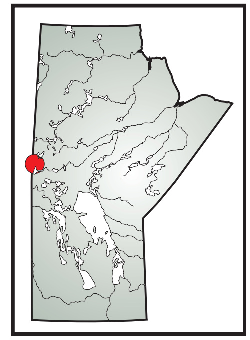
GS-1 Highlights of the new 1:10 000 scale geology map of the Flin Flon area, Manitoba and Saskatchewan (part of NTS 63K12, 13)[1]

by R-L. Simard and K. MacLachlan



Simard, R-L. and MacLachlan, K. 2009: Highlights of the new 1:10 000 scale geology map of the Flin Flon area, Manitoba and Saskatchewan (part of NTS 63K12, 13); *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 6–14.

Summary

A five year collaboration between the Manitoba Geological Survey, the Saskatchewan Geological Survey, the Geological Survey of Canada, researchers from Laurentian University, and Hudson Bay Exploration and Development Company Limited has led to the production of a new 1:10 000 scale bedrock geological map for the Flin Flon mining camp. A coherent lithostratigraphic and structural framework now spans the provincial border and has resulted in recognition of the volcanogenic massive sulphide–hosting stratigraphy in areas well outside the immediate mine surroundings. An improved understanding of the importance of subsidence structures and associated high-temperature hydrothermal alteration in the generation of the volcanogenic massive sulphide (VMS) deposits has led to recognition of exploration potential in the hangingwall in both Saskatchewan and Manitoba. Both early thrust faulting that predates deposition of the Missi Group and late thrust faulting that imbricates the Missi Group with the older volcanic rocks have been recognized. The critical role of thrust faulting at various scales in the overall architecture of the camp has been revealed by the integration of surface map data into a 3-D (three-dimensional) model constrained by drillholes and 3-D seismic surveys. Based on new U-Pb geochronology, the VMS-hosting volcanic rocks of the Flin Flon Block are ca. 1.89 Ga, as are rocks in the western Hook Lake Block. Volcanic rocks in the eastern Hook Lake Block, however, are about 10 Ma younger.

Introduction

The Flin Flon area of the Paleoproterozoic Flin Flon Belt is world-renowned for its volcanogenic massive sulphide (VMS) deposits (Figure GS-1-1). Three active (Callinan, 777 and Trout Lake) and three past-producing (Flin Flon, Mandy and Schist Lake) VMS mines occur in the immediate vicinity of the town of Flin Flon, which makes this area one of the most productive base-metal regions in Canada.

The Flin Flon area has been mapped at various scales by geologists of several organizations during the last 70 years. Despite the fact that each of these mapping efforts was successful in increasing our understanding of this prolific base-metal area, the need for a new, comprehensive, crossborder, state-of-the-art, detailed lithostratigraphic bedrock map of the area to support exploration for VMS deposits still existed in the early 2000s.

In November 2009, the Manitoba Geological Survey and the Saskatchewan Geological Survey announced the release of a new 1:10 000 scale crossborder geological map of the Flin Flon area (Figure GS-1-2). This major collaboration between the Manitoba Geological Survey, the Saskatchewan Geological Survey, the Geological Survey of Canada, researchers from Laurentian University, and Hudson Bay Exploration and Development Company Limited was initiated in 2005 under the Government of Canada Targeted Geoscience Initiative (TGI-3) with the intent of stimulating private-sector resource exploration in areas of high base-metal potential in established mining communities.

This report is intended to highlight the breakthroughs accomplished during the last five years, leading to the production of this new map. Detailed accompanying notes for this map are planned for release in 2010 (R-L. Simard et al., work in progress, 2009), along with a DVD that will include a digital version of the map, a geochemistry and geochronology database for the area, extensive references and a photo atlas of rocks of the Flin Flon area.

Summary of previous work

Conditions for bedrock mapping in the Flin Flon area are exceptional in many respects. Exposure is commonly 40–80%, the outcrops are lichen-free and the regional metamorphic grade is lower-greenschist facies (epidote-chlorite; Bailes and Syme, 1989), allowing for good preservation of primary textures and structures. These exquisite conditions have attracted repeated mapping efforts in the area over time.

The following section summarizes the most recent contributions to the volcanology and structure of the Flin Flon area by participants in the TGI-3 project. For more details on previous work, please refer to Bailes and Syme (1989) and Thomas (1989). An extensive list of previous work will be included in an upcoming geological report on the geology of the Flin Flon area (R-L. Simard et al., work in progress, 2009).

[1] Also to be published in Summary of Investigations 2009, Volume 2, Saskatchewan Geological Survey, Saskatchewan Energy and Resources, Miscellaneous Report 2009-4.2.

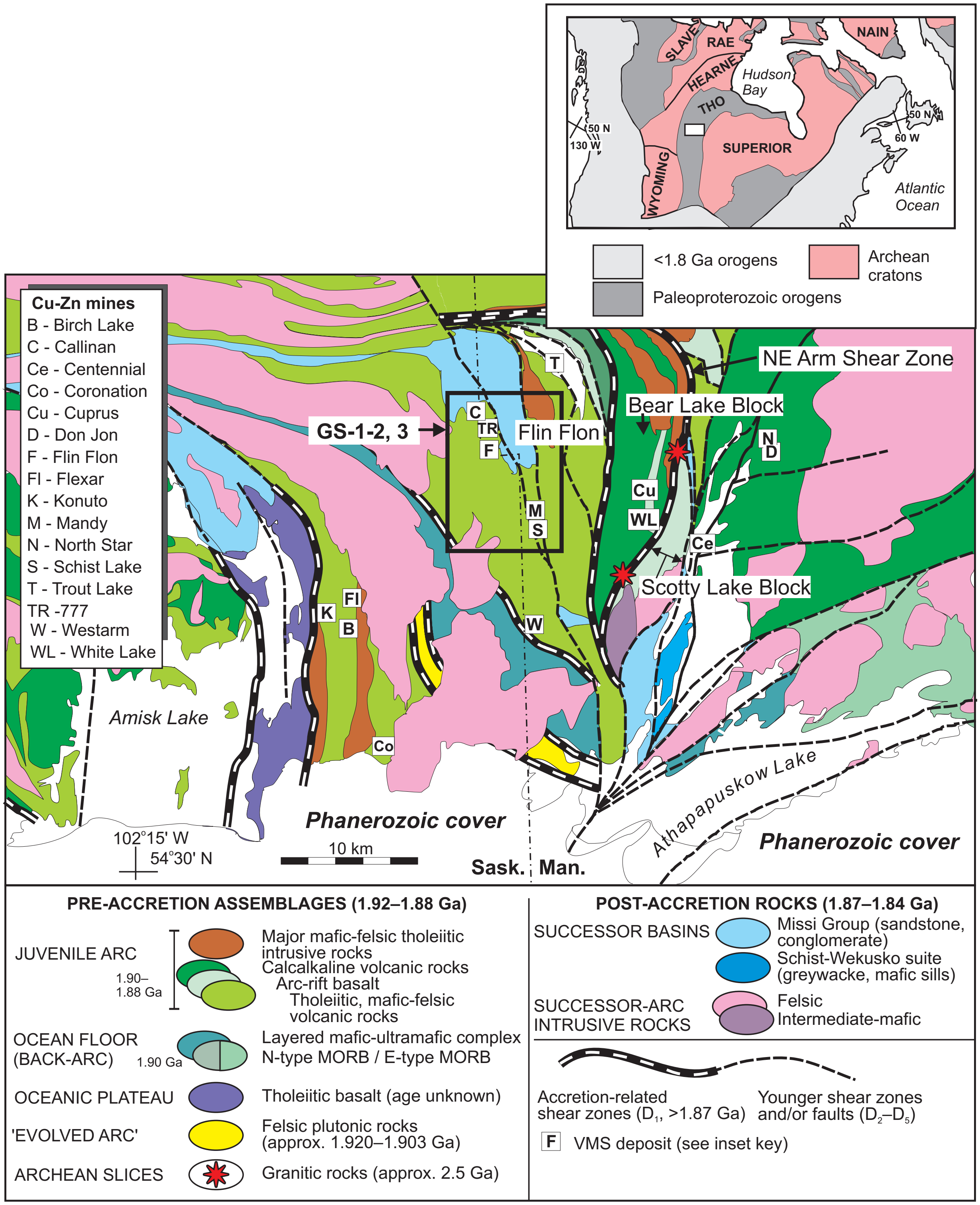


Figure GS-1-1: *Geology of the Flin Flon Belt, showing locations of known volcanogenic massive sulphide (VMS) deposits (modified from* Syme et al., 1999*); inset map shows the location of the Flin Flon Belt within the Trans-Hudson Orogen (THO).*

Three major mapping efforts from the 1950s to the 1990s have left 'legacy' maps of the Flin Flon area. To date, the detailed 1:12 000 scale map by Stockwell (1960) was the only map of the area that showed coherent stratigraphy and structure across the provincial border. More recent maps of the area were produced on each side of the border in the 1980s and 1990s, namely the 1:20 000 scale bedrock map of the Flin Flon–White Lake area by Bailes and Syme (1989) of the Manitoba Geological Survey and the 1:10 000 scale bedrock map of the Douglas–Phantom

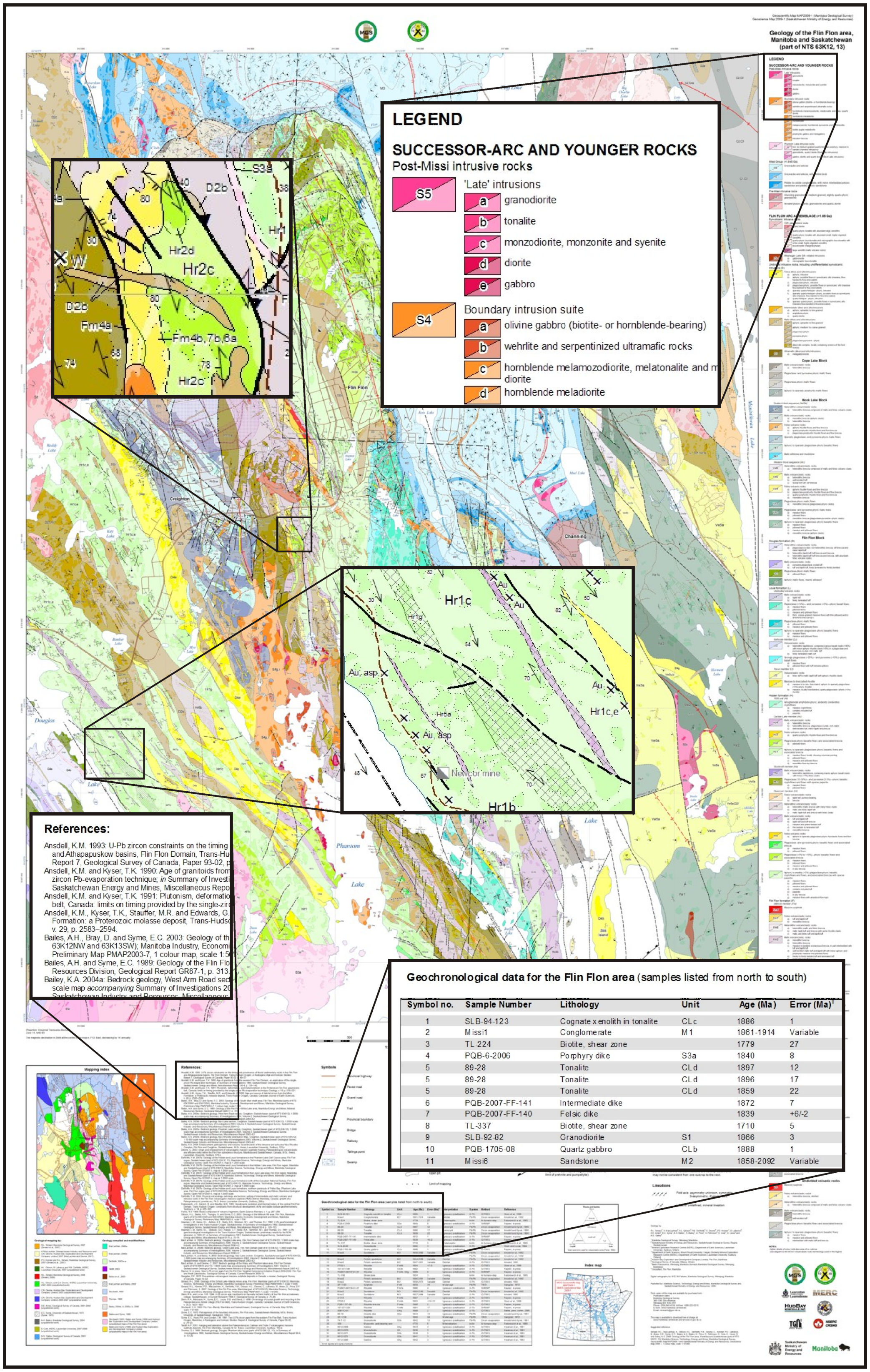


Figure GS-1-2: *The new 1:10 000 scale bedrock geology map of the Flin Flon area, Manitoba and Saskatchewan (Simard et al., 2009). Small insets show various features found on the map, such as (from top to bottom) one lithostratigraphic legend showing split-colour boxes with the lighter shade indicating an area of no outcrop; two close-ups of the geology showing outcrops, various structures, and mineral occurrences/past producers and their commodities; an extensive reference list of previous work in the area used to build the map; and a geochronology table for the area.*

Lake area by Thomas (1990, 1992) of the Saskatchewan Geological Survey. Although these mapping efforts significantly increased our understanding of the geology of the area and the setting of the VMS deposits it hosts, these maps did not provide a coherent geological framework that allowed correlation of map units and structures across the provincial border.

Starting in the early 2000s under the TGI-1 and later TGI-3 programs, detailed work on the volcanic rocks by Ames et al. (2002), MacLachlan et al. (2002), Devine (2003), Gibson et al. (2003, 2006, 2007, 2009; unpublished work, 2000–2009), Tardif (2003), Bailey (2004a, b; 2005a, b; 2006), DeWolfe and Gibson (2005, 2006), MacLachlan (2006a–c), Simard (2006a, b), Cole et al. (2007, 2008), Kremer and Simard (2007), MacLachlan and Devine (2007), Simard and Creaser (2007), Simard et al. (2007) and DeWolfe (2008) has shaped the newly proposed transborder stratigraphy for the area (Figures GS-1-3 and -4).

Structural studies by Lewis et al. (2006, 2007), MacLachlan (2006c), Lafrance (unpublished work, 2006–2009), Pehrsson (unpublished work, 2006–2008), Kremer and Simard (2007), Cole et al. (2007), Lafrance et al. (2007) and MacLachlan and Devine (2007), in conjunction with 3-D modelling of the area based on 2-D (two-dimensional) and 3-D seismic data recently acquired by HudBay Minerals Inc. and the Geological Survey of Canada (Schetselaar, 2009) have greatly helped advance and refine our understanding of the structural history of the area and unify it across the border (Figures GS-1-3 and -4).

Highlights from the new Flin Flon map

- One comprehensive, coherent lithostratigraphic legend has been developed across the provincial border.
- One VMS-hosting stratigraphy for the Flin Flon–Callinan–777 deposits (Figures GS-1-3 and -4) has been recognized:
  - The stratigraphy and geochemistry of the volcanic rocks associated with the Flin Flon–Callinan–777 VMS deposits record the infilling of a subsidence basin with abundant volcaniclastic material, localized felsic magmatism and the development of an intense hydrothermal alteration system (Flin Flon formation; Bailes and Syme, 1989; Syme et al., 1999; Devine, 2003), which terminated with a hiatus in volcanism and formation of the VMS deposits. Following VMS deposition there was resurgence in volcanism and subsidence marked by the development of one or more mafic shield volcanoes atop this subsidence structure (Hidden and Louis formations; Syme et al., 1999; DeWolfe and Gibson, 2005, 2006; DeWolfe, 2008).
  - The VMS-hosting stratigraphy has been mapped across major structures in the Flin Flon Block, including the Flin Flon Lake Fault, which has considerably enlarged the prospective area away from the immediate mine surroundings. New areas such as the Phantom Lake and Green Lake peninsulas just south of Phantom Beach are now considered as part of the southern extension of the main VMS host horizon for the Flin Flon–Callinan–777 deposits.
- New prospective areas in the hangingwall sequence have been recognized, including the following:
  - A semiconformable alteration zone exists in the hangingwall stratigraphy on the west side of the Flin Flon Lake Fault just east of Douglas Lake, Saskatchewan. This alteration horizon sits a few hundreds of metres below the former Newcor mine, which was known for its gold-bearing arsenopyrite, pyrite and sphalerite. The nature of this alteration system is similar to footwall alteration in a number of other VMS deposits in the world, which might suggest potential for VMS mineralization in the Douglas Lake area (MacLachlan, 2006c).
  - A synvolcanic subsidence structure complete with associated synvolcanic faults and mafic and felsic magmatism occurs within the hangingwall stratigraphy just southeast of Carlisle Lake, Manitoba. This kind of synvolcanic structure hosts VMS deposits in the Flin Flon area, and in this case is also spatially associated with a well-developed gossan (Simard, 2006a). In addition, smaller subsidence structures were also recognized in the hangingwall rocks just north of Louis Lake (DeWolfe, 2008).
- A new structural model has been developed and is fully integrated with the new lithostratigraphy. This structural model includes the recognition of the following:
  - Multiple episodes of thrusting exist in the area, both early and late in the structural history (pre- and postdeposition of the Missi Group). Some of the early thrust faults (mainly north-striking, west-vergent structures) repeat the VMS host stratigraphy including the VMS mineralization and are reworked by a series of late thrust faults (mainly east-striking, north-vergent structures), which imbricated the Missi Group sedimentary rocks with the volcanic rocks.
  - Early thrust movement occurred on major north-striking structures, namely the Cliff Lake Fault and most likely the Hook Lake Fault.
  - Improved geochronological controls have been obtained on the age of volcanic rocks that host the

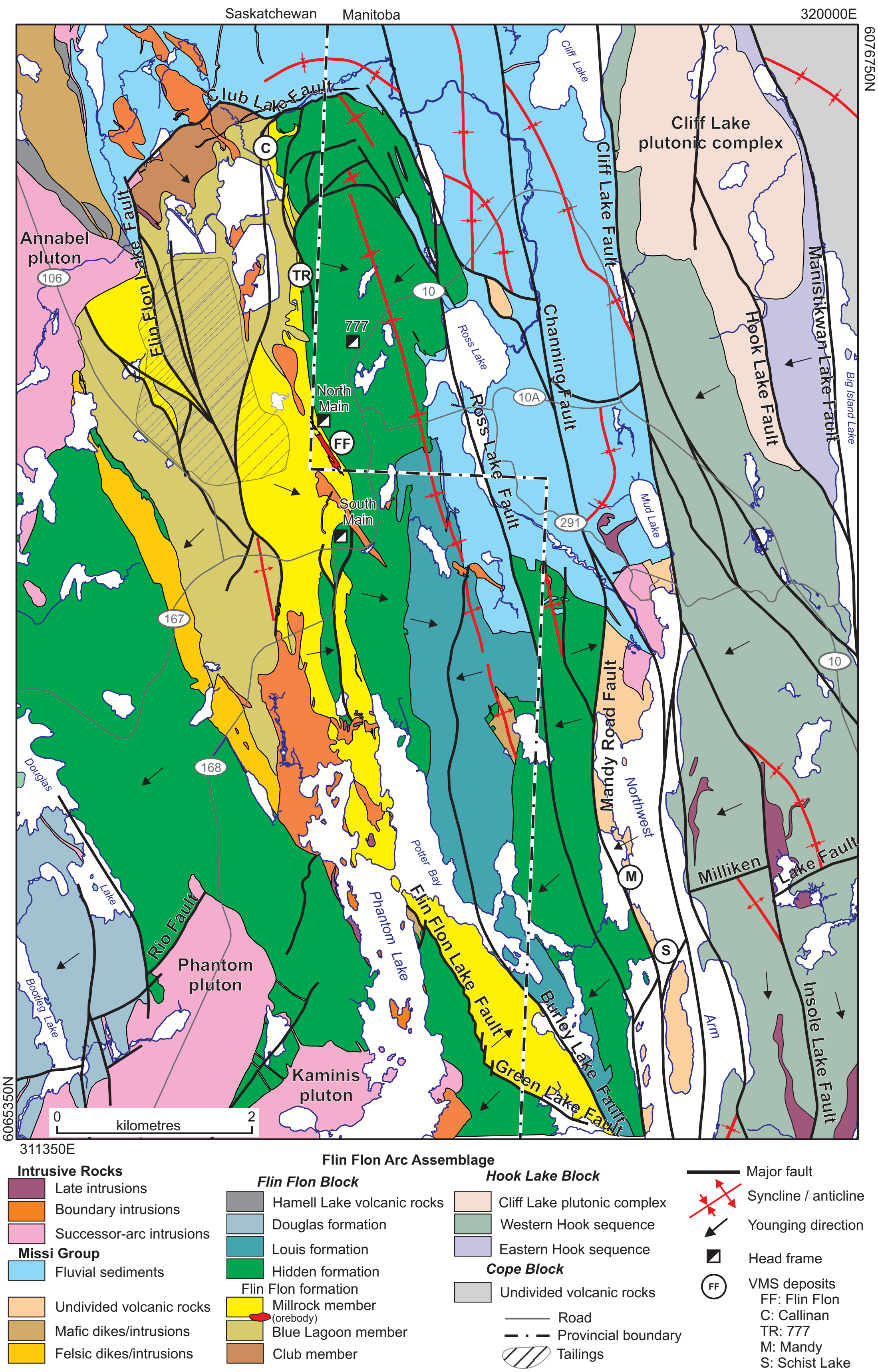


Figure GS-1-3: *Simplified geology of the Flin Flon area, outlining the major stratigraphic units and structures (from Simard et al., 2009).*

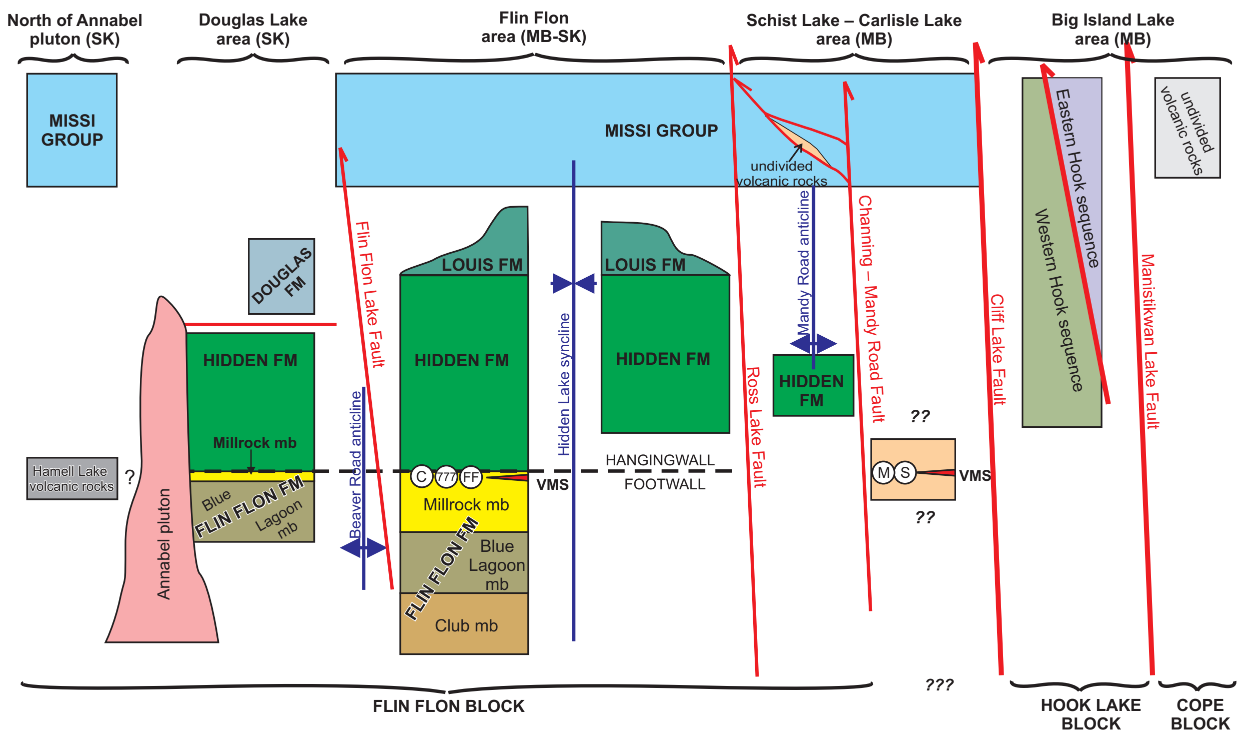


***Figure GS-1-4:** Schematic stratigraphic sections of the Flin Flon area (modified from Devine, 2003; DeWolfe and Gibson, 2006; Simard, 2006a; Kremer and Simard, 2007; MacLachlan and Devine, 2007; Simard and Creaser, 2007; DeWolfe, 2008; Gibson et al., 2009). Please refer to references listed or R-L. Simard et al. (work in progress, 2009) for more details on the stratigraphy of the area.*

mineralization and other units in the Flin Flon area, including the following:

- Several VMS-hosting felsic volcanic rocks of the Flin Flon formation are now dated at ca. 1890 Ma (Rayner, in press), which indicates that this is the predominant age of volcanism in the Flin Flon Block. This age is 10 Ma younger than previously recognized (see geochronology table for the Flin Flon area on the map face [e.g., Figure GS-1-2] for a detailed list of available age data).
- A quartz-porphyritic rhyolitic sill (previously referred to as the Myo intrusions), dated at 1888.9 ±1.7 Ma (Bailey, pers. comm., 2006), cuts the top of the ca. 1890 Ma Flin Flon formation (Rayner, in press) and the base of the overlying Hidden formation on the west side of the Flin Flon Fault at a very low angle. These relationships suggest a very short hiatus in volcanism between the formation of the VMS deposits and the resurgence of volcanism and subsidence recorded in the hangingwall stratigraphy.
- The base of the Western Hook sequence of the Hook Lake Block is intruded by an early dioritic phase of the Cliff Lake pluton dated at 1888 ±1 Ma (Rayner, in press), which suggests that the Western Hook sequence is age correlative with the VMS-hosting rocks of the Flin Flon Block to the west.
- The Eastern Hook sequence of the Hook Lake Block has an age of 1882 ±1 Ma (Rayner, in press), which makes it younger than the VMS-hosting rocks of the Flin Flon Block and the western sequence of the Hook Lake Block.

• The 1:10 000 scale bedrock map provides the surface, 2-D base layer for the development of a 3-D model for the Flin Flon area:
  - The 3-D modelling integrates surface mapping and the newly defined stratigraphy with subsurface drillhole and seismic data (Schetselaar, 2009). The emerging 3-D model emphasized the importance of thrust faulting observed at the surface in the 3-D architecture of the mine area.

Economic considerations

Detailed remapping of the Flin Flon area has greatly enhanced our understanding of the setting of the numerous VMS deposits in the area, which will be valuable in improving exploration models for the area.

By refining the VMS-bearing stratigraphy and improving the understanding of the structural history of the Flin Flon area, this project has resulted in the recognition of the mine horizon well beyond the immediate mine surroundings, opening potentially prospective ground for exploration. The expert understanding of volcanology required to map and interpret the Flin Flon rocks in greater detail than previous studies has resulted in the recognition of new alteration systems and subsidence structures in the hangingwall stratigraphy of the Flin Flon–Callinan–777 deposits on both sides of the border. Ability to recognize these subsidence structures has proven essential for exploring for this type of VMS deposit in and around the Flin Flon area, and may be applicable to greenstone belts elsewhere in Manitoba and Saskatchewan.

The geochronology that has accompanied the mapping yielded a revised age of ca. 1890 Ma for the volcanism that hosts the VMS deposits in the main Flin Flon mining camp, and demonstrates that the Western Hook sequence of the Hook Lake Block is correlative in age. The new ages provide an additional tool for evaluating the prospectivity of contemporaneous but previously unexplored successions.

Acknowledgments

The authors thank the numerous collaborators on this project without whom this map would not have been possible, namely H. Gibson, M. DeWolfe, C. Devine, P. Kremer, B. Lafrance, D. Ames, E.C. Syme, A. Bailes, K. Bailey, D. Price, S. Pehrsson, E. Cole, D. Lewis and A. Galley, along with the many enthusiastic field assistants over the years required to complete this project. Hudson Bay Exploration and Development Company Limited is thanked for their full collaboration and support on this project.

Special thanks go to M. McFarlane from the Manitoba Geological Survey for exceptional work on the digital cartography of the map and P. Lenton for incredible support in all stages of the map production.

Thanks to P. Kremer and C. Bohm for reviewing this manuscript and to B. Lenton for helping with drafting the figures.

References

Ames, D.E., Tardif, N., MacLachlan, K. and Gibson, H.L. 2002: Geology and hydrothermal alteration of the hanging-wall stratigraphy to the Flin Flon–777–Callinan volcanogenic massive sulphide horizon (NTS 63K12NW and 13SW), Flin Flon area, Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 20–34.

Bailes, A.H. and Syme, E.C. 1989: Geology of the Flin Flon–White Lake area; Manitoba Energy and Mines, Geological Report GR87-1, 313 p.

Bailey, K.A. 2004a: Bedrock geology, West Arm Road section, Creighton, Saskatchewan (part of NTS 63K/12); *in* Summary of Investigations 2004, Volume 2, Saskatchewan Geological Survey, Saskatchewan Industry and Resources, Miscellaneous Report 2004-4.2, 1:2000 scale map.

Bailey, K.A. 2004b: Bedrock geology, Myo Lake section, Creighton, Saskatchewan (part of NTS 63K/12); *in* Summary of Investigations 2004, Volume 2, Saskatchewan Geological Survey, Saskatchewan Industry and Resources, Miscellaneous Report 2004-4.2, 1:2000 scale map.

Bailey, K.A. 2005a: Bedrock geology, Phantom Lake section, Creighton, Saskatchewan (part of NTS 63K/12); *in* Summary of Investigations 2005, Volume 2, Saskatchewan Geological Survey, Saskatchewan Industry and Resources, Miscellaneous Report 2005-4.2, 1:2000 scale map.

Bailey, K.A. 2005b: Bedrock geology, Myo rhyolite distribution map, Creighton, Saskatchewan (part of NTS 63K/12); *in* Summary of Investigations 2005, Volume 2, Saskatchewan Geological Survey, Saskatchewan Industry and Resources, Miscellaneous Report 2005-4.2, 1:10 000 scale map.

Bailey, K.A. 2006: Emplacement, petrogenesis and volcanic reconstruction of the intrusive and extrusive Myo rhyolite complex, Flin Flon and Creighton, Saskatchewan; M.Sc. thesis, Laurentian University, Sudbury, 123 p.

Cole, E.M., Gibson, H.L. and Lafrance, B. 2007: Preliminary description of the lithofacies and structure of the Schist Lake mine area, Flin Flon, Manitoba (part of NTS 63K12); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 33–42.

Cole, E.M., Piercey, S.J. and Gibson, H.L. 2008: Geology and geochemistry of the Schist Lake mine area, Flin Flon, Manitoba (part of NTS 63K12); *in* Report of Activities 2008, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 18–28.

Devine, C. 2003: Origin and emplacement of volcanogenic massive sulphide-hosting, Paleoproterozoic volcaniclastic and effusive rocks within the Flin Flon subsidence structure, Manitoba and Saskatchewan, Canada; M.Sc. thesis, Laurentian University, Sudbury, 279 p.

DeWolfe, Y.M. 2008: Physical volcanology, petrology and tectonic setting of intermediate and mafic volcanic and intrusive rocks in the Flin Flon volcanogenic massive sulphide (VMS) district, Manitoba, Canada: growth of a Paleoproterozoic juvenile arc; Ph.D. thesis, Laurentian University, Sudbury, 269 p.

DeWolfe, Y.M. and Gibson, H.L. 2005: Physical description of the Bomber, 1920 and Newcor members of the Hidden formation, Flin Flon, Manitoba (NTS 63K16SW); *in* Report of Activities 2005, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p. 7–19.

DeWolfe, Y.M. and Gibson, H.L. 2006: Stratigraphic subdivision of the Hidden and Louis formations, Flin Flon, Manitoba (NTS 63K16SW); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 22–34.

Gibson, H.L., Bailes, A.H., Tourigny, G. and Syme, E.C. 2003: Geology of the Millrock Hill area, Flin Flon, Manitoba (parts of NTS 63K13SW and 63K12NW); Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, Preliminary Map PMAP2003-6, scale 1:500.

Gibson, H.L., Lafrance, B., DeWolfe, M., Devine, C., Gilmore, K. and Pehrsson, S. 2009: Volcanic reconstruction and post depositional modification of a cauldron subsidence structure within the Flin Flon VMS district; Prospectors and Developers Association of Canada, Annual Meeting, Toronto, Ontario, Program (special session on Flin Flon: New developments in an old camp).

Gibson, H.L., Bailey, K., DeWolfe, M., Gilmore, K., Devine. C., Sims, D., Bailes, A. and MacLachlan, K. 2006: Evidence for cauldron subsidence at the Flin Flon mining camp: implications for the location of volcanogenic massive sulphide deposits (abstract); Saskatchewan Industry and Resources Convention 2006, Saskatoon, Saskatchewan, Program, p. 24.

Gibson, H.L., DeWolfe, M., Lafrance, B., Bailey, K., Devine. C., Sims, D., Gilmore, K., Bailes, A., Simard, R-L. and MacLachlan, K. 2007: The relationship between rifting, subsidence, volcanism, and VMS deposits at Flin Flon, Manitoba (abstract); Manitoba Mining and Minerals Convention 2007, Winnipeg, Manitoba, Program, p. 55.

Kremer, P.D. and Simard, R.L. 2007: Geology of the Hook Lake Block, Flin Flon area, Manitoba (part of NTS 63K12); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 21–32.

Lafrance, B., Gibson, H.L., Pehrsson, S., DeWolfe, Y.M. and Lewis, D. 2007: Structural investigations in the Flin Flon mining camp (abstract); Manitoba Mining and Minerals Convention 2008, Winnipeg, Manitoba, Program, p. 54–55.

Lewis, D., Lafrance, B. and MacLachlan, K. 2007: Kinematic evidence for thrust faulting and reactivation within the Flin Flon mining camp, Creighton, Saskatchewan; *in* Summary of Investigations 2007, Volume 2, Saskatchewan Geological Survey, Saskatchewan Industry and Resources, Miscellaneous Report 2007-4.2, CD-ROM, Paper A-2, 10 p.

Lewis, D., Lafrance, B., MacLachlan, K. and Gibson, H. 2006: Structural investigations of Millrock Hill and the Hinge Zone of the Beaver road anticline, Creighton, Saskatchewan; *in* Summary of Investigations 2006, Volume 2, Saskatchewan Geological Survey, Saskatchewan Industry and Resources, Miscellaneous Report 2006-4.2, CD-ROM, Paper A-10, 11 p.

MacLachlan, K. 2006a: Bedrock geology Douglas Lake area, Flin Flon Domain (part of NTS 63K12); Saskatchewan Geological Survey, Saskatchewan Industry and Resources, Miscellaneous Report 2006-4.2, Geological Map, scale 1:3 000.

MacLachlan, K. 2006b: Bedrock geology Green Lake area, Flin Flon Domain (part of NTS 63K12); Saskatchewan Geological Survey, Saskatchewan Industry and Resources, Miscellaneous Report 2002-4.2, Geological Map, scale 1:3 000.

MacLachlan, K. 2006c: Stratigraphy, structure, and silicification: new results from mapping in the Flin Flon mining camp, Creighton, Saskatchewan; *in* Summary of Investigations 2006, Volume 2, Saskatchewan Geological Survey, Saskatchewan Industry and Resources, Miscellaneous Report 2006-4.2, 25 p.

MacLachlan, K. and Devine, C. 2007: Stratigraphic evidence for volcanic architecture in the Flin Flon mining camp: implications for mineral exploration; *in* Summary of Investigations 2007, Volume 2, Saskatchewan Geological Survey, Saskatchewan Energy and Resources, Miscellaneous Report 2007-4.2, CD-ROM, Paper A-1, 29 p.

MacLachlan, K., Gibson, H.L. and Bailey, K.A. 2002: Stratigraphic and intrusive relationships in the Myo Lake Section, Flin Flon mine sequence, Creighton, Saskatchewan; *in* Summary of Investigations 2002, Volume 2, Saskatchewan Geological Survey, Saskatchewan Industry and Resources, 2002-4.2, CD-ROM, Paper B-2, 10 p.

Rayner, N. (in press): New U-Pb zircon ages from the Flin Flon Targeted Geoscience Initiative Project 2006–2009: Flin Flon and Hook Lake blocks; Geological Survey of Canada, Current Research 2009-13.

Schetselaar, E. 2009: 3D Modelling in the Flin Flon exploration camp: interpretative and numerical methods for enhancing 3D geological insight & targeting; Prospectors and Developers Association of Canada, Annual Meeting, Toronto, Ontario, Program (special session on Flin Flon: New developments in an old camp).

Simard, R.L. 2006a: Geology of the Schist Lake–Mandy mines area, Flin Flon, Manitoba (part of NTS 63K12); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 9–21.

Simard, R.L. 2006b: Geology of the Schist Lake–Mandy mines area, Flin Flon, Manitoba (parts of NTS 63K12); Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Preliminary Map, PMAP2006-1, scale 1:5 000.

Simard, R.L. and Creaser, R.A. 2007: Implications of new geological mapping, geochemistry and Sm-Nd isotope data, Flin Flon area, Manitoba (part of NTS 63K12); *in* Report of Activities 2007, Manitoba Sciences, Technology, Energy and Mines, Manitoba Geological Survey, p. 7–20.

Simard, R.L., Kremer, P.D., MacLachlan, K., DeWolfe, Y.M., Gibson, H.L., Devine, C., Lafrance, B., Ames, D., Price, D.P. and Pehrsson, S. 2007: Geology of the Flin Flon area, Manitoba (part of NTS 63K12); Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Preliminary Map, PMAP2007-1, scale 1:10 000.

Simard, R-L., MacLachlan, K., Gibson, H.L., DeWolfe, Y.M., Devine, C., Kremer, P.D., Lafrance, B., Ames, D.E., Syme, E.C., Bailes, A.H., Bailey, K., Price, D., Pehrsson, S., Cole, E., Lewis, D. and Galley, A.G. 2009: Geology of the Flin Flon area, Manitoba and Saskatchewan (part of NTS 63K12, 13); Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Geoscientific Map MAP2009-1 and Saskatchewan Energy and Resources, Geoscience Map 2009-1, 1 colour map, scale 1:10 000.

Stockwell, C.H. 1960: Flin Flon–Mandy area, Manitoba and Saskatchewan; Geological Survey of Canada, Map 1078A, scale 1:12 000, with descriptive notes.

Syme, E.C., Lucas, S.B., Bailes, A.H. and Stern, R.A. 1999: Contrasting arc and MORB-like assemblages in the Paleoproterozoic Flin Flon Belt, Manitoba, and the role of intra-arc extension in localizing volcanic-hosted massive sulphide deposits; Canadian Journal of Earth Sciences, v. 36, p. 1788–1767.

Tardif, N.P. 2003: Hanging wall alteration above the Paleoproterozoic, Callinan and Triple 7 volcanogenic massive sulphide deposits, Flin Flon, Manitoba, Canada; M.Sc. thesis, Laurentian University, Sudbury, 100 p.

Thomas, D.J. 1989: Geology of Douglas Lake–Phantom Lake area (part of NTS 63K12–13); *in* Summary of Investigations 1989, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 89-4, p. 44–54.

Thomas, D.J. 1990: Bedrock geology, Douglas-Phantom lakes area (parts of NTS 63K12–13); *in* Summary of Investigations 1989, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 90-4, p. 13–20.

Thomas, D.J. 1992: Highlights of investigations around the Flin Flon mine: reassessment of structural history; *in* Summary of Investigations 1992, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 92-4, p. 3–13.