GS2024-2

Updated structural interpretations in the Bird River domain, southeastern Manitoba (parts of NTS 52L5, 6, 11, 12)

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In Brief:

- The Bird River domain contains a wide range of commodities and styles of mineralization
- Bedrock mapping in 2024 involved structural studies of rare-element–bearing pegmatites
- Findings suggest that mineralized pegmatite dikes intruded during the start of brittle deformation in the Bird River domain, in two dominant orientations

Citation:

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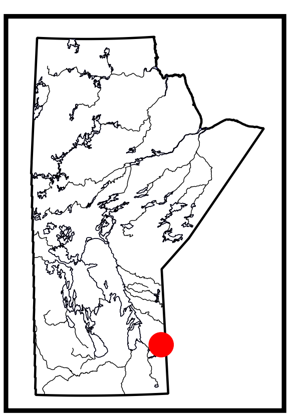

Summary

In 2023, the Manitoba Geological Survey began a project to revisit the Bird River domain, an area rich in critical minerals ranging from pegmatite-hosted commodities such as lithium, cesium, and tantalum, to ultramafic-associated commodities including nickel, chromium, and platinum-group elements. Recent findings relating to structural controls on the emplacement of rare-element-bearing pegmatites are described in this report. Combined with findings from past studies, results from this study suggest that the mineralized pegmatite dikes intruded in two dominant orientations during the start of brittle deformation in the Bird River domain: the first generally belt-parallel (following an overall eastward trend along reactivated shears, many following major lithological boundaries such as greenstone belt margins) and the second dominantly north-northeast-trending along late sinistral brittle-ductile shears.

Introduction

During the summer of 2024, Manitoba Geological Survey (MGS) geologists and field assistants spent approximately five weeks documenting the bedrock geology of the Bird River domain, which included structural studies on pegmatite occurrences. This work was undertaken as part of a mapping and data compilation project in collaboration with the Geological Survey of Canada, University of New Brunswick, and MGS (Cawood et al., 2024; Hodder and Lian, 2024; Nambaje et al., 2024) to

- compile and digitize existing geoscience data—including regional and local geophysical survey data, recent mapping, and new mineral occurrence data—to produce a new geological map of the eastern part of the Bird River domain in southeastern Manitoba;
- evaluate the application of till exploration techniques in the region, particularly for pegmatite-associated commodities, including lithium (see Hodder and Lian, 2024 for more information);
- investigate structural controls on pegmatite emplacement in the region; and
- improve spatial coverage of known mineral occurrences and commodity types, ultimately allowing for more comprehensive evaluations of the timing, geodynamic setting, and structural controls on the various mineral systems in the Bird River domain.

Fieldwork in 2023 and 2024 was partly intended to document the structural geology of known pegmatite occurrences. While mapping and compilation are ongoing, recent structural findings provide an update to the preliminary structural model for pegmatite emplacement in the Bird River domain presented in this report. The updated model builds on past models (especially Kremer, 2010), with new details that highlight the role of both early (ductile) and later (brittle-ductile) structures in pegmatite emplacement and geometry.

Structural geology of the Bird River domain

The Bird River domain refers to all rocks north of the Winnipeg River domain (bounded by the poorly defined Winnipeg River fault) and south of the English River domain (bounded by the Cat Lake–Euclid Lake fault zone; Figure GS2024-2-1). Within the Bird River domain, supracrustal rocks south of the Maskwa Lake batholith make up the southern limb of the Bird River greenstone belt (see Gilbert, 2006; Gilbert et al., 2008) and pegmatites in that region are assigned to the Winnipeg River pegmatite district (Černý et al., 1981). Supracrustal rocks north of the Maskwa batholith (near the Cat Lake–Euclid Lake fault zone in Figure GS2024-2-1) are contiguous and likely cogenetic with the main part of the Bird River belt (Yang and Houlé, 2020). Pegmatites along that northern limb of the Bird River belt are assigned to the Cat Lake–Maskwa Lake pegmatite district (Černý et al., 1981).

The structural geology of the Bird River domain has been described by several workers, including Duguet et al. (2005), Duguet et al. (2009), Gilbert et al. (2008), Kremer and Lin (2006), and Kremer (2010). As summarized in Table GS2024-2-1, the study area records a relatively early episode of orog-

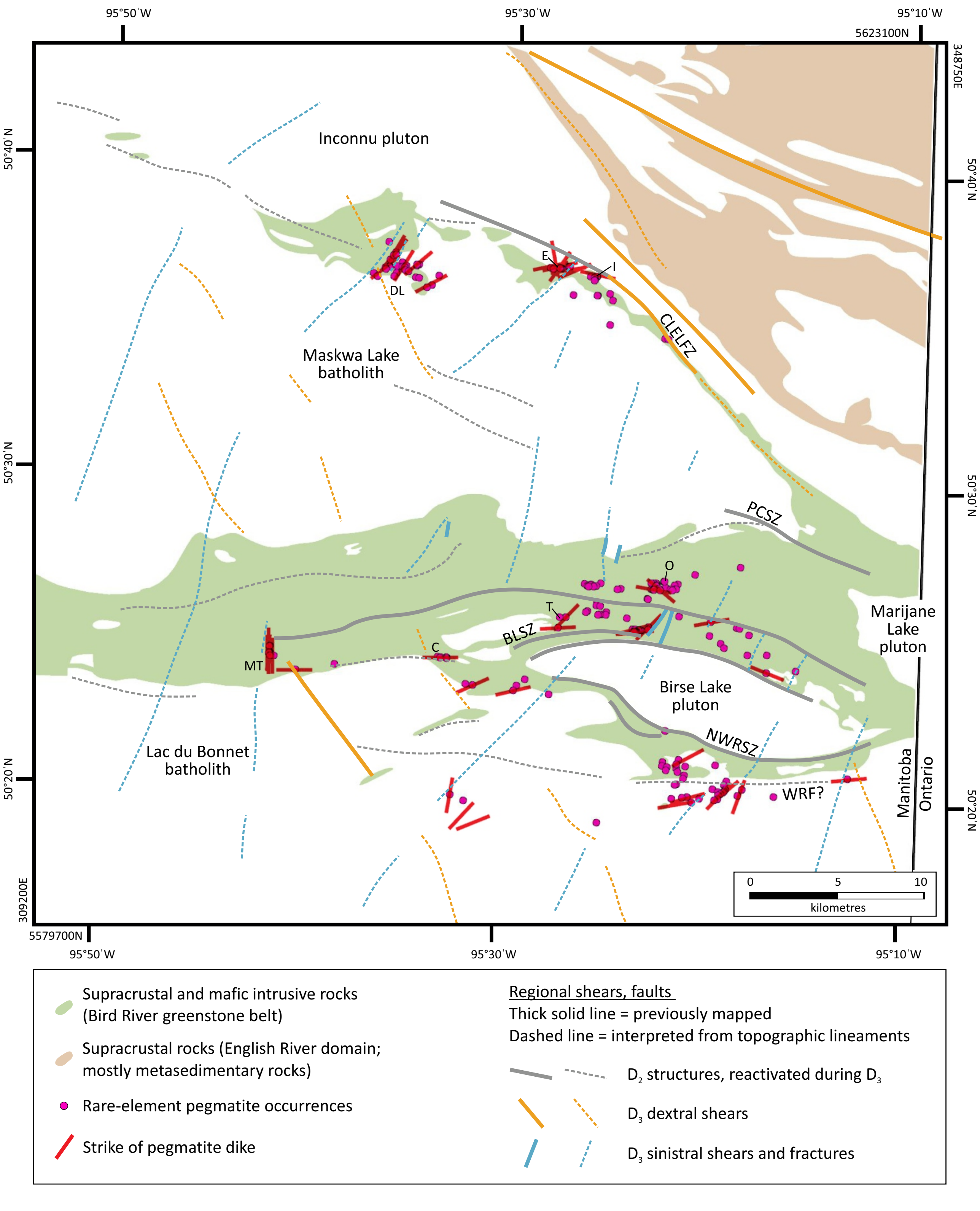

Figure GS2024-2-1: *Simplified map of the Bird River domain, with major structural elements labeled (modified from Martins et al., 2023). For clarity, lakes, rivers, and road networks are omitted, and background geology has been simplified to show only supracrustal-dominant and mafic intrusive units (i.e., approximate greenstone belt outlines). Rare-element–bearing pegmatite occurrences indicated with red dots are from Rinne (2024) and exclude barren (unmineralized or simple granitic) pegmatites, subsurface findings and questionable occurrences such as the Ben Group pegmatites. Red lines indicate the approximate strike of steeply dipping pegmatite dikes, compiled from a series of industry reports cited in Rinne (2024). Abbreviations for labeled structures: BLSZ, Bernic Lake shear zone; CLELFZ, Cat Lake–Euclid Lake fault zone; NWRSZ, North Winnipeg River shear zone; PCSZ, Peterson Creek shear zone; WRF, Winnipeg River fault. Abbreviations for selected pegmatite occurrences: C, Crocodile; DL, Donner Lake area (including West and Main dikes); E, Eagle; I, Irgon; MT, Matty and Tappy; O, Odd; T, Tanco. Corner co-ordinates are in UTM Zone 15, NAD83.*

Table GS2024-2-1: Summary of deformation events in the Bird River domain (after Kremer, 2010).

Deformation event	Related structures	Association with rare-element–bearing pegmatites
D_1	Rare, locally preserved isoclinal folds	Predates intrusion of pegmatites
D_2	Pervasive planar fabric in supracrustal rocks Upright isoclinal folds Formation-bounding shear zones with mostly vertical offset	Predates pegmatite intrusion, but D_2 structures are strong pre-existing fabric and commonly follow major rheological contrasts like greenstone belt margins; D_2 shears (reactivated during D_3) are sites of later pegmatite emplacement
D_3	Repeated reactivation of D_2 shear zones Conjugate near-vertical[1] brittle-ductile shears±fractures (NNE-trending sinistral±south-side-up; SE-trending dextral shears)	Initial pegmatite emplacement along D_2 shears (possibly ductile during intrusion; e.g., Oompa Loompa pegmatite), then into D_3 brittle-ductile shears (more brittle) Continued D_3 deformation results in pegmatites (all orientations) locally overprinted and crosscut by D_3 shears
D_4	Late brittle fractures (dominantly north-trending, subvertical; and northeast-southwest-trending, moderately dipping)	Postdates pegmatite intrusion

[1] In Tanco gabbro, late D_3 expressed as conjugate near-horizontal fractures (local vertical dilation?)

eny resulting in a strong pervasive planar fabric in most supracrustal rocks (D_2), with significant vertical displacement along D_2 structures. Most major units or crustal blocks in Figure GS2024-2-1, including the Birse Lake pluton and Maskwa Lake batholith, were in place prior to D_2 deformation; one younger exception is the Marijane Lake pluton (2645.6 ±1.3 Ma; Gilbert et al., 2008).

Regional deformation progressed to increasingly brittle failure during D_3, when south- or south-southeast-directed stresses were accommodated by a combination of reactivated D_2 shears and a set of conjugate, near-vertical, brittle-ductile D_3 shears. Deformation phases D_1–D_4, and the D_2–D_3 transition in particular, may represent stages of one prolonged orogenic episode; for example, Duguet et al. (2006) described the entire Bird River domain as a "pop-up structure assumed to have developed during a progressive single transpressive event."

The D_3 phase of deformation also records the first appearance of brittle deformation, manifest as brittle-ductile shears with small fracture planes, and minor fractures. Lithium-bearing pegmatites appear to have been emplaced specifically during (or at) the D_3 brittle-ductile transition, a finding emphasized by Kremer (2010) and further supported by recent bedrock observations described in this report.

A preliminary compilation of dike orientations (indicated by red lines in Figure GS2024-2-1) suggests that most of the pegmatite dikes in the Bird River domain are steeply or vertically dipping, and trend either parallel to the Bird River greenstone belt (approximately east-west; along reactivated D_2 shears) or approximately north to northeast (along D_3 structures; Figure GS2024-2-2). In general, pegmatites emplaced into reactivated D_2 shears show

1) overall high strain, some possibly developed during pegmatite cooling and/or during emplacement of repeated pegmatite injections (see Cawood et al., 2024);
2) some features consistent with emplacement into a hot ductile shear, such as bulbous lobate contacts, lack of well-developed chill margins or, in the case of the Oompa Loompa pegmatite, "incipient boudinage that is interpreted to record increments of [D_3] strain" (Kremer, 2010); and
3) a surface trend following the general trend of the Bird River greenstone belt and D_2 structures, generally east to southeast (Figure GS2024-2-1).

whereas pegmatites emplaced into brittle-ductile D_3 shears and fractures generally show

1) relatively low strain (though commonly overprinted by discrete brittle-ductile D_3 shears; e.g., Figure GS2024-20-2f);
2) features consistent with emplacement into brittle or brittle-ductile structures, such as near-planar margins parallel to the associated structures;
3) an overall north-northeast or northeast surface trend; and
4) slightly later emplacement than the D_2-parallel dikes.

Most of the D_3-parallel features documented in the field are clearly dikes (i.e., magmatic in origin and showing characteristics such as chill margins or complex zoning). However, a few of the thinner examples (such as the crosscutting spodumene- or quartz and spodumene-filled features in Figures GS2024-2-2b, d) have characteristics perhaps more consistent with a magmatic-hydrothermal transition. Further investigation could explore the possible role of late hydrothermal fluids in lithium mineralization or remobilization during late D_3 deformation.

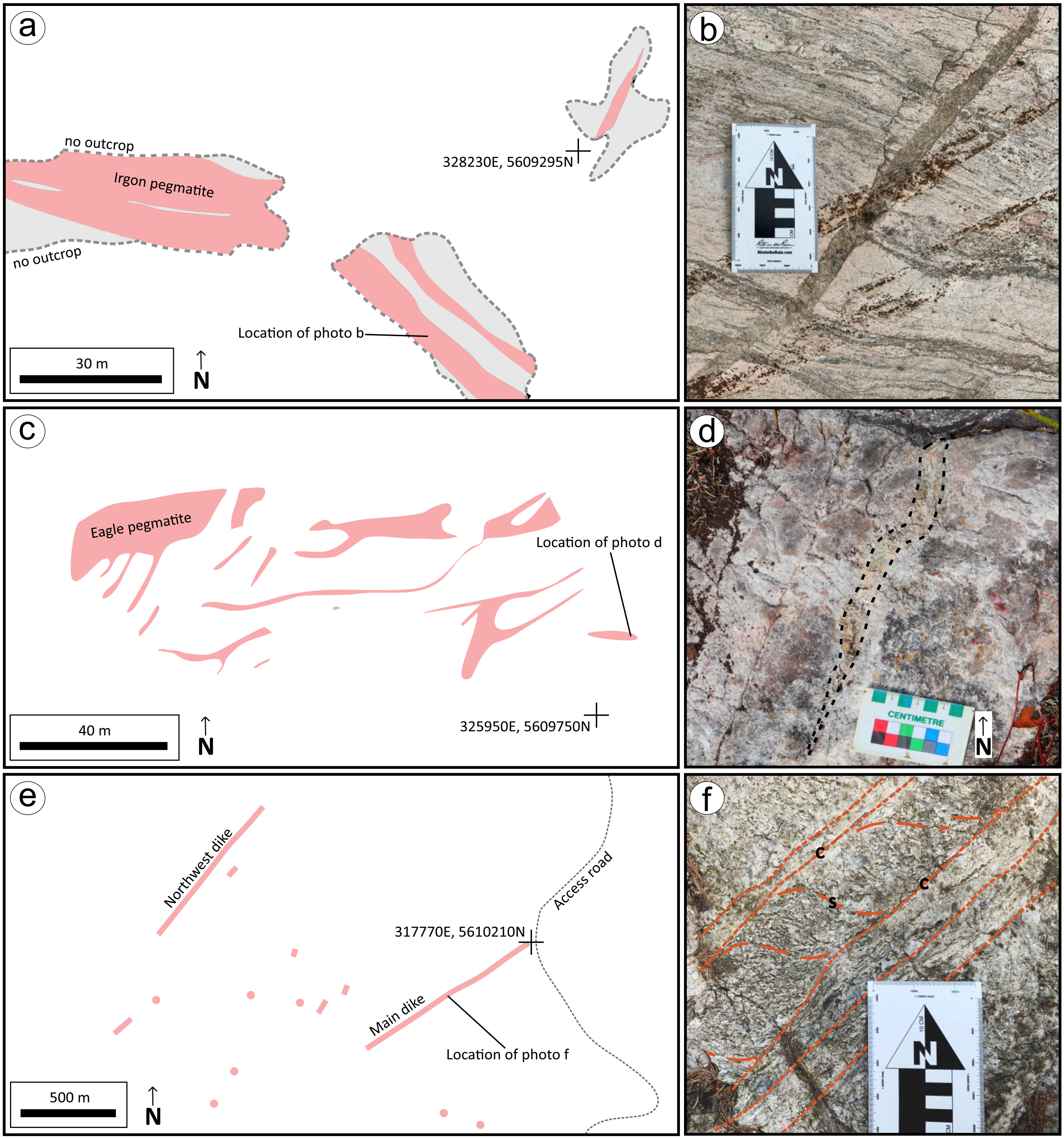

Figure GS2024-2-2: *Simplified pegmatite traces and outcrop photographs of selected occurrences in the Cat Lake–Maskwa Lake pegmatite district, showing* ***a)*** *a map of the eastern exposed portion of the Irgon pegmatite, with the main part of the dike locally bifurcated and striking parallel to the regional D_2 fabric, along with a north-northeast-striking and less-deformed spodumene-bearing dike to the northeast;* ***b)*** *sheared (by D_3) spodumene-bearing Irgon dike crosscut by north-northeast-striking brittle D_3 structures infilled with quartz and spodumene;* ***c)*** *outcrop map of the eastern part of the Eagle pegmatite, with the main or thickest portions following the regional D_2 fabric, and a series of apophyses striking north-northeast along D_3 structures;* ***d)*** *part of the Eagle pegmatite crosscut by brittle-ductile D_3 shears and associated late spodumene (outlined);* ***e)*** *map of pegmatite exposures near Donner Lake, with surface traces of the steeply-dipping Main and Northwest dikes labeled, along with pink dots and short line segments indicating the locations and trend of other pegmatite dikes;* ***f)*** *part of the northeast-striking Main dike, crosscut by northeast-striking D_3 shears with a sinistral C-S fabric (labeled). Eagle pegmatite outlines in panel c are simplified from detailed bedrock mapping (unpublished data from New Age Metals Inc., 2024). All co-ordinates are in UTM Zone 15, NAD83.*

The Eagle and Irgon pegmatites display higher D_3 strain along the D_2-parallel dikes and lower strain generally along north-northeast-striking (D_3 sinistral shear-hosted) dikes or apophyses. This is interpreted to reflect local partitioning of D_3 strain mostly along reactivated D_2 structures (and/or D_3 strain partitioned strongly along major lithological boundaries), as opposed to a generation of much earlier and more deformed lithium-bearing pegmatite.

In the Donner Lake area, pegmatite dikes are mostly steeply dipping and follow a north-northeast or northeast trend (Figure GS2024-2-2e). This includes the largest two dikes in the area, the Main and Northwest dikes, which have a combined inferred resource estimate of 6.81 Mt of ore grading 1.39% Li_2O (Millar et al., 2023). These dikes are interpreted to have been emplaced along D_3 sinistral brittle-ductile shears and were found to have been crosscut by the same set of structures (Figure GS2024-2-2f).

South of the Maskwa batholith (Winnipeg River pegmatite district), there are several north-northeast-trending pegmatite dikes, along with a series of likely related north-northeast-trending structures evident in previous mapping (thick blue lines in Figure GS2024-2-1) and prominent topographic lineaments. Both the Odd dike and the Crocodile pegmatite were found to have minor north- or north-northeast-trending apophyses from a D_2-parallel main dike, perhaps similar to the Eagle pegmatite dikes depicted in Figure GS2024-2-2c. It is also possible that the Matty and Tappy dikes are controlled by sinistral D_3 shears that trend northward in that part of the belt (Figure GS2024-2-1). In general, however, the relationship between rare-element-bearing pegmatites and late D_3 structures is currently not as clear in the Winnipeg River pegmatite district as it is in the Cat Lake–Maskwa Lake district.

Emplacement model for Li-bearing pegmatites

Based on a combination of past and recent field observations, and previous models (especially Kremer, 2010), the emplacement of rare-element-bearing pegmatite intrusions in the Bird River domain appears to have involved

1) During early D_3: ascent of highly fractionated magmas specifically along major reactivated D_2 shears such as the Bernic Lake shear zone. In some locations, injections along these reactivated structures may have occurred repeatedly to produce banded and variably strained pegmatite dikes (Cawood et al., 2024).

2) Late D_3: continued uplift, exhumation and/or cooling promote increasingly brittle rock failure. Continued south- or south-southeast-directed stress is partly accommodated along the reactivated D_2 shears, but they are at this point nearly perpendicular to the regional stress field; consequently, more shortening is being accommodated by a developing network of vertical, brittle conjugate structures that trend mostly north-northeast (with sinistral offset) and southeast (dextral offset).

3) Late D_3: continued proliferation of dilatant sites in D_3 structures, allowing for larger volumes of magma emplacement; at this time, rare-element-bearing magmas ascending along reactivated D_2 shears are also injected into the newly opened D_3 structures, particularly into the set of sinistral brittle-ductile shears and fractures trending north-northeast. Along with dikes, some late spodumene may precipitate in D_3-parallel veins, possibly from fluids derived from pressure-controlled exsolution and local accumulation of magmatic volatiles.

This sequence of events closely follows the genetic model proposed by Kremer (2010) for the Tanco pegmatite. One important exception is that in the Tanco area, while the conjugate D_3 brittle-ductile structures continued to form in a north-northwest-directed stress field, the least principal stress (or the direction of likely dilation for magma emplacement) apparently rotated from an east-west to a near-vertical axis (Kremer, 2010). This could reflect a transition from a wrench to a thrust regime in progressively shallowing crust during D_3. Alternatively, Kremer (2010) suggested that this simply reflects differing strain responses by different hostrock units, with the Tanco gabbro representing an unusually competent, large, and vertically oriented unit that was perhaps more prone to vertical dilation during the end of D_3.

Economic considerations

The Bird River domain is a geologically diverse and well-mineralized area, and study and compilation work is ongoing. With respect to rare element-bearing pegmatites specifically, recent findings and structural interpretations suggest targeting major D_2 shear zones, dilatant sites within those zones (e.g., jogs or releasing bends, especially viewed in a north–south section), D_3 shear zones, and zones where D_3 shears intersect D_2 structures or major lithological boundaries such as batholith margins.

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