GS2024-6

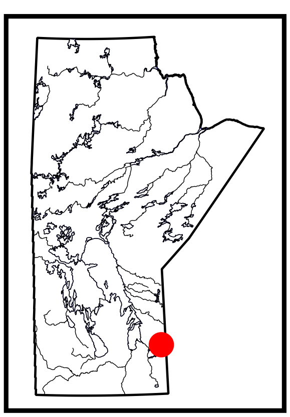
Preliminary observations from the Cat Lake–Winnipeg River pegmatite field, southeastern Manitoba (parts of NTS 52L5, 6, 11): evidence for the effect of structural setting and emplacement mechanism on the size and morphology of lithium-bearing pegmatites

by T.K. Cawood[1], S.R. Beyer[1], N. Mohammadi[1], C.J.M. Lawley[1], T. Martins and M.L. Rinne

In Brief:

- Field observations were made at several lithium-bearing pegmatites and their hostrocks in southeastern Manitoba to investigate how the structural setting and emplacement mechanisms may influence their size and shape
- The shape of the pegmatite-host rock contacts vary significantly among the pegmatites visited, reflecting the rheology of the host rock at the time of emplacement
- The pegmatites display a variety of internal fabrics, ranging from randomly oriented crystals formed by static crystallization from a melt with no subsequent deformation, to well-developed planar fabric that likely accommodated deformation during emplacement

Citation:
Cawood, T.K., Beyer, S.R., Mohammadi, N., Lawley, C.J.M, Martins, T. and Rinne, M.L. 2024: Preliminary observations from the Cat Lake–Winnipeg River pegmatite field, southeastern Manitoba (parts of NTS 52L5, 6, 11: evidence for the effect of structural setting and emplacement mechanism on the size and morphology of lithium-bearing pegmatites); *in* Report of Activities 2024, Manitoba Economic Development, Investment, Trade and Natural Resources, Manitoba Geological Survey, p. 38–48.



Summary

In August 2024, field observations were made at several lithium-bearing pegmatites in southeastern Manitoba to investigate how their structural setting and emplacement mechanisms may influence their size and shape. The observed pegmatites intrude a variety of hostrock types (including metamorphosed basalt, intermediate volcanics, gabbro and granodiorite). These pegmatite intrusions display a range of sizes (with dike widths ranging from less than 1 m up to 100 m) and morphologies (ranging from planar dikes to subequidimensional bodies). Contacts between pegmatite and hostrocks are typically sharp but vary from planar to bulbous and irregular in form. Whereas most of the observed pegmatites display internal fabrics indicative of static crystallization, one has well-developed compositional banding that is likely magmatic in origin, and another displays high-strain zones due to solid-state ductile deformation. Future work will include thin-section microstructural observations and analysis by electron backscatter diffraction to distinguish between fabrics resulting from magmatic flow and those resulting from solid-state ductile shearing.

Introduction

Rare-metal–bearing granitic pegmatites are an important source of lithium, cesium and tantalum (e.g., Tanco, Manitoba; Bikita, Zimbabwe; Greenbushes, Australia). They are also potentially significant sources of various other metals and minerals that are considered 'critical' (Natural Resources Canada, 2024), including bismuth, fluorspar, niobium, the rare-earth elements, tin, titanium and uranium.

Granitic pegmatites typically occur in groups, which may be dominated by a single large pegmatite (such as the Tanco pegmatite, which is up to 1520 m long, 1060 m wide, and ~100 m thick [Stilling et al., 2006], and is significantly larger than other known pegmatites in its immediate vicinity), or may comprise a sheeted swarm of numerous parallel, narrow (metre-scale) pegmatite dikes separated by barren hostrock (like the Little Nahanni pegmatite group, Northwest Territories; Groat et al., 2003). This has major implications for whether a pegmatite or pegmatite group can be mined economically. The shape of the pegmatite group, and the morphology of the individual pegmatite dikes within it, is likely a result of the mechanism of emplacement and the presence or absence of subsequent deformation. However, few studies have directly addressed the emplacement mechanisms of pegmatites and how different structural controls can result in different morphologies (e.g., Brisbin, 1986; Kremer, 2010; Silva et al., 2023).

Factors that may influence the emplacement mechanism (and resulting morphology) of pegmatites and pegmatite groups include the volume and addition rate of melt; melt pressure versus confining pressure; the stress state of the crust (compressional, extensional or transform); the rheology of the hostrock (which is a function of lithology, grain size, temperature and fluid content, among others); the degree of strain localization (with more localized deformation possibly channeling melts into fewer, larger pegmatite bodies); the presence and nature of structural-trap sites; and the possible superposition of multiple melt pulses (Brisbin, 1986; Passchier and Trouw, 2005; Hall and Kisters, 2012; Plunder et al., 2022; see also summary in Ching, 2024). Empirically, it is noted by industry geologists that pegmatites emplaced into coarse-grained granitic or gabbroic rocks tend to be planar dikes with sharp contacts, whereas those emplaced into fine-grained metasedimentary or mafic metavolcanic rocks tend to be highly irregular in shape.

[1] Natural Resources Canada, Geological Survey of Canada–Central, Ottawa, Ontario

This report details field observations made on pegmatites in the Cat Lake–Winnipeg River pegmatite field of Manitoba, as part of a larger field campaign investigating the structural setting and emplacement mechanisms of more than 30 pegmatites across the western Superior province. The size and morphology of the pegmatites and the characteristics of the hostrock are documented for each. Results will be compiled with similar data (e.g., Černý et al., 1981; Martins et al., 2013, Table 1) from Canada and globally to investigate potential relationships between the mechanisms of pegmatite emplacement and the resultant size and morphology of the pegmatites and pegmatite groups.

Geological setting

The Cat Lake–Winnipeg River pegmatite field is hosted largely by the Bird River domain, located in the western portion of the Archean Superior province (Figure GS2024-6-1). The Bird River domain includes the northern Cat Creek–Euclid Lake area (Yang and Houlé, 2020) and a southern area that is subdivided into north and south panels separated by the metasedimentary Booster Lake and Flanders Lake formations (Gilbert, 2006).

Pegmatites of the Cat Lake–Winnipeg River field are divided into the Cat Lake–Maskwa Lake and Winnipeg River pegmatite districts, each of which comprises a number of distinct groups of pegmatites that are spatially, mineralogically and geochemically related (Černý et al., 1981). The term pegmatite 'series' is used when the relationships between the pegmatites is less clear.

Rare-metal pegmatites of the Cat Lake–Maskwa Lake pegmatite district intruded largely metabasalt of the Lamprey Falls Formation, north of the Maskwa Lake batholith (Černý et al., 1981). The Donner Main Dike (Figure GS2024-6-1) forms part of the Maskwa Lake pegmatite series. Most of the pegmatites in this series are subvertical, northeast-striking dikes, parallel to nearby shear and fault zones (Černý et al., 1981). The spodumene-bearing Main Dike comprises three closely spaced parallel pegmatites, all of which are ~3–5 m thick with some pinch-and-swell variation, up to 550 m in length and display sharp contacts (Černý et al., 1981; Bannatyne, 1985). The Donner NW Dike contains petalite and is similarly narrow (~5 m), with an exposed length of ~250 m, and has sharp contacts (Černý et al., 1981). The Eagle, F.D. No. 5 and Irgon pegmatites form part of the Eagle-Irgon pegmatite group. Most of these pegmatites form lenticular, subvertical bodies that strike westerly, are concordant with the hostrock foliation and have common pinch-and-swell variations in thickness (Černý et al., 1981), although F.D. No. 5 forms part of a plug-shaped granitic intrusion (Bannatyne, 1985). Irgon displays a banded gneissic fabric parallel to the dike contacts (Bannatyne, 1985), suggesting subsolidus deformation (Černý et al., 1981). If continuous, the Eagle pegmatite may be 1100 m long and 6–12 m thick (Černý et al., 1981).

Rare-metal pegmatites of the Winnipeg River pegmatite district intrude the south panel of the Bird River greenstone belt (Figure GS2024-6-1). The Tanco, Buck and Coe pegmatites form part of the Bernic Lake pegmatite group, which intrudes mafic metavolcanics and associated subvolcanic gabbroic intrusions along the sheared contacts between and within the Southern MORB-type and Bernic Lake formations (Černý et al., 1981; Martins and Kremer, 2012). Pegmatite/hostrock contacts are sharp and straight or bulbous, and attitudes vary from east to northeast striking and subhorizontal to subvertical (Martins et al., 2013). All the larger pegmatites of this group form flat subhorizontal sheets with sharp straight contacts that occupy late fractures, such as the Tanco pegmatite (~1520 m long, 1060 m wide and up to ~100 m thick; Stilling et al., 2006) and the thinner Pegli pegmatite (at least 2.5 km long, but a maximum of 10 m thick), whereas the more steeply dipping dikes in the group are much smaller and have strongly brecciated wallrocks (Černý et al., 1981). The Tappy pegmatite likely forms part of the Lac du Bonnet pegmatite group. Pegmatites in this group strike north-northwest (parallel to a nearby dextral strike-slip fault), dip steeply to vertically, crosscut the layering and foliation of the hostrocks with sharp contacts, and have exposed lengths up to 40 m and widths up to 3 m (Černý et al., 1981; Roush et al., 2023). Some of the smaller pegmatites display brecciated textures and appear deformed (Černý et al., 1981).

Previous work on pegmatite emplacement in Manitoba

The mechanism by which pegmatite-forming melts are emplaced into the crust is directly linked to the shape and size of the resulting pegmatites. Several important studies that have looked at the emplacement of such melts were focused on localities in Manitoba. One study, by Brisbin (1986), used examples of pegmatites in the Winnipeg River field (along with other examples from around the world) to demonstrate how pegmatites emplaced in the brittle upper crust are typically tabular sheets, oriented perpendicular to the direction of minimum resistance to intrusion (which is determined by lithostatic and deviatoric stresses, as well as local factors such as strength anisotropies in the hostrock). In contrast, pegmatites emplaced into ductile hostrock deep in the crust are typically lensoid to irregular in morphology.

A second study, reported in Kremer and Lin (2006) and Kremer (2010), investigated the Bernic Lake pegmatite group and suggested that the exceptionally large, generally flat-lying, tabular Tanco pegmatite formed during the late stages of deformation. They suggest that melt was emplaced into a subhorizontal, brittle, conjugate fracture set in a unit of competent, coarse-grained gabbro surrounded by less competent, finer grained, foliated metavolcanic and volcaniclastic rocks in a brittle-ductile shear zone. In contrast, nearby pegmatites of the same age as Tanco (like the Oompa Loompa pegmatite) were emplaced into the surrounding metavolcanic rocks, which were undergoing ductile deformation at the same time as the stronger, coarse-grained metagabbro was experiencing brittle fracture. As a result, these pegmatites are smaller and highly irregular in shape, and were

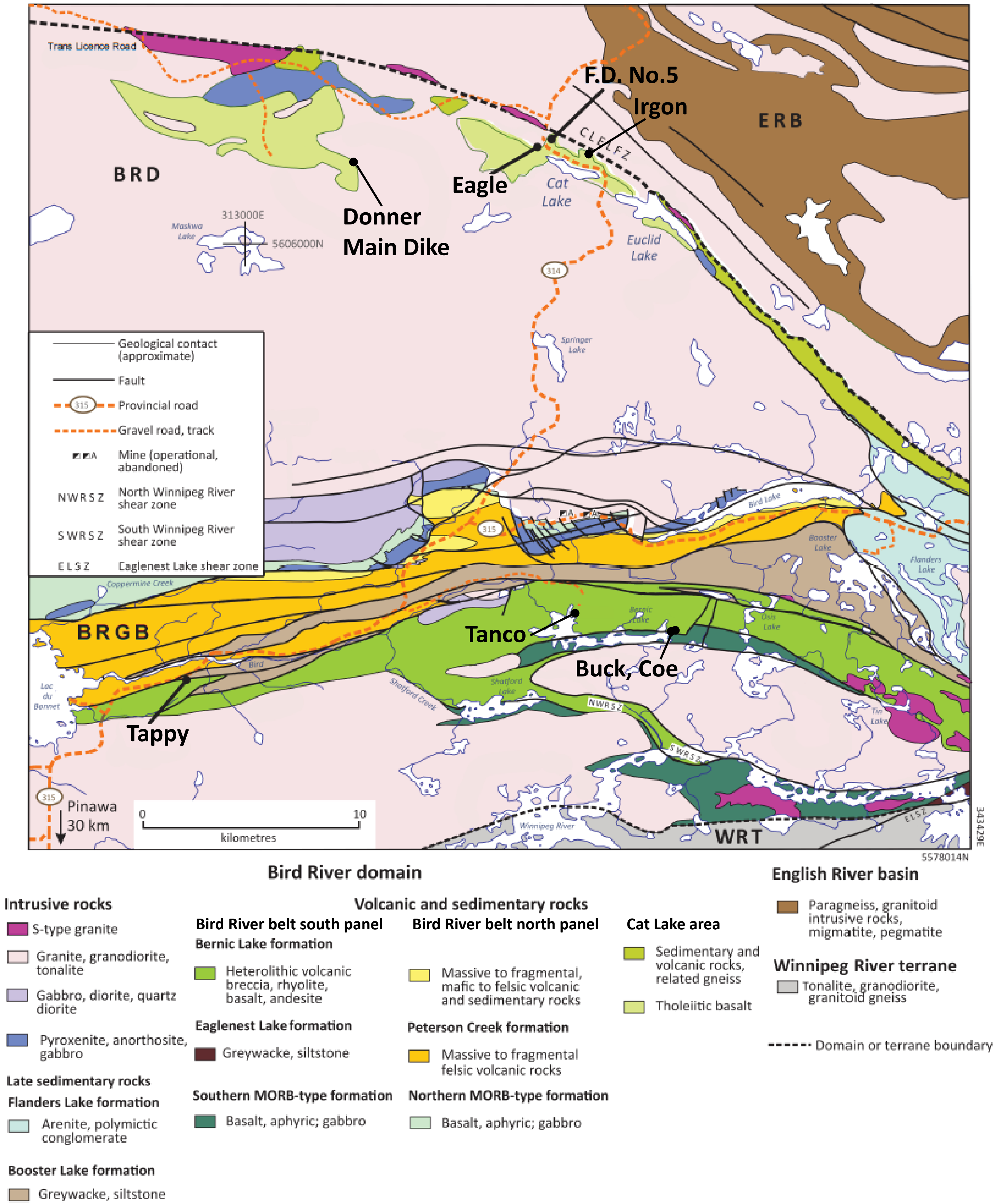


Figure GS2024-6-1: *Tectonic assemblages of the Bird River greenstone belt (from Yang and Houlé, 2020), labelled with the locations of pegmatites visited. Abbreviations: BRD, Bird River domain; BRGB, Bird River greenstone belt; CLELFZ, Cat Lake–Euclid Lake fault zone; ERB, English River basin; MORB, mid-ocean–ridge basalt; WRT, Winnipeg River terrane.*

deformed during ongoing shear. The difference in emplacement styles and resulting pegmatite morphologies is thus attributed to the difference in the rheologies of the hostrocks (Kremer and Lin, 2006; Kremer, 2010).

A third study found that the orientation of spodumene-bearing pegmatites in the Wekusko Lake pegmatite field can be attributed to their spatial relationship to regional-scale fault zones (Silva et al., 2023). One group of pegmatites was emplaced into tension gashes (extensional fractures), another into extensional shear fractures and a third into en échelon fractures between strike-slip structures.

Summary of fieldwork

Between August 12 and 15, 2024, various pegmatites in the Cat Lake–Winnipeg River pegmatite field were visited, including Tanco, Coe pegmatites 7 and 8, Buck pegmatite 9, Irgon, Eagle, F.D. No. 5, Tappy and the Donner Main Dike (Figure GS2024-6-1). At each site where there was sufficient outcrop, observations were made on

- the quality of the outcrop;
- the morphology of individual pegmatites (whether they are planar dikes, pipe-like bodies or irregular in shape);
- the nature of the pegmatite group (a single isolated pegmatite, a dominant large pegmatite in a swarm of smaller pegmatites or a sheeted swarm of similar-size pegmatites);
- the approximate size of the dominant pegmatites (as the cross-sectional width);
- the nature and form of the pegmatite/hostrock contacts (sharp or gradational; planar, gently curved, bulbous or highly irregular);
- the pegmatite orientation relative to hostrock fabrics;
- the characteristics of the hostrock (lithology, grain size, tectonic fabrics and interpreted rheology during pegmatite emplacement);
- and whether the pegmatites display internal fabrics indicative of magmatic flow or solid-state deformation.

These observations are summarized in Table GS2024-6-1. Where feasible, observations were documented with photographs, aerial photographs (using a drone) and field sketches. The hostrock at selected localities was also sampled for future petrographic studies, to better constrain the metamorphic grade and conditions of deformation.

In addition to the key characteristics listed in Table 1, several pegmatites display other notable features. Coe pegmatites 7 and 8 both host abundant angular xenoliths of metabasalt, with lesser metagabbro (Figure GS2024-6-2a).

Most of the pegmatites observed display no internal deformation fabrics (Table GS2024-6-1) and comprise crystals with random orientations, or locally crystals oriented perpendicular to contacts with hostrock or xenoliths. In contrast, the main dike at Irgon displays well-developed decimetre-scale compositional banding parallel to the overall orientation of the dike (subvertical, easterly trend) and the main foliation in the hostrock (Figure GS2024-6-3a, d). The banding is defined by variations in texture, mineralogy and grain size. Bands include fine-grained aplite and coarse K-feldspar-spodumene-quartz-muscovite pegmatite, and are parallel to a variably developed foliation defined by the preferred orientation of micas and mica-rich lenses or schlieren. Abundant meso-scale structures are also observed, such as boudinage of coarse pegmatitic bands, symmetrical 'eyes' to asymmetrical sigma clasts of feldspar, and S-C fabrics (Figure GS2024-6-3b, c).

Like many of the other pegmatites, parts of the steeply dipping, northeast-trending Donner Main Dike comprise randomly oriented crystals with no internal fabrics. Along strike, however, other parts display strongly developed anastomosing to planar fabrics parallel to the dike walls (Figure GS2024-6-4). These fabrics include ~10–20 cm wide zones in which the pegmatite-forming minerals have undergone major grain-size reduction. The asymmetry of foliation curved into these high-strain zones indicates sinistral shear. Other shear sense indicators, including S-C bands and centimetre-scale quartz sigma porphyroclasts, consistently indicate a sinistral shear sense, although no lineations were observed; thus, the true direction of motion remains unknown. The hostrock (a fine-grained metavolcanic rock with abundant decimetre-scale feldspar glomerocrysts) appears unstrained, as does the curvilinear to bulbous pegmatite/hostrock contact, with local 5–20 cm irregular pegmatite apophyses.

At the northwestern corner of the F.D. No. 5 outcrop, a narrow (0.5 m wide) shear zone is developed in the relatively undeformed host granitoid (Figure GS2024-6-5). The shear zone contains highly foliated, fine-grained mylonite or ultramylonite having sharp contacts with the coarse-grained undeformed granitoid on either side. It trends approximately east-northeast with a steep dip to the north-northwest before disappearing to the east, where it is obscured by a narrow apophysis extending out from the main body of the pegmatite. This apophysis appears to grade gradually into the mylonite of the shear zone.

Preliminary interpretations

The shapes of the pegmatite/hostrock contacts vary significantly among the pegmatites visited, reflecting the rheology of the hostrock at the time of emplacement (Table GS2024-6-1). Pegmatites with planar contacts that sharply crosscut the hostrock fabrics (e.g., the subhorizontal Buck pegmatite 9), along with pegmatites with planar contacts that host angular xenoliths of wallrock (e.g., the subvertical, xenolith-rich Coe pegmatites 7 and 8) are interpreted to reflect melt emplaced into brittle fractures. Similarly, the Tanco pegmatite is thought to have been emplaced into subhorizontal brittle fractures (Kremer, 2010). Rock may fail in a brittle manner at relatively shallow crustal levels and low temperatures. Alternatively, brittle failure may be induced in deeper, hotter conditions by hydrofracturing if

Table GS2024-6-1: Summary of field observations made on pegmatites and their hostrocks in the Cat Lake–Winnipeg River pegmatite field. Abbreviations: bt, biotite; fsp, feldspar; ms, muscovite; peg, pegmatite; PT, pressure-temperature; qz, quartz; spod, spodumene; SQUI, spodumene-quartz intergrowth

Pegmatite	Location (Decimal degrees)		Location (UTM, Zone 15)		Outcrop	Pegmatite morphology	Nature of pegmatite group	Dike width	Contact		Orientation	
	N	E	E	N					Nature	Form	Relative to host foliation	Dip
Tanco	50.429	-95.453	325813.616	5589149.478	None: underground mine	Sheet/saddle-like sill	Single dominant	Up to 100 m[1] total	Sharp[2]	Planar to curvilinear[2]	Cross cuts[2]	Subhorizontal
Coe, pegmatite 7*	50.422	-95.391	330174.009	5588278.376	Poor: small exposure in forest	-	-	1 m exposed	Sharp	Planar	-	-
Coe, pegmatite 8*	50.422	-95.389	330284.131	5588253.688	Good: clear outcrop in forest	Broad sheet-like dike	Part of a loose group	5 m total	Sharp	Planar	Subparallel	Subvertical
Buck, pegmatite 9*	50.422	-95.388	330344.964	5588243.942	Good: clear outcrop in small cliff on edge of swamp	Sheet-like sill	Part of a loose group	4 m exposed	Sharp	Planar	Cross cuts	Subhorizontal
Irgon - NE apophysis	50.610	-95.428	328245.553	5609307.480	Excellent: large clear exposure	Two subparallel sheet-like dikes	Two ~2-4 m wide branches	Two 2-4 m branches total	Sharp	Bulbous to curvilinear	Cross cuts	Likely subvertical
Irgon - main dike	50.610	-95.428	328194.991	5609255.715	Excellent: large clear exposure	One dominant s heet-like dike	Single dominant dike, with several narrower parallel dikes	Up to 20 m total	Sharp	Mostly planar (small area on N side has irregular, bulbous contact)	Parallel	Subvertical
Eagle	50.614	-95.460	325960.174	5609776.857	Moderate: scattered small exposures on hills	Sheet-like dikes	Multiple parallel dikes[3]	Parallel dikes cm to several m total[3]	Sharp	Bulbous, curvilinear to irregular	Cross cuts	-
F.D. No. 5	50.615	-95.454	326390.664	5609881.669	Good: large outcrop in forest, cleaned	Sub-equidimensional body (pipe?)	Single pegmatite visible	Blob/pipe shape, up to 15 m across	Sharp to diffuse over mm	Planar to curvilinear	Cross cuts	-
Tappy	50.403	-95.693	308661.022	5586926.294	Moderate: discontinuous, small exposures	Sheet-like dikes	At least two parallel dikes	1.5-4 m[3] total	Sharp	Planar to curvilinear	Cross cuts	Steep
Donner - main dike	50.614	-95.579	317521.646	5610034.923	Good: ~200 m-long clear ridge plus other smaller outcrops	Sheet-like dike	Single pegmatite visible	1.5-5 m total	Sharp	Gently undulating to irregular; locally planar	Cross cuts	Steep

*Names according to Bannatyne (1985)

References:

[1] Stilling et al. (2006); [2] Kremer (2010); [3] Roush et al. (2023)

Table GS2024-6-1 (continued): Summary of field observations made on pegmatites and their hostrocks in the Cat Lake–Winnipeg River pegmatite field. Abbreviations: bt, biotite; fsp, feldspar; ms, muscovite; peg, pegmatite; PT, pressure-temperature; qz, quartz; spod, spodumene; SQUI, spodumene-quartz intergrowth

Pegmatite	Host lithology (meta-…)	Grain size	Fabric	Interpreted rheology during emplacement	Li-minerals	Concentric zoning	Banding/ compositional layering	Magmatic fabric	Solid state fabric	Notes
Tanco	Gabbro	Medium to coarse	Massive to moderately foliated	Brittle[2]	SQUI	Yes	-	-	No	
Coe, pegmatite 7*	Basalt	Fine	-	Brittle	Petalite, SQUI	-	-	-	No	
Coe, pegmatite 8*	Basalt, local gabbro	Fine to medium (<mm)	Massive to weakly foliated	Brittle	-	Yes: contact - aplite - coarse qz-ms - qz core	No	No	No	Abundant angular xenoliths of host rock
Buck, pegmatite 9*	Basalt	Fine	Moderately foliated	Brittle	SQUI, spodumene	No: irregular variations	No	No	No	
Irgon - NE apophysis	Intermediate volcanics, vari-able	Fine to medium (~mm), locally porphyritic	Weak to moderately foliated	Ductile	SQUI	No	No	No	No	
Irgon - main dike	Gabbro & basalt	Coarse to fine	Gabbro highly sheared, with anastomosing high-strain zones; basalt strongly foliated	Ductile	SQUI	No	Yes	Possibly	Possibly	Peg emplacement at PT conditions of bt stability; into major dextral shear zone
Eagle	Granodiorite	Coarse	Most weakly foliated, with rare cm-scale localized shear zones	Ductile	Spodumene	No	No	No	No	
F.D. No. 5	Granodiorite (& lesser basalt)	Coarse (& fine)	Weakly foliated (& strongly foliated)	Semi-brittle to ductile	Spodumene	Yes: weak, diffuse qz-spod core	No	Weak: aligned xenoliths	No	At W edge, peg extends into a 0.5m localized shear zone in granodiorite: replacive?
Tappy	Basalt	Fine	Weak to moderately foliated	Semi-brittle to ductile	Spodu-mene[3]	-	No	No	No	
Donner - main dike	Glomerocrystic volcanic	Fine with dm-scale fsp glomerocrysts	Massive	Ductile	Spodumene	No	-	Possibly	Yes: high-strain zones with grainsize decrease	Peg accommodated sinistral shear, host undeformed.

Abbreviations: bt, biotite; fsp, feldspar; ms, muscovite; peg, pegmatite; PT, pressure-temperature; qz, quartz; spod, spodumene; SQUI, spodumene-quartz intergrowth.

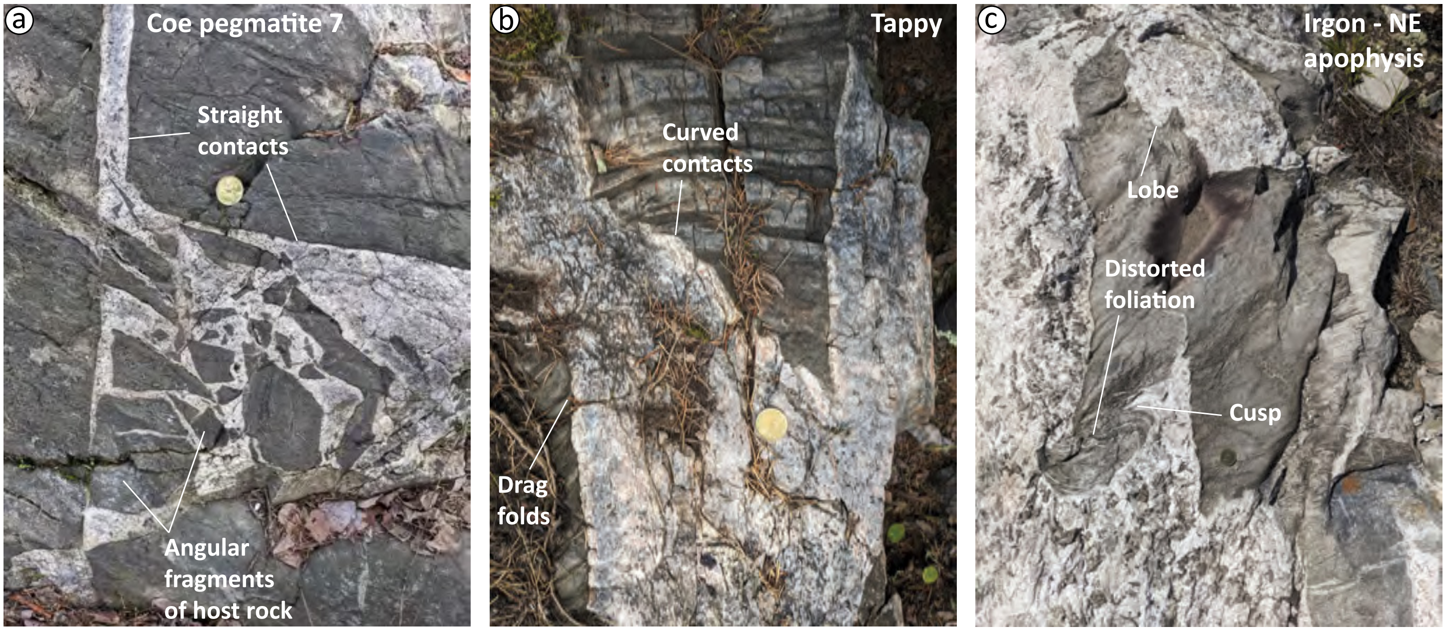


Figure GS2024-6-2: *Different styles of pegmatite/hostrock contacts:* ***a)*** *planar contacts at Coe pegmatite 7, where the host foliation is sharply truncated and the abundant hostrock xenoliths are angular;* ***b)*** *curved to gently bulbous contacts at Tappy; note the gentle curvature of the host foliation against the pegmatite, defining a weak drag fold;* ***c)*** *an irregular contact, characterized by abundant cusps and lobes, at the Irgon–NE apophysis; the hostrock foliation is locally highly distorted.*

the fluid pressure of the pegmatite-forming melt is high enough to overcome the compressive-stress conditions plus the tensile strength of the hostrock (Brisbin, 1986).

Other pegmatites, with curvilinear to bulbous and locally highly irregular contacts that crosscut the hostrock fabric, are interpreted as being emplaced when the hostrock was ductile. These include the Irgon NE apophysis, Eagle and Donner Main Dike pegmatites, which were emplaced into a variety of host lithologies, including mafic and intermediate metavolcanics, metagabbro and metagranodiorite. This indicates that melt emplacement occurred at a deep enough crustal level that ambient temperatures were high enough for all these different lithologies to be ductile. Several pegmatites in the Separation Lake greenstone belt in Ontario display similar irregular pegmatite/hostrock contacts, and Ching (2024) suggested that the pegmatite-forming melts acted as viscous indenters into the weakened, ductile hostrock.

At the roughly east-trending Irgon main dike, a small area on the north side preserves an irregular, bulbous pegmatite/host contact, whereas most of the main dike has strongly planar contacts that are parallel to the ductile foliation in the adjacent hostrocks. This suggests that the Irgon main dike was emplaced into ductile hostrock but that most of the pegmatite was controlled by the pre-existing anisotropy of the sheared host, or that the contacts were smoothed during subsequent ductile shearing.

The pegmatites also display a variety of internal fabrics that reflect different emplacement and subsequent deformation histories. Most of them comprise randomly oriented crystals or crystals that grew perpendicularly from hostrock or xenolith contacts. These pegmatites are interpreted to have crystallized from a melt under static conditions and do not record any subsequent solid-state deformation.

In contrast, Irgon and parts of the Donner Main Dike display strong internal fabrics. The compositional banding in the Irgon main dike resembles banding/layering described from within the Separation Rapids pluton in Ontario and from the nearby Glitter, Big Mack and Big Whopper pegmatites (Ching, 2024), and banding in pegmatites in the Red Cross Lake pegmatite field in Manitoba (Brisbin et al., 2012) that has been interpreted as primary magmatic layering developed during emplacement or subsequent flow of the melt. The authors support these interpretations and further suggest that each individual compositional band could represent a distinct pulse of melt. This is supported by unpublished observations made by some of the authors in Ontario where the wide (tens of metres) Big Whopper and Bolt pegmatites transition from banded pegmatite with banding-parallel rafts of hostrock into hostrock with abundant narrow (metres to centimetres), parallel, sheeted dikes of pegmatite. These narrow dikes typically each display a single composition, mineral assemblage and grain size (e.g., a single dike may comprise only aplite or only coarse K-feldspar–rich pegmatite). One possible interpretation is that these narrow dikes each formed from a single pulse of melt and, where numerous such pulses were emplaced in the same location, they built up a wide composite pegmatite dike over time.

The various meso-scale structures observed within the Irgon pegmatite, such as boudinage, asymmetrical porphyroclasts and S-C fabrics, could reflect three processes: 1) magmatic flow dur-

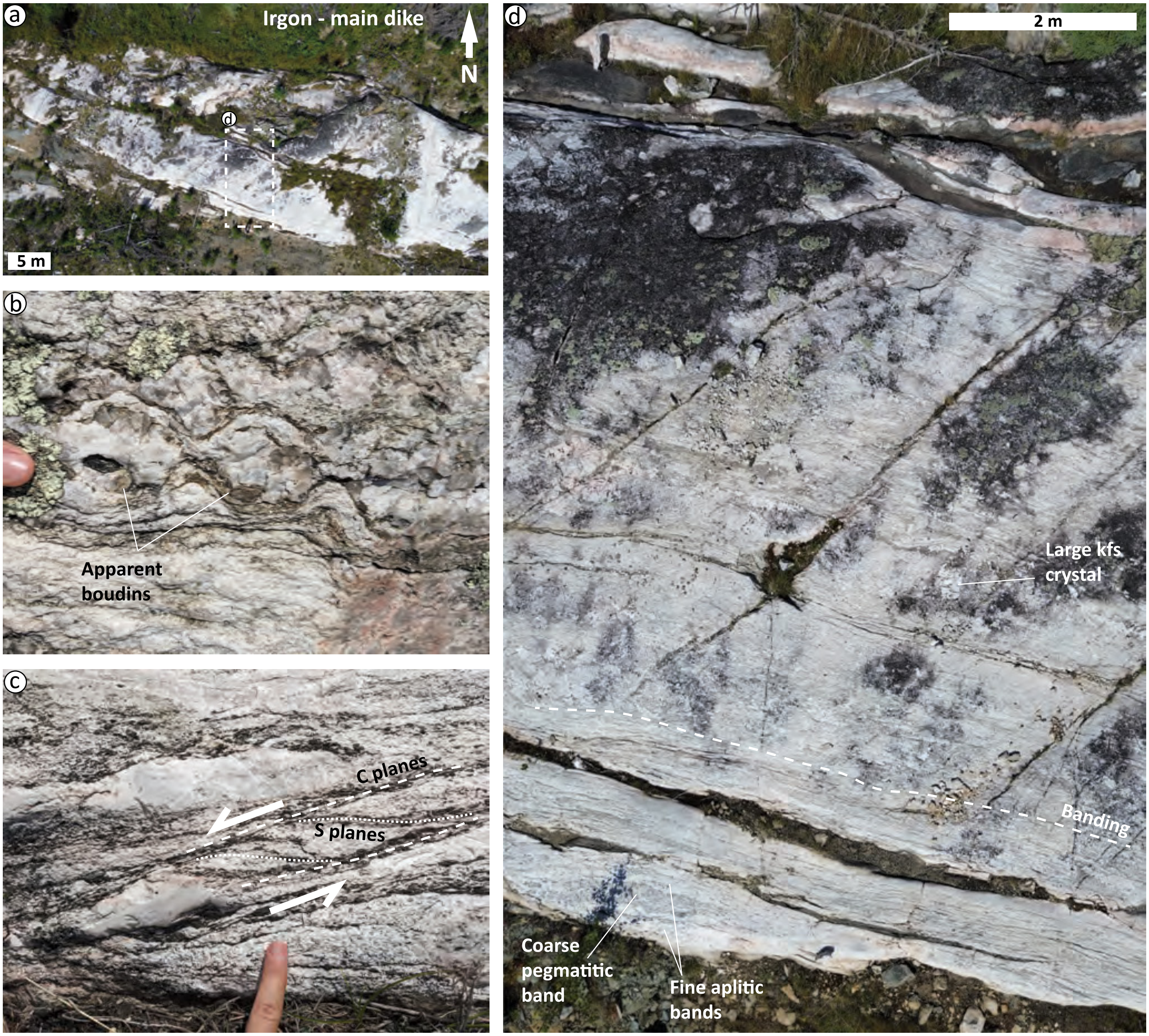


Figure GS2024-6-3: *Key characteristics of the Irgon pegmatite:* ***a)*** *aerial drone photograph of the western portion of the main Irgon dike;* ***b)*** *apparent boudins of coarse pegmatitic material within the main dike;* ***c)*** *S-C structures developed within the pegmatite;* ***d)*** *higher resolution image of aerial drone photograph in (a), showing compositional banding parallel to the pegmatite walls. Abbreviation: kfs, K-feldspar.*

ing melt emplacement; 2) magmatic flow during deformation that occurred before the pegmatite had fully crystallized; or 3) solid-state deformation that occurred under ductile conditions after complete crystallization. Microstructural observations are required to distinguish these possible origins.

Those parts of the Donner Main Dike composed of randomly oriented crystals may have formed by static crystallization from a melt with no subsequent deformation. The parts with a well-developed fabric, however, likely accommodated deformation. The apparent reduction in grain size in some internal high-strain zones suggests that minerals experienced dynamic recrystallization, indicating that at least some of the deformation occurred during solid-state ductile deformation. In contrast, the hostrock and the pegmatite/hostrock contact appear unstrained, suggesting that all deformation was accommodated within the pegmatite itself (or within a narrow shear zone/fault that was intruded and obscured by the pegmatite).

At F.D. No. 5, the occurrence of a narrow pegmatite apophysis extending into and along a discrete shear zone in the hostrock suggests that the pegmatite-forming melts may have locally

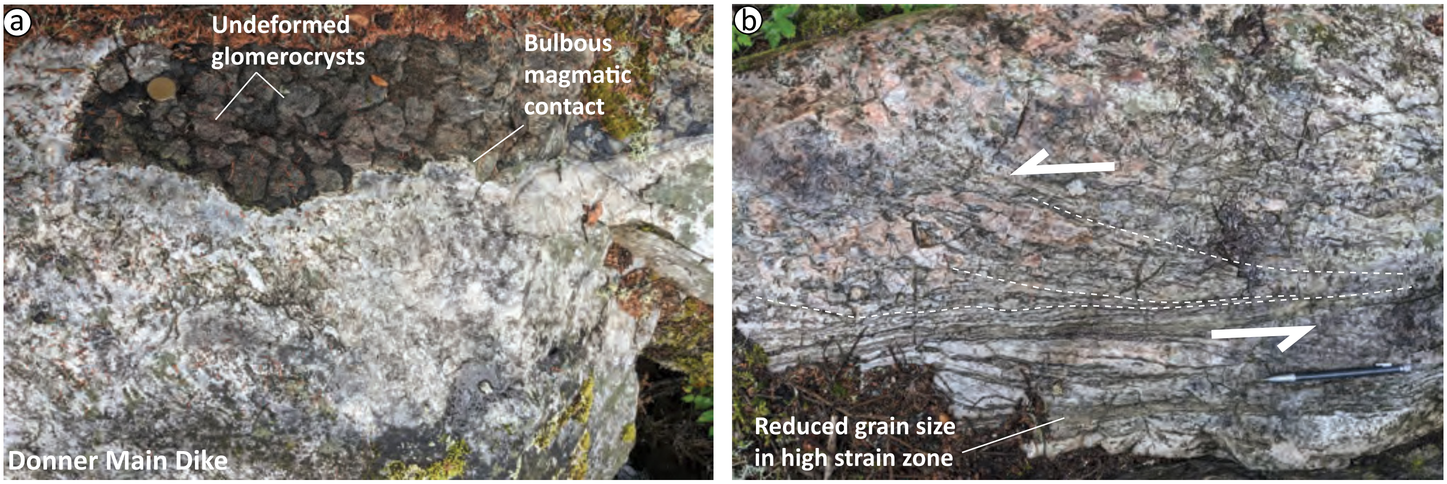


Figure GS2024-6-4: *Outcrop photographs of the Donner Main Dike:* ***a)*** *undeformed part of the dike, with a curved, bulbous magmatic contact; the hostrock is everywhere undeformed;* ***b)*** *highly sheared part of the dike, with asymmetric foliation development indicating sinistral shear, and grain-size reduction in high-strain zones.*

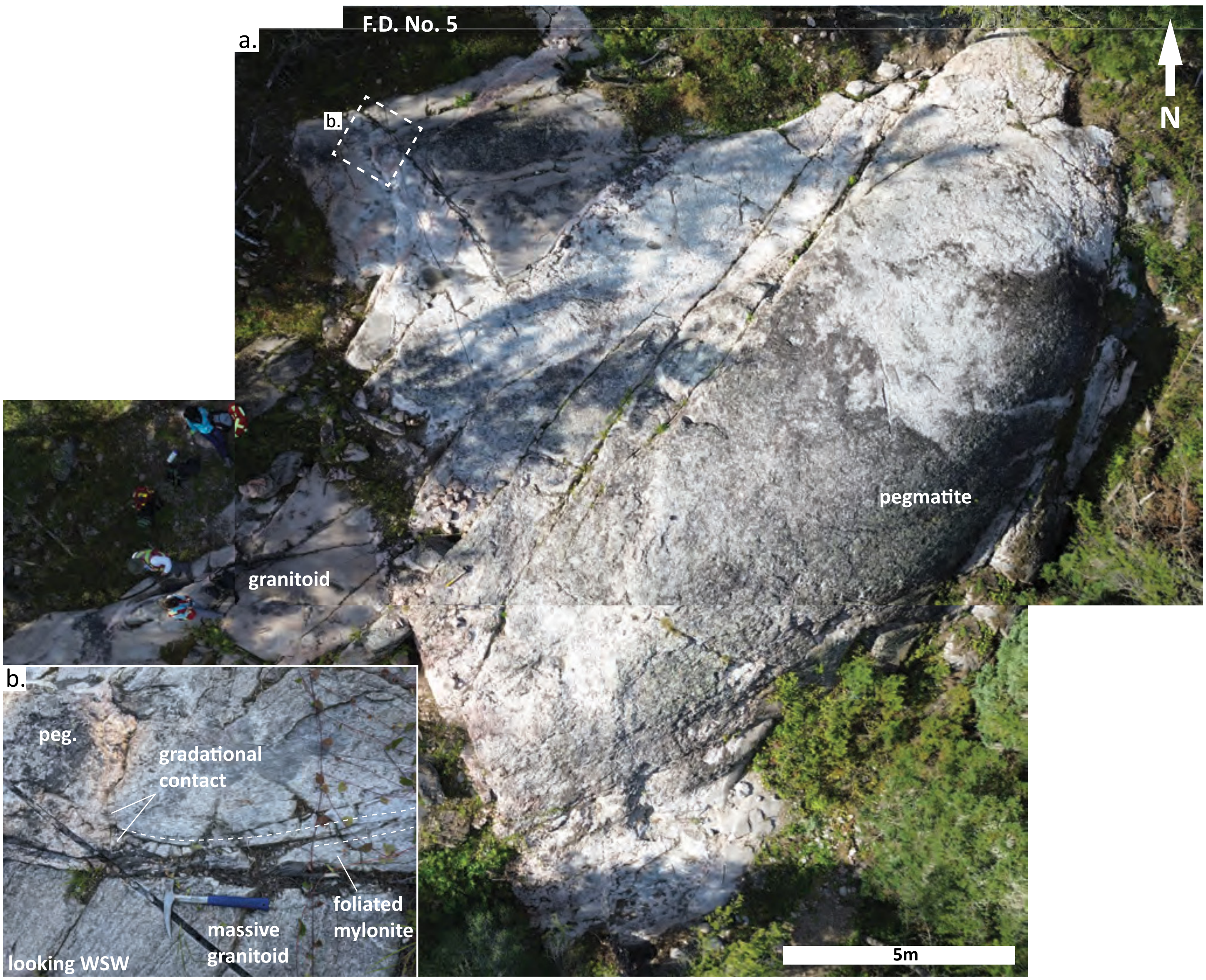


Figure GS2024-6-5: *The F.D. No. 5 pegmatite:* ***a)*** *aerial drone photograph;* ***b)*** *close-up photograph of a small shear zone in the host metagranitoid, partially invaded by an apophysis of the pegmatite.*

intruded pre-existing ductile shear zones. Similarly, the Irgon and Donner Main Dikes may have also intruded pre-existing shear zones, with ongoing deformation along the shear zones being accommodated by magmatic flow (while the dikes were still molten) and subsequent solid-state ductile deformation (as they cooled and crystallized). The gradational contact at F.D. No. 5 further suggests that the melt may have partially replaced material within the shear zone.

Economic considerations

Rare-metal pegmatites host a wide variety of metals and minerals that are considered critical by Canada and other countries (Bauer et al., 2023; Natural Resources Canada, 2024), because of their importance in the modern global economy and the 'green transition' (e.g., Linnen et al., 2012). In particular, Li is a crucial component of Li-ion batteries, which are widely used in applications from electric vehicles to cellphones. Manitoba, and Canada as a whole, host numerous occurrences of Li-bearing rare-metal pegmatites. However, only the largest (and most evolved) pegmatites, such as Tanco in Manitoba and the North American Lithium complex in Quebec, are currently being exploited. This highlights the importance of the size and shape of rare-metal pegmatites in making them attractive for mining.

Understanding what controls the morphology of pegmatites is therefore important for exploration targeting (e.g., Silva et al., 2023). The preliminary observations presented here tentatively suggest that large pegmatites may develop in long-lasting structural trap sites that were reactivated numerous times or continuously over a period of time. If correct, this suggests that exploration for large pegmatites should target structural trap sites along or within major shear zones or faults (similar to those targeted for orogenic gold mineralization; e.g., Groves et al., 2018).

Acknowledgments

The authors thank the First Nations of Treaty 3 for kindly sharing access to their traditional territories, and Sinomine, New Age Metals and Grid Metals Corp. for their support of this fieldwork. The logistical support and guidance provided by the Manitoba Geological Survey, along with K. Roberts and L. Lé Leannec of Grid Metals Corp., and M. Kaczmer of Axiom Group, is greatly appreciated. This study is supported by the Critical Minerals Geoscience and Data (CMGD) initiative of the Geological Survey of Canada (GSC).

References

Bannatyne, B.B. 1985: Industrial minerals in rare-element pegmatites of Manitoba; Manitoba Energy and Mines, Geological Services, Economic Geology Report ER84-1, 96 p., URL <https://manitoba.ca/iem/info/libmin/ER84-1.pdf> [October 2024].

Bauer, D., Khazdozian, H., Mehta, J., Nguyen, R.T., Severson, M.H., Vaagensmith, B.C., Toba, L., Zhang, B., Hossain, T., Sibal, A.P., Smith, B.J., Riddle, M.E., Graziano, D.J., Mathew, T., Cuscaden, P., Dai, Q., Iloeje, C., Edgemon, L., Sarna, C. and Quaresima, J. 2023: 2023 Critical materials strategy; United States Department of Department of Energy, 270 p., URL <https://doi.org/10.2172/1998242>.

Brisbin, W.C. 1986, Mechanics of pegmatite intrusion; American Mineralogist, v. 71, p. 644–651.

Brisbin, W.C., Eby, R.K., Corkery, M.T., Cerny, P., Chackowsky, L.E., Ferreira, K., Halden, N.M., Meintzer, R.E. and Trueman, D.L. 2012: Extreme fractionation and deformation of the leucogranite-pegmatite suite at Red Cross Lake, Manitoba, Canada, III. Description of shearing and mylonitization textures in the lepidolite pegmatites; The Canadian Mineralogist, v. 50, p. 1823–1838, URL <https://doi.org/10.3749/canmin.50.6.1823>.

Černý, P., Trueman, D.L., Zeihlke, D.V., Goad, B.E. and Paul, B.J. 1981: The Cat Lake–Winnipeg River and the Wekusko Lake pegmatite fields, Manitoba; Manitoba Department of Energy and Mines, Mineral Resources Division, Economic Geology Report ER80-1, 216 p.

Ching, J.G.W. 2024: Field, textural, and geochronological investigations into the intrusion dynamics and crystallization histories of the Separation Rapids rare-metal pegmatites, northwestern Ontario; M.Sc. thesis, University of Manitoba, 173 p.

Gilbert, H.P. 2006: Geological investigations in the Bird River area, southeastern Manitoba (parts of NTS 52L5N and 6); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 184–205.

Groat, L.A., Mulja, T., Mauthner, M.H.F., Ercit, T.S., Raudsepp, M., Gault, R.A. and Rollo, H.A. 2003: Geology and mineralogy of the Little Nahanni rare-element granitic pegmatites, Northwest Territories; The Canadian Mineralogist, v. 41, p. 139–160.

Groves, D.I., Santosh, M., Goldfarb, R.J. and Zhang, L. 2018: Structural geometry of orogenic gold deposits: implications for exploration of world-class and giant deposits; Geoscience Frontiers, v. 9, p. 1163–1177, URL <https://doi.org/10.1016/j.gsf.2018.01.006>.

Hall, D. and Kisters, A. 2012: The stabilization of self-organized leucogranite networks — implications for melt segregation and far-field melt transfer in the continental crust; Earth and Planetary Science Letters, v. 355–356, p. 1–12, URL <http://doi.org/10.1016/j.epsl.2012.08.033> [October 2024].

Kremer, P.D. 2010: Structural geology and geochronology of the Bernic Lake area in the Bird River greenstone belt, Manitoba: evidence for syn-deformational emplacement of the Bernic Lake pegmatite group; M.Sc. thesis, University of Waterloo, 91 p.

Kremer, P.D. and Lin, S. 2006: Structural geology of the Bernic Lake area, Bird River greenstone belt, southeastern Manitoba (NTS 52L6): implications for rare element pegmatite emplacement; *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 206–213.

Linnen, R.L., Van Lichtervelde, M. and Černý, P. 2012: Granitic pegmatites as sources of strategic metals: Elements, v. 8, p. 275–280, URL <https://doi.org/10.2113/gselements.8.4.275>.

Martins, T. and Kremer, P.D. 2012: Rare metals in southeastern Manitoba: pegmatites from Bernic Lake and Rush Lake (parts of NTS 52L6); *in* Report of Activities 2012, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 54–58.

Martins, T., Kremer, P. and Vanstone, P. 2013: The Tanco mine: geological setting, internal zonation and mineralogy of a world-class rare element pegmatite deposit; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Field Trip Guidebook FT-C1; Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Open File OF2013-8, 17 p.

Natural Resources Canada 2024: Canada's critical minerals; Natural Resources Canada, URL <https://canada.ca/en/campaign/critical-minerals-in-canada/critical-minerals-an-opportunity-for-canada.html> [September 2024].

Passchier, C.W. and Trouw, R.A.J. 2005: Microtectonics, 2nd edition; Springer Science and Business Media, Würzburg, 366 p.

Plunder, A., Le Pourhiet, L., Räss, L., Gloaguen, E., Pichavant, M. and Gumiaux, C. 2022: Pegmatites as geological expressions of spontaneous crustal flow localization: Lithos, v. 416–417, URL <https://doi.org/10.1016/j.lithos.2022.106652>.

Roush, J., Martins, T., McFarlane, C.R.M., Rinne, M.L. and Groat, L. 2023: Preliminary examination of the Tappy, Eagle and F.D. No. 5 pegmatites in the Cat Lake–Winnipeg River pegmatite field, southeastern Manitoba (parts of NTS 52L5, 11); *in* Report of Activities 2023, Manitoba Economic Development, Investment, Trade and Natural Resources, Manitoba Geological Survey, p. 20–26.

Silva, D., Groat, L., Martins, T. and Linnen, R. 2023. Structural controls on the origin and emplacement of lithium-bearing pegmatites; The Canadian Journal of Mineralogy and Petrology, v. 61, p. 1–10, <https://doi.org/10.3749/2300045>.

Stilling, A., Černý, P. and Vanstone, P.J. 2006: The Tanco pegmatite at Bernic Lake, Manitoba, XVI. Zonal and bulk compositions and their petrogenetic significance; The Canadian Mineralogist, v. 44, p. 599–623.

Yang, X.M. and Houlé, M.G. 2020: Geology of the Cat Creek–Euclid Lake area, Bird River greenstone belt, southeastern Manitoba (parts of NTS 52L11, 12); Manitoba Agriculture and Resource Development, Manitoba Geological Survey, Geoscientific Report GR2020-1, 105 p., 1 map at 1:20 000 scale.