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LITHIUM–CESIUM–TANTALUM (LCT) PEGMATITES IN SOUTHWESTERN NEWFOUNDLAND

J. Conliffe, D.B. Archibald[1] and B.A. Sparkes[2]
Mineral Deposits Section
[1]Earth and Environmental Sciences Department, St. Francis Xavier University, Antigonish, Nova Scotia
[2]Benton Resources Inc., Thunder Bay, Ontario

ABSTRACT

Lithium is identified by Canada as a key critical mineral due to its use in battery technologies, and demand is expected to grow along with the transition to a green economy. Lithium–cesium–tantalum (LCT) pegmatites are a global source of lithium, and the recent discovery of LCT pegmatites in southwestern Newfoundland, ~30 km north of Burgeo, has shown the potential for the province to host lithium deposits.

Southwestern Newfoundland has favourable geology for hosting significant lithium resources including voluminous, geochemically evolved plutonic rocks, crustal-scale geological structures, and fertile metasedimentary and metavolcanic rocks. The geology in the Burgeo area can be divided into two terranes, separated by a major crustal-scale shear zone (Bay d'Est Fault Zone; BDFZ). South of the BDFZ, the Hermitage Flexure terrane consists of Neoproterozoic peri-Gondwanan basement and Silurian volcanosedimentary cover rocks. North of the BDFZ, the Bay du Nord terrane is dominated by amphibolite-facies Cambrian–Silurian metavolcanic and metasedimentary rocks. Both terranes were subsequently intruded by diverse suites of Silurian–Devonian granites, including several peraluminous granite plutons that have potential as parent magmas to LCT pegmatites.

Two areas of LCT pegmatites have been discovered since 2021. The Kraken pegmatite field consists of at least ten spodumene-bearing pegmatite dykes over an area of ~1 x 2 km. In trenches, the dykes are up to >5 m thick, and diamond drilling has intersected up to 15.23 m grading @ 1.04% Li_2O. The pegmatites intrude metavolcanic and metasedimentary rocks of the Dolman Cove Formation and are associated with well-developed metasomatic alteration halos and abundant tourmaline in the country rocks close to the dykes. Pegmatite dykes are weakly zoned, with spodumene-rich areas containing ~10–50% spodumene forming up to 12 cm elongate crystals. The Hydra pegmatite is located ~10 km northeast of the Kraken pegmatite field and is a 2–8 m thick-zoned pegmatite grading up to 8.75% Cs_2O and 0.41% Li_2O over 1.2 m (channel sample). Pollucite is the main Cs-bearing mineral, with Li occurring in fine-grained spodumene and Li-rich mica.

*Ongoing research at the Geological Survey of Newfoundland and Labrador (GSNL), in collaboration with partners in academia, industry and the Geological Survey of Canada (GSC), aim to model the complex regional and local geological controls, and timing of pegmatite forming events. New data will allow for testing rival models of pegmatite formation and enhance exploration efficiencies. In addition, ongoing regional geochemical and geological studies throughout the Gander and Avalon zones will help determine the potential for LCT pegmatites and other granite-related critical mineral deposits (*e.g., *W, Mo, Sn, Bi) elsewhere in southern and central Newfoundland.*

INTRODUCTION

Lithium is a critical mineral required for the green energy transition because of its applications in battery technologies, and is identified as a priority mineral in Canada's Critical Mineral Strategy for its potential to spur economic growth and support domestic supply chain management (Natural Resources Canada, 2022). Pegmatites enriched in lithium, cesium and tantalum (commonly known as LCT pegmatites) are a major global source of lithium, with hard-rock lithium mining operations in Australia accounting for more than 45% of global lithium production in 2022 (U.S. Geological Survey, 2023). In addition, LCT pegmatites are an important source of other critical minerals on Newfoundland and Labrador's critical mineral list (DIET, 2023), including cesium, tantalum, beryllium, high-quality silica and feldspar

(Linnen *et al.*, 2012; Bradley *et al.*, 2017; McCaffrey and Jowitt, 2023).

LCT pegmatites are highly fractionated, rare-metal granitic pegmatites that form in collisional orogenic to post-orogenic tectonic settings (Černý, 1991; Bradley *et al.*, 2017). Typically hosted in greenschist- to amphibolite-facies metasedimentary or metavolcanic rocks, they commonly have a close spatial association with geochemically evolved, peraluminous granite plutons and major crustal-scale structures. Most LCT pegmatites have traditionally been thought to be associated with late-tectonic peraluminous magmas that form due to anatexis of accretionary sediments during crustal thickening (Černý, 1991; London, 2008, 2018). During fractional crystallization, residual granitic melts become enriched in incompatible elements (*e.g.*, Li, Be, Rb, Cs, Nb, Ta and Sn), and volatiles (*e.g.*, H_2O, B, F and P) that are not easily accommodated in the common rock-forming minerals (London, 2008, 2018). These residual melts are emplaced as pegmatites in the surrounding country rocks up to 10 km away from the parental pluton, with emplacement controlled by major crustal structures such as shear zones (Baker, 1998; London, 2008; Linnen *et al.*, 2012; Silva *et al.*, 2023). Pegmatites in some districts show concentric zoning around the parental granite pluton, with the most evolved magmas enriched in Li, Ta, Be and Cs located farthest from the pluton (Černý, 1991; Baker, 1998; London, 2018). Recent research (*e.g.*, Müller *et al.*, 2017; Wise *et al.*, 2022; Knoll *et al.*, 2023) has proposed alternative mechanisms to generate LCT pegmatites, including *via* direct anatexis of metasedimentary rocks and crystallization of small volumes of a lithium-enriched melt or by multistage melting with initial anatexis of a enriched metasedimentary rock and subsequent remelting of the granitic crust (Koopmans *et al.*, 2024). Ongoing research is underway to test the validity of these models, particularly in districts where no parental granite pluton is identified.

The eastern edge of the Appalachian–Caledonian orogenic belt is characterized by peri-Gondwanan terranes (Ganderia, Avalonia, Meguma, Carolinia) that were accreted to composite Laurentia during the Ordovician to Carboniferous closure of the Iapetus and Rheic oceans (Pollock *et al.*, 2012; van Staal and Barr, 2012). Several significant LCT pegmatite districts are located in these peri-Gondwanan terranes, including the Leinster pegmatites in Ireland (Barros and Menuge, 2016), Brazil Lake in Nova Scotia (Kontak, 2006), Plumbago pegmatite in Maine (Simmons *et al.*, 2020) and the Carolina Tin-Spodumene Belt (Swanson, 2012). These pegmatites were all emplaced into peri-Gondwanan metasedimentary and metavolcanic rocks in a collisional orogenic to post-orogenic tectonic setting during the Salinic, Acadian, Neoacadian and Alleghanian orogenies (~420–280 Ma; van Staal and Barr, 2012). Many of these pegmatite districts have a close spatial and temporal association with peraluminous granite suites and/or crustal-scale shear zones. Romer and Kroner (2016) considered that these peri-Gondwanan terranes were particularly fertile for LCT mineralization (and associated Sn–W deposits) due to the pre-enrichment of clay minerals in the Gondwanan-derived sediments that were subsequently melted during later crustal thickening.

Peri-Gondwanan terranes of southern Newfoundland (Ganderia and Avalonia) host numerous peraluminous granite suites that are associated with significant granite-related critical mineral occurrences including the Grey River tungsten deposit, Moly Brook Mo–Cu deposit, and Moulting Pond Sn prospect (Figure 1). The potential of this region to host LCT mineralization, was first reported by Magyarosi (2020), who recognized highly evolved pegmatites enriched in Li, Cs and Ta in the Snowshoe Pond area of central Newfoundland (Figure 1). This was followed in 2021 by the discovery of LCT pegmatites at the Kraken pegmatite field, north of Burgeo, by Benton Resources Inc. and Sokoman Minerals Corp. The Kraken pegmatite field consists of spodumene-bearing pegmatites over an area of approximately 1 x 2 km, and drilling in 2022 and 2023 intersected up to 1.04% Li_2O over 15.23 m (Benton Resources Inc. press release, February 2023). The Hydra pegmatite was discovered ~10 km northeast of the Kraken pegmatites in late 2022. This pegmatite is enriched in cesium, with channel samples of 8.76% Cs_2O, 0.41% Li_2O, 0.025% Ta_2O_5, and 0.33% Rb_2O over 1.2 m (Benton Resources Inc. press release, December 2022) and drilling intersecting 1.22 m grading 0.51% Cs_2O (Benton Resources Inc. press release, September 2023). These pegmatites are now collectively known as the Killick Lithium Project, which is actively being explored by Vinland Lithium, a consortium of Benton Resources Inc., Sokoman Minerals Corp., and Piedmont Lithium Inc.

This paper provides the first geological and mineralogical description of the Kraken and Hydra pegmatites, based on field visits in 2022 and 2023. Petrographic descriptions of outcrop and drillcore samples from the Kraken and Hydra pegmatites were carried out using a combination of optical microscopy at the GSNL and Scanning Electron Microscopy-Mineral Liberation Analysis (SEM-MLA) at Memorial University. In addition, mineralogy of three samples were completed by powder X-ray diffraction (XRD) analyses for bulk-rock fractions at the Mineralogy Lab of GSC-Ottawa. This study is a collaboration between the GSNL, St. Francis Xavier University, Vinland Lithium Inc., Memorial University, and the Geological Survey of Canada, investigating the geological controls on formation of LCT pegmatites in southwestern Newfoundland and the broader granite-related critical minerals (Li, Cs, W, Mo, Sn, Ta, Bi)

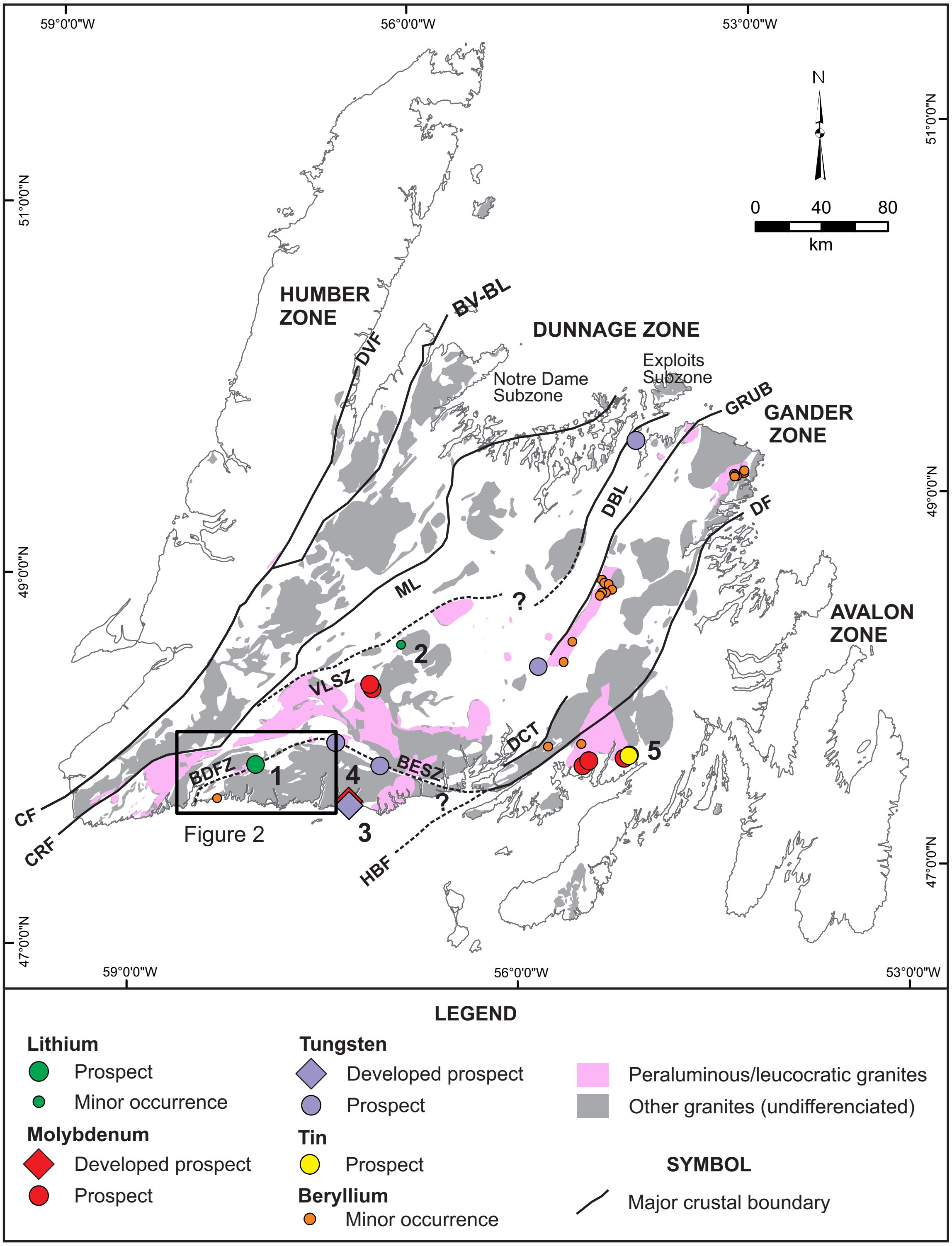

Figure 1. *Simplified map of the island of Newfoundland, showing major lithotectonic zones, large-scale crustal structures, distribution of Silurian to Devonian peraluminous and leucocratic granites, and location of major critical mineral occurrences associated with granites (adapted from Colman-Sadd* et al., *1990). 1. Kraken pegmatite field. 2. Snowshoe Pond Li occurrence. 3. Grey River W deposit. 4. Moly Brook Mo–Cu deposit. 5. Moulting Pond Sn prospect. BDFZ=Bay d'Est Fault Zone, BESZ=Bay d'Espoir Shear Zone, BV–BL=Baie Verte–Brompton Line, CF=Cabot Fault, CRF=Cape Ray Fault, DBL=Dog Bay Line, DCT=Day Cove Thrust, DF=Dover Fault, DVF=Doucers Valley Fault Zone, GRUB=Gander River Complex, HBF=Hermitage Bay Fault, ML=Mekwe'jit Line, VLSZ=Victoria Lake Shear Zone. Location of Figure 2 shown.*

potential of southern and central Newfoundland. In addition, this report will provide a brief overview of ongoing research projects assisting regional exploration of these deposit types.

REGIONAL GEOLOGICAL SETTING

The geology of southwestern Newfoundland consists of a sequence of peri-Gondwanan Neoproterozoic basement rocks, Cambrian–Ordovician arc–back-arc complexes, Silurian volcanosedimentary cover rocks, and Silurian–Devonian intrusive suites (Figure 2; Chorlton, 1980a; Dunning and O'Brien, 1989; Dunning *et al.*, 1990; O'Brien *et al.*, 1991, 1993; Valverde-Vaquero *et al.*, 2006). The region is divided into two terranes (Hermitage Flexture and Bay du Nord), separated by the Bay d'Est Fault Zone (BDFZ; Figure 2), a major long-lived shear zone correlated with the Eastern Highlands Shear Zone on Cape Breton Island (Barr *et al.*, 2014; van Staal *et al.*, 2021).

HERMITAGE FLEXURE TERRANE

The Hermitage Flexture terrane south of the BDFZ is largely obscured by later Silurian and Devonian intrusive rocks but is inferred to underlie much of the south coast of Newfoundland (van Staal *et al.*, 2021). It consists of a number of isolated inliers of Cryogenian–Ediacaran sedimentary and magmatic rocks, including the Cinq-Cerf Bay and Grandys Brook inliers (Figure 2), and the Grey River inlier farther to the east (Dunning and O'Brien, 1989; O'Brien *et al.,* 1991, 1993; Valverde-Vaquero *et al.*, 2006). Early work suggested that these inliers were correlative with the Avalonian rocks of eastern Newfoundland, based on their

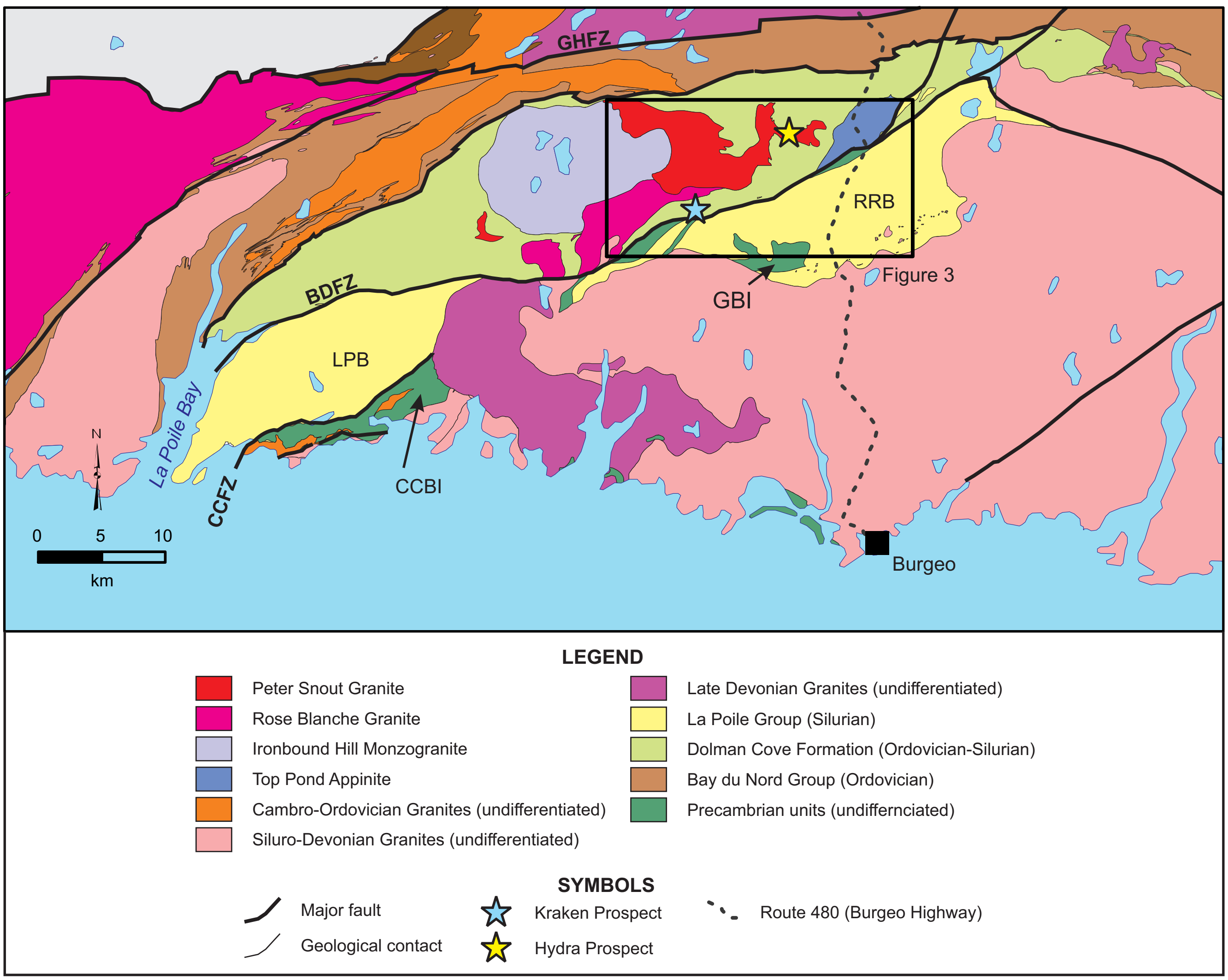

Figure 2. *Geology map of the La Poile, Peter Snout and Burgeo area of southwest Newfoundland, compiled from published geological maps (Chorlton, 1978, 1980a, b; O'Brien, 1982, 1990; O'Brien and O'Brien, 1989; O'Brien and Tomlin, 1983). BDFZ=Bay d'Est Fault Zone, CCBI=Cinq Cerf Bay Inlier, CCFZ=Cinq Cerf Fault Zone, GBI=Grandys Brook Inlier, GHFZ=Gunflaps Hill Fault Zone, LPB=La Poile sub-basin, RRB=Rocky Ridge sub-basin. Location of Figure 3 shown.*

common late Neoproterozoic tectonic and magmatic history (O'Brien *et al.*, 1996; Valverde-Vaquero *et al.*, 2006). However, other authors have highlighted that the Hermitage Flexure terrane is unlike typical Avalonian sequences due to the presence of high-grade metamorphic rocks, absence of a Cambrian shelf succession, and negative (evolved) εNd(t) values (Fryer *et al.*, 1992; Kerr *et al.*, 1995; van Staal *et al.*, 1996b; Waldron *et al.*, 2022). They have instead correlated the Hermitage Flexure terrane with the Bras d'Or and Aspy terranes of Cape Breton Island, which are part of Ganderia (Lin *et al.*, 2007; Barr *et al.*, 2014; van Staal *et al.*, 2021; Waldron *et al.*, 2022).

The Cinq Cerf Gneiss is the oldest Neoproterozoic unit (675 +12/−11 Ma; Valverde-Vaquero *et al.*, 2006) and is unconformably overlain by Ediacaran sandstone and tuff (~585 Ma; Dubé *et al.*, 1995), which are host to the past producing Hope Brook high-sulphidation epithermal gold deposit (Dubé *et al.*, 1995). These are intruded by intrusive rocks of the Roti Intrusive Suite (~584–562 Ma; Dunning and O'Brien, 1989; O'Brien *et al.*, 1991; Stewart, 1992; Dubé *et al.*, 1995) and Late Cambrian granite and gabbro plutons (~499 to 495 Ma; Dunning and O'Brien, 1989; O'Brien *et al.*, 1991).

The Neoproterozoic inliers are in fault contact or unconformably overlain by Silurian volcanic and sedimentary rocks of the La Poile Group (O'Brien *et al.*, 1991). The La Poile Group is divided into two elongate, northeast trending sub-basins; the La Poile Bay sub-basin in the west and the Rocky Ridge sub-basin in the east (Figure 2; O'Brien *et al.*, 1991). The La Poile Bay sub-basin is in fault contact with the Neoproterozoic Cinq Cerf inlier along the Cinq Cerf Fault Zone (CCFZ, Figure 2), and is predominantly comprises felsic tuff, rhyolite and quartz–feldspar-porphyry and lesser agglomerate, conglomerate and coarse-grained, poorly sorted sandstone (O'Brien *et al.*, 1991). The Rocky Ridge sub-basin is dominated by quartz-feldspathic, well-sorted and crossbedded sandstone with subordinate felsic tuff and conglomerate, and locally unconformably overlies ~584 Ma granite of the Roti Intrusive Suite (O'Brien *et al.*, 1991). The northern margin of both sub-basins is marked by the BDFZ (Figure 2), which is the boundary between the Heritage Flexure and Bay du Nord terranes. Both the Cinq Cerf and Bay d'Est fault zones are interpreted to represent southeast dipping, northwest verging thrust faults, which developed during thrust imbrication in the Salinic orogeny, that postdated deposition of the La Poile Group (O'Brien, 1989; O'Brien *et al.*, 1991).

BAY DU NORD TERRANE

To the north of the BDFZ, lies a belt of deformed and metamorphosed Ordovician to Silurian volcanic and sedimentary rocks commonly referred to as the Bay du Nord Group (Chorlton, 1980a, b; O'Brien, 1983; O'Brien *et al.*, 1986; Tucker *et al.*, 1994), but referred to herein as the Bay du Nord terrane. The Bay du Nord terrane has been less extensively studied than the Hermitage Flexure terrane, but it is commonly included in the Exploits Subzone of the Dunnage Zone as defined in central and northeastern Newfoundland (Williams, 1979). However, recent studies suggested that the Bay du Nord Group formed part of the Ordovician to Silurian cover sequence of Ganderia and therefore included in the Gander terrane (van Staal *et al.*, 2021; Waldron *et al.*, 2022). Geophysical surveys across the Cabot Strait between Newfoundland and Cape Breton Island indicate that the Bay du Nord terrane may be continuous with the Aspy terrane on Cape Breton Island (Barr *et al.*, 2014; van Staal *et al.*, 2021).

The Bay du Nord Group as defined by O'Brien *et al.* (1986) consists of an eastward-thinning package of felsic volcanic rocks interbedded with, and overlain by, pelitic and psammitic metasedimentary rocks. It also includes lesser mafic volcanic rocks and amphibolite (Chorlton, 1980a; O'Brien and Tomlin, 1984; O'Brien *et al.*, 1986). A sheared and deformed belt of mafic–ultramafic rocks may represent an ophiolitic basement to the Bay du Nord Group (Chorlton, 1980a; O'Brien and Tomlin, 1984).

Tucker *et al.* (1994) showed that rather than forming an internally conformable stratigraphic group, the Bay du Nord Group comprises at least three distinct lithotectonic belts, which were juxtaposed during later tectonic reconfiguration. The northernmost belt, termed the North Bay belt, consists predominantly of graphitic and pelitic metasedimentary and lesser felsic volcanic rocks (Tucker *et al.*, 1994) that host volcanogenic massive sulphide mineralization, including the Strickland VMS deposit (Wynne and Strong, 1984). The age of the North Bay belt is unknown, but correlative rocks to the east of the study area were dated at 466 ± 3 Ma (Dunning *et al.*, 1990). The Rattling Brook belt is located to the south of the North Bay belt. It is strongly deformed and locally mylonitic sedimentary, volcanic and ophiolitic rocks that were intruded by the Ordovician Baggs Hill Granite (477.6 ± 1.8 Ma; Tucker *et al.*, 1994). As proposed by Tucker *et al.* (1994), the North Bay and Rattling Brook belts are included in the Bay du Nord Group as defined by O'Brien *et al.* (1986), although more research is needed to determine the relative ages of these belts.

The Dolman Cove belt is the southernmost belt (Tucker *et al.*, 1994), and predominantly comprises felsic tuff and minor sandstone, shale, conglomerate and amphibolite (Dolman Cove Formation; Chorlton, 1980a, b; Tucker *et al.*, 1994). It also includes a distinctive pink, fine-grained rhyolite known as the Piglet Brook rhyolite (Chorlton, 1980b).

These rocks were subjected to the same amphibolite-grade metamorphism as Bay du Nord Group to the north, but do not show evidence for the pervasive, pre-Salinic deformation observed in the Rattling Brook belt (Tucker *et al.*, 1994). In addition, conglomerate in the Dolman Cove Formation contains distinctive clasts of deformed Baggs Hill granite and other volcanic and sedimentary units typical of the Rattling Brook belt, indicating that deposition of the Dolman Cove Formation postdated deformation in the Rattling Brook belt and should not be included in the Bay du Nord Group (Tucker *et al.*, 1994). The only published geochronological constraint from the Dolman Cove Formation is an imprecise U–Pb zircon age of 449 ± 20 Ma (Chorlton, 1980a) and some authors have suggested that the Dolman Cove Formation may represent a metamorphosed Silurian cover sequence equivalent to the La Poile Group in the Hermitage Flexure terrane (O'Brien *et al.*, 2006).

SILURIAN TO DEVONIAN INTRUSIVE ROCKS

All rock units in the Heritage Flexure and Bay du Nord terranes are intruded by syn- to posttectonic Silurian and Devonian plutons. The largest intrusion in southern Newfoundland is the Burgeo Intrusive Suite (BIS), which has a surface extent of more than 2200 km^2 and occupies a large proportion of the Heritage Flexure terrane (Dickson *et al.*, 1996). The BIS is a composite intrusive body predominantly composed of an early phase of foliated K-feldspar and plagioclase porphyritic granodiorite and granite, and a later phase of less deformed biotite ± muscovite granite (Dickson *et al.*, 1996). U–Pb geochronology indicates that the BIS was emplaced between 428 and 411 Ma during the Salinic and Acadian orogenies (Dunning *et al.*, 1990; Kerr and McNicoll, 2012). The calc-alkaline I-type geochemistry and limited Sm, Nd and O isotopic data suggest that it formed from melting of a lower crustal gneissic material with a possible mantle component and only limited assimilation of upper crustal rocks (Fryer *et al.*, 1992; Kerr *et al.*, 1995, Dickson *et al.*, 1996). Other smaller plutons intruded Neoproterozoic to Silurian rocks of the Hermitage Flexure terrane west of Burgeo (Figure 2). These include the syntectonic Western Head (430 ± 2 Ma; O'Brien *et al.*, 1991) and Otter Point (419 ± 2 Ma; O'Brien *et al.*, 1991) granite plutons, which intruded Neoproterozoic units, and the posttectonic Chetwyn granite, which is the youngest dated granite in the study area (390 ± 3 Ma; O'Brien *et al.*, 1991).

Available geochronological data from north of the BDFZ are limited, but several presumably Silurian and Devonian granite plutons are located in the Bay du Nord terrane (Figure 2). These include the large, syntectonic Rose Blanche (418 ± 2 Ma; van Staal *et al.*, 1996a) and La Poile (*ca.* 416 Ma; Chorlton and Dallmeyer, 1986) granite plutons to the west of La Poile Bay (Chorlton, 1980a). Farther east, a diverse suite of granitic bodies intruded the metasedimentary and metavolcanic host rocks (Figure 3; Chorlton, 1980a, b; O'Brien, 1983). These include the Top Pond appinite, monzodiorite to granodiorite of the Ironbound Hill pluton, and several other syn- to posttectonic peraluminous granite plutons (Chorlton, 1980b; O'Brien, 1983). The peraluminous granite are biotite–muscovite-granite (local garnetiferous) and are divided into strongly foliated granite that is a presumed equivalent of the Rose Blanche granite (Chorlton, 1980b) and unfoliated posttectonic granite referred to as the Peter Snout granite (O'Brien, 1983). The Peter Snout granite has diffuse contacts with the host Dolman Cove Formation, and is associated with abundant pegmatites (O'Brien, 1983).

PEGMATITES IN SOUTHWESTERN NEWFOUNDLAND

Pegmatites along the south coast of Newfoundland were first described by Tater (1964), and numerous pegmatites were noted during regional geological mapping of the area in the 1970s and 1980s (Chorlton, 1978, 1980a, b; O'Brien, 1983; O'Brien and Tomlin, 1984). These pegmatites can be divided into two main types; pegmatites hosted in Silurian–Devonian granite plutons and pegmatites that are hosted in metamorphosed Ordovician to Silurian metavolcanic rocks (including the LCT pegmatites at Kraken and Hydra). Pegmatites hosted in granite are relatively common in some granite plutons (*e.g.*, Burgeo Intrusive Suite, Western Head, Rose Blanche, La Poile) and represent the final stages of crystallization of the granitic magma. These pegmatites are generally mineralogically simple, reflecting the composition of the host granite and consisting primarily of quartz, K-feldspar, plagioclase and muscovite, with minor biotite and garnet and rare tourmaline and beryl in some pegmatites.

The highest concentration of rare-metal-enriched pegmatites is north of the BDFZ, primarily hosted in metamorphosed volcanic rocks of the Dolman Cove Formation or rarely in foliated peraluminous granites. These pegmatites are commonly associated with abundant tourmaline + quartz veins and disseminations in the surrounding host rocks. These veins can be traced east of the Burgeo Highway, where abundant quartz–tourmaline–pyrite veins are recorded crosscutting sandstone of the Dolman Cove Formation in a roadside quarry (associated with minor quartz-feldspar–muscovite pegmatites). The relative timing of emplacement of these pegmatites is uncertain, and it is unknown if they represent a single or multiple generations of pegmatite emplacement. However, in all cases they crosscut S1 foliations in the host metasedimentary rocks (Plate 1A), and some pegmatites are folded or boudinaged indicating that

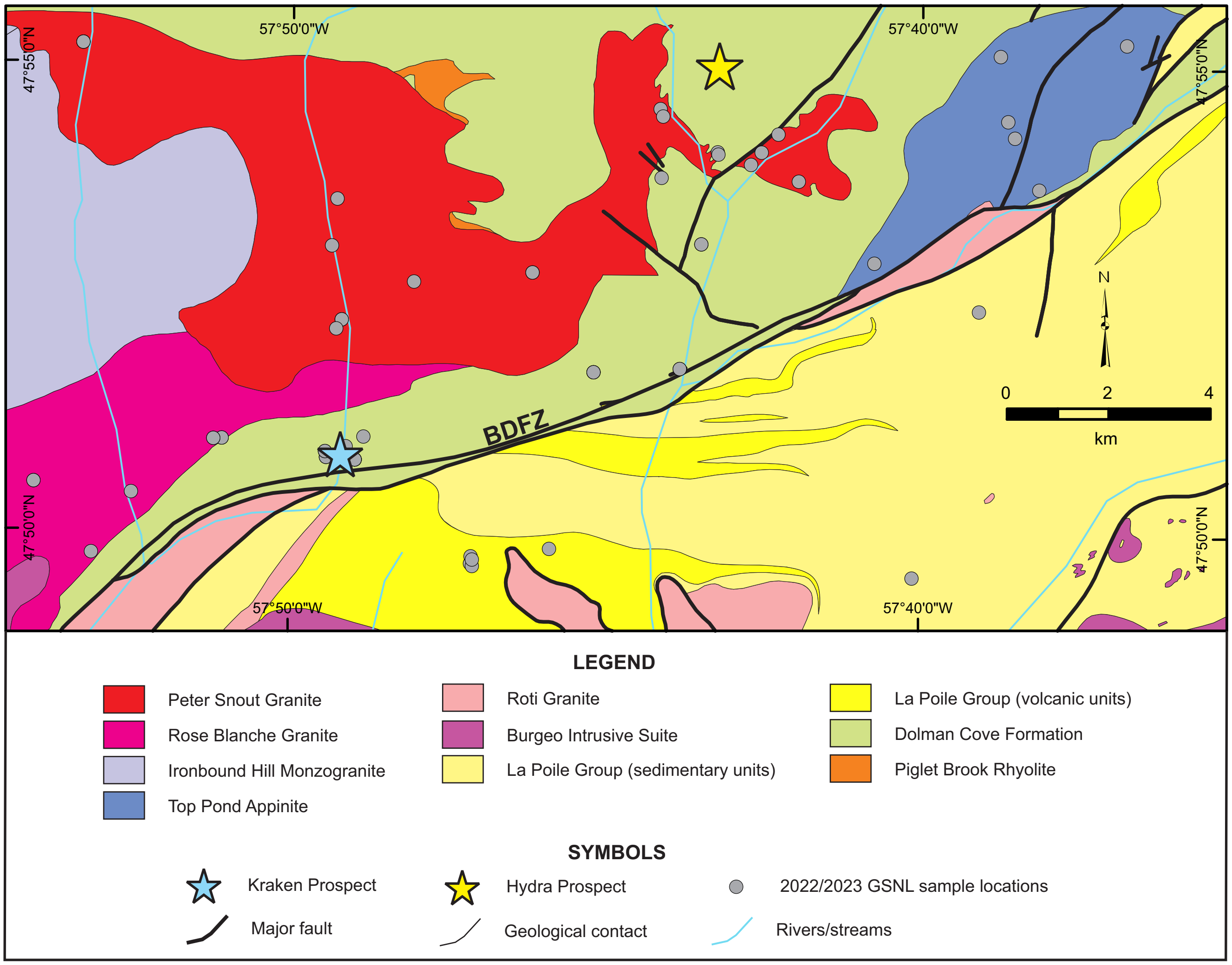

Figure 3. *Detailed geological map (from Chorlton, 1980b; O'Brien 1982) showing the location of Kraken pegmatite field, Hydra pegmatite, and 2022 and 2023 GSNL sample locations. BDFZ=Bay d'Est Fault Zone.*

they may have been emplaced during subsequent movement(s) along the BDFZ.

The pegmatites north of the BDFZ are generally medium to very coarse grained (up to 50 cm), with fine grained, aplitic zones in some pegmatites. Mineralogically simple, less evolved pegmatites consist of quartz, K-feldspar, plagioclase, muscovite, garnet, biotite with trace amounts of apatite, zircon, and tourmaline. Muscovite is commonly light green and forms either elongate books or plumose intergrowths with quartz and feldspar. Green beryl crystals, up to 5 cm in length, are found in some pegmatites (Plate 1B), and rare rosettes of molybdenite have also been observed. The more chemically evolved LCT pegmatites at the Kraken and Hydra prospects are described in detail below.

Another zone of pegmatites was observed in the eastern part of the study area, north of La Poile River, where metasedimentary rocks of the Bay du Nord Group are intruded by numerous subhorizontal pegmatite sheets. These pegmatites are close to the northern boundary of the peraluminous Rose Blanche granite, which is interpreted to represent an S-type granite formed during anatexis of the host metasediments (Genkin, 1996). They are generally fine to medium grained and consist of quartz, K-feldspar, albite, muscovite, biotite and garnet, with trace amounts of tourmaline, apatite and zircon (Plate 1C). No beryl or Li-bearing minerals were observed in these pegmatites.

Kraken Pegmatite Field

The Kraken pegmatite field covers an area of approximately 1 by 2 km having multiple highly evolved LCT pegmatites, located <500 m north of the trace of the BDFZ (Figure 4). The pegmatites are hosted in amphibolite-facies metamorphic rocks of the Dolman Cove Formation and out-

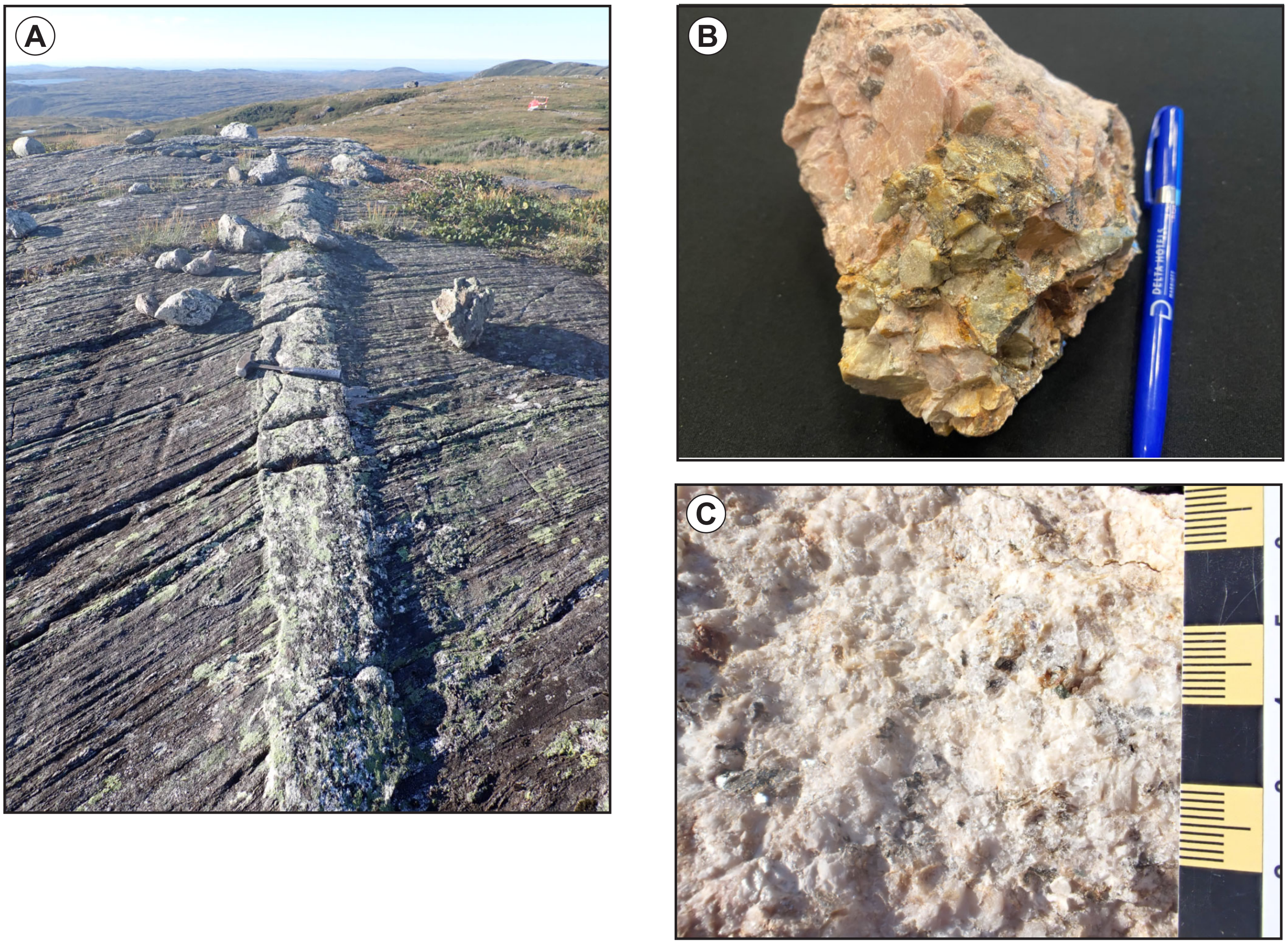

Plate 1. *Photos of pegmatites in southwestern Newfoundland. A) Thin pegmatite crosscutting the foliation in the Dolman Cove Formation, north of the BDFZ; B) Large green beryl crystals in pegmatite from north of the BDFZ; C) Fine-grained pegmatite, and quartz, albite, biotite and green apatite, from north of La Poile River.*

crop <1 km from the contact with the peraluminous Rose Blanche Granite (Figure 4). Following the initial discovery of the Kraken main dyke in late 2021, at least 10 additional pegmatite dykes were discovered using a combination of prospecting, soil sampling, trenching, and diamond drilling. Pegmatite dykes are generally steeply dipping at surface, and range in thickness from <1 to >5 m in exposed outcrops and trenches (Plate 2A, B). Diamond drilling intersected thicker pegmatite dykes (up to 15.23 m @ 1.04% Li_2O at the Killick Dyke), but the orientation and true thickness of these dykes is uncertain. Although the dykes have clearly been folded, the general trend of the dykes is approximately north-northeast–south-southwest and oblique to the regional trend along the BDFZ (Figure 4). All pegmatite dykes crosscut S1 foliations in the biotite and muscovite schists. However, these dykes were likely emplaced syntectonically, with thinner dykes and offshoots from the main pegmatite dykes displaying spectacular ptygmatic folding (Plate 2C) and well-developed boudins (Plate 2D).

The pegmatite dykes intrude strongly foliated biotite and muscovite schist and lesser rhyolite tuff, pelite, and amphibolite and porphyritic gabbro. The margin of the pegmatites is commonly marked by a 2–5 cm zone having abundant tourmaline, which is particularly prominent in the biotite schists (Plate 2E). In addition, tourmaline veins and rosettes having leucocratic (quartz–albite) margins are common in the country rock surrounding the pegmatite dykes (Plate 2F). This tourmaline is, locally, altered to purple dumortierite (identified by powder XRD analysis) in the alteration halo around the Kraken main dyke. Observations in 2023 suggest that tourmaline ± quartz veinlets, adjacent to LCT pegmatites at Kraken, may predate the emplacement of the spodumene-bearing pegmatite dykes, although the timing of these events remains uncertain. Assay data from diamond drilling indicates that the pegmatite dykes are surrounded by a geochemical alteration halo that extends for 10s of metres away from the dykes, and altered host rocks are characterized by elemental concentrations higher than

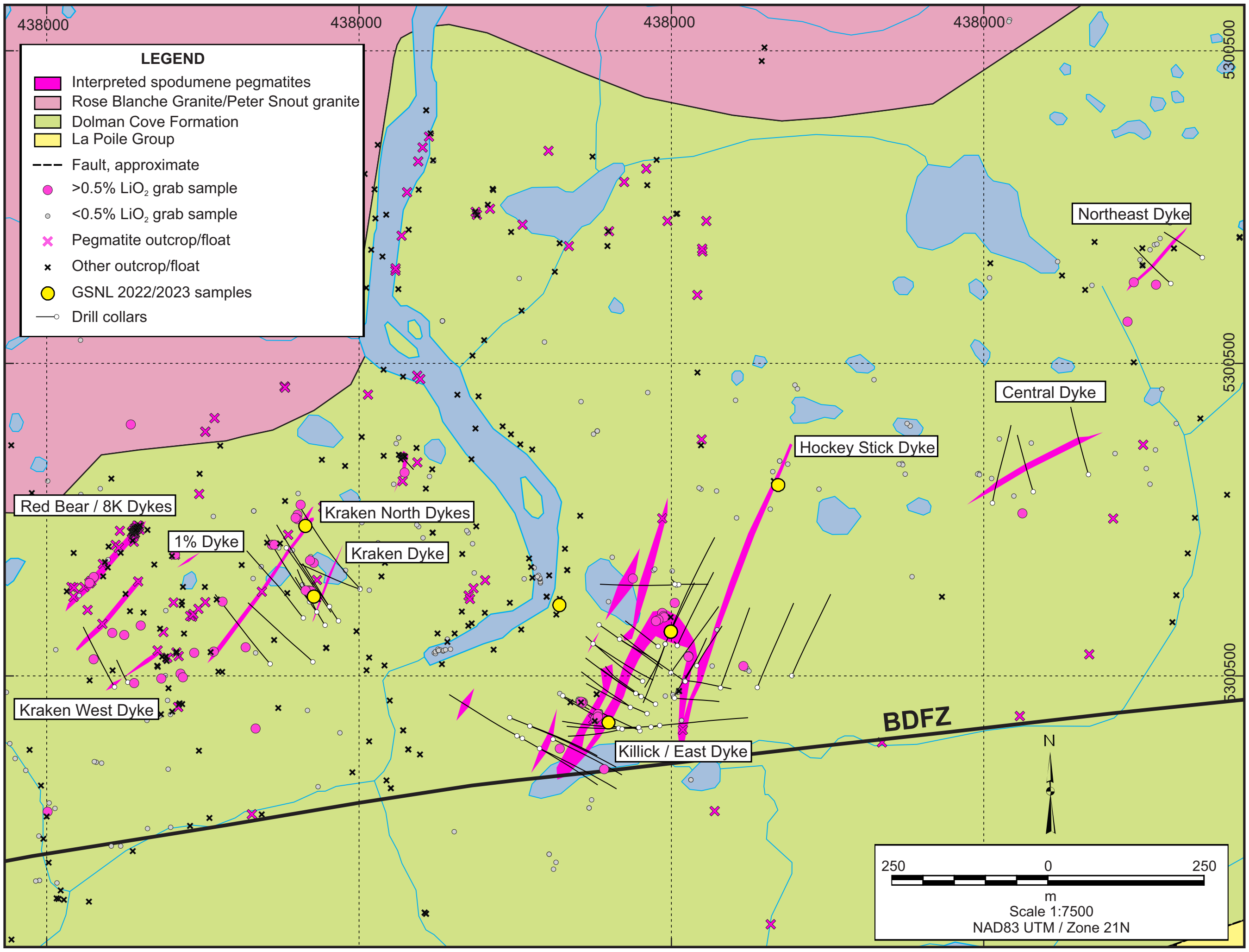

Figure 4. *Detailed geological map of Kraken pegmatite field, showing location of the named pegmatite dykes, drillhole collars and outcrop locations. Adapted from Benton Resources Inc. mapping, and Chorlton (1980b).*

1000 ppm Li, 200 ppm Cs, 500 ppm Rb and 1000 ppm B. Close to the BDFZ, the pegmatites are variably but strongly altered by a later alteration phase, where spodumene is partially- to completely replaced by clay minerals.

Individual pegmatites vary from being unzoned with fine- to medium-grained spodumene distributed evenly throughout the dyke, to zoned pegmatites having mineralogically distinct zones parallel to the margins of the dykes. The Kraken main dyke is generally unzoned, with a thin aplitic border zone (± tourmaline) and the rest of the dyke has fine- to medium-grained pegmatite textures, and locally up to 50% spodumene. At the Killick/East dyke, multiple mineralogically distinct zones are interpreted to represent at least two distinct pulses of magmatism. In each pulse, a layered aplite (Plate 3A) interpreted to represent the base of the dyke (London, 2014) is overlain by a medium- to very coarse-grained pegmatite having abundant spodumene crystals (up to 12 cm long; Plate 3B, C) that are oriented with their long axis perpendicular to the margins of the pegmatite. At the hockey-stick dyke, spodumene abundance is generally lower (<10%) and the mineralogy more complex, with layered aplite and alternating pegmatite layers with blocky coarse-grained K-feldspar, green plumose muscovite and grey quartz (± garnet, white beryl, albite; Plate 3D).

The spodumene-rich zones consist of spodumene (20–50%) in a groundmass of albite (30–40%), quartz (20–30%), muscovite (5–10%) and orthoclase (1–10%; Plates 4 and 5A, B). Small (<2 mm) red spessartine garnet crystals are common (Plate 5C) but make up <1% of the modal mineralogy. Accessory minerals include small (<500 µm) columbite–tantalite (coltan) typically zoned with Nb-rich cores and Ta-rich rims (Plate 5D, G, H and Figure 5A, B). Other accessory minerals include zircon, apatite, biotite, and Ce-rich monazite. Zircon grains are irregular in shape and erratically zoned,

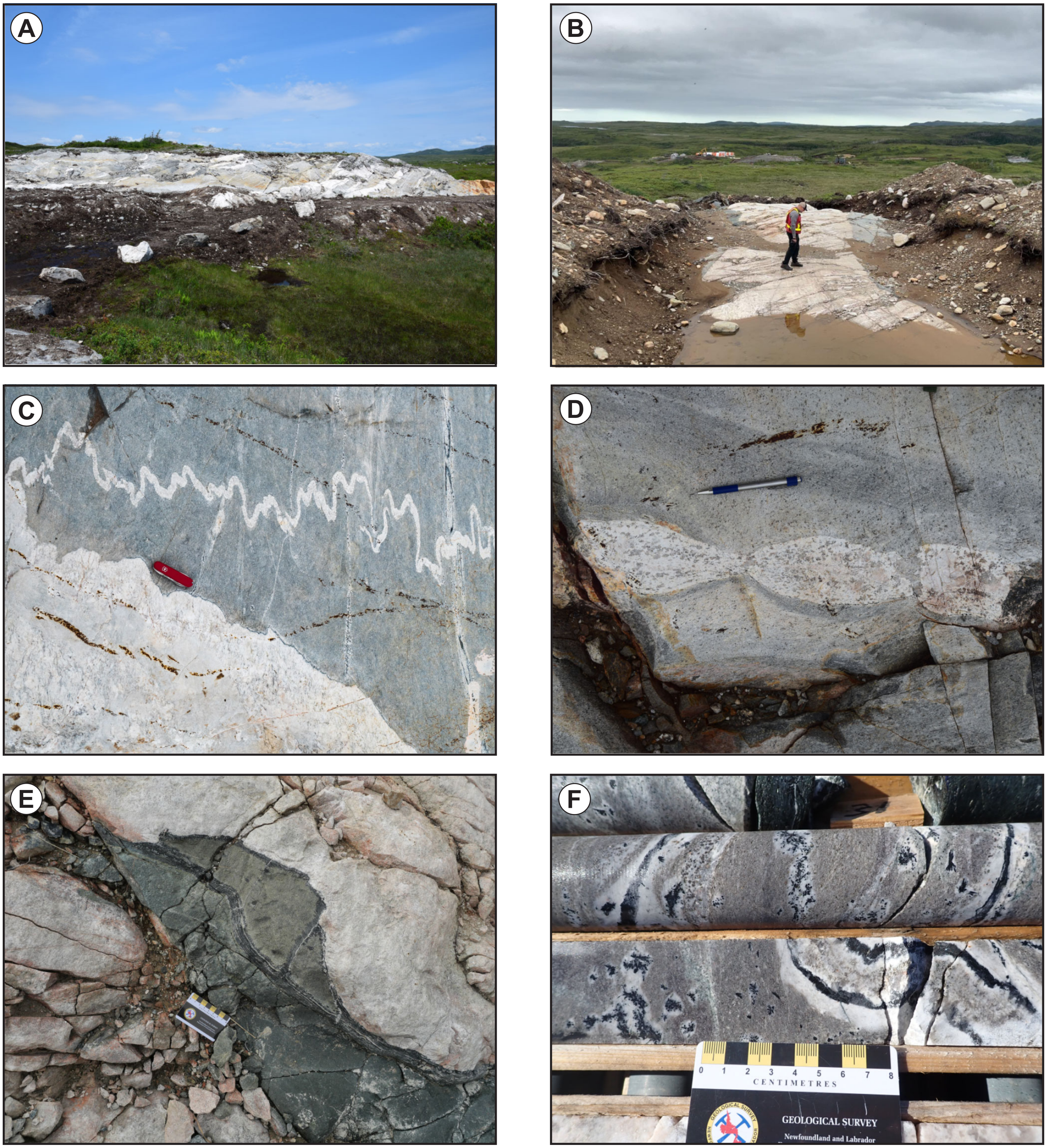

Plate 2. *Photos from the Kraken pegmatite field. A) Kraken main dyke and trench; B) Hockey-stick dyke trench; C) Ptygmatic folding in thin pegmatite vein at margin of the Kraken north dyke; D) Boudins in pegmatite; E) Boundary between spodumene pegmatite and biotite schist, showing abundant black tourmaline at the margin of the pegmatite (east dyke); F) Biotite schist close to margin of the hockey-stick dyke, and veins and rosettes of tourmaline surrounded by leucocratic rims (drillhole GH-22-20 at 33.8 m).*

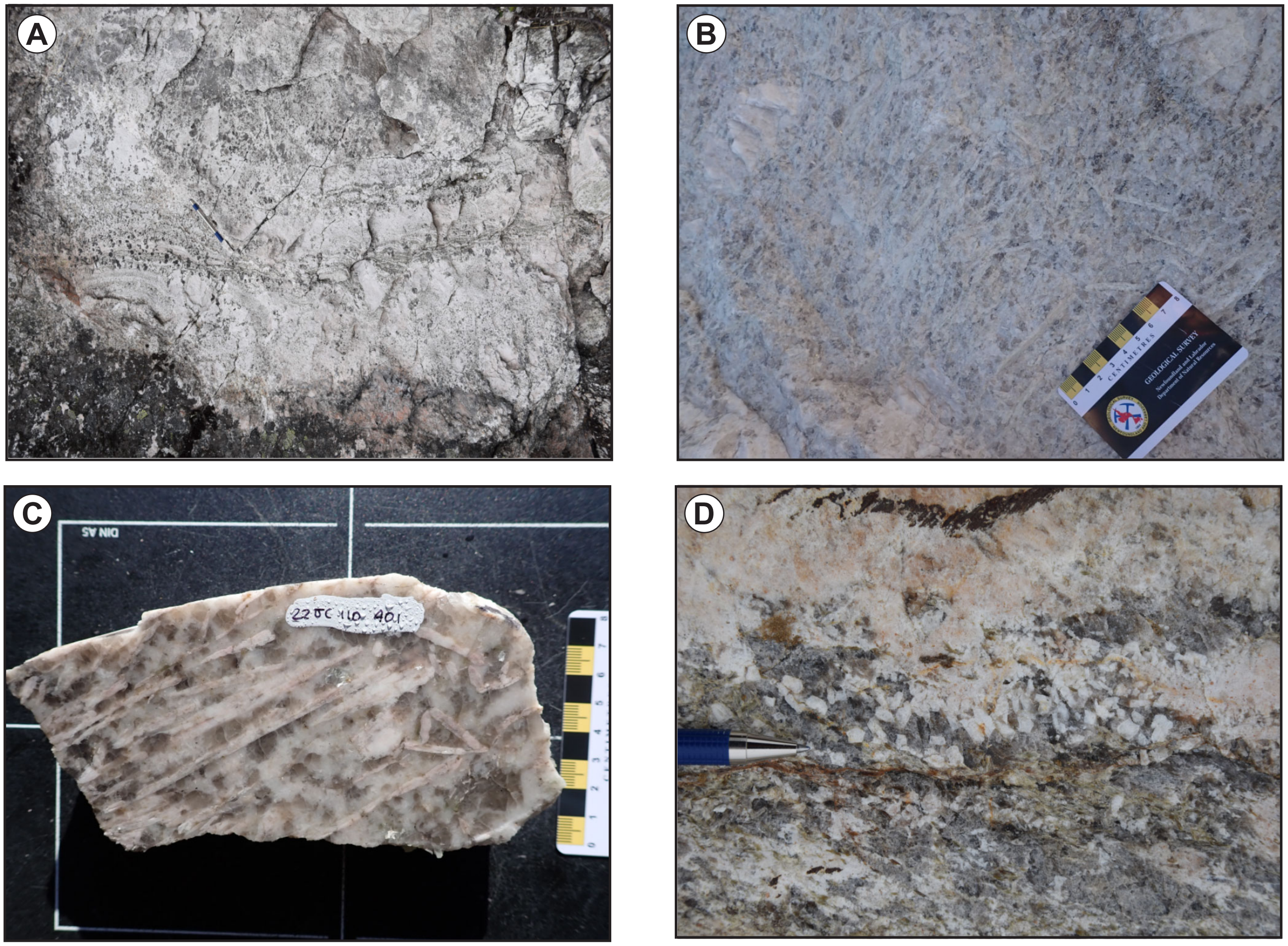

Plate 3. *Photos of LCT pegmatites from Kraken pegmatite field. A) Layered aplite in bottom border zone of the east dyke; B) Abundant, coarse-grained spodumene crystals, east dyke; C) Elongate spodumene crystals in quartz, albite and muscovite matrix (east dyke); D) White, euhedral beryl crystals and quartz in the hockey-stick dyke.*

with high Hf contents and U-rich zones (Plate 5H and Figure 5C). The layered aplitic sections consist predominantly of albite (>70%), with lesser amounts of quartz, muscovite, garnet and accessory coltan, apatite and zircon (Plate 5E, F).

Hydra Pegmatite

The Hydra pegmatite, discovered in late 2022, is located approximately 10 km northeast of the Kraken pegmatite field and 5 km north of the BDFZ. The pegmatite intrudes biotite schist of the Dolman Cove Formation and is located ~1–2 km from the surface mapped contact with the peraluminous Peter Snout granite. The latter crops out in valleys below the Hydra pegmatite. Channel sampling identified high-grade zones with 8.75% Cs_2O, 0.41% Li_2O, 0.025% Ta_2O_5 and 0.33% Rb_2O (Benton Resources Inc. press release, December 2022). Diamond drilling has intersected a broad mineralized interval with 13.55 m grading 0.14% Cs_2O, 0.16% Li_2O, 0.01% Ta_2O_5 and 0.12% Rb_2O from 4.85–18.4 m, including 1.22 m grading 0.51% Cs_2O (Benton Resources Inc. press release, September 2023).

The northeast–southwest trending, steeply dipping pegmatite ranges in thickness from >8 m to <2 m (Plate 6A) and can be traced for over 100 m before it disappears under overburden in both directions. It is relatively undeformed and crosscuts S1 foliations in the host schists. In the main trench, the Hydra pegmatite is mineralogically and texturally complex, with distinct zones oriented roughly parallel to the margins of the pegmatite (Plate 6B). From southeast to northwest, these zones consist of a border zone, lower layered aplitic zone, a medium- to coarse-grained (up to 10 cm) pegmatitic zone, a second layered aplitic zone, an upper zone of very coarse-grained pegmatite with K-feldspar crystals up to 30 cm, and a top border zone with abundant tourmaline (Plate 6C, D). Irregular shaped xenoliths of partially digested biotite schist occur in the upper very coarse-grained pegmatite.

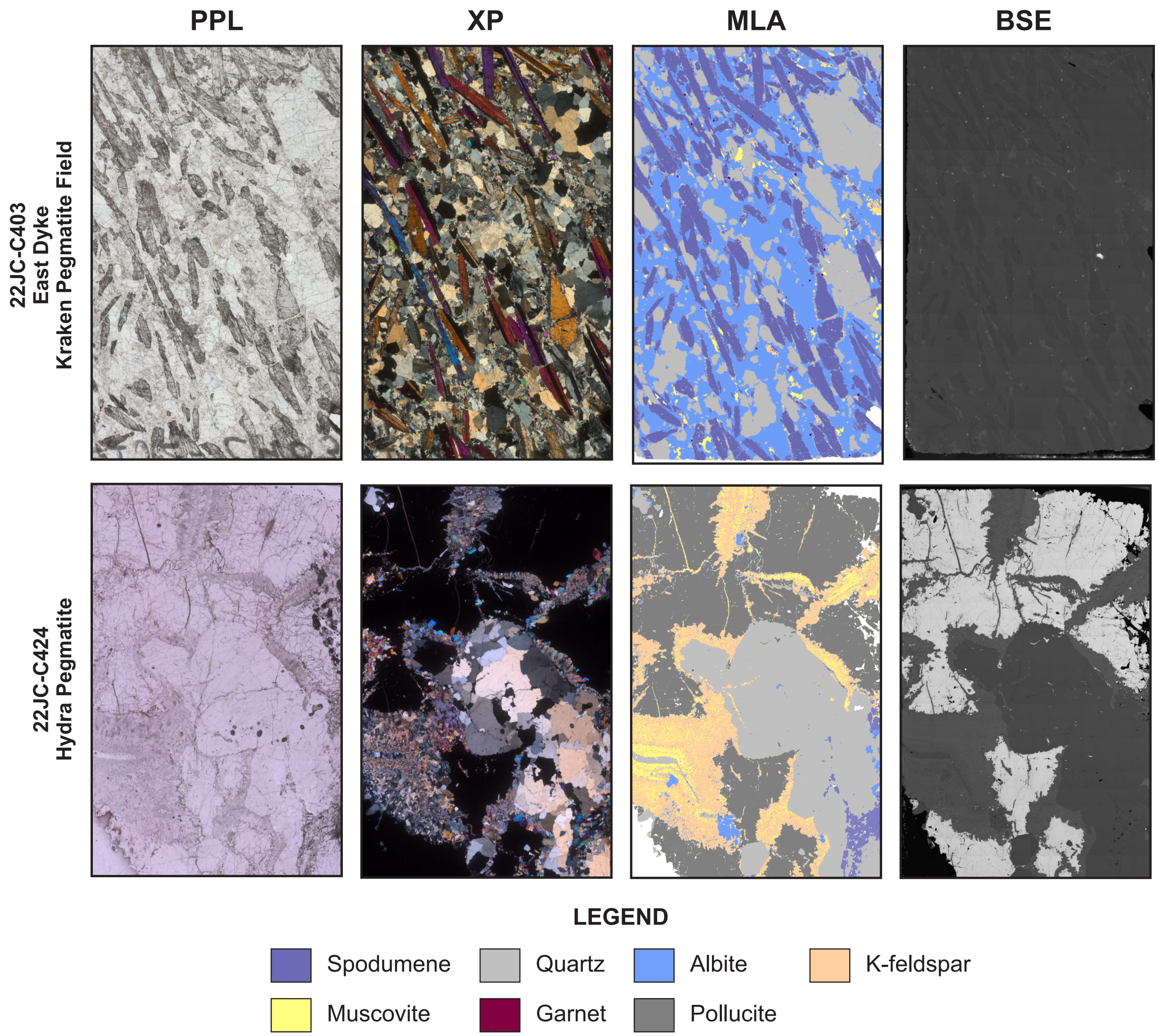

Plate 4. *Thin section images from the east dyke at the Kraken pegmatite field (sample 22JC-C403) and Hydra pegmatite (sample 22JC-C424). Images are shown in plane-polarized light (PPL), crossed polars (XP), false-colour images generated from SEM-MLA analysis (MLA) and backscatter electron images (BSE). Width of thin sections approximately 25 mm.*

The layered aplitic zones consist primarily of fine-grained albite and quartz, minor muscovite, and distinct layers of fine-grained garnet and black, acicular tourmaline (Plate 6B). Petrographic analysis has also identified coltan crystals up to 1 mm in length (Plate 7E). Texturally, the Hydra pegmatite is highly variable: coarse to very coarse-grained sections consisting primarily of blocky K-feldspar crystals in a matrix of grey quartz and white albite. Cesium and lithium mineralization is predominantly hosted in the coarse-grained pegmatites (Plate 6E), with high-grade sections consisting of white to grey, glassy pollucite (10–40%), grey glassy quartz (30–50%), orthoclase (5–15%), muscovite (5–10%), albite (2–10%) and fine-grained spodumene (3–10%), and accessory garnet, tourmaline, biotite, coltan, zircon, apatite, and Ce-rich monazite (Plate 4). At least two generations of muscovite are present including large primary books of muscovite with spectacular zoning visible in hand sample (Plate 6F) and in thin section (Plate 7C), and a later generation of fine-grained purple muscovite intergrown with orthoclase along fractures and grain boundaries in the pegmatite.

Pollucite ($(Cs,Na)_2(Al_2Si_4O_{12}).2H_2O$) is the main Cs-bearing phase but it is virtually indistinguishable from

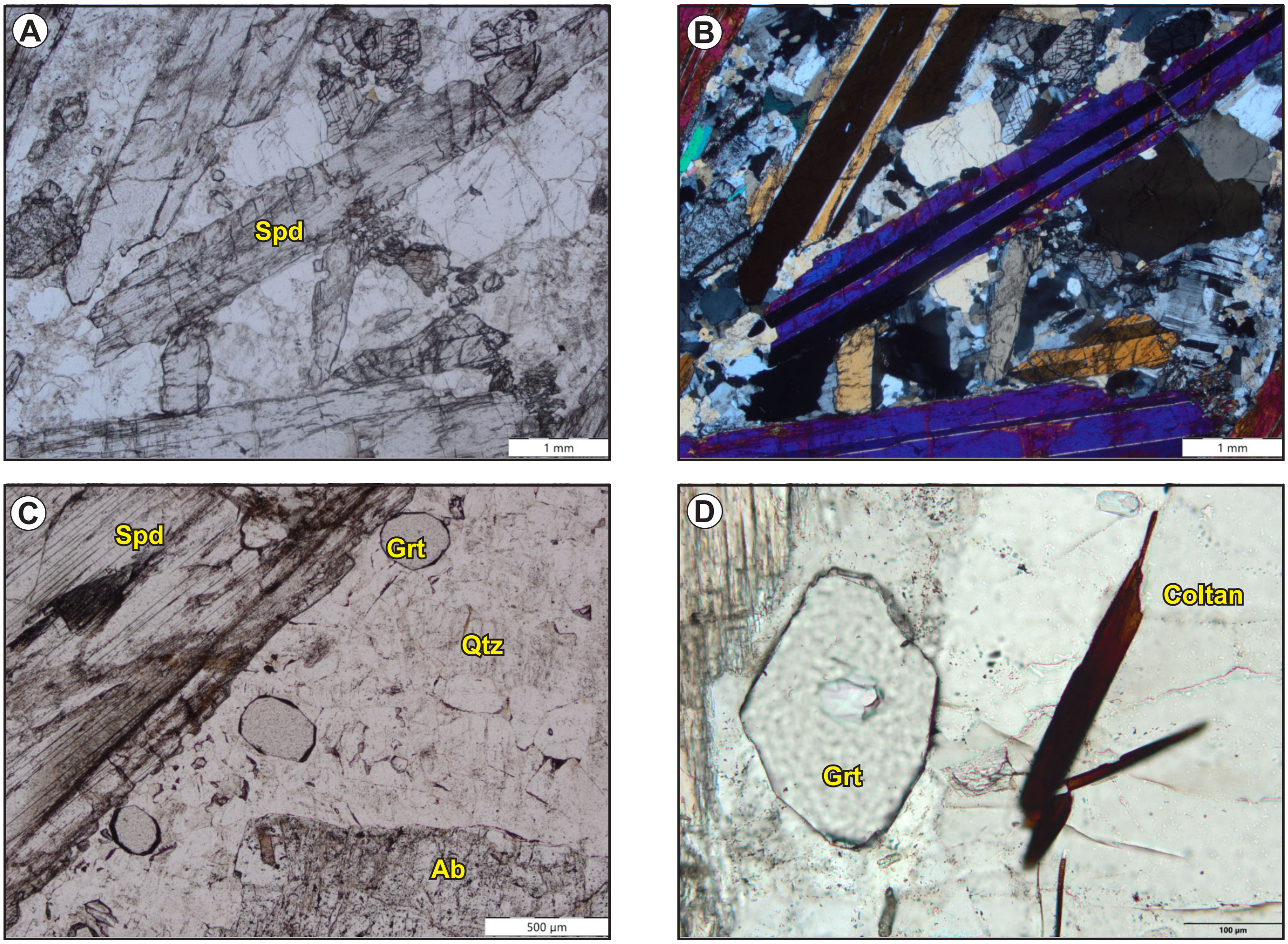

Plate 5. *Photomicrographs and BSE images from the Kraken pegmatite field. A) Elongate spodumene crystals in matrix of quartz and albite (PPL, drillhole GH-22-01 at 12.4 m); B) Same view as A, in crossed polars; C) Typical mineral assemblage in mineralized pegmatite, with spodumene, quartz, albite and garnet (PPL, grab sample from east dyke); D) Subhedral high-relief garnet and brown to opaque coltan crystal (PPL, drillhole GH-22-01 at 12.4 m). Spd=spodumene, Grt=garnet, Qtz=quartz, Ab=albite.*

quartz in hand specimens. It was identified in thin section because of its isotropy under crossed polars (Plates 4 and 7A, B), and its high reflectance in BSE images (Plate 7F), and distinctive mineral chemistry determined from EDS spectra (Figure 5D). BSE imaging also showed that pollucite is weakly zoned having thin Na-rich rims at the margins of individual crystals.

ONGOING RESEARCH

The following two collaborative projects between GSNL and partners at Memorial University, St. Francis Xavier University, the Geological Survey of Canada and Vinland Lithium are ongoing. They are projected to enhance our understanding of the formation of LCT pegmatites at the Kraken and Hydra prospects, as well as supporting regional exploration for LCT pegmatites and other granite-related critical minerals (*e.g.*, W, Mo, Sn, Bi) in southern and central Newfoundland. These studies include:

The Origin of LCT Pegmatites in Southwestern Newfoundland

D.B. Archibald, J. Conliffe, D.G.L. Lowe, E.J. Thiessen, B.A. Sparkes, D. Saha, K.M. Malay and N. Rogers

This multidisciplinary investigation combines field data and petrography, geochemistry, mineral chemistry, and geochronology to improve our understanding of the intrusive, structural, and sedimentological history of southwestern Newfoundland, and the geological processes that resulted in pegmatite emplacement. The objectives are: 1) to characterize the age, petrography and detailed mineral chemistry

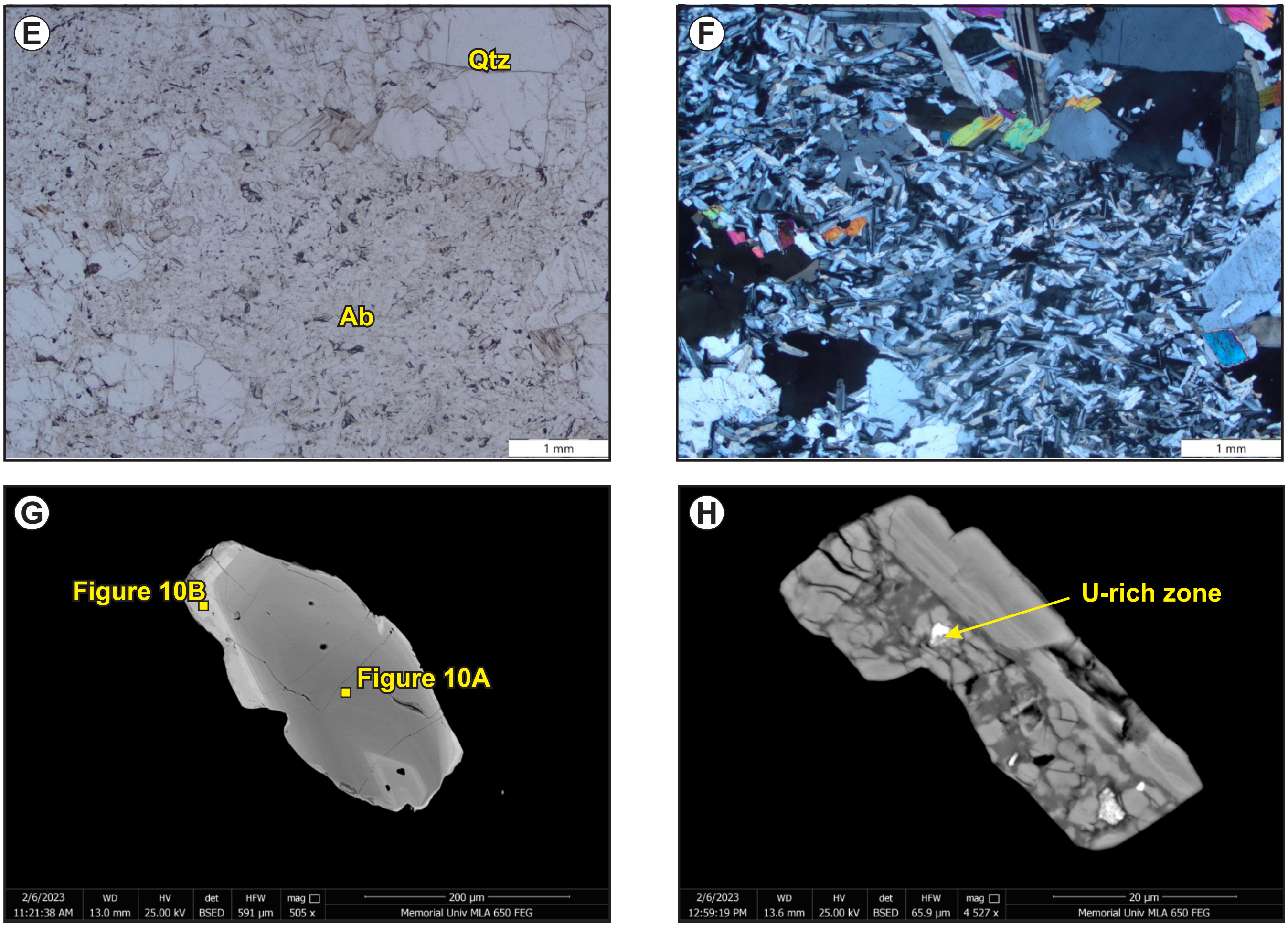

Plate 5. Continued *Photomicrographs and BSE images from the Kraken pegmatite field. E) Fine-grained aplite with albite and lesser amounts of quartz and muscovite (PPL, grab sample from east dyke); F) Same view as A, in crossed polars; G) BSE image of coltan, showing well-developed concentric zones and location of EDS spectra shown in Figure 5 (BSE, grab sample from east dyke); H) Irregularly zoned zircon, with bright spot representing U-rich zone (BSE, drillhole GH-22-01 at 12.4 m). Qtz=quartz, Ab=albite.*

of mineralized and unmineralized pegmatites; 2) to investigate the age and petrogenesis of granitic plutons to determine their relationship to the lithium pegmatites using a combination of mineral chemistry and geochronology; and 3) to improve our understanding of the geological framework of southwest Newfoundland in terms of its relationship to formation of LCT pegmatites, including the structural geology of the BDFZ, age and geological setting of the Dolman Cove Formation and geological relationship between geological units either side of the BDFZ. This work will generate new data that will aid in our assessment of the regional potential for LCT pegmatite mineralization elsewhere in southern and central Newfoundland.

The project is funded by a Targeted Geoscience Initiatives (TGI)-6 grant to D.B. Archibald, with J. Conliffe as the primary collaborator.

Granite-related Critical Mineral Potential of the Gander and Western Avalon Zones

J. Conliffe, D.B. Archibald and N. Rogers

The Gander and western part of the Avalon zone are host to several known critical mineral deposits and prospects associated with granitic rocks (Figure 1), including LCT pegmatites in the Burgeo area, vein hosted W deposits (*e.g.*, Grey River Deposit), porphyry Mo–Cu deposits (Moly Brook Deposit) and Sn-greisen (Moulting Pond Prospect). In addition, the prospectively of these lithotectonic zones to host other deposits is highlighted by the numerous smaller Li, W, Mo, Sn, Bi and Be occurrences, as well as abundant peraluminous granites intruded into greenschist to amphibolite facies metasedimentary and metavolcanic rocks. This multi-year, GSNL-led project will document known occurrences and determine the regional geological factors that may control the localization of deposits. In addition, mineral

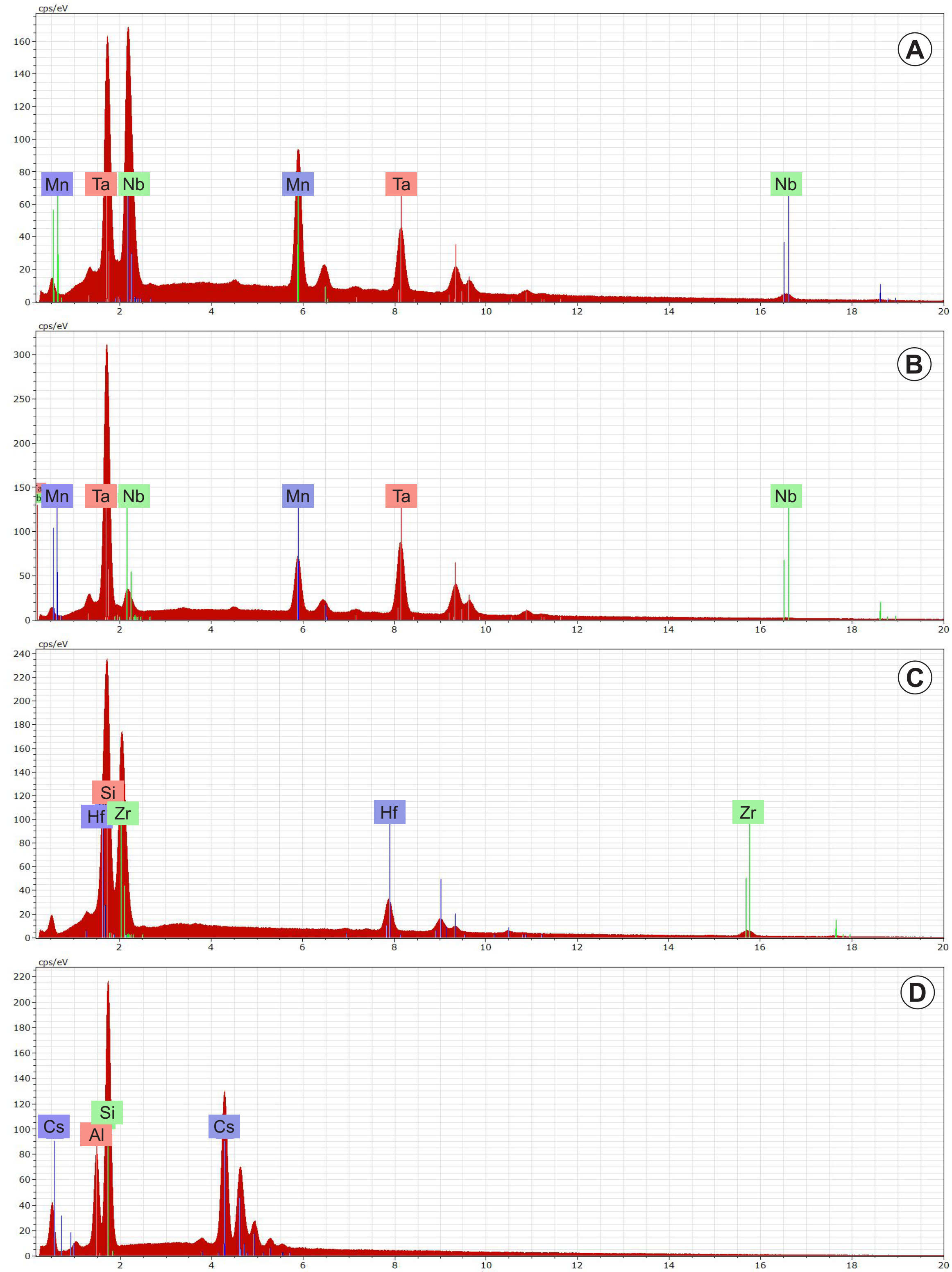

Figure 5. *Energy dispersive spectroscopy (EDS) for select minerals, obtained during backscatter electron (BSE) imaging. A) Spectra from core of coltan crystal shown in Plate 5G, showing strong Ta and Nb peaks; B) Spectra from rim of coltan crystal shown in Plate 5G, showing Ta >> Nb; C) Spectra from typical zircon crystal, showing strong Hf peak; D) Typical spectra from pollucite, showing composition of Cs, Al and Si.*

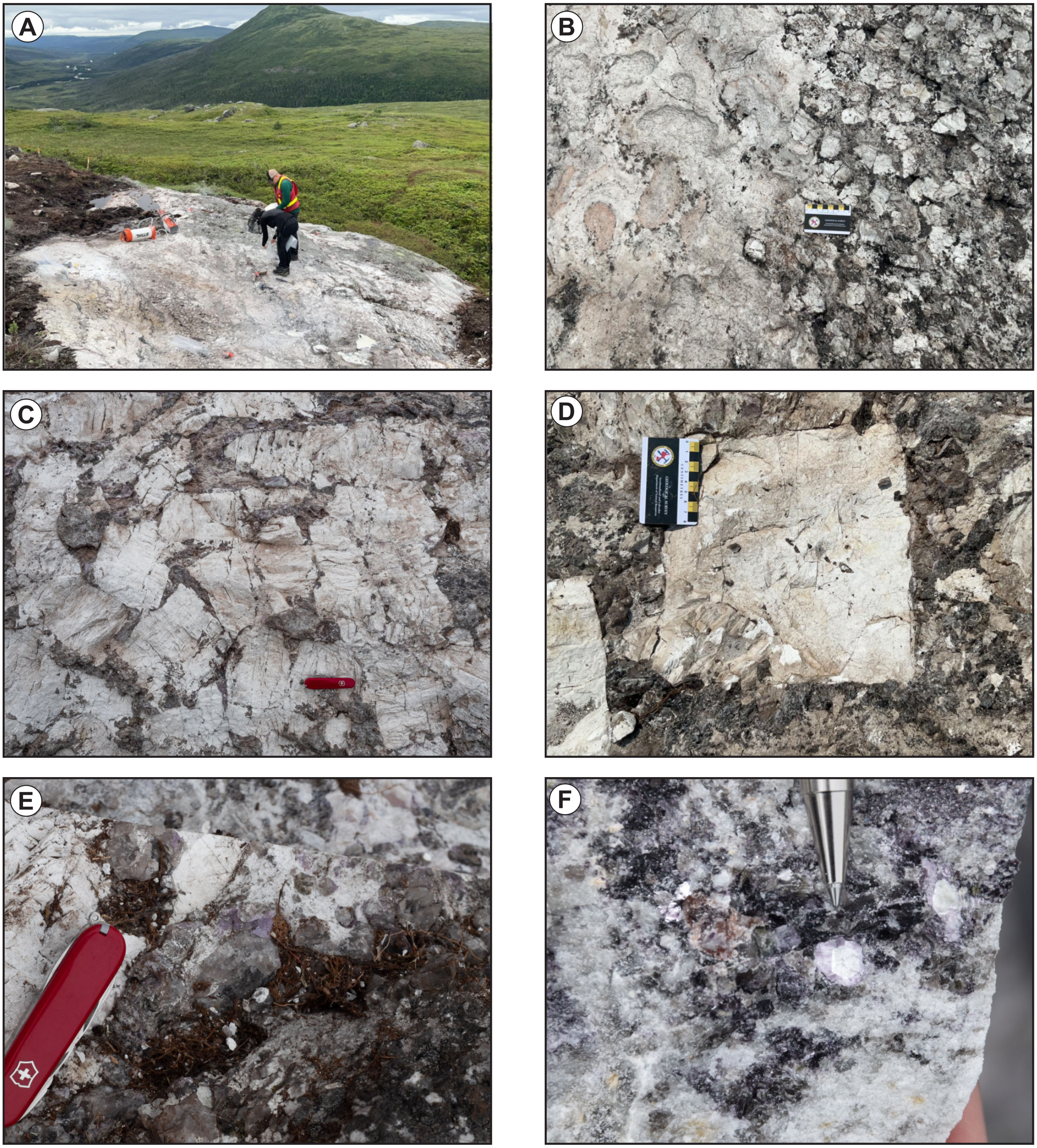

Plate 6. *Photos of the Hydra pegmatite. A) Overview of exposed trench, on hill facing south overlooking Grandys Brook; B) Contact between fine-grained aplite with garnet and tourmaline layers, and coarse-grained pegmatite; C) Coarse-grained pegmatite with blocky, sub- to euhedral white K-feldspars; D) Large euhedral K-feldspar crystal with graphic intergrowths of quartz and inclusions of black tourmaline; E) Mineralized pegmatite, with grey glassy quartz, white albite, grey glassy pollucite (above knife) and late purple muscovite–orthoclase; F) Close-up of mineralized pegmatite, with zoned muscovite.*

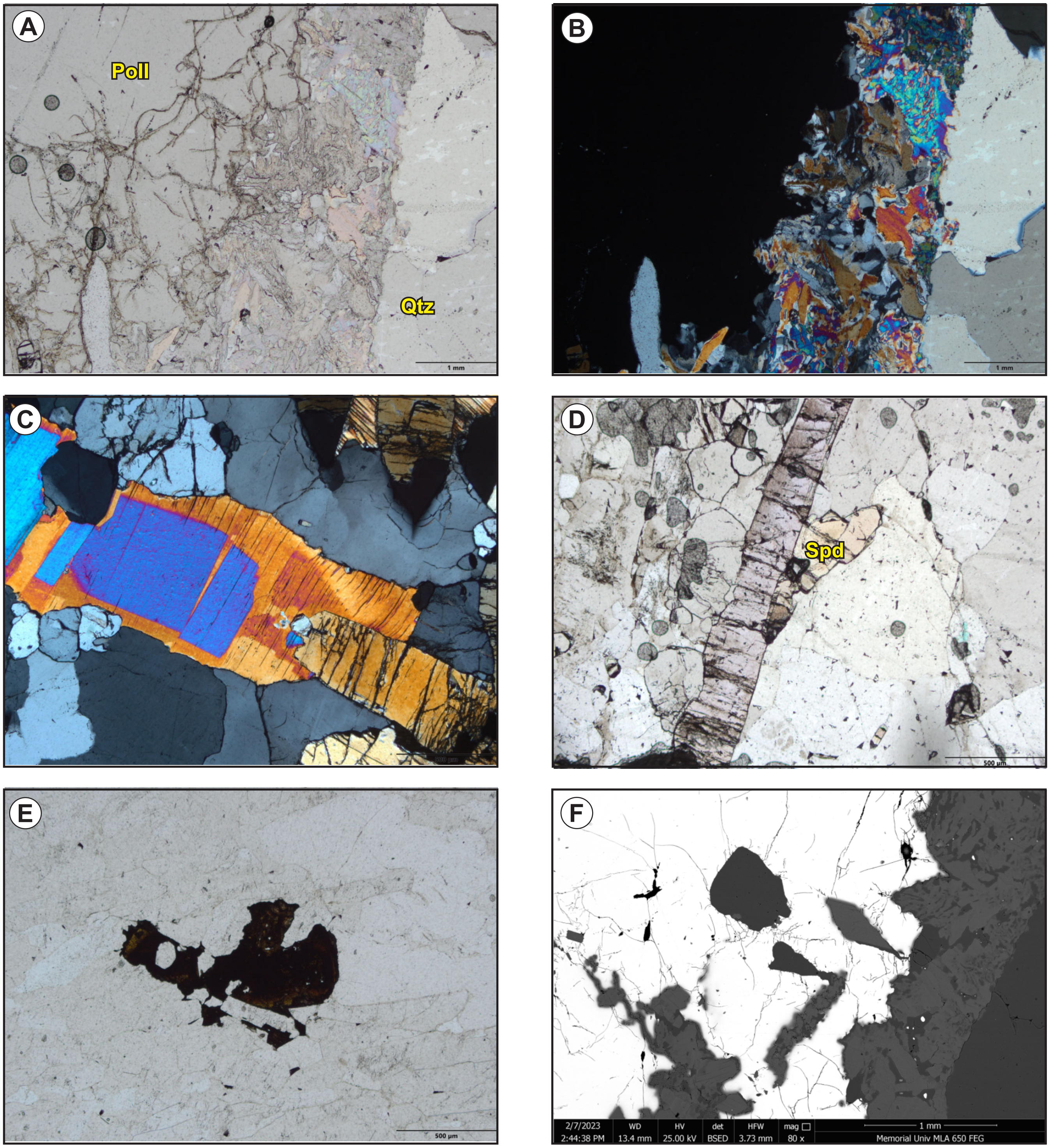

Plate 7. *Photomicrographs and BSE images from the Hydra pegmatite field, all images come from grab samples in main trench. A) PPL image of low-relief pollucite (left) and quartz (right), separated by fine-grained muscovite and orthoclase; B) Same view as A, in crossed polars; C) Zoned muscovite grain in crossed polars; D) Elongate spodumene crystals in matrix of quartz and albite (PPL); E) Brown to opaque coltan crystal in fine-grained aplite (PPL); F) BSE image of pollucite (left), showing bright response compared to quartz (right) due to presence of heavy elements (Cs). Poll=pollucite, Qtz=quartz, Spd= spodumene.*

geochemistry from known deposits will be compared with smaller showings and prospects, to decipher any possible vectors towards mineralization and aid in future mineral exploration.

CONCLUSIONS

The recently discovered LCT pegmatites in southwestern Newfoundland represent the most significant lithium discoveries in Newfoundland and Labrador to date. They occur as a series of highly fractionated lithium and cesium-bearing pegmatites hosted in amphibolite-facies metavolcanic and metasedimentary rocks of the Dolman Cove Formation, close to the BDFZ, and several peraluminous granite plutons that may represent parent granites to the pegmatite melts.

The Kraken pegmatite field currently consists of 10 spodumene-bearing pegmatite dykes, several of which are >5 m in thickness over a strike length of >2 km. These dykes are associated with abundant tourmaline in the surrounding country rocks, and alteration halos with enrichment in Li, Cs, Rb and B. The pegmatites are unzoned to weakly zoned, with spodumene-rich areas comprising spodumene, quartz, albite, muscovite and orthoclase, minor garnet and accessory coltan, zircon, apatite, biotite and Ce-rich monazite.

The Hydra pegmatite is located ~10 km northeast of the Kraken pegmatite field. It is a zoned pegmatite, up to 8 m thick and at least 100 m long. It is characterized by zones of Cs enrichment, and high-grade zones of 8.75% Cs_2O over 1.2 m in channel samples. Pollucite is the main Cs-bearing mineral, and petrographic analysis shows that it occurs with quartz, albite, muscovite and spodumene (± garnet, tourmaline, biotite, coltan, zircon, apatite and Ce-rich monazite) and is crosscut by late muscovite–orthoclase veinlets.

Given the predicted increase in global demand for critical minerals *e.g.*, lithium in green technology, these discoveries are important in showing that Newfoundland and Labrador has the potential to host LCT-pegmatite mineralization. Ongoing research at the GSNL, with partners in academia, industry, and the federal government aims to better understand how these LCT pegmatites formed and assess the potential for other similar deposits elsewhere in southern and central Newfoundland.

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