-geology compilation-map series. A total of 134 such cross-sections, each representing a 5 km wide east-west transect across the province, between latitudes 49°N and 55°N, were released as a digital set of downloadable 'vertical maps' on the new GIS Map Gallery; these cross-sections form the basis of Manitoba's 3-D geological model. The sections have been imported into 3-D software and modelling of the lower stratigraphic units is in progress. Manitoba's 3-D geological model and cross-sections unite disparate datasets into a single standardized nomenclature and represent a significant contribution to a variety of geoscience knowledge bases relevant to Phanerozoic stratigraphy, hydrocarbon, groundwater and industrial-mineral resource development, and geological education.

Community liaison

The MGS liaison program (Murphy, GS-17, this

volume) is designed to provide mineral information to First Nations communities. In the summer of 2013, in partnership with the Cree communities of Norway House, Gods Lake Narrows and Oxford House, participant groups were provided with basic information on the requirements needed to attain jobs, build careers or develop economic opportunities in the mineral-resource sector. In addition, educators, land-use role models and Elders worked with the MGS to reconnect Indigenous youth participants with their communities' industrious history. Community liaison through the MGS aims to encourage a respectful, balanced, communicative approach that bridges the perspectives of Manitoba's First Nations communities, government and the mineral-resource sector.

Compilation and partnerships

The MGS is engaged in many partnered initiatives, including contributions from the federal government, the mineral and energy industry, several Canadian universities and Red River College. These partnerships provide the MGS access to expertise and technologies that enhance our ability to provide a state-of-the-art geoscience database for Manitoba. In addition, they facilitate the training of future geoscience professionals, which in 2012–2013 included three Ph.D. candidates, one M.Sc. candidate, three B.Sc. (Honours) thesis projects and one college Advanced Diploma.

Geoscience Information Services Section

The Geoscience Information Services Section of the MGS is responsible for maintenance and expansion of the geological component of the Internet-based GIS Map Gallery, Mineral Deposit Database and Geochronology Database, and for supplying the organization with cartographic, GIS, CAD and database-management services.

Staff in this section have initiated a new compilation of the sub-Phanerozoic Precambrian geology south of the Flin Flon–Snow Lake belt, in an area that extends south from the exposed Precambrian shield to latitude 54°N and east from approximately longitude 101°W to the extension of the Thompson nickel belt (approximately 7000 km²). All nonconfidential data from 603 assessment files and approximately 1700 diamond–drill holes are being compiled into databases. Importantly, the database will also include whole-rock geochemical data acquired by industry and the MGS from exploration drillholes. Nonconfidential high-resolution geophysical surveys from industry and the Geological Survey of Canada will provide the base for the compilation map.

The geological component of the GIS Map Gallery continues to expand with the addition of new theme layers for surficial geology, including surficial point features (>25 000), surficial line features (>68 000) and 111 major moraines. Currently the data cover the

area north of 54°N. The GIS Map Gallery now includes 255 geophysical surveys available for download, with improved content for many of the downloadable survey files.

Geological compilation at provincial scales of 1:250 000 and 1:1 000 000 is ongoing and will be incorporated into a revised Geological Highway Map of Manitoba.

Client Services and Outreach

GAC-MAC Winnipeg 2013

The Joint Annual Meeting of the Geological Association of Canada and the Mineralogical Association of Canada (GAC-MAC), Canada's premier geoscience conference, was held in Winnipeg from May 22 to 24, 2013. The Manitoba Geological Survey played a significant role in organizing this event, in conjunction with the University of Manitoba, University of Winnipeg and the Manitoba Museum. Survey staff chaired the Technical Program, Field Trips and Transportation subcommittees of the local organizing committee, which entailed a significant commitment during the past three years. The diverse technical program offered four symposia and 30 special and general sessions spanning the gamut of Earth-science research and teaching in Canada and internationally. The well-attended field trips covered many aspects of Manitoba geology, including gold deposits in the Rice Lake mine trend, VMS and gold deposits at Snow Lake, magmatic Ni-Cu-PGE and chromite deposits in the Bird River belt, VMS deposits in the Flin Flon camp, the Ordovician–Silurian boundary interval in the Williston Basin, and the geology of the Manitoba Legislative Building. More than half of the field trips were organized by MGS technical staff and thus required a major commitment of MGS resources in the five months leading up to the conference. Eight of the resulting field-trip guidebooks are available for free download from the Mineral Resources Division website. By all accounts, GAC-MAC Winnipeg 2013 was a very successful meeting, and brought more than 740 national and international geoscientists together “at the centre of the continent”.

Publications

A complete list of Manitoba Geological Survey publications, including reports, maps and data released since the last *Report of Activities* (November 2012), is contained in the back of this volume.

The MGS continues to release the majority of its publications in hard copy (print and/or CD-ROM or DVD) for purchase through Publication Sales, as well as electronic format for free download from the Mineral Resources Division website.

Outreach

Approximately 250 Winnipeg and area Grades 4 to 7 students participated in the 2012 Manitoba Mining and Minerals Convention, held November 15–17 at the Winnipeg Convention Centre, as part of the MGS ‘Manitoba Rocks!’ school-tours program. Activities involved gold-panning and information displays, and included the participation of the Mineral Society of Manitoba, the Canadian Fossil Discovery Centre and the Manitoba Prospectors and Developers Association. A gold-panning activity was also held at Children's Hospital. Teachers received Manitoba Rocks! ‘back-pack’ information kits, with a variety of posters and geoscience materials.

The Manitoba Innovation, Energy and Mines Bursary in Geology, a \$3000 Brandon University scholarship given annually to a full-time Geology student with financial need, was awarded in November 2012 as part of the Survey's outreach support.

Mineral-education activities in the spring of 2013 included outreach to 2000 Grades 4 to 12 students during two northern career-day events in Norway House and Thompson. Outreach co-ordinator S. Michaels and MGS community-liaison geologist L. Murphy provided in-class presentations and distributed geoscience information. Teacher's kits included geoscience career information from the Mining Industry Human Resources Council, Mining Matters posters from the Prospectors and Developers Association of Canada, and the first publication in a new *Geological History of Manitoba* poster series (‘Cold Manitoba – the Quaternary’), produced by the MGS in a bilingual English and French format.

The Manitoba Innovation, Energy and Mines Award (now Manitoba Mineral Resources Award) was presented to Jordan B., a Grade 5 student from École Bannatyne in the St. James–Assiniboia School Division, at the Manitoba Schools Science Symposium in April 2013. Other outreach activities included a tour of the Midland facility by the Mineral Society of Manitoba to coincide with Earth Day; participation in the annual international Aboriginal Vision Quest Conference; and four days of information-sharing about Manitoba's rich mineral potential during the annual national CANDO (Council for the Advancement of Native Development Officers) trade show and conference, which took place at the end of October in Winnipeg.

In October 2013, the MGS launched a new and exciting geoscience website (www.ManitobaRocks.info) to encourage young Manitobans to explore and learn more about the province's second-largest primary-resource industry—minerals and petroleum. Schools across Manitoba were introduced to Kids Rock!—a children's Fun Zone with memory and word games, puzzles, colouring and activity books, and geomysteries—and to Teens Rock!—a more in-depth look at the history

of mining and exploration in Manitoba directed toward teenage students.

On the ManitobaRocks website, students can learn about the rock cycle; examine a geological time chart; explore facts and legends on topics ranging from nickels and arrowheads to gold, space rocks and fossils; and gain knowledge of the Aboriginal perspective on Mother Earth and Turtle Island. Teens can also take a video-guided geotour around the province; visit the Legends of Rock section to learn about some of the early explorers, geologists and prospectors whose spirit of adventure led to exciting mineral discoveries in Manitoba; and explore Opportunity Rocks, a web section devoted to information on mining-related careers. The website offers a dynamic online learning tool for anyone interested in exploring or expanding their knowledge of Manitoba's diverse geological history and the importance of minerals and petroleum in everyday life.

The Geolocalities/Roadside Geology of Manitoba project is a series of YouTube™ videos that was created to aid in education about the geology of Manitoba by MGS geologist J. Bamburak and videographer M. Pacey. These videos provide the public and budding geoscientists with a quick geology lesson on select rock outcrops in southern Manitoba, as well as information on the industrial and common uses of these rocks; all sites are accessible by road or trail. These videos also serve as an archive to

capture the extensive scientific and historical knowledge held by the MGS staff. The Manitoba Virtual GeoTours can be accessed at <http://www.youtube.com/playlist?list=PL56BA2DBA79F307CD>.

Throughout the year, MGS geologists are asked to give informal presentations in elementary and middle schools to students in Grades 4 to 7 on the geological profession, and on rocks and minerals and their importance and occurrence in everyday life.

Acknowledgments

Six long-serving staff of the Manitoba Geological Survey have retired since November 2012 (listed in order of retirement): Ric Syme (Director), Monique Lavergne (Manager, Client Services), Elaine Hunter (Library/Publications Clerk), Lynne Bobier (Accounts Clerk), Cathy McGregor (Geologist) and Bob Sales (Promotions Co-ordinator). All of them made significant contributions to the MGS—their knowledge and experience will be missed.

The careful work of MGS geologists, lab technicians, expeditors, students, cartographers, publication staff and administration went into the production of the *Report of Activities 2013*. Bob Davie and his team from RnD Technical carefully performed technical editing and Craig Steffano completed the final layout for publication.