Bird River greenstone belt, southeastern Manitoba: geological setting, stratigraphy and details of the principal felsic volcanic component (part of NTS 52L5, 6, 11 and 12)

by H.P. Gilbert

Summary

The Neoarchean Bird River Belt (BRB) in southeastern Manitoba is part of an east-trending supracrustal belt that extends for 150 km from Lac du Bonnet in the west to Separation Lake (Ontario) in the east. This greenstone belt, located within the western Superior Province (Percival et al., 2006) has been a focus of geological investigations ever since the discovery of Cr deposits near the Bird River over 70 years ago (Brownell, 1942; Bateman, 1943). In 2005, the Manitoba Geological Survey initiated a four year, 1:20 000 scale mapping program of the BRB that focused on the supracrustal rocks of the belt. This poster is based on the results of that mapping and follow-up investigations. The regional setting and a geological overview of the belt are presented, followed by a more detailed description of the felsic volcanic Peterson Creek Formation that makes up one third of all the supracrustal rocks (***Figure 1***).

Regional setting and structure of the Bird River Belt

The Bird River Belt (BRB) is a continental-type, arc–back-arc complex of tholeiitic to calcalkaline volcanic and sedimentary rocks that document a sequence of subduction, rifting and final convergent plate movements, resulting in ca. 2.70 Ga collision of the bounding cratonic terranes (Maskwa Lake Batholith to the north, Winnipeg River Subprovince to the south; ***Figure 1***). Granitoid plutonism that accompanied ca. 2.73 Ga volcanism may have been associated with localized uplift and unconformities within the arc sequence. Intrusive suites include synvolcanic granitoid plutons and distinctive sanukitoid-type dikes and sills, and later post-orogenic granitoid intrusions that include the 2640 ±7 Ma rare-element–bearing pegmatite at TANCO mine.

The results of previous mapping (Trueman, 1980; Černý et al., 1981) led to an interpretation of the BRB as a collage of various tectonostratigraphic components that were deformed in a regional synclinorial structure. Although the available structural data are consistent with this model, recent work (Gilbert et al., 2008) has subdivided the BRB into north and south panels of continental arc-type rocks that are geochemically and stratigraphically distinct and separated in age by approximately 6–10 Ma (***Table 1***). The volcanic rocks of the two panels have distinctive geochemical profiles that signify differences within their continental margin setting, as shown in the following summaries.

North panel (Peterson Creek Formation and Diverse Arc assemblage)

Calcalkaline volcanism (2735–2731 Ma Peterson Creek Formation and Diverse Arc assemblage) in a supra-subduction, convergent crustal setting resulted in mainly intermediate to felsic volcanic rocks that are compositionally similar to modern arc magmas (***Figure 2a, b***).

South panel (Bernic Lake Formation)

Transitional/tholeiitic, mafic to felsic volcanism in the BRB south panel (2725 Ma Bernic Lake Formation) was probably located away from the site of earlier calcalkaline volcanism of the north panel. Geochemical signatures (***Figure 2c***) indicate initial convergence, gradational to an extensional crustal setting in the upper Bernic Lake Formation. The upper part of the Bernic Lake Formation (duration unknown, age estimated between 2725 Ma and 2710 Ma) consists mainly of volcaniclastic deposits (commonly reworked) and subordinate massive volcanic flows.

BRB north panel stratigraphy

The arc-type succession of the BRB north panel consists largely of felsic volcanic rocks of the Peterson Creek Formation that extend through the length of the greenstone belt from Lac du Bonnet in the west to the east end of Bird Lake (***Figure 1***). The remainder of the north panel—the Diverse Arc assemblage (DAA)—consists of a wide variety of volcanic and sedimentary rocks that are interpreted as mainly younger than the PCF. The DAA is of more limited extent (~30 km along strike, and up to 540 m in thickness) and is largely confined to the north margin of the BRB, where it is assumed to be in structural contact with back-arc basalt to the north. Contacts between the PCF and DAA are interpreted as locally conformable or gradational. Details of the DAA—as well as the Bernic Lake Formation of the south panel—are available in Gilbert et al. (2008); the remainder of this poster will focus on the Peterson Creek Formation.

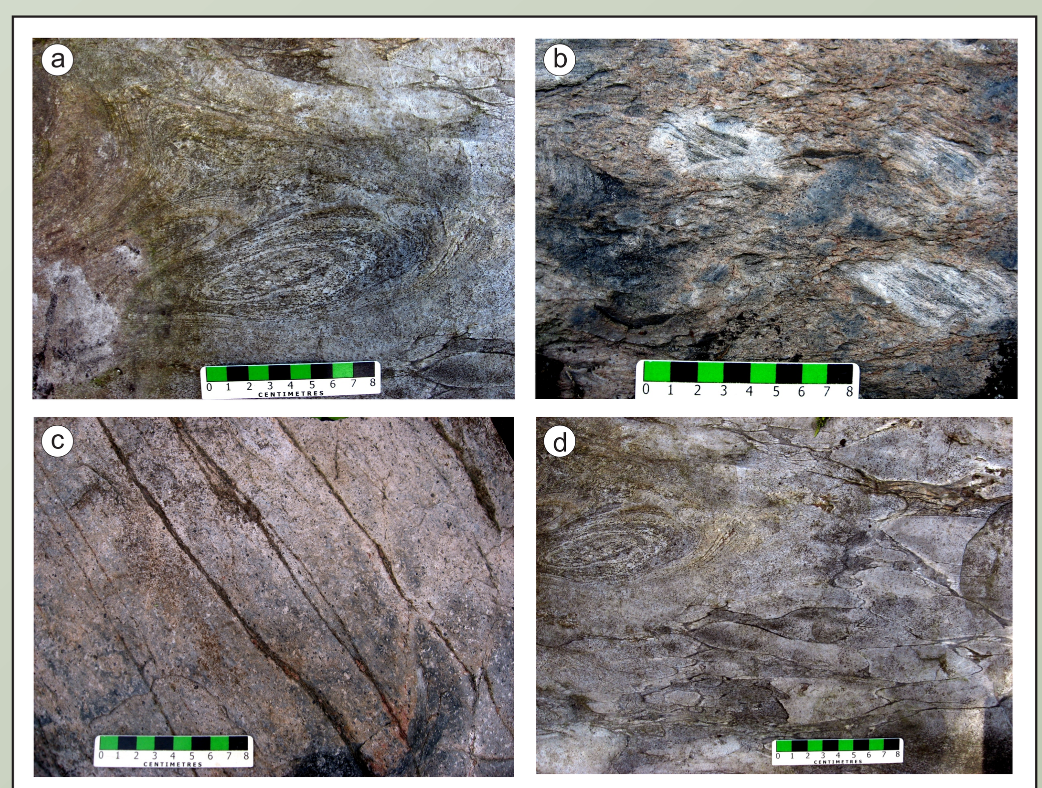


Figure 3: Field photographs of massive felsic volcanic flows, Peterson Creek Formation: ***a)*** Flow lamination and in situ brecciation of sparsely porphyritic rhyolite; ***b)*** Partly assimilated rhyolite clasts within autoclastic flow-breccia; the finely laminated fabric of the clasts is presumably due to their derivation—and subsequent transportation—from a zone of laminar flow within the extrusive unit, unlike the environment of the enclosing non-laminated matrix; flow banding of some clasts has different orientations; ***c)*** Marginal part of a plagioclase-quartz-phyric rhyolite flow, showing parallel fractures attributed thermal stress during cooling; ***d)*** Aphyric to sparsely plagioclase-phyric rhyolite exhibits in situ brecciation at the margins of concentrically flow-laminated cells; brecciated zone is gradational with autoclastic breccia.

Late intrusive rocks	
Granite, pegmatite, granodiorite, tonalite, quartz diorite	
(TANCO pegmatite, 2640 ±7 Ma[1]	
Marijane Lake pluton, 2645.6 ±1.3 Ma[2]; Lac du Bonnet Batholith, 2660 ±3[3] Ma)	
Diabase, gabbro and andesitic to dacitic intrusive rocks	
BIRD RIVER BELT	**BIRD RIVER BELT, NORTHERN ARM**
Sedimentary rocks	
FLANDERS LAKE FORMATION (2697 ±18 Ma[4])	
Lithic arenite, polymictic conglomerate	
Fault, inferred	
BOOSTER LAKE FORMATION (2712 ±17 Ma[4])	
Greywacke-siltstone turbidite, conglomerate	
Fault, inferred	
Intrusive rocks	
SYNVOLCANIC INTRUSIONS	
Gabbro, diorite, quartz-feldspar porphyry; granodiorite	
(Birse Lake pluton, 2723.2 ±0.7 Ma[2]; Maskwa Lake Batholith II, 2725 ±6 Ma[3]; Pointe du Bois Batholith, 2729 ±8.7 Ma(3); TANCO gabbro, 2723.1 ±0.8 Ma[2])	
Metavolcanic and metasedimentary rocks	
BIRD RIVER BELT NORTH PANEL	
DIVERSE ARC ASSEMBLAGE (2729 ±10 Ma[5]; 2706 ±23 Ma[5])	
Basalt, andesite, rhyolite, heterolithic volcanic fragmental rocks; greywacke-siltstone turbidite, chert, iron-formation; polymictic conglomerate (with clasts from the Bird River Sill)	
PETERSON CREEK FORMATION (2731.1 ±1 Ma[2]; 2734.6 ±3.1 Ma[6])	
Dacite, rhyolite; felsic tuff and heterolithic felsic volcanic breccia	
BIRD RIVER BELT SOUTH PANEL	
BERNIC LAKE FORMATION (2724.6 ±1.1 Ma[2])	
Basalt, andesite, dacite and rhyolite; heterolithic volcanic breccia	
Unconformity/Fault	EUCLID LAKE METASEDIMENTARY ROCKS
	Greywacke, siltstone, polymictic conglomerate
Intrusive rocks	**Intrusive rocks**
BIRD RIVER SILL (2744.7 ±5.2 Ma[3]; 2743.0 ±0.5[7])	MAYVILLE MAFIC-ULTRAMAFIC INTRUSION (2742.8 ±0.8 Ma[8])
Dunite, peridotite, picrite, anorthosite and gabbro	Gabbro, leucogabbro, anorthosite, intrusion breccia and pyroxenite
Metavolcanic and metasedimentary rocks	**Metavolcanic and metasedimentary rocks**
MORB-type VOLCANIC ROCKS	MORB-type VOLCANIC ROCKS (Mayville assemblage, Bailes et al., 2003)
Basalt, aphyric to plagioclase-phyric; locally megacrystic; oxide-facies iron formation	Basalt, aphyric to plagioclase-phyric locally megacrystic
Fault, inferred	
EAGLENEST LAKE FORMATION	
Greywacke-siltstone turbidite	
Older intrusive rocks	
Granodiorite, diorite (Maskwa Lake Batholith I, 2782 ±11 Ma[3], 2832.3 ±0.9 Ma[2], 2852.8 ±1.1 Ma[2], 2844 ±12 Ma[3])	
References for geochronological data: [1] Baadsgaard and Černý, 1993; [2] Gilbert et al., 2008; [3] Wang, 1993; [4] Gilbert, 2006; [5] Gilbert, 2008; [6] H.P. Gilbert, unpublished data, 2013, 2007; [7] Scoates and Scoates, 2013; [8] Houlé et al., 2013	

Table 1: Principal geological formations, their ages and contact relations in the Bird River Belt.

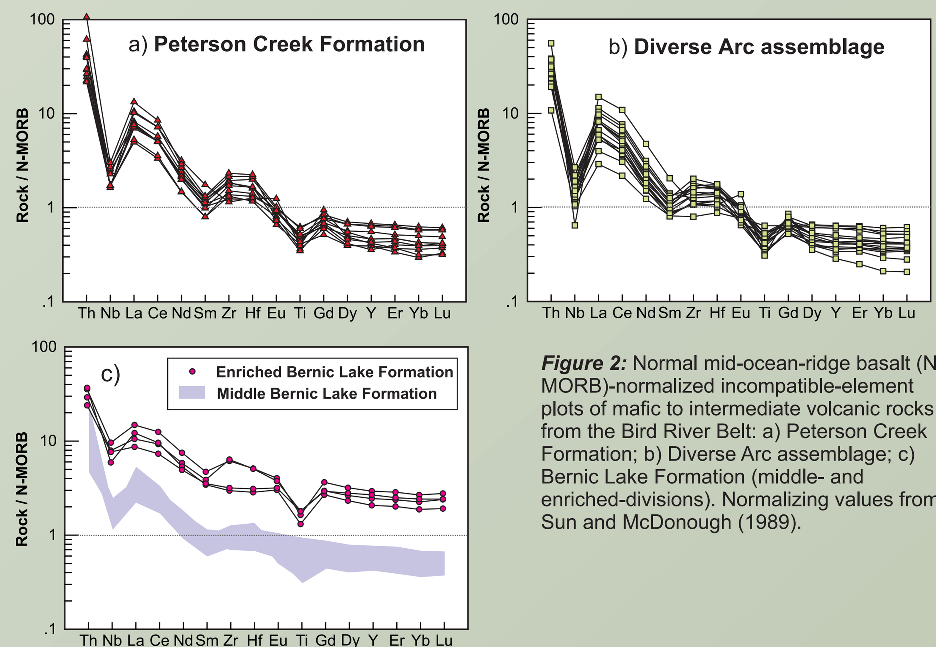


Figure 2: Normal mid-ocean-ridge basalt (N-MORB)-normalized incompatible-element plots of mafic to intermediate volcanic rocks from the Bird River Belt: a) Peterson Creek Formation; b) Diverse Arc assemblage; c) Bernic Lake Formation (middle- and enriched-divisions). Normalizing values from Sun and McDonough (1989).

Peterson Creek Formation

The Peterson Creek Formation (PCF; 2731.1 ±1 Ma, 2734.6 ±3.1 Ma; Gilbert et al., 2008 and unpublished data) is the largest geological map unit in the BRB, representing over 85% of arc-type rocks in the BRB north panel. With a bedrock area of approximately 85 km², the PCF is probably the largest felsic volcanic terrane within Precambrian greenstone belt rocks in Manitoba. The PCF extends laterally for approximately 45 km and attains a width of approximately 4 km in its western part. Factoring structural repetition due to inferred folding in the PCF, the true thickness of the formation is estimated to be 900 m in the western part, diminishing eastwards to 150 m in the vicinity of the east end of Bird Lake.

PCF facies types include:

- massive flows or domes, locally gradational—via in situ fragmentation—with zones of autoclastic breccia,
- localized lithophysae-bearing or spheruloidal[1]/spherulitic and perlitic zones that are thought to occupy the upper margins of massive flow units,
- extrusive felsic volcanic flows with juvenile, accessory and accidental fragmental components, thought to have been derived from the walls of magma conduits and/or substrate of extrusive flows/domes,
- volcaniclastic rocks including pyroclastic and/or mass-flow deposits.

Felsic volcanic flows and related intrusive rocks

Massive volcanic flows in the PCF are mainly rhyolitic; of 60 analyzed volcanic rocks, rhyolite (52%) and dacite (33%) are predominant over andesite (15%). Extrusive features include flow lamination which, however, is not commonly preserved in massive flows (***Figure 3a***); flow laminae also occur in sporadic, cognate fragments within massive rhyolite (***Figure 3b***). Small (0.5–2 cm), dark lensoid clasts/flakes—possibly originally glassy—within massive flows may have originated due to spalling of fragments from chilled margins. Parallel fractures attributed to stresses associated with cooling at the margins of flows/domes are common (***Figure 3c***), and in situ brecciation is widespread; massive domains are gradational—through zones of anastomosing fractures—with autoclastic breccia (***Figure 3d***).

[1] Spheruloidal (Bryan, 1941, 1954; Breitkreuz, 2013): felsic volcanic rock containing microcrystalline, quartzofeldspathic orbicular structures akin to lithophysae, but without radial crystalline texture or internal cavities diagnostic for lithophysae; the orbicular structures are akin to microcrystalline HTCD.

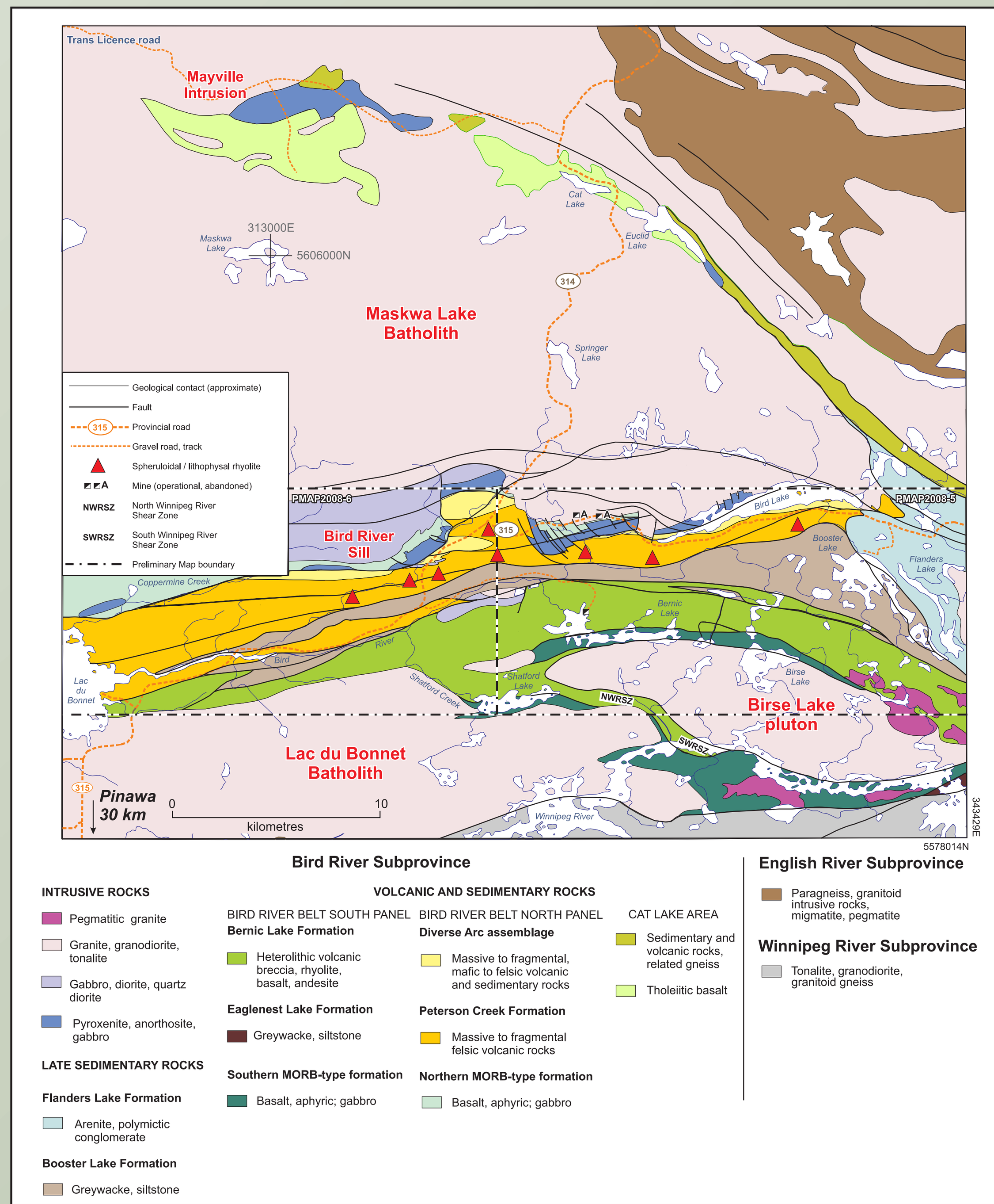


Figure 1: Geology of the area between Winnipeg River and the area north of Cat Lake, showing the main part of the Bird River greenstone belt between Lac du Bonnet and Flanders Lake, and the northern arm extending as far as the Mayville intrusion. Spheruloidal rhyolite (red triangles) extends along the south margin of the Peterson Creek Formation.

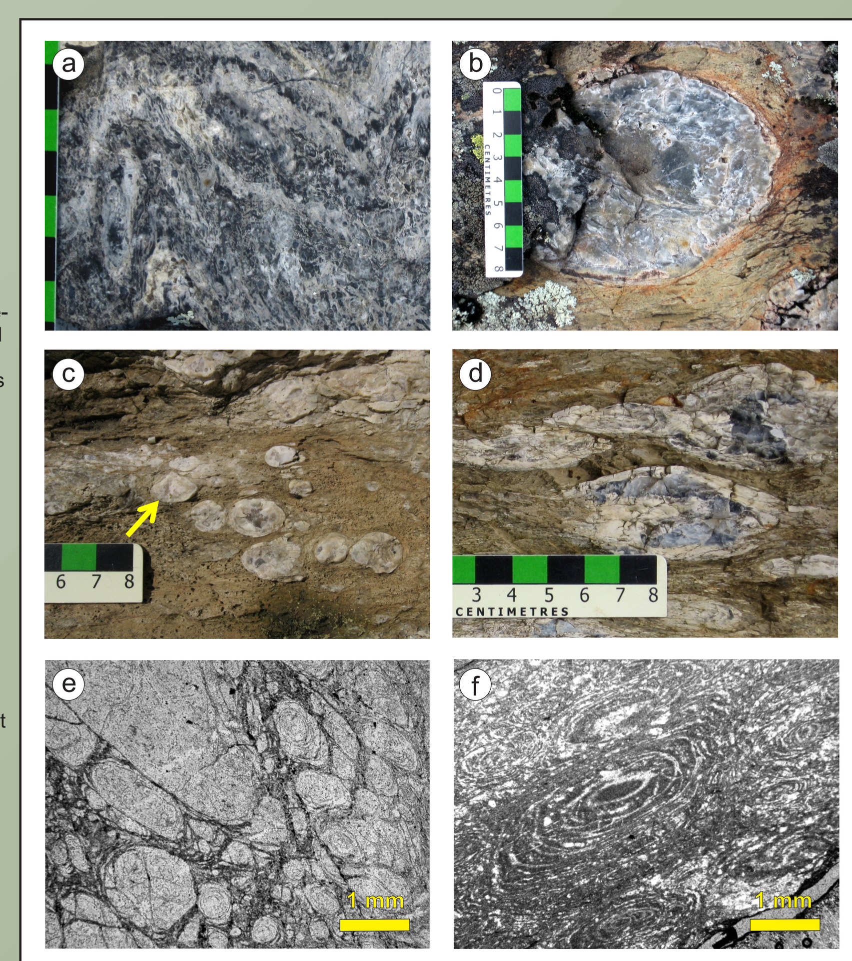
Rhyolite with spheruloidal, lithophysal and perlitic texture

Spheruloidal rhyolite that extends along the south margin of the PCF is characterized by a variety of features associated with devitrification of rapidly cooling, glassy lava, such as lithophysae and perlitic, spherulitic and spheruloidal textures. These rocks are aphyric to sparsely porphyritic with up to 10% quartz and feldspar phenocrysts; they constitute a discontinuous map unit (up to 180 m wide) that extends laterally as a series of lenses for over 20 km (***Figure 1***). Original volcanic textures correspond to those associated with high temperature crystallization domains (HTCD) in rapidly cooled felsic magma (HTCD = fibrous or microcrystalline domain with or without cavities that form in silicate melt or hot glass; Breitkreuz, 2013).

Spherulitic rhyolite *senso stricto*—in which spherulites are characterized by fibrous, confocally radiating crystalline textures (Lofgren, 1971)—is known at only one locality in the PCF (***Figure 4a***). Genetically related, larger and more conspicuous lithophysae and/or spheruloidal structures are the definitive features for this map unit; they are lensoid to near spheroidal in shape and typically 1-10 cm in diameter (***Figure 4b***). Internal cavities—filled generally with quartz—locally display classic, star-shaped forms (***Figure 4c***). The quartz-filled cavities are commonly deformed/folded due to flattening (***Figure 4d***); elsewhere, spheroidal lithophysae are concentrically zoned.

The matrix in which the HTCD-type structures developed is a generally olive-green-weathering, massive sericite rock derived from the viscous, silicate melt in which the lithophysae nucleated. Perlitic texture is common in the sericite-rock domains (***Figure 4e, f***); the fabric is generally attributed to stress resulting from hydration during cooling of felsic magma (McPhie et al., 1993). Devitrification—alteration of the obsidian matrix to sericite rock—and development of perlitic texture is thought to have immediately followed the growth of the HTCD structures (Bryan, 1954).

Figure 4: Field photographs and photomicrographs of spherulitic, lithophysal, spheruloidal and locally perlitic rhyolite, Peterson Creek Formation: **a)** Spherulitic rhyolite crowded with ovoid structures with fine radial fibrous texture; trails of spherulites are probably controlled by patterns of flow laminae upon which the spherulites were nucleated; **b)** Rhyolite with silica-rich, ovoid spheruloidal structure within a sericite-rock matrix, which probably nucleated above the glass transition temperature; **c)** Lithophysal structures in rhyolite, showing diagnostic star-shaped internal cavities (now quartz-filled) and locally partly broken margins; pie-shaped fragments (yellow arrow) may represent segments of disrupted lithophysae entrained in the sericitic (formerly glassy) matrix prior to consolidation; **d)** Ovoid lithophysae with (inferred) quartz-filled internal cavities, subsequently disrupted by folds; **e)** Plane-polarized light image showing perlitic texture defined by cells of concentric, sericite-filled microfractures; **f)** Plane-polarized light image showing perlitic texture with clusters of concentric patterns of sericitic microlaminae (microfracture fillings).



Geochemistry, origin and setting of spheruloidal rocks

Substantial, progressive changes of the initial melt composition are known to accompany devitrification and development of HTCD, which occurred mostly above, but likely continued somewhat below the glass transition temperature (Castro et al., 2008).

The main geochemical changes (***Table 2***) may be summarized as follows:

- Silicification and K-metasomatism are conspicuous, and associated with a substantial net loss of Na; Ca is also much depleted.
- Light rare earth elements (LREE) are depleted, and heavy rare earth elements (HREE) enriched (***Figure 5***).
- Sr, Ba and Zr are strongly depleted, but Th and U are notably enriched.
- Loss of FeO results in an approximate two-fold increase in Mg#.

HTCD features in SiO_2-rich rocks have long been recognized and discussed, yet their origin remains to some extent uncertain (Best, 2003). HTCD structures in felsic volcanic flows/domes are necessarily associated with their marginal zones, with widths ranging from metre to decametre in scale (Holzhey, 2001). The outermost, chilled zone of a felsic flow was likely to have been all glassy, whereas the contiguous spheruloidal zone with obsidian would have been slightly less rapidly cooled (McPhie et al., 1993). The spheruloidal rocks at the south margin of the PCF are thought to represent the marginal facies of several rhyolite flows/domes aligned roughly along strike within the original volcanic complex.

Averages for various Peterson Creek Formation rock units and their component parts	Number of analyses	SiO_2	Al_2O_3	FeO	CaO	Na_2O	K_2O	TiO_2	LOI	Ba	Sr	Zr	Rb	Nb	La	Ce	Pr	Nd	Sm
Spheruloids and lithophysae	3	81.1	9.9	0.9	0.6	1.8	4.8	0.03	0.4	173	38	89	174	15.1	10.6	28.5	3.9	16.8	4.5
Devitrified matrix (sericite rock)	2	78.1	12.3	1.1	0.3	0.3	4.8	0.04	1.6	80	16	118	248	13.5	3.6	11.7	1.3	6.1	2.1
Spheruloidal rhyolite (whole rock, lithophysae + matrix)	8	79.5	11.0	0.9	0.3	1.2	5.8	0.04	0.7	149	26	99	233	14.2	7.8	21.4	2.8	12.3	3.4
Regular-facies rhyolite in the central and eastern Bird River Belt	22	74.6	12.3	3.03	1.7	2.9	3.3	0.27	0.9	534	113	138	103	7.3	27.2	54.9	5.9	19.3	3.5
INCREASED ELEMENTS IN SPHERULOIDAL ROCKS, COMPARED WITH REGULAR-FACIES RHYOLITE		*					*		*				*	*					
DECREASED ELEMENTS IN SPHERULOIDAL ROCKS, COMPARED WITH REGULAR-FACIES RHYOLITE				*	*	*		*		*	*	*			*	*	*	*	*

Table 2: Select geochemical data (averages) for spheruloidal rhyolite compared with regular-facies, massive rhyolite of the Peterson Creek Formation.

Intermediate to felsic volcanic fragmental rocks

Lapilli crystal-tuff and volcanic breccia are major components of the PCF, collectively with subordinate massive felsic volcanic flows and related flow-breccia; they are especially abundant in the central and western parts of the PCF. The setting and petrographic textures of the fragmental rocks suggest they are mainly extrusive felsic volcanic flows with both juvenile and accessory, entrained clasts derived from unrelated rocks in the conduit of the rising magmas and/or the substrate of the extruded volcanic flows ('extrusive breccia'). A primary pyroclastic origin is inferred for subordinate, clast-rich, monolithic lapilli-tuff and breccia; some deposits are interpreted as reworked fragmental rocks, emplaced by gravity-induced mass flow.

Heterolithic extrusive breccia consists largely of felsic clasts in a crystal-rich, rhyolite matrix (***Figure 6a***). Subordinate intermediate to mafic siltstone clasts exhibit very fine grained, detrital texture (***Figure 6a, b***). Accidental clast types are rare; one occurrence of a ballistic-shaped, flow-laminated felsic clast (***Figure 6c***) displays a dark (formerly glassy?) margin and slightly twisted, spindle shape that was evidently imparted prior to incorporation in the breccia.

The extrusive breccia exhibits a hiatal texture, with large (1-5 mm) quartz, K-feldspar and plagioclase phenocrysts—typically euhedral to subhedral or partly broken in shape—within a very fine grained to aphanitic, quartzofeldspathic-sericitic matrix. The matrix extends into embayed, subhedral to subrounded crystals of feldspar and quartz (***Figure 6d***); some corroded quartz crystals display finely crenulated margins gradational with the matrix, suggesting active assimilation of the phenocryst by a surrounding melt (***Figure 6e***). Whereas the partly assimilated phenocrysts are generally well preserved even in strongly foliated rocks, the siltstone fragments are typically flattened to highly attenuated (***Figure 6d***). Clast distribution in much of the matrix-supported extrusive breccia is consistent with a fluid (magmatic or gaseous) rather than a clastic matrix (***Figure 6f***); the clasts typically lack sorting and are evenly distributed.

Depositional setting, structure and origin of Peterson Creek Formation

The PCF is interpreted as a felsic complex consisting of probably several, largely subaerial volcanic edifices; the magmatic source apparently generated at least two lava types, distinguished by different phenocryst content. The abundance of quartz and feldspar in some rocks (***Figure 6a, b***) is attributed to phenocryst enrichment, possibly by filter pressing in the conduit of the rising magma and/or, for clastic deposits emplaced by ash- or mass-flow processes, elutriation in a gaseous or fluid medium. A subaerial environment for the massive flows is inferred from the lack of features characteristic of subaqueous felsic volcanic flows, as well as the virtual absence of epiclastic rocks within the felsic volcanic complex.

The felsic complex is interpreted as the lower part of the BRB arc stratigraphy. The PCF terrane within the map area, as well as similar felsic volcanic rocks in a northern arm of the BRB north of Maskwa Lake (Yang, 2012), is interpreted as allochthonous and locally juxtaposed against relatively older MORB-type back-arc segments of the continental arc edifice (***Table 1***). Contacts between the felsic volcanic complex and substantially older cratonic rocks of the Maskwa Lake Batholith (2.78–2.85 Ga; ***Table 1***) have not been observed, but the influence of the craton is indicated by detrital zircon data. Felsic fragmental rocks close to Cat Creek that are interpreted as part of the PCF contain detrital zircons ranging in age from 2820 Ma to 2700 Ma (Yang et al., 2013). The older zircons within the sample population (>2.78 Ga) are interpreted as derived from granitoid rocks of the Maskwa Lake Batholith, or a similar but unexposed cratonic source (***Table 1***). Isotope data—ε_{Nd} values in the PCF range from -0.7 to +0.5 at 2733 Ma—and crustal residence ages (T_{CR} = 3.0–3.1) are also consistent with derivation, in part, from older, isotopically evolved Mesoarchean crust. A substantial component of assimilated, continental crust may explain the abundance of felsic volcanic rocks in the BRB, compared with greenstone belts elsewhere in the western Superior Province that are comparable with modern oceanic island arcs, and in which felsic volcanic rocks are far less abundant.

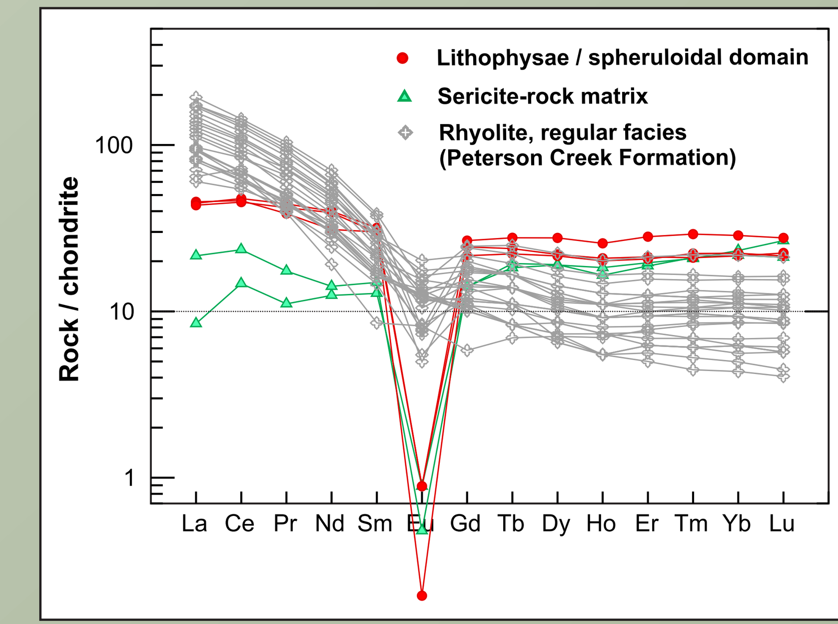


Figure 5: Chondrite-normalized incompatible-element plot of rhyolitic rocks of the Peterson Creek Formation, showing the distinction between 'regular-facies' and spherulitic rhyolite types (lithophysae/spheruloidal domain and the sericite-rock matrix of spherulitic types are shown separately). Normalizing values from Sun and McDonough (1989).

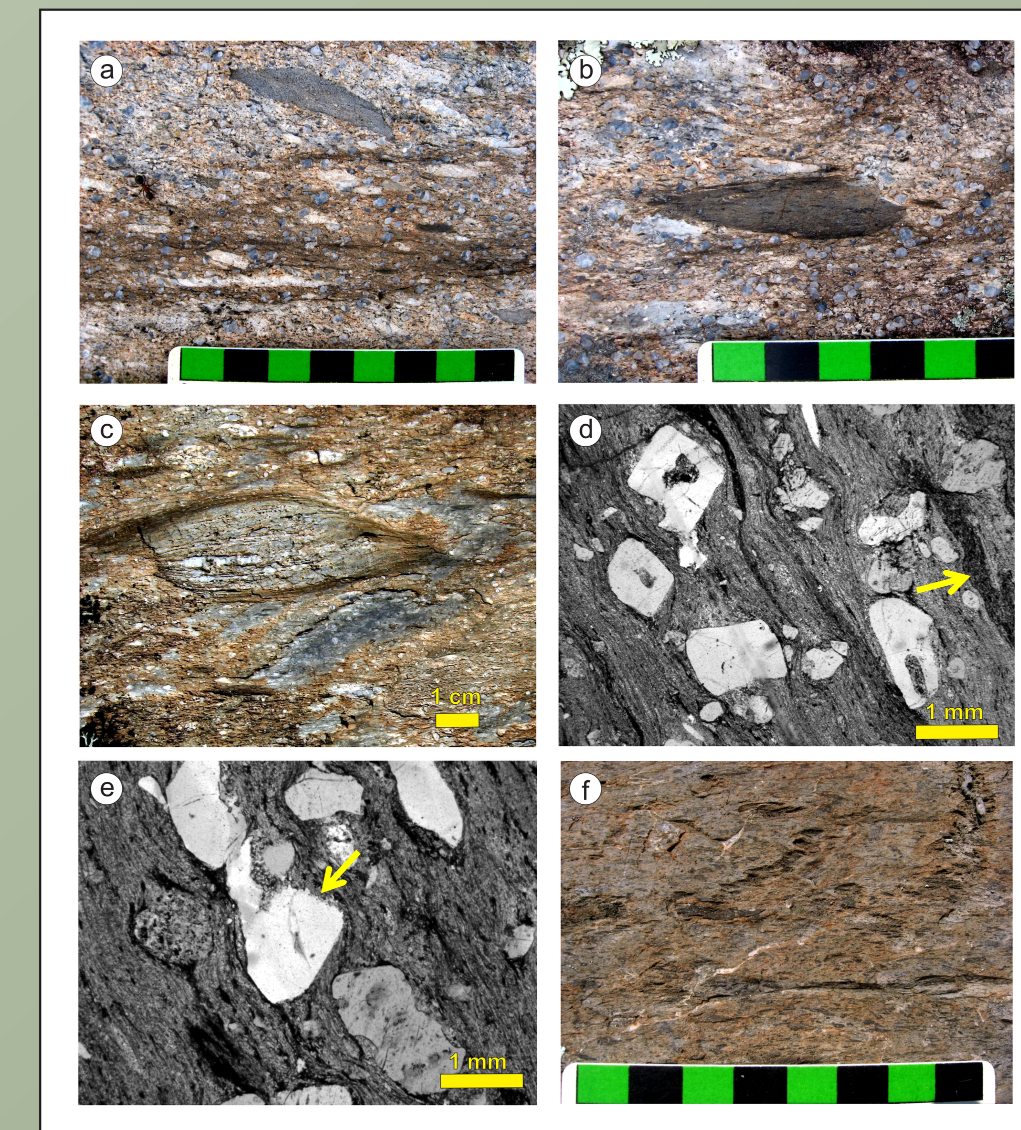


Figure 6: Field photographs and photomicrographs of felsic fragmental rocks, Peterson Creek Formation: ***a)*** Extrusive breccia with abundant felsic volcanic and subordinate fine-grained epiclastic clasts, in a rhyolitic matrix with ~25% quartz crystals; ***b)*** Extrusive breccia containing intermediate-mafic epiclastic fragment with detrital texture; ***c)*** Flow-laminated felsic fragment with dark (formerly glassy?) margin and spindle shape, possibly of ballistic origin; ***d)*** Plane-polarized light image showing subhedral, partly corroded and locally deeply embayed quartz and feldspar crystals within tuff; dark grey, micaceous argillitic siltstone clasts (yellow arrow) are highly attenuated/wispy in shape; ***e)*** Plane-polarized light image showing (at yellow arrow) corrosion and assimilation of an ovoid quartz crystal by the magmatic matrix of extrusive breccia; ***f)*** Field photograph showing dark grey, evenly spaced clasts—possibly representing glassy chips—within a fluid medium (magmatic or gaseous, e.g. ash-flow); few, if any, clasts are in contact.

References

Bateman, J.D. 1943: Bird River chromite deposits, Manitoba; Canadian Institute of Mining and Metallurgy, Transactions, v. 46, p. 154-183.
Best, M. 2003: Igneous and metamorphic petrology. Blackwell, Malden, 729 p.
Breitkreuz, C. 2013: Spherulites and lithophysae: 200 years of investigation on high temperature crystallization domains in silica-rich volcanic rocks. [Ed. S. Self]; Bulletin of Volcanology, v. 75:705.
Brownell, G.M. 1942: Chromite: Manitoba's gift to war industry; geology and character of a discovery deposit; Precambrian Magazine, v.15, no. 12, p. 3-5.
Bryan, W.H. 1941: Spherulites and allied structures, part I; Proceedings Royal Society of Queensland, Australia, v. 52, p. 41-53.
Bryan, W.H. 1954: Spherulites and allied structures, part II-V. The spheruloids of Binna Burra. Proceedings Royal Society of Queensland, Australia, v. 65, p. 51-69.
Castro, J.M., Beck, P., Tuffen, H., Nichols, A.R.L., Dingwell, D.B. and Martin, M.C. 2008: Timescales of spherulite crystallization in obsidian inferred from water concentration profiles; American Mineralogist v. 93, p. 1816-1822.
Černý, P., Trueman, D.L., Ziehlke, D.V., Goad, B.E. and Paul, B.J. 1981: The Cat Lake-Winnipeg River and the Wekusko Lake pegmatite fields, Manitoba; Manitoba Energy and Mines, Mineral Resources Division, Economic Geology Report ER80-1, 216 p. + 5 maps.
Gilbert, H.P., Davis, D.W., Duguet, M., Kremer, P.D., Mealin, C.A. and MacDonald, J. 2008: Geology of the Bird River Belt, southeastern Manitoba (parts of NTS 52L5, 6); Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Geoscientific Map MAP2008-1, scale 1:50 000 (plus notes and appendix).
Lofgren, G. 1971: Experimentally produced devitrification textures in natural rhyolitic glass; Geological Society of America Bulletin, v.82, p. 111-124.
Holzhey, G. 2001: Contribution to petrochemical-mineralogical characterization of alteration processes within the marginal facies of rhyolitic volcanics of Lower Permian age, Thuringian Forest, Germany; Chemie der Erde, v. 61, p. 149-186.
McPhie, J., Doyle, M. and Allen, R. 1993: Volcanic textures—a guide to the interpretation of textures in volcanic rocks; University of Tasmania, Centre for ore deposit and exploration studies. 196 p.
Percival, J.A., Sanborn-Barrie, M., Skulski, T., Stott, G.M., Helmstaedt, H. and White, D.J. 2006: Tectonic evolution of the western Superior Province from NATMAP and Lithoprobe studies; Canadian Journal of Earth Sciences, v. 43, p. 1085-1117.
Sun, S.S. and McDonough, W.F. 1989: Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes; Geological Society, Special Publication 42, p. 313-345.
Trueman, D.L. 1980: Stratigraphy, structure and metamorphic petrology of the Archean greenstone belt at Bird River, Manitoba; Ph.D. thesis, University of Manitoba, Winnipeg, Manitoba, 150 p.
Yang, X.M. 2012: Bedrock geology of the Cat Creek area, Bird River greenstone belt, southeastern Manitoba (part of NTS 52L12); Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Preliminary Map PMAP2012-3, scale 1:12 500.
Yang, X.M., Gilbert, H.P. and Houlé M.G. 2013: The Cat Lake–Euclid Lake area in the Bird River greenstone belt, southeastern Manitoba (parts of NTS 52L11, 12): preliminary results of bedrock geological mapping and their implications for geodynamic evolution and metallogeny; in Report of Activities 2013, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey.

MGS Manitoba