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MOLYBDENUM AND TUNGSTEN IN NEWFOUNDLAND: A GEOLOGICAL OVERVIEW AND A SUMMARY OF RECENT EXPLORATION DEVELOPMENTS

A. Kerr, T.S. van Nostrand[1], W.L. Dickson[1] and E.P. Lynch[2]
Mineral Deposits Section
[1] Regional Geology Section
[2] Department of Earth Sciences, National University of Ireland, Galway, Ireland

ABSTRACT

Molybdenum mineralization was first discovered in Newfoundland in the 1880s, and tungsten mineralization has been known for over 50 years. There has been intermittent exploration for these commodities, but they have not received the systematic attention that has been devoted to the base metals or gold. Commodity price increases in 2007 and 2008 led to more interest, and there are now two advanced exploration projects in southern Newfoundland. Based on the empirical evidence from surficial geochemical patterns and known mineralization, this region of the Island appears to have the greatest potential for future discoveries.

Molybdenum is best known in the Devonian Ackley Granite, where it forms syngenetic, endocontact, disseminated deposits in evolved granitoid rocks, close to the original roof of the magma chamber. Locally, these occurrences have high grades (up to 0.5% Mo), but are of limited extent. However, buried extensions of the Ackley Granite may exist in the Fortune Bay area, and these could be associated with both endocontact and exocontact mineralization. In the Grey River area, a potentially significant, bulk-tonnage Mo deposit consists of epigenetic, sheeted to stockwork-style quartz veins in an older (unrelated) granitoid pluton. This is considered to be a porphyry-style deposit. Although grades are relatively low (<0.1% Mo), this is a large system that also contains Cu mineralization. The vein system is probably linked to a subsurface granite pluton that locally forms sheets and dykes within the deposit. These veins contain disseminated syngenetic molybdenite, suggesting a close genetic and temporal relationship. Molybdenum mineralization recently delineated in the Granite Lake area of south-central Newfoundland is also associated with sheeted and stockwork-style quartz veining, and may have similar origins, although such genetic connections remain to be established.

Vein-style tungsten mineralization is also best known in the Grey River area, where one such deposit contains a significant resource. It seems probable that this mineralization is genetically connected to the same buried pluton implicated for nearby Mo mineralization, and associated base-metal (± Au, Ag) veins may also be part of a larger zoned hydrothermal system. Tungsten is also associated with Mo mineralization in the Granite Lake area. Skarn-type W mineralization is uncommon, but it occurs in central Newfoundland, spatially associated with a large leucogranite pluton. This area may merit more detailed investigation for lower grade but larger W deposits, akin to those known in western Canada.

INTRODUCTION

Molybdenum (Mo) and tungsten (W) are commodities whose prices remained stable but low for decades, limiting industry interest in exploration for new deposits. Interest has grown in recent years because the prices of both have increased rapidly. For example, the price of molybdenum (expressed as Fe–Mo oxide, or ferromolybdenum) moved from about US$6 per kilogram (November 2002) to over US$70 per kilogram (May 2008), and the price of tungsten (expressed as ammonium paratungstate or ATP) moved from US$6 per kilogram to over US$30 per kilogram during the same time period. Both metals have important primary applications in the steel industry, and a variety of uses connected to specialized alloys, chemicals and high-technology industries. In many of these applications, there are no viable substitutes and the production of molybdenum in the west is dominantly as a byproduct from porphyry copper deposits; thus, increasing production of molybdenum alone is not possible. The largest supplier of molybdenum and tungsten is

China, which has recently restricted exports, leading to a combination of supply shortfall and increased demand.

The increased interest in Mo and W has created a need for a synthesis of information on known deposits and potential exploration environments within the province. This review is drawn from the historical database of exploration and scientific studies, but it also provides some essential geological information concerning recent exploration developments in Newfoundland.

Molybdenum mineralization also exists in Labrador, notably within the Central Mineral Belt, where one deposit was explored to the point of resource definition. Labrador examples are not discussed in this report, but some general information on the potential for granite-hosted mineralization in Labrador is contained in a report by Kerr (1994).

MOLYBDENUM AND TUNGSTEN: GEOLOGICAL FACTORS

For background information on history, properties, applications and markets, readers are referred to two industry associations, namely the International Molybdenum Association (IMOA) and the International Tungsten Industry Association (ITIA), who maintain comprehensive websites. There are also many geological links between these two elements, and they often occur together or in close proximity.

Molybdenum has essentially one ore mineral, molybdenite (MoS_2), easily identified by its distinctive metallic-blue colour, and its soft and flaky habit. In addition to its commercial value, molybdenite now has considerable scientific importance as a geochronometer, with the development of the Re–Os technique (Stein *et al.*, 2001; *see* also Lynch *et al.*, *this volume*). From a geological perspective, molybdenum mineralization is most commonly associated with granitoid magmatism, and minor quantities of molybdenite are relatively widespread in evolved granites, pegmatites and aplites. Productive molybdenum deposits form part of the 'porphyry' clan, and most porphyry Cu deposits contain low levels of associated Mo, which is a by-product. However, at copper grades of 0.5 to 1.5% Cu, associated Mo contents are only 0.01% to 0.05% (100 to 500 ppm). Molybdenum-dominated porphyry deposits are less common, and these still have relatively low grades of 0.1% to 0.3% Mo (1000 to 3000 ppm). Porphyry-style Mo deposits include 'endocontact' deposits in which the host rocks are related altered granites and the mineralization is in disseminated and veinlet form, to sheeted-vein and/or stockwork deposits developed in unrelated country rocks above high-level granite cupolas. The latter are termed 'exocontact' types here. Vein-hosted and pegmatite-hosted molybdenite mineralization is more widespread than porphyry-style mineralization, but such deposits rarely have any size or economic value. Skarn-type mineralization is also known, but this generally has a relationship to granitic magmatism and associated fluids, rather than to regional metamorphism.

There are two main ore minerals for tungsten, namely wolframite ($(Fe,Mn)WO_4$) and scheelite ($CaWO_4$). Wolframite is a hard, blue-black mineral that resembles an iron oxide aside from habit, but scheelite more closely resembles a silicate mineral, and is difficult to identify; fortunately, it is fluorescent under UV light. Like molybdenum, tungsten is overwhelmingly associated with granitoid plutonic rocks, and in some cases, it may be associated with molybdenum. Wolframite and scheelite are most commonly found in veins or vein swarms, associated with quartz, assorted base metals and sometimes gold. Tungsten is normally the main product from mining operations, rather than a byproduct. In association with tin (Sn), tungsten deposits occur as porphyry-like sheeted-vein systems and stockworks, sometimes with associated bismuth (Bi) and other unusual elements. Scheelite also occurs in these settings, but is also commonly associated with skarn-type deposits, notably in calcareous host rocks that have undergone metasomatic reactions with fluids from nearby granites.

REGIONAL GEOLOGICAL FRAMEWORK

TECTONIC AND MAGMATIC EVOLUTION

Accretionary History of the Newfoundland Appalachians

The latest Precambrian to Devonian evolution of the Newfoundland Appalachians records the development and destruction of the Iapetus (or proto-Atlantic) Ocean and its marginal basins, culminating in collision between Laurentia and (a) continental block(s) forming part of Gondwanaland cratons (*e.g.*, Wilson, 1966; Williams, 1979; Williams and Hatcher, 1985). The final coalescence of Laurentia and these accreted blocks was accompanied, and followed, by a protracted period of magmatism and strike-slip faulting, as the supercontinent of Pangaea was assembled during the Carboniferous and Permian. Modern plate-tectonic models for the Canadian Appalachians (*e.g.*, van Staal, 2007) are vastly more complex than the initial proposals of Wilson (1966), but this basic evolutionary framework remains unchanged. In Newfoundland, the Appalachian Orogen consists of four principal tectonostratigraphic zones (Figure 1), which can be traced along the length of the mountain chain. From northwest to southeast, these are the Humber, Dunnage, Gander and Avalon zones. Generally, the Humber Zone represents the ancient continental margin of Laurentia, and the Avalon Zone represents a Gondwanan cratonic block. These regions generally escaped the early Paleozoic orogenic

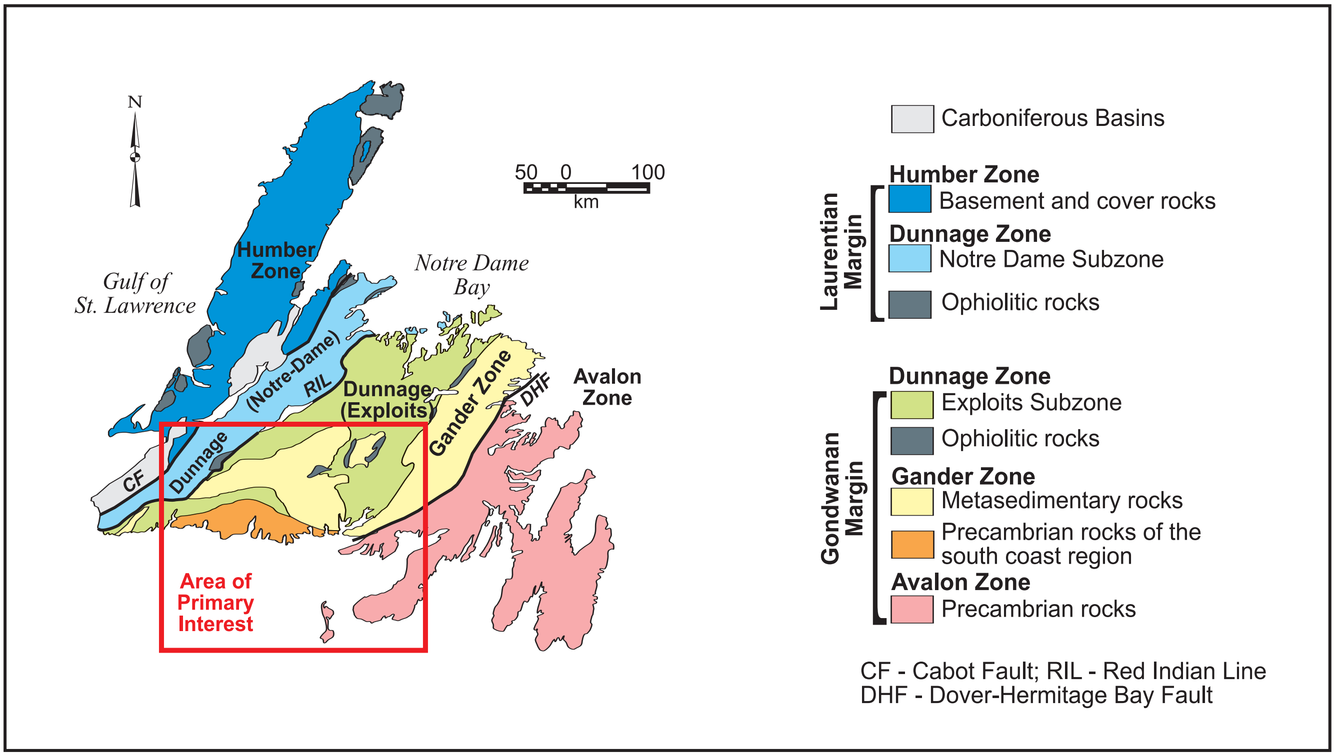

Figure 1. *Tectonic subdivisions of the Newfoundland Appalachians, showing the area that forms the focus of this report. Regional subdivisions after Williams* et al. *(1988).*

events, except at their eastern and western fringes, respectively. The Dunnage Zone consists of two contrasting segments termed the Notre Dame and Exploits subzones; these, respectively, represent collages of peri-Laurentian and peri-Gondwanan arcs and back-arc basin environments (Williams *et al.*, 1988). The Gander Zone consists of a late Precambrian basement overlain by early Paleozoic siliciclastic rocks, and its relationship to the Avalon Zone is not entirely clear, because the contact region is obscured by plutonic rocks and affected by faulting (*see* below). Although late Precambrian remnants, within the eastern Dunnage Zone and on the south coast of Newfoundland, formed at about the same time as rocks within the Avalon Zone, they are now generally considered to represent a separate late Precambrian block termed 'Ganderia' (van Staal *et al.*, 1998). The distinction between 'Avalonia' and 'Ganderia' is most clearly shown by the contrasting Nd isotopic signatures of granites across the Gander Zone–Avalon Zone boundary, a pattern that persists through Nova Scotia (Kerr *et al.*, 1995; Barr *et al.*, 1998). There is little doubt that Ganderia was accreted to the Laurentian margin prior to the mid-Silurian, and perhaps somewhat earlier in Newfoundland, but there is less agreement about accretion of the Avalon Zone to Laurentia. Some believe that it is simply an extension of the Ganderia Block, to which it was always attached, whereas others believe that they only came together in the Devonian following subduction of a narrow intervening oceanic tract. For a discussion of the latest plate-tectonic models for the Newfoundland Appalachians, see van Staal (2007), and references therein.

Appalachian-Cycle Magmatism in Space and Time

The formation of Mo and W deposits is linked to the plutonic history of Newfoundland, which has a much looser link to its accretionary tectonics. Although granites in Newfoundland range in age from Neoproterozoic to Devonian, the most abundant (at least in terms of areal extent) formed during the Silurian and the Devonian (Currie, 1995; Kerr, 1997). The major pulse of magmatism thus postdates both the accretion of peri-Laurentian and peri-Gondwanan arcs to Laurentia, and the final collision of Laurentia and Ganderia. The youngest Devonian plutonic rocks also postdate any later juxtaposition of Ganderia and Avalonia, because they intrude the boundary between these regions. The plate-tectonic setting of the widespread Siluro-Devonian plutonic suites is keenly debated, and the divergent viewpoints reflect contrasting interpretations of Ganderia–Avalonia relationships. In some models, these granitoid suites are viewed as 'distal' manifestations of subduction-zone magmatism (*e.g.*, van Staal, 2007), whereas in others they are interpreted as post-collisional and largely ensialic (*e.g.*, Kerr, 1997).

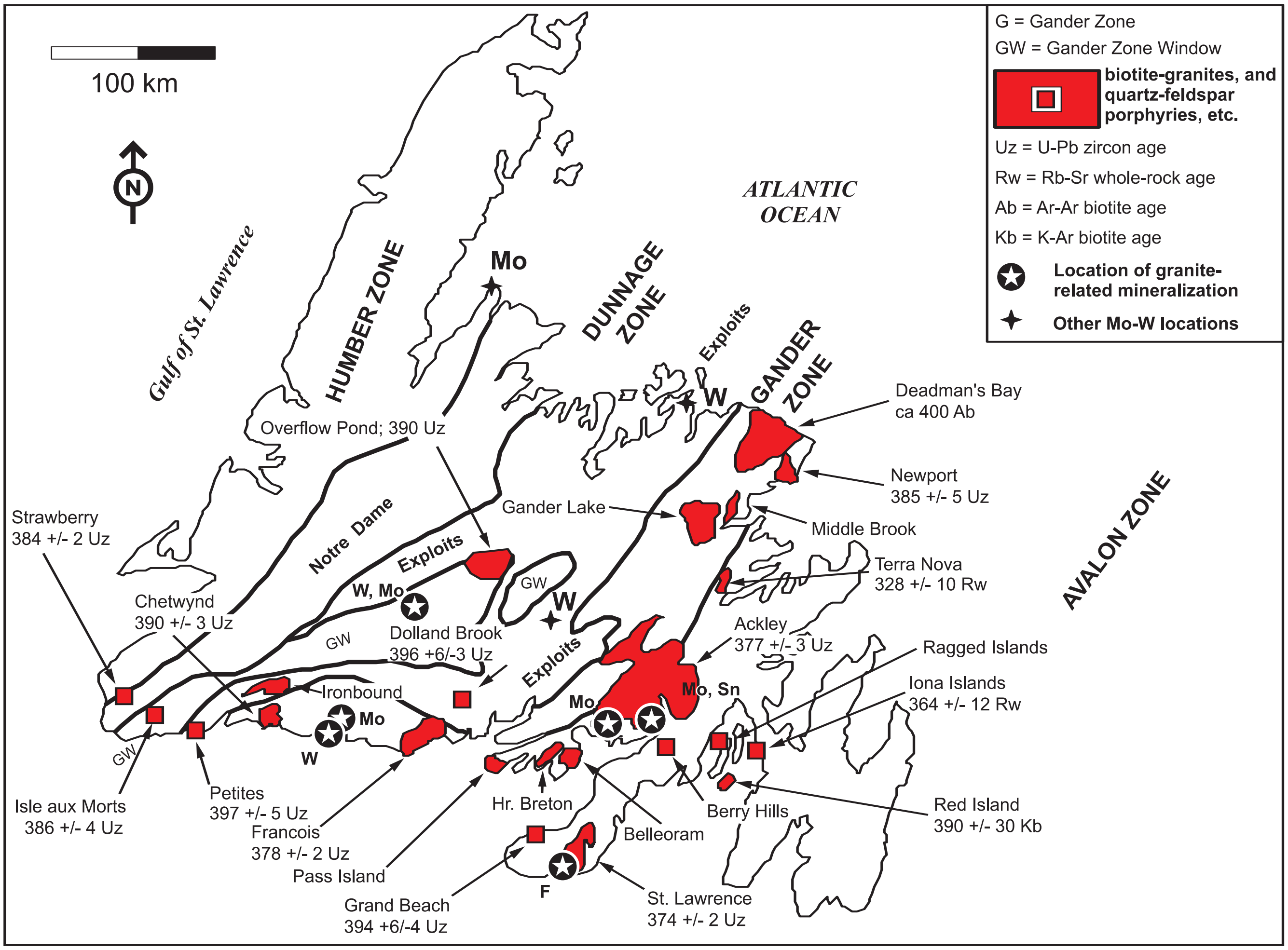

Figure 2. *The distribution of late-stage (Devonian) plutonic rocks in Newfoundland, showing available radiometric ages, and the main locations of granophile mineralization. Modified and updated after Kerr (1997); see this source for references to most of the age determinations. Plutons too small to be denoted accurately at this scale are shown by symbols.*

The distribution of Devonian plutonic suites is indicated in Figure 2, together with the locations of the main occurrences of granite-related mineralization, including tungsten and molybdenum. Note that geochronological data for the youngest suites are less than ideal, because these posttectonic plutons are not useful tectonic markers and there is, thus, less incentive to date them. Nevertheless, available data indicate a gradual shift in the locus of magmatic activity through time (Kerr, 1997). Silurian to earliest Devonian suites are widespread across central Newfoundland, and even extend into the marginal portion of the Humber Zone, but there is a general younging of their ages from northwest to southeast. The youngest granites have a much more restricted distribution (Figure 2); the available geochronological data from these rocks are also summarized in Figure 3. Most are located along the south coast of the Island, and on both sides of the Gander–Avalon boundary. Aside from mafic sills in the Cape St. Mary's area, there are no Silurian plutonic rocks in the western part of the Avalon Zone. This broad northwest to southeast age progression could be interpreted in terms of subduction rollback, or attributed to propagating lithospheric delamination, or could even be viewed as migration of conjoined Laurentian and Gondwanan blocks across a relatively static thermal anomaly (*see* discussion by Kerr, 1997).

GRANITE-RELATED MINERALIZATION IN NEWFOUNDLAND

Known examples of granite-related mineralization mostly occur in Silurian and Devonian igneous rocks (Figure 2), although the age of the mineralization is not necessarily the same as that of its host rocks. Vein-style deposits occur in a variety of other rock types, but in most cases are not far removed from granites. The only example that has been mined to date is the vein-style fluorite deposit at St. Lawrence (Teng and Strong, 1976; Collins and Strong, 1984; Howse *et al.*, 1983). Fluorite-bearing veins here are

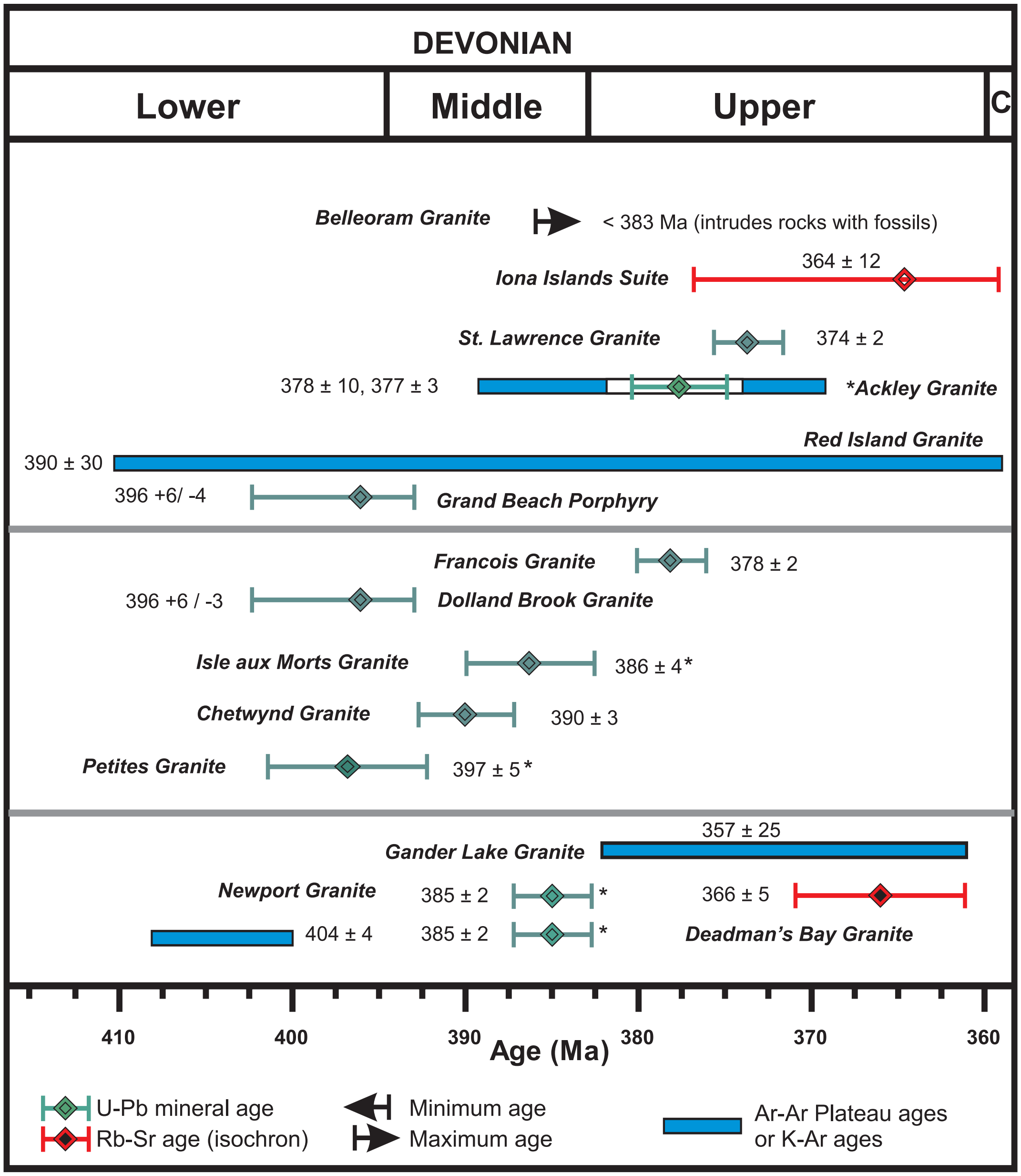

Figure 3. *Time chart showing geochronological data from late granites in the Avalon Zone (top) south coast region (middle) and northeast Gander Zone (bottom). The U–Pb ages indicated by asterisks are unpublished results obtained under contract to the Geological Survey by G.R. Dunning or R.D. Tucker. See the text and Kerr (1997) for sources of other results.*

both spatially and genetically linked to the St. Lawrence Granite, a high-level, geochemically evolved pluton of peralkaline composition. The hydrothermal veins associated with the granite locally contain barite, Pb and Zn, and there are also minor Mo occurrences. Elsewhere in the Avalon Zone, molybdenum mineralization is best known within the Ackley Granite, a large and probably composite plutonic body that straddles the Gander–Avalon boundary. The mineralization is generally assumed to be the same age as its host rocks, *i.e.*, syngenetic. Minor Mo mineralization is also associated with parts of the late Precambrian Harbour Breton Granite and the adjacent, Devonian granite of the Old Woman Stock (O'Brien *et al.*, 1995), in the western Avalon Zone.

The Grey River area on the south coast (Figure 2) contains the most abundant and diverse granite-related mineralization, even though there is a general absence of 'young' posttectonic granitoid rocks, at least at the surface. The history of mineral exploration and geological research in this area, up to 1996, is summarized in Dickson (1997). Mineralization at Grey River includes W-bearing quartz veins that now form the focus for an advanced exploration project, and myriad smaller veins containing W, and minor base metals. The country rocks to these veins are mostly late Precambrian rocks but mineralization also occurs in adjacent Silurian granites, and mineralization has long been inferred to have a link to younger granitoid magmas (*e.g.*, Bahyrycz, 1956; Higgins, 1985). Also in this area, there is extensive low-grade Mo mineralization associated with sheeted quartz veins at the Moly Brook prospect (Figure 2). The dominant host rocks to the vein system are heterogeneous, variably deformed granites, but there is likely no genetic relationship between these and the mineralization. The Grey River area also contains numerous vein-style showings of gold and silver, and assorted base metals (Cu, Pb and Zn) and some bismuth (Bi).

In south-central Newfoundland, the main locus of tungsten and molybdenum mineralization is in the Granite Lake area (Dickson, 1982; Tuach, 1996), where numerous showings are known. For the most part, these are hosted by the Wolf Mountain Granite, which is a subunit of the regionally extensive North Bay Granite Suite of Dickson (1990).

Other instances of Mo and W mineralization in Newfoundland do not have obvious spatial or genetic relationships to granitic rocks (Figure 2). These include the Mo mineralization north of Baie Verte (Parrell prospect), and W mineralization in northeastern and southern Newfoundland at the Charles Cove and Great Gull Lake prospects, respectively. It is also worth noting scattered base- and precious-metal-bearing quartz-carbonate veins and barite veins in the Placentia Bay region. There is a prominent positive aeromagnetic anomaly beneath Placentia Bay, which includes known granites at Red Island and on the Ragged Islands (Figure 2). Kerr *et al.* (1993a) suggested that some of these occurrences might represent distal hydrothermal veins associated with a large batholithic body in the subsurface.

SETTINGS AND CHARACTERISTICS OF MINERALIZATION

There is an obvious spatial connection between Mo and W occurrences in Newfoundland, suggestive of a genetic association. For this reason, this section of the report is organized in a geographic manner, rather than by commodity. Figure 4 shows the distributions of all known instances of Mo and W mineralization in Newfoundland, and specifically indicates localities discussed below. Attention here is focused mostly on three areas, *i.e.*, the Ackley Granite, the Grey River area, and the Granite Lake area, with some brief discussion of other areas containing Mo and/or W showings. Table 1 lists all occurrences with essential information from the Mineral Occurrence Database System (MODS); note that some individual MODS entries may lack the most recent information.

ACKLEY GRANITE AREA

Regional and Local Setting

The Ackley Granite is a large posttectonic granitic body that underlies some 5000 km^2 of mostly barren, upland country north of Fortune Bay (Figures 2 and 4). It straddles the tectonic boundary between the Gander and Avalon zones, and has long been regarded as an example of a 'stitching pluton' whose emplacement postdates the final juxtaposition of these tectonic elements. The geology and geochemistry of the Ackley Granite were described by Whalen (1980, 1983), Dickson (1983), Tuach *et al.* (1986), Kontak *et al.* (1988), and Kerr *et al.* (1993a). On its northwest side, granites intrude metasedimentary country rocks correlated with the Cambrian Gander Group of northeastern Newfoundland, whereas on its southeast side, the country rocks are late Precambrian sedimentary and volcanic rocks assigned to several stratigraphic units. Locally, the Ackley Granite also intrudes late Precambrian intrusive rocks of the Cross Hills Plutonic Suite, which hosts minor Zr–Y–REE mineralization (Tuach, 1991).

Dickson (1983) defined several subunits within the Ackley Granite, which have partial gradational boundaries, and noted that granites in the northwest are typically coarse-grained, K-feldspar porphyritic granites, whereas those in the southeast are texturally variable, evolved and leucocratic, biotite granites. It seems likely that the body is composite in detail, although the significance of apparent age differences between its various 'facies' is unclear. The regional attitude of the southeastern contact is unknown, but it is generally thought to dip at shallow to moderate angles beneath the country rocks, and to represent the roof zone of the original batholith. Whalen (1980, 1983) and Dickson (1983) suggested that this southeastern region represents the highest levels of the magma chamber, where evolved magmas developed and accumulated. This interpretation is supported by systematic geochemical trends from northwest to southeast, first noted by Whalen (1983) and documented in detail by Tuach *et al.* (1986). The southeastern edge of the body contains the most geochemically evolved rocks, both in terms of major- and trace-elements, and these rocks are also enriched in Mo. Close to the contact, aplitic and pegmatitic phases are common, and there are also many examples of greisens, *i.e.*, rocks that are rich in magmatic or hydrothermal muscovite. Topaz-bearing greisens and 'quartzolites' (highly siliceous rocks representing a transition from magmatic to hydrothermal settings) are reported from the Sage Pond area, but are not known in other parts of the southern contact (Dickson, 1983).

Like many such rocks in Newfoundland, the Ackley Granite was initially suggested to be as young as Carbonif-

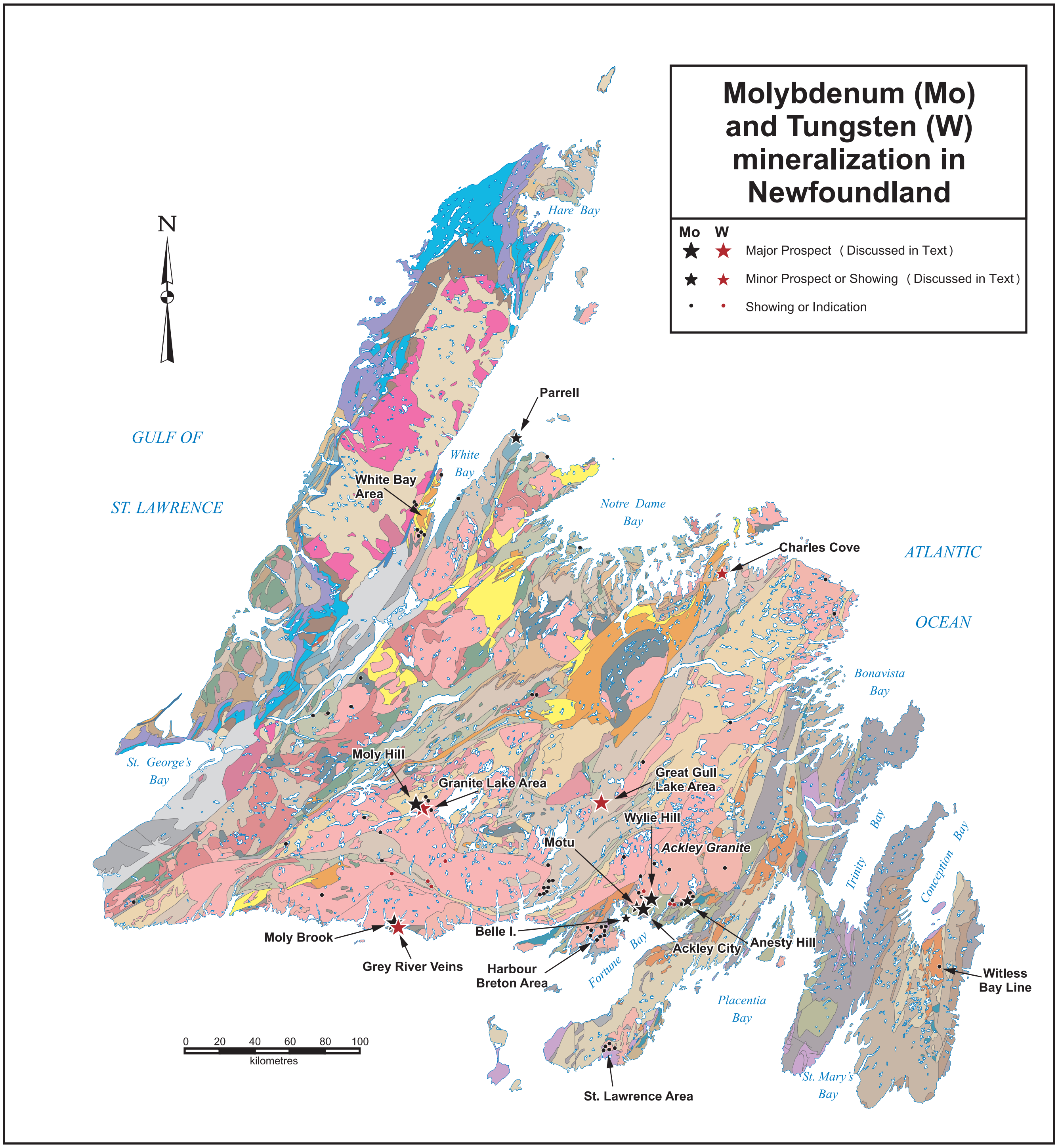

Figure 4. *The locations of Mo and W mineralization in Newfoundland. The geological background is the same as the existing 1:1 000 000-scale map of the Island, and is provided without a detailed legend for illustrative purposes only. For a listing of Mo and W occurrences,* see *Table 1.*

erous on the basis of Rb–Sr, K–Ar and Ar–Ar data (Bell *et al.*, 1977; Whalen *et al.*, 1980; Dallmeyer *et al.*, 1983), but it is more likely of Devonian age (378 to 375 Ma), based on more recent Ar–Ar studies (Kontak *et al.*, 1988). An U–Pb zircon age of 377 ± 3 Ma (R. Tucker, unpublished data, 2008) was reported from Long Harbour by O'Brien (1998). Although mutual contacts appear to be in large part gradational, it remains possible that individual units within this larger area have slightly different ages. Whalen (1980) suggested that Mo mineralization developed at 338 ± 7 Ma,

Table 1. Molybdenum and tungsten locations in Newfoundland

MODS Number	Easting	Northing	Deposit Name	Status	Secondary Commodities
001M/11/Mo 002	634530	5283570	Ackley City	Developed Prospect	Zn, Cu
001M/10/Mo 001	659400	5286300	Anesty Hill South	Prospect	Sn, F
001M/11/Mo 005	638050	5286300	Wylie Hill	Prospect	W, Sn, U
011P/11/Mo 001	492230	5273500	Moly Brook	Prospect	Cu, Au, Ag
012A/02/Mo 001	511660	5339360	Granite Lake Molybdenum #1	Prospect	Cu, W, Zn
012I/01/Mo 001	562350	5552190	Parrell Prospect	Prospect	Cu, Pb
001L/13/Mo 001	611800	5202800	North Lawn No. 1-Snake Anomaly	Showing	Cu
001L/13/Mo 002	611740	5200900	Lawn Molybdenum No. 1	Showing	F
001L/13/Mo 003	611600	5200790	Lawn Molybdenum No. 2	Showing	F
001L/13/Mo 005	612590	5203000	North Lawn No. 2-Snake Anomaly	Showing	Cu
001L/14/Mo 001	614950	5204640	Hjelm Ridge	Showing	
001L/14/Mo 004	614840	5201160	Three Sticks Pond	Showing	
001M/10/Mo 006	659340	5286700	Anesty Hill East	Showing	W, F, Sn
001M/11/Mo 001	632740	5283430	Motu	Showing	
001M/11/Mo 003	635650	5284200	Crow Cliff	Showing	
001M/11/Mo 004	635930	5284800	Dunphey Brook Molybdenum	Showing	
001M/11/Mo 006	633260	5288600	Frank's Pond	Showing	
001M/11/Mo 007	624400	5276670	Belle Island	Showing	Cu, Ba, F
001M/11/Mo 008	634650	5286850	North Hill Molybdenum	Showing	
001M/12/Mo 004	612210	5269050	Leonard's Find	Showing	
001M/13/Mo 014	578455	5291610	Northwest Cove No. 7	Showing	Beryl
001M/14/Mo 001	623200	5311400	Medonnegonix Lake	Showing	
011P/14/Mo 001	484950	5309350	East White Bear Showing	Showing	Mo, W, Sn, Ag, Au
012A/02/Mo 002	508250	5340300	Granite Lake Molybdenum #2	Showing	
012A/16/Mo 001	571220	5404190	Coronation Lake South #1	Showing	Cu, Au, Ag
012A/16/Mo 002	570880	5404540	Coronation Lake South #2	Showing	Cu, Au, Ag
001L/13/Mo 004	613730	5200700	Three Sticks	Indication	Cu, Pb, Sn
001L/14/Mo 002	614580	5201930	Lanes Pond	Indication	
001L/14/Mo 003	618000	5202000	Lawn River	Indication	
001M/10/Mo 002	657000	5286000	Eastern Lookout Molybdenum	Indication	Sn, F
001M/10/Mo 003	660600	5290150	Sage Pond North	Indication	
001M/10/Mo 004	659950	5285580	Deer Pond	Indication	
001M/10/Mo 005	650180	5286420	Young Bight	Indication	F
001M/10/Mo 007	661930	5287480	Moulting Pond South #3	Indication	
001M/12/Mo 001	604130	5266340	Shoal Cove	Indication	
001M/12/Mo 002	609620	5265910	Salmonier Pond No. 1	Indication	
001M/12/Mo 003	608290	5264580	Salmonier Pond No. 2	Indication	
001M/12/Mo 005	612500	5271490	Southwest Brook #1	Indication	
001M/12/Mo 006	611810	5271700	Road Cut	Indication	
001M/12/Mo 007	610820	5266880	Furey's Find	Indication	
001M/12/Mo 008	612510	5270420	Southeast Brook #2	Indication	
001M/12/Mo 009	604000	5270090	Rattling Brook West	Indication	
001M/12/Mo 010	602730	5270800	Taylor Bay Hills	Indication	
001M/13/Mo 001	579890	5306685	Gonzo Pond East	Indication	
001M/13/Mo 002	582600	5297950	Rattling Brook Pond	Indication	Bi, Beryl, Au
001M/13/Mo 003	580380	5297690	Roti Valley	Indication	Pb, Au
001M/13/Mo 004	580190	5295310	North Gull Pond	Indication	Beryl
001M/13/Mo 005	579950	5293920	Northeast Gull Pond	Indication	Zn, P
001M/13/Mo 006	578830	5293900	Gull Feeder	Indication	Cu, Pb
001M/13/Mo 007	578090	5293370	Dales Pond South	Indication	Cu
001M/13/Mo 008	579125	5291600	Northwest Cove No. 1	Indication	
001M/13/Mo 009	578980	5291660	Northwest Cove No. 2	Indication	
001M/13/Mo 010	578860	5291530	Northwest Cove No. 3	Indication	

Table 1. Continued

MODS Number	Easting	Northing	Deposit Name	Status	Secondary Commodities
001M/13/Mo 011	578530	5291680	Northwest Cove No. 4	Indication	Zn, Beryl, W
001M/13/Mo 012	578430	5291735	Northwest Cove No. 5	Indication	
001M/13/Mo 013	578430	5291630	Northwest Cove No. 6	Indication	Cu
001M/13/Mo 015	578520	5291545	Northwest Cove No. 8	Indication	Cu
001M/13/Mo 016	578230	5291540	Northwest Cove No. 9	Indication	
001M/13/Mo 017	578140	5291370	Northwest Cove No. 10	Indication	
001M/13/Mo 018	578610	5291265	Northwest Cove No. 11	Indication	Beryl
001M/13/Mo 019	578455	5291140	Northwest Cove No. 12	Indication	Cu, Zn, W, Beryl, P
001M/13/Mo 020	576450	5291500	Bill Don't Know Pond	Indication	Cu
001M/13/Mo 021	577430	5290350	Lampidoes Molybdenite	Indication	
001M/13/Mo 022	576250	5290050	Noah's Fee Simple	Indication	
001M/13/Mo 023	575000	5290580	North Bay Granite No. 1	Indication	Cu
001M/13/Mo 024	575200	5289900	North Bay Granite No. 2	Indication	
001M/14/Mo 002	640650	5307600	Hungry Grove Pond	Indication	
001M/14/Mo 003	632775	5300350	Big Blue Hill Pond	Indication	
001M/14/Mo 004	632175	5290500	Spout Pond	Indication	
001M/14/Mo 005	649210	5304150	Kane Brook	Indication	
001M/15/Mo 001	649210	5304150	Sandy Harbour Ridge	Indication	
001N/07/Mo 001	350110	5242740	Witless Bay Line Molybdenum	Indication	Cu, Au, Ag
002D/06/Mo 001	634170	5365700	Little Gander Pond	Indication	
002D/10/Mo 001	684020	5388370	Gambo Pond	Indication	
002E/12/Mo 001	598160	5488450	Brighton Island	Indication	
002F/04/Mo 001	306100	5448620	Southshore Northwest Pond	Indication	Fe
002F/05/Mo 001	302700	5468550	Deadman's Bay	Indication	
002L/04/Mo 001	579430	5540370	Teakettle Cove West	Indication	Feldspar, Mica
011O/11/Mo 001	343150	5285600	Long Range Molybdenite Showing	Indication	
011P/13/Mo 001	450600	5289650	Burgeo Road Molybdenum	Indication	
012A/02/Mo 003	508110	5339950	Granite Lake Molybdenum #3	Indication	
012A/02/Mo 004	511180	5339200	Granite Lake Molybdenum #4	Indication	Cu
012A/02/Mo 005	511530	5339230	Granite Lake Molybdenum #5	Indication	Cu
012A/02/Mo 006	511660	5339230	Granite Lake Molybdenum #6	Indication	Cu, F, W
012A/02/Mo 007	512000	5339360	Granite Lake Molybdenum #7	Indication	Cu
012A/02/Mo 008	511440	5343580	Caribou Lake Molybdenum	Indication	Mn, Zn
012A/03/Mo 001	474750	5334000	Burnt Pond Canal	Indication	Cu
012A/03/Mo 002	484120	5325490	Granite Lake Quarry	Indication	
012A/04/Mo 001	430100	5318900	North Moraine Pond Molybdenum	Indication	
012A/07/Mo 001	511010	5345040	Cowey Lake Molybdenum SW #1	Indication	Bi, Ag, W
012A/07/Mo 002	510630	5344880	Cowey Lake Molybdenum SW #2	Indication	W
012A/11/Mo 001	467300	5397500	Whalen's Molybdenum	Indication	
012A/12/Mo 001	454080	5393700	High Lake	Indication	
012A/12/Mo 002	445595	5392360	Gun Creek	Indication	Cu
012A/14/Mo 001	472850	5413840	Harrys Brook	Indication	Cu
012H/10/Mo 001	505580	5498460	Gull Lake	Indication	Cu
012H/10/Mo 002	507460	5496150	Gull Pond Brook	Indication	
012H/10/Mo 003	507400	5497300	Brown's Cove Barrens Mo #1	Indication	
012H/10/Mo 004	506440	5498020	Gull Lake SE Molybdenum #2	Indication	
012H/10/Mo 005	506020	5498180	Brown's Cove Barrens Mo #3	Indication	
012H/10/Mo 006	506150	5495540	Gull Pond South	Indication	
012H/10/Mo 007	508630	5496300	Gull Pond Brook	Indication	
012H/15/Mo 001	528620	5516510	Westport Road Molybdenite	Indication	
012H/15/Mo 002	503570	5514500	Main Road #2	Indication	Cu
012H/15/Mo 003	504450	5512890	Doucers Brook Northwest	Indication	Cu
012H/15/Mo 004	518870	5530080	Birchy Cove North	Indication	Cu, Au

based on K–Ar data from muscovites in associated greisens, but this is not supported by new Re–Os age determinations, which suggest an average age of 380 ± 2 Ma for the three main showings (Lynch *et al.*, *this volume*). This age is closely similar to the 377 ± 3 Ma U–Pb age, located some 10 km to the east.

Molybdenum Mineralization

Molybdenum mineralization, locally associated with W and Sn, occurs in several places at, or close to, the southeastern contact of the Ackley Granite. A molybdenum showing in Precambrian country rocks on Belle Island in Fortune Bay (Figure 4) is a possible example of related mineralization above a subsurface extension of the pluton. The most important localities in terms of previous work are the Ackley City, and Wylie Hill and Motu prospects (Figure 4); the remainder appear to be minor on the basis of existing data, and are not discussed in detail. A general summary of previous work on these prospects was also provided by O'Brien *et al.* (1995).

Ackley City Prospect

The Ackley City prospect was probably the first molybdenite occurrence to be discovered in the province, reportedly around 1882. It is located near the shore of Rencontre Lake, and is accessible from the community of Rencontre East. The surface mineralization was assessed by several individuals and groups between 1900 and 1935, and it is reported that small amounts of high-grade ore were removed in the earliest years. In the late 1930s, an adit about 60 m long was driven into the hillside, and a shallow shaft was excavated to allow about 200 m of lateral exploration at deeper levels. A report by McKinstry (1938) outlines early efforts in search of a viable deposit, and White (1940) provided the first geological overview, based upon work completed for a Ph.D. thesis. The deposit was drilled by the Newfoundland Government and considered for production during World War II (Quinn, 1944), when molybdenum was a strategic metal, but the prospect was judged to be too small. There was sporadic exploration through the 1950s and 1960s, by Newfoundland and Labrador Corporation (NALCO), Caledon Minerals, and Canadian Javelin, amongst others (*e.g.*, Bradley, 1955; Fogwill, 1965). Norlex Mines completed the most ambitious drilling program in 1968, and the report by Nolan (1969) provides some detailed information on this work. There has been little subsequent activity, although the mineral rights at the site were recently acquired by exploration companies. Published accounts of the geology and mineralization at the site are provided by White (1940) and Whalen (1980).

Several general estimates were made of the resource at Ackley City in the early days. The greatest was 125 000 tons at 0.58% MoS_2 (Smith, 1936), but more conservative estimates were 65 000 to 80 000 tons at essentially the same grades (McKinstrey, 1938; Nolan, 1969). These grades equate to about 0.4% Mo (the weight proportion of Mo in MoS_2 is about 0.6). Exploration at the site can hardly be described as exhaustive, as the deepest drillhole is less than 200 m, but the near-surface mineralized zone has been well-defined by previous work.

Mineralization is located at the contact between leucocratic granite (with associated aplite–pegmatite segregations) and rhyolitic country rocks; the latter sit topographically above the mineralized zone and the contact between granite and older rhyolite is inferred to dip southward. Sporadic molybdenite occurs over an outcrop area of several thousand square metres, but the highest grade mineralization is restricted to a zone of some 50 by 20 m in the vicinity of the adit and shaft. The best mineralization is preserved in a spoil heap on the lakeshore, where material removed from the adit was dumped. The host granite outcrops at the site are variable in texture, but most are fine- to medium-grained equigranular biotite granites, which are cut (or locally grade into) fine-grained sugary aplites or coarse pegmatitic zones. There are irregular zones of muscovite-rich greisen that appear gradational with 'normal' granites. Molybdenite distribution does not obviously favour any one rock type over another; the mineral occurs as disseminations, fracture fillings and coatings, and local high-grade pods. Molybdenite is present within, and outside, greisenized zones, and more rarely, in discrete pegmatites and quartz veins but other sulphides are rare. Purple fluorite is present on fracture surfaces.

White (1940) reported the presence of local chalcopyrite, sphalerite, galena and barite, but these are certainly not obvious in the field. Locally, molybdenite crystals form spectacular book-like masses, centimetres in diameter. Whalen (1980) described the distribution of mineralization and greisen alteration as very erratic, with no sign of zoning, and this is certainly an apt description. The style of mineralization varies from clearly syngenetic (*i.e.*, interstitial clots of molybdenite associated with miarolitic cavities) to locally epigenetic (*i.e.*, crosscutting quartz veins). However, this likely reflects nothing more than diachronous crystallization and solidification of the host rocks; there is no reason to suspect a significant difference in age between molybdenite and its host rocks. Drilling in the 1960s demonstrated that the granite was present at depth beneath the felsic volcanic country rocks, and that these were cut by granitic veins and dykes that contain disseminated molybdenite (Nolan, 1969).

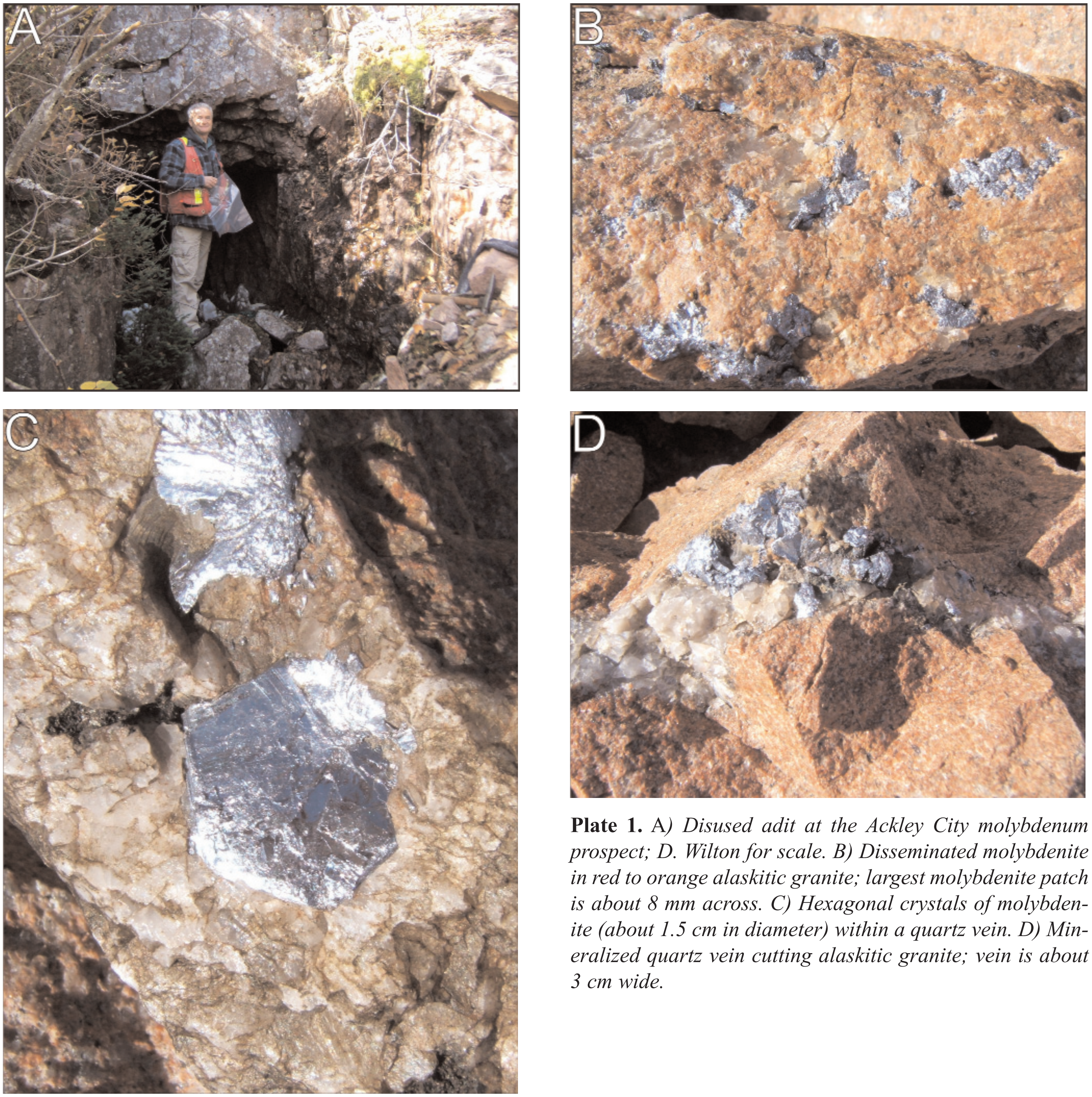

Plate 1. A*) Disused adit at the Ackley City molybdenum prospect; D. Wilton for scale. B) Disseminated molybdenite in red to orange alaskitic granite; largest molybdenite patch is about 8 mm across. C) Hexagonal crystals of molybdenite (about 1.5 cm in diameter) within a quartz vein. D) Mineralized quartz vein cutting alaskitic granite; vein is about 3 cm wide.*

The erratic nature of the mineralization, and the difficulties in assaying molybdenite-rich samples, make it difficult to assess bulk grades. However, American Cyanamid Company collected a bulk sample of about 200 kg in the 1930s, and determined the head grade to be 0.45% Mo; processing tests suggested recoveries in the range of 85 to 90% (McKinstry, 1938). This suggests that the earlier estimates are broadly accurate. Compared to grades reported from potential bulk tonnage deposits (commonly 0.1% Mo or less) these are certainly attractive under current commodity prices. Typical examples of mineralization from Ackley City are shown in Plate 1.

Wylie Hill Prospect

The Wylie Hill prospect is located several kilometres inland from the Ackley City site, and is much less accessible. It was also explored in the 1930s, when several trenches were excavated and a shallow shaft was sunk (McKinstrey, 1938). The prospect has two separate zones, of which one was reported to give grades of 0.35 to 0.48% MoS_2. Diamond drilling was conducted in the 1950s and in 1968 (Nolan, 1969), from which the best intersection was about 20 m grading 0.345% MoS_2 (0.21% Mo), within a wider intersection of about 44 m at 0.17% MoS_2 (0.1% Mo). Sur-

Plate 2. A*) Flooded shaft at the Wylie Hill prospect B) Disseminated pyrite, chalcopyrite and molybdenite at Wyllie Hill; the molybdenite is distinctly blue, rusting of surfaces indicates the abundance of pyrite. C) High-grade, disseminated molybdenite at Wylie Hill. D) Rusty nodules in weathered granite at Wylie Hill, indicating the irregular distribution of sulphides.*

face samples from trenches collected by Dickson and Howse (1982) gave generally low assays below 0.1% Mo, although the same authors report that a zone of about 200 m^2 had higher grade mineralization of about 0.2% Mo. The best grades reported from drillcore in 1960s exploration were around 1% MoS_2 (0.6% Mo) over narrow widths (Nolan, 1969). The wide variation in assay results is likely an indication of the heterogeneity of mineralization, coupled with problems in assaying molybdenite-rich samples. Tungsten and tin analyses reported by Dickson and Howse (1982) are low, generally less than 10 ppm of each. Following the most extensive assessment by drilling, Nolan (1969) declined to make any resource estimate for Wylie Hill, due to "the irregularity of the mineralization thus far encountered as well as the uncertainties and inadequacies of the older sampling procedures".

Like Ackley City, Wylie Hill sits adjacent to the contact between the granite and the adjoining felsic volcanic rocks, and sits structurally beneath the latter. The host rocks show less textural variation than at Ackley City and are dominated by fine- to medium-grained leucocratic granite, with lesser amounts of aplite and pegmatite. The mineralogy is also distinct, because other sulphides (mostly pyrite and lesser chalcopyrite) are, at least, as abundant as molybdenite, whereas they are rare at Ackley City. Over a wide area, the granite displays nodular rusty patches that represent sulphide-rich zones where the pyrite appears to have either replaced quartz, or filled in cavities within the rock. The molybdenite is generally associated with pyrite (although the latter occurs alone over a wider area) and is in disseminated form, and present on fracture surfaces. In places, mineralization is heavily disseminated and spectacular, but its

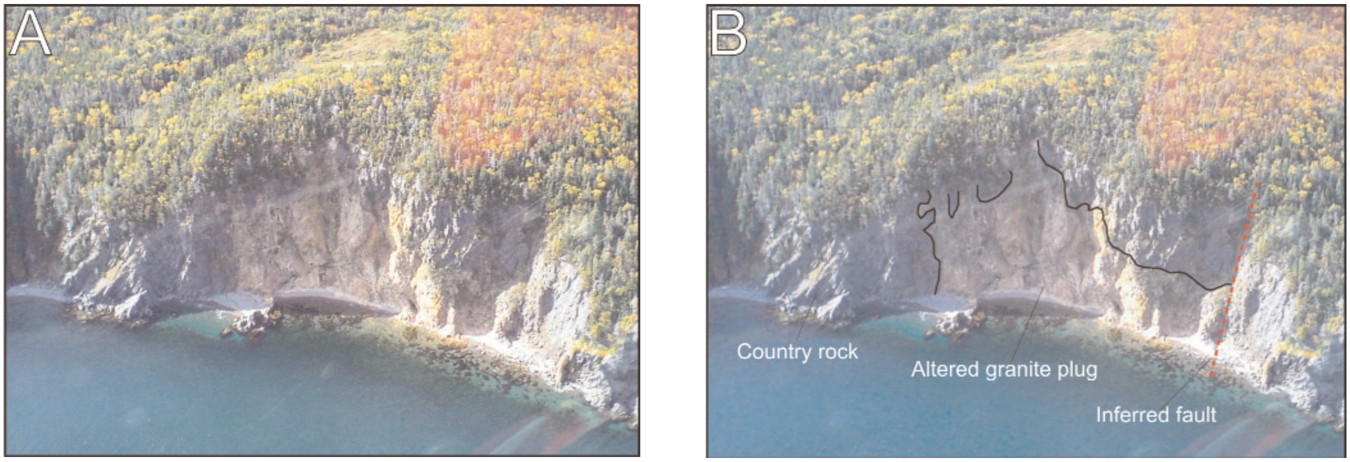

Plate 3. A*) The granitic dyke or stock on Belle Island, photographed from a helicopter; note the gossan development around the contacts of the pink granitic unit. B) Annotated version of the same photograph, showing the locations of contacts.*

appearance can be deceptive in cases where molybdenite is present on fracture surfaces. Molybdenite is locally reported to also occur in veinlets in the adjacent felsic volcanic country rocks. Whalen (1980) reported quartz–feldspar-porphyry dykes of post-mineralization timing. Typical examples of mineralization from Wylie Hill are shown in Plate 2.

Motu Prospect

The Motu prospect is located about 2 km west of Ackley City, and is in an analogous location *i.e.*, adjacent to, and structurally below, the rhyolitic country rocks on the southern edge of the pluton. It was discovered in the 1930s, and was trenched, but no underground evaluation was attempted. Information on grades is limited, but reports from the 1930s (McKinstry, 1938) quote values of 0.3 to 0.5% MoS_2 (0.2 to 0.4% Mo). Subsequent drilling in the 1950s provided disappointing results, with most grades below 0.1% Mo (Fogwill, 1965). These results were confirmed by the work of Dickson and Howse (1982). Samples were generally poor in W and Sn, aside from one sample that contained 10 ppm W and 38 ppm Sn.

The mineralization at the Motu prospect most closely resembles that seen at the Ackley City prospect, although the grade and continuity of mineralization are inferior.

Belle Island Showing

This showing is located on Belle Island in Fortune Bay, some 8 km southwest of the Ackley City and Motu prospects (Figure 4). The regional host rocks are late Precambrian sedimentary rocks of the Rencontre Formation, but the Mo mineralization is associated with a plug or dyke of quartz–feldspar-porphyry that is exposed in cliff faces on the island. The granitic rocks are reported to be aplitic and fine-grained granites that resemble those hosting Mo mineralization at Ackley City and Motu (Whalen, 1980). Pyrite, chalcopyrite, fluorite and barite are also reported to occur in lesser quantities. Sampling in the 1930s suggested grades of 0.2 to 0.35% MoS_2 from altered and mineralized country rocks (Howse, 1936). It is not clear from these descriptions if any mineralization is present in the granitic rocks. Fogwill (1965) was the first to suggest a link between this showing and a buried extension of (or equivalent of) the Ackley Granite, an opinion later shared by Whalen (1980) and Kerr *et al.* (1993a). An aerial photograph of the mineralized zone on Belle Island is shown in Plate 3. It has not yet been visited by the authors.

Other Molybdenite Occurrences

Several small occurrences of molybdenite in the southwestern part of the Ackley Granite are not associated specifically with the contact of the pluton. Some of them resemble the Ackley City and Motu prospects, in that molybdenite is generally disseminated, and locally high-grade. The Dunphey's Brook-Crow Cliff showing, located across Rencontre Lake from the Ackley City prospect (Figure 4), contains up to 0.4% Mo, and contains well-developed pegmatites containing giant quartz crystals up to 50 cm in diameter, and also breccia-like rocks interpreted as tuffisites (Whalen, 1980). Showings north of Rencontre Lake, such as Frank's Pond and North Hill (Figure 4) are reported to consist largely of quartz-vein-hosted mineralization, containing sparse molybdenite (White, 1940).

Molybdenum Mineralization Associated with Tin

Sage Pond Area

This group of showings lies about 10 km to the east of the area described above in the area around Sage Pond and Hungry Grove Pond (Figure 4). Molybdenite is present in

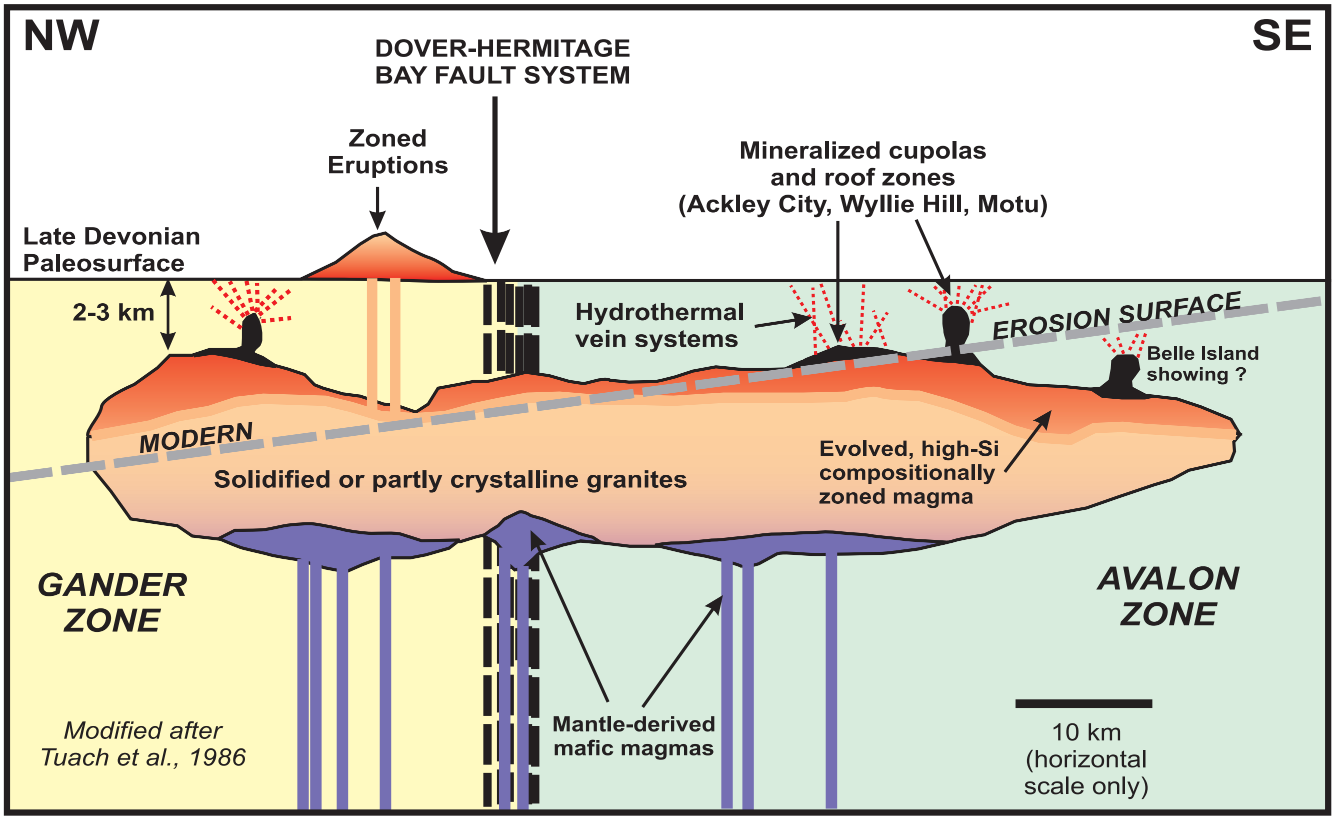

Figure 5. *Conceptual model for the Ackley Granite of southeastern Newfoundland, showing the modern erosion surface and its relationship to the original plutonic architecture, and evolved magmas concentrated near the roof of the magma chamber. Modified after Tuach* et al. *(1986).*

many, but the area is probably better known for the only Sn occurrences presently known in Newfoundland. Minor W mineralization is also reported here. The area lies several kilometres from the nearest road, but there is now access along a well-developed ATV trail that leads to Long Harbour.

The most significant showings in this area are Anesty Hill South (Mo, Sn) and the Dicks Pond West and Moulting Pond South showings (Sn with minor Mo), all of which were discovered in the early 1980s, and are described by Dickson (1983). The mineralization is hosted by pods and sheets of quartz–topaz greisen, which contains molybdenite, pyrite, fluorite and cassiterite. Drilling at the site indicated the presence of low-grade Sn mineralization (up to 0.79% Sn over narrow widths) and anomalous Mo (O'Sullivan, 1982, 1983). In the field, pyrite is the most obvious constituent, and molybdenite is rare. The other showings in this area are hosted by similar topaz-bearing rocks, and also by 'quartzolites'. Molybdenite is subordinate to cassiterite. For more detailed descriptions of this area, see Dickson (1983) and company reports (O'Sullivan, 1982, 1983).

Discussion and Interpretation

The general model proposed by Tuach *et al.* (1986), in part, built on earlier work by Whalen (1980, 1983) and Dickson (1983), provides a logical explanation of the general features of mineralization associated with the Ackley Granite, although it may need to be refined to account for some local variations. In this model (shown schematically in Figure 5) the Ackley Granite is viewed as a large, sheet-like magma chamber that has been tilted to the southeast, such that the modern erosion surface represents an oblique horizontal section. The upper section of the magma chamber is inferred to have been the site of the most evolved and volatile-rich magmas, developed through crystallization at depth, and through liquid-state processes such as convective fractionation and volatile transfer (*e.g.*, Rice, 1986; Hildreth, 1986). The mineralized locations represented by Ackley City, Wylie Hill and Motu are inferred to be embayments in the roof of the magma chamber where evolved magmas and related hydrothermal fluids were trapped during the final crystallization of the host rocks. The Belle Island showing is inferred to represent a small satellite intrusion derived from the main body, and it is likely that similar 'offshoots' were associated with other mineralized locations. Such a model implies that the region south of the Ackley Granite may have potential for molybdenite deposits that lack clear surface expression.

The greisen-hosted, Sn-dominant mineralization, documented in the Sage Pond area is more difficult to fit into this conceptual model. It is possible that these zones represent alteration and metal deposition in rocks that were already solidified, suggesting that they were produced by the actions of circulating hydrothermal fluids. Molybdenite is present in these areas, but it is not the main commodity of interest, suggesting that the fluids were Mo-poor, or that Mo was deposited elsewhere in the system. Also, although the model of Tuach *et al.* (1986) originally showed the Ackley Granite as a single huge magma chamber, it is more likely that it actually consisted of several discrete, coalesced intrusions developed over a protracted time period. Thus, it is possible that the Sn-rich mineralization in the Sage Pond area is not directly related to the Mo deposits known elsewhere.

OTHER PARTS OF THE AVALON ZONE

Several molybdenite occurrences are known elsewhere in the Avalon Zone (Figure 4). One of these is located in the Precambrian Holyrood Granite, south of the Witless Bay Line road near St. John's. It is described by Rose (1952) as three narrow (<20 cm) quartz veins in red granite, traceable over a distance of some 80 m, but there is little recent information. Molybdenite is associated with chalcopyrite, and is locally high-grade (over 7% MoS_2); minor associated Au and Ag were reported. This location has not yet been visited by the authors.

Although known primarily for its fluorite deposits, the St. Lawrence Granite (374 ± 2 Ma; Kerr *et al.*, 1993b) is also associated with minor base-metal-bearing veins and molybdenite. Descriptions of molybdenite mineralization in the area near Lawn are given by Pearse (1971), and indicate that these are hosted by quartz veins. Molybdenum occurrences at Lawn and Three Sticks Pond were visited in 2007 by one of us (EL) in conjunction with Dr. D. Wilton of Memorial University of Newfoundland and Labrador, but mineralization was confirmed at only two localities, where it is associated with quartz veining. There has been some discussion of the potential of the St. Lawrence area for large bulk-tonnage Mo deposits (Black, 1973) based on regional geology, till-geochemical anomalies and induced-polarization (IP) anomalies.

Small molybdenite occurrences are recorded in Harbour Breton (Figure 4) Granite and Old Woman Stock, in southern Newfoundland. O'Brien *et al.* (1995) report that the Old Woman Stock contains several small occurrences of fluorite ± molybdenite ± bornite ± chalcopyrite in quartz veins, locally up to 10 cm wide, and situated in hydrothermally altered zones along the margin of the intrusion. Disseminations are also reported in granitic rocks. The most significant showing appears to be 'Leonard's Find' (MODS 01M/12/Mo004), but the grades here were visually estimated at <1% MoS_2. Mineralization is reported to be hosted mostly by quartz veins at the contact between the granite and adjacent country rocks.

GREY RIVER AREA

Regional and Local Setting

The Grey River area, located approximately midway along the south coast of Newfoundland, hosts diverse granite-related mineralization, and includes tungsten and molybdenum deposits of potential economic importance. The geology of the area is shown, in simplified form, in Figure 6. The following summary of the geology is drawn from published sources (Higgins and Smyth, 1980; Blackwood, 1985; Dickson *et al.*, 1985; O'Brien *et al.*, 1986; Higgins *et al.*, 1990). Most of the mapping effort in this area was directed at the Precambrian rocks, and their contact relationships with the plutonic rocks in the north remains poorly known.

The Grey River area contains two main geological elements, *i.e.*, a package of metamorphic rocks of mainly Precambrian age (the Grey River Enclave of Blackwood, 1985), and a complex package of Paleozoic plutonic rocks, ranging from deformed, compositionally variable granitoid rocks to posttectonic granites. The latter are generally assigned to the Burgeo Intrusive Suite, part of which is dated at 428–412 Ma in areas to the west (Dunning *et al.*, 1990). The Precambrian rocks are dominated by variably migmatized amphibolites, interlayered with metasedimentary rocks of broadly pelitic composition, lesser amounts of granitic orthogneiss, and metaquartzites of potential importance as a source of silica (Butler and Greene, 1976). The Precambrian rocks have a complex structural history (Higgins *et al.*, 1990). These older rocks are in fault contact to the north with an extensive unit of variably deformed granitoid rocks that are broadly granodioritic, but range in composition from gabbro to granite (*s.s.*). Characteristically, these are K-feldspar megacrystic granites, containing biotite as the dominant mafic phase. The megacrystic biotite granites are cut by more evolved leucocratic granitoid rocks, but these appear to share the same deformational history. The southern boundary of this granitoid unit, running through Long Pond is strongly sheared, and cataclastic fabrics are locally developed elsewhere in the unit (Higgins, 1985). However, the presence of late porphyroblasts in the adjacent Precam-

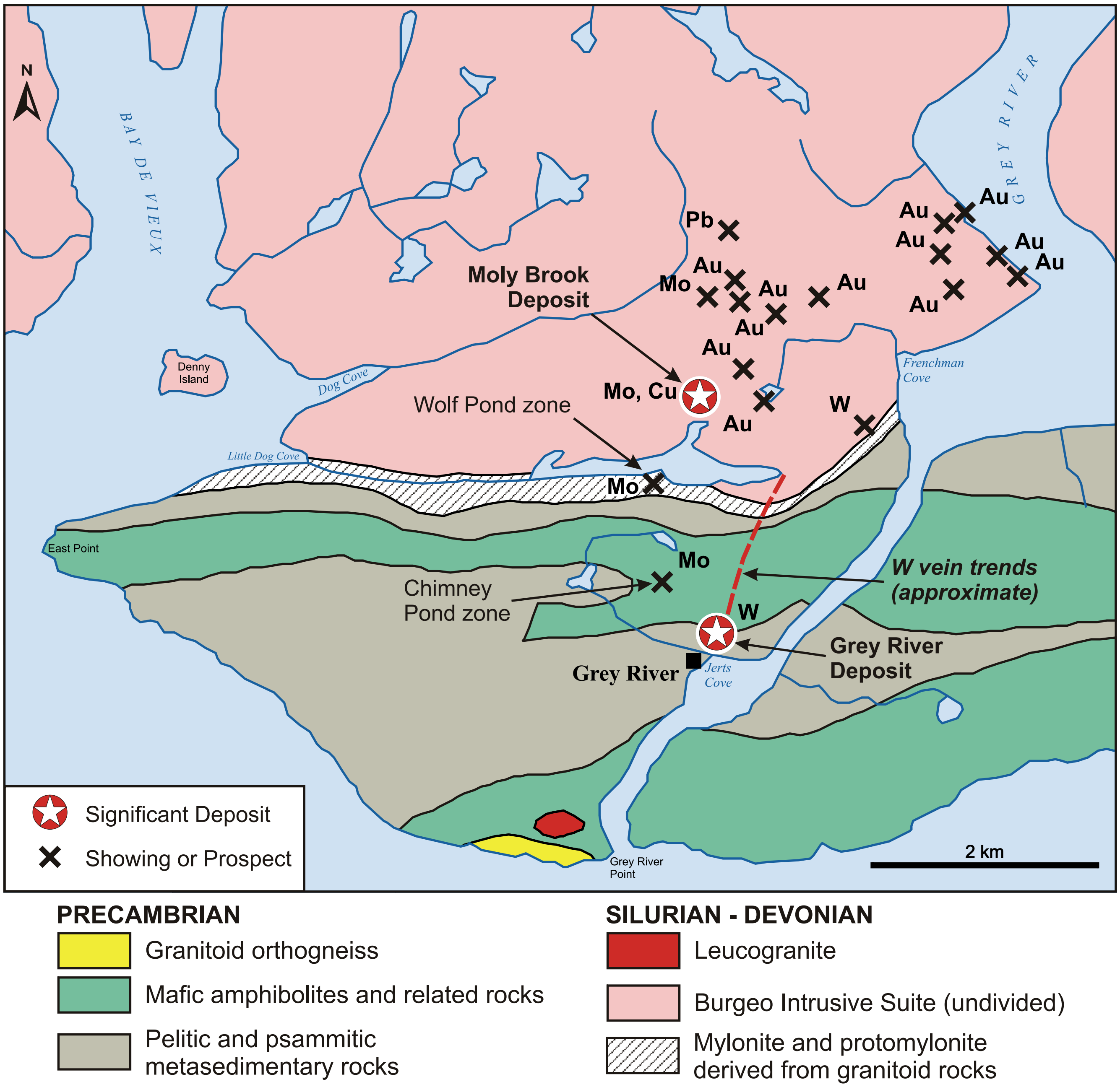

Figure 6. *Simplified geological map of the Grey River area, on the southcoast of Newfoundland, showing the distribution of mineral occurrences potentially linked to a large magmatic hydrothermal system. Geology after Higgins (1985), Blackwood (1985) and Higgins* et al. *(1990), and also unpublished assessment reports by Royal Oak Mines (Lendrum and Mercer, 1997).*

brian rocks suggests that the granites originally intruded them, but their mutual contact was disrupted by later shearing. Posttectonic granitic rocks are relatively rare, at least at the current level of exposure, but a small stock is present in the area around the entrance to Grey River Harbour (Figure 6). East of Grey River, around La Hune Bay, the Precambrian rocks and syntectonic megacrystic granites are intruded by massive equigranular granites of the Francois Granite. The Francois Granite was dated at 378 ± 2 Ma using U–Pb methods, and is one of the youngest plutons in Newfoundland (Kerr *et al.*, 1993b). It is geochemically highly evolved (Dickson *et al.,* 1996), and associated with lake-sediment geochemical anomalies for molybdenum and uranium, and also airborne radiometric anomalies.

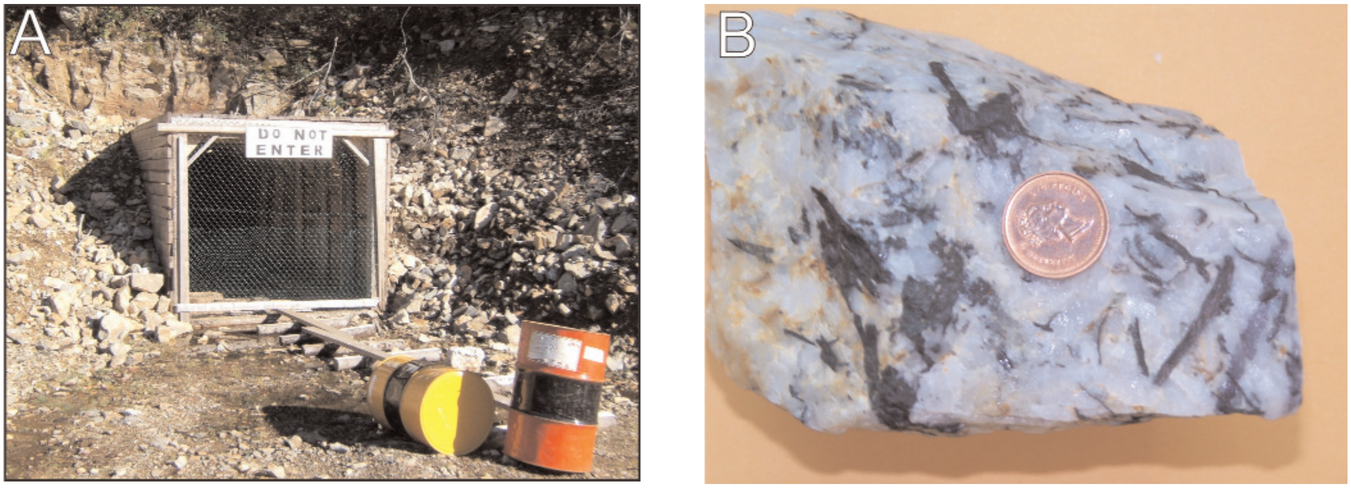

Plate 4. A*) Adit at the Grey River tungsten prospect. B) Wolframite-bearing quartz vein material typical of the mineralization at Grey River.*

Tungsten Mineralization

Grey River Quartz–Wolframite Veins

The initial discovery of wolframite-bearing quartz veins on the hills behind Grey River is attributed to Henry Rose, a local trapper, and samples were first shown to a mining company in 1955. The veins were assessed initially by the Buchans Mining Company (later ASARCO), and prospecting efforts eventually located over 600 individual veins, of which just two were deemed to have sufficient size for further assessment (Bahyrycz, 1956; Higgins and Swanson, 1957). These are termed the #6 and #10 veins; the latter is the larger of the two, and can be traced for about 2 km from the coast in a northeasterly direction (Figure 6). This vein was eventually assessed through underground development, using a 2-km-long adit driven just above sea level. A resource assessment by ASARCO suggested a total resource of about 520 000 tonnes at 1.09% WO_3. This was considered too small for any further development, and the property lay fallow for many years. Dearin (2004) provides a comprehensive review of exploration work on the property for tungsten, and also for gold-bearing quartz veins. A Ph.D thesis was completed on the mineralization by Higgins (1980), and this remains the main source of detailed geological information on the tungsten deposits. The property was eventually acquired by South Coast Ventures, and then passed to the current operators, Playfair Mining. Since 2004, the company has completed additional drilling in search of a larger resource, and in 2007 a new estimate was completed, raising the total resource to about 852 000 tonnes at 0.86% WO_3 (cut-off grade at 0.2% WO_3).

The tungsten mineralization at Grey River is entirely vein-hosted, and these veins appear to be some of the youngest elements of the local geology, cutting all other units, and also extending across the shear zone running through Long Pond. The northeastern end of the adit is situated within granitoid rocks, rather than the Grey River Enclave. Veins 6, 7 and 10 have widths of about 1 m, although they are locally variable. Higgins (1980, 1985) recognized several stages in vein development, with an initial stage containing molybdenite, followed by the main W-bearing veins. The later stages consist of other base-metal sulphides (*e.g.*, galena, sphalerite and pyrite and are locally gold-rich) followed by veins containing fluorite, calcite and barite. This pattern is recognizable in the main vein paragenesis, and also in crosscutting relationships amongst smaller veins throughout the area. There is also a spatial zonation of vein types from south to north that mirrors the paragenetic relationships seen in individual parts of the system. Higgins (1980) characterized the fluids associated with various stages through inclusion studies, and verified that the sequence observed corresponded to decreasing temperatures within the hydrothermal system. The ore minerals include both wolframite and scheelite. Although it may not be especially large, the Grey River deposit was described by Mulligan (1984) as "one of the largest typical wolframite-quartz deposits in Canada", and possibly indicative of much wider potential for W in the general area. Features of the mineralization at Grey River are illustrated in Plates 4A and B.

The timing of mineralization at Grey River is not well constrained, other than that it is younger than the country rocks to the veins. Higgins (1980) and Higgins *et al.* (1990) present K–Ar data from muscovites in greisen zones, suggesting that they formed between 387 and 370 Ma. The early work by Bahyrycz (1956) raised the idea that mineralization might be connected to a subsurface plutonic body. Higgins (1980, 1985) subsequently suggested that the undeformed leucogranites, such as the one exposed near the entrance to Grey River Harbour, might be genetically connected to the W-bearing veins.

Molybdenum Mineralization

Molybdenum mineralization was initially discovered here in the 1950s, associated with the W-bearing veins, and also in its own right in the area south of Long Pond. In 1964, the Buchans Mining Company drilled packsack holes on a small showing southwest of the lake (Swanson, 1964), which now represents the Chimney Pond showing, likely an extension of the nearby Moly Brook deposit. The latter is now defined as the principal Mo resource in the area.

Moly Brook Deposit

The Moly Brook deposit is located in an upland, partially barren area north of Long Pond, about 5 km north of Grey River (Figure 6). It had a sporadic exploration history prior to 1994, when Royal Oak Mines investigated galena–sphalerite-rich veins in the general area for gold. A galena-bearing vein in this area was initially documented by Bahyrycz (1956) and found to contain almost three ounces per ton. Prospecting along a small unnamed stream gully revealed altered granitoid rocks cut by numerous Mo- and Cu-bearing quartz veins. The mineralization was tested with five drillholes, of which four returned interesting intervals; the best result was 237 m at 0.06% Mo and 0.04% Cu. Royal Oak Mines recognized "the potential to host a major porphyry Mo–Cu deposit" (Mercer, 1996; Lendrum and Mercer, 1997), but the exploration program was shelved within 2 years. However, their efforts did also discover several new Au-bearing zones (Figure 6).

The property lay fallow for many years, although there was some activity in the area related to gold (*e.g.*, Wilton and Taylor, 1999). A brief period of exploration by Cornerstone Resources (Froude, 2004) was also aimed primarily at intrusion-related gold deposits, rather than molybdenum. However, the potential similarity of the Moly Brook mineralization to porphyry Mo–Cu systems was noted. In 2007, Tenajon Resources optioned the property and commenced a drilling program to further evaluate the extent of Mo–Cu mineralization. Over 20 drillholes now have been completed, all of which have intersected mineralization. High-grade sections of individual holes contain up to 0.16% Mo, but the bulk of the material grades between 0.06% Mo and 0.1% Mo. The highest grade intersection to date was 88.4 m of 0.12% Mo. The mineralized intersections are extremely long, ranging up to 360 m of 0.07% Mo, and many of them have ended in mineralization. No resource figure has yet been released, although work is presently underway to meet this objective.

The Moly Brook deposit lies in the extensive unit of variably deformed granitoid rocks correlated with the Silurian Burgeo Intrusive Suite (Figure 6). Work by Royal Oak Mines defined several granitoid subunits in this area, but the criteria used to define these are partially related to deformation state and alteration, so it is not clear if they are truly discrete geological units. The 'Moly Brook Stock' of Mercer (1996) is the host to mineralization, and was described as 'composite in nature', ranging from diorite to granite and syenite (Mercer, 1996). Examination of drillcore from recent exploration suggests that the wide range of composition observed in these host rocks represents gradational (but often abrupt) variation within a single petrological unit.

Some essential geometric information on the deposit is summarized in Figure 7. The features of the mineralization and host rocks are illustrated in Plate 5. Mineralization is now well defined over an area of some 500 by 500 m, and to vertical depths of some 350 m. The host rocks to the mineralization are compositionally and texturally varied plutonic rocks and have a bulk composition that probably approximates granodiorite; typical examples contain K-feldspar phenocrysts and megacrysts, and lesser plagioclase, within a melanocratic matrix. Rocks containing abundant feldspar phenocrysts commonly appear syenitic or granitic, whereas those that are phenocryst-poor rare appear dioritic; most lie between these extremes. The general absence of sharp contacts between dark and light 'facies' in drillcore suggests that these compositional variants are gradational, but it does not exclude the possibility of local mafic dykes cutting more leucocratic rocks. However, no chilled contacts were observed on any mafic rocks. Alteration is widespread in the host rocks at Moly Brook, but it does not cause their heterogeneity; rather, it is superimposed on existing heterogeneity and accentuates it. Weak to moderate cataclastic fabrics are developed locally in the host rocks, and these fabrics are cut by the molybdenite- and chalcopyrite-bearing quartz veins described later in this paper.

Essentially, all molybdenite and chalcopyrite at Moly Brook are associated with quartz or quartz–feldspar veins. The orientation of mineralized veinlets is locally variable, and cannot be discerned from drillcore, but surface exposures suggest that the dominant trends are roughly north–south. Numerical data collected from recently excavated trenches confirm this general pattern, suggesting that veins have an average trend of about 010°, with steep dips (>80°) to the east or west. However, the veins appear to have more varied strikes and dips in trenches at lower elevations compared to those in the upper part of the system, suggesting that there is a shift from strong structural anisotropy to a more random stockwork-like pattern at greater depth. This transition may be associated with increased Mo grades, although this may in part simply be a function of greater vein density. The intensity of veining varies widely, and the Mo and Cu grades appear directly linked to this factor. The discordant relationship between such veins and cataclastic fabrics suggests that the veins (and related alteration) are significantly younger than their host rocks, and not connected to them genetically. The host rocks must have solidified, undergone some ductile deformation, and then behaved in a brittle manner during later alteration and mineralization. No folded or deformed veinlets were observed, although they are offset by small fractures in drillcore. An epigenetic relationship to their host is also suggested by rare intervals of apparently younger granitic rocks with disseminated (syngenetic) molybdenite. The style of mineralization is simple in the broad sense but complex in detail, and veins vary greatly in appearance. Many are simple, consisting either of quartz or granitic material, but some are composite. For example, there may be a pink aplitic margin and an interior quartz zone, but this pattern can also be reversed. Individual quartz veins show internal selvages containing molybdenite, suggesting that they are themselves multistage. Green or purple fluorite occurs in some veins. The age relationships between different styles of veins are contradictory, and there is presently no indication that certain vein types are 'early' or 'late', although veins containing carbonate and green sericite are usually the youngest features.

The alteration in the host rocks is complex, and needs more detailed study. There is an obvious correlation between reddening of the core and the density of mineralized quartz veins in quartz- and feldspar-rich host rocks suggesting potassic alteration. Mercer (1996) also noted the presence of fine-grained biotite in intensely altered rocks. The obvious development of muscovite and/or sericite in darker (more 'mafic') core intervals around mineralized veins also indicates potassic alteration. However, there is also earlier regional alteration, manifested by dark chloritic and/or biotitic veinlets, which dissect feldspar phenocrysts, yielding a texture that resembles mechanical brecciation. In areas where mineralized quartz veins are present they always crosscut dark alteration veinlets. The regional 'dark' alteration is likely also associated with the formation of disseminated pyrite, which is far more widespread than molybdenite or chalcopyrite. Chalcopyrite is less abundant than molybdenite and there is some correlation between Mo and Cu in analytical data from the Royal Oak exploration program. Other element associations have yet to be assessed in detail.

One of the most interesting findings of recent drilling is the recognition of fine-grained, leucocratic granites that are very distinct from the dominant host rocks, and which may represent offshoots from a younger subjacent plutonic body. The longest intersection to date consists of at least 40 m of homogeneous, pink, medium-grained granite in Hole MB-08-18, and probably represents a dyke. This has a sharp upper contact with the dominant host rocks (although not obviously chilled), and it is generally free of quartz veins compared to the latter. However, it does contain a few quartz veins that have associated marginal molybdenite mineralization, and (more significantly) it contains disseminated pyrite and molybdenite. The regular distribution of the latter and its interstitial habit suggest that it is syngenetic, which implies that the hole MB-08-18 granite has a direct genetic relationship with the vein-style Mo–Cu mineralization. Geophysical surveys completed in the 1990s showed several 'bulls-eye' positive magnetic anomalies that could also reflect the presence of granitic bodies at depth, as speculated by Lendrum and Mercer (1997).

Other Molybdenum Showings

Regional exploration at Moly Brook has located Mo mineralization of similar aspect in several other locations, implying that there is a large footprint to the associated hydrothermal system. The most significant are at Wolf Pond and Chimney Pond (Figure 6); the latter was originally drilled in the 1960s, but not followed up. The generally north–south strike of veining at Moly Brook is orthogonal to the trace of the fault zone through Long Pond, and the mineralized corridor may continue south into the Precambrian Grey River Enclave. Mineralization at Chimney Pond is associated with very similar molybdenite- and chalcopyrite-bearing quartz veins, although the host rocks are entirely different (Tenajon Resources, press release, Oct 15, 2008). This regional relationship also supports a relatively young (post-Silurian) timing for the mineralizing event. The grades reported from the Wolf Pond and Chimney Pond zones resemble those from the Moly Brook area, *i.e.*, 0.06% Mo to 0.22% Mo (Tenajon Resources, press release, Oct 15, 2008).

Discussion and Interpretation

The tungsten-bearing veins at Grey River, and the Mo–Cu-bearing veins at Moly Brook are the products of similar magmatic–hydrothermal systems, and it seems logical that they are linked in some way. Minor veins containing base metals, gold and silver, could also be part of such a regional system (Figure 6). The trends of mineralized veins at Grey River and at Moly Brook differ slightly, suggesting that they were perhaps generated at different stages in the evolution of the hydrothermal system. As noted by Mercer (1996) and Lendrum and Mercer (1997), there is also a regional concentric zonation at Moly Brook, where Au- and Ag-bearing base-metal veins surround the central core of Mo–Cu mineralization (Figure 6). The exact temporal and spatial relationships between these different styles of mineralization remain undefined, and make an interesting subject for further research. The distribution of mineralization and the relationships seen in drillcore, at Moly Brook, indicate that the mineralizing event is significantly younger than the (probable) Silurian host granitoid rocks, and also younger

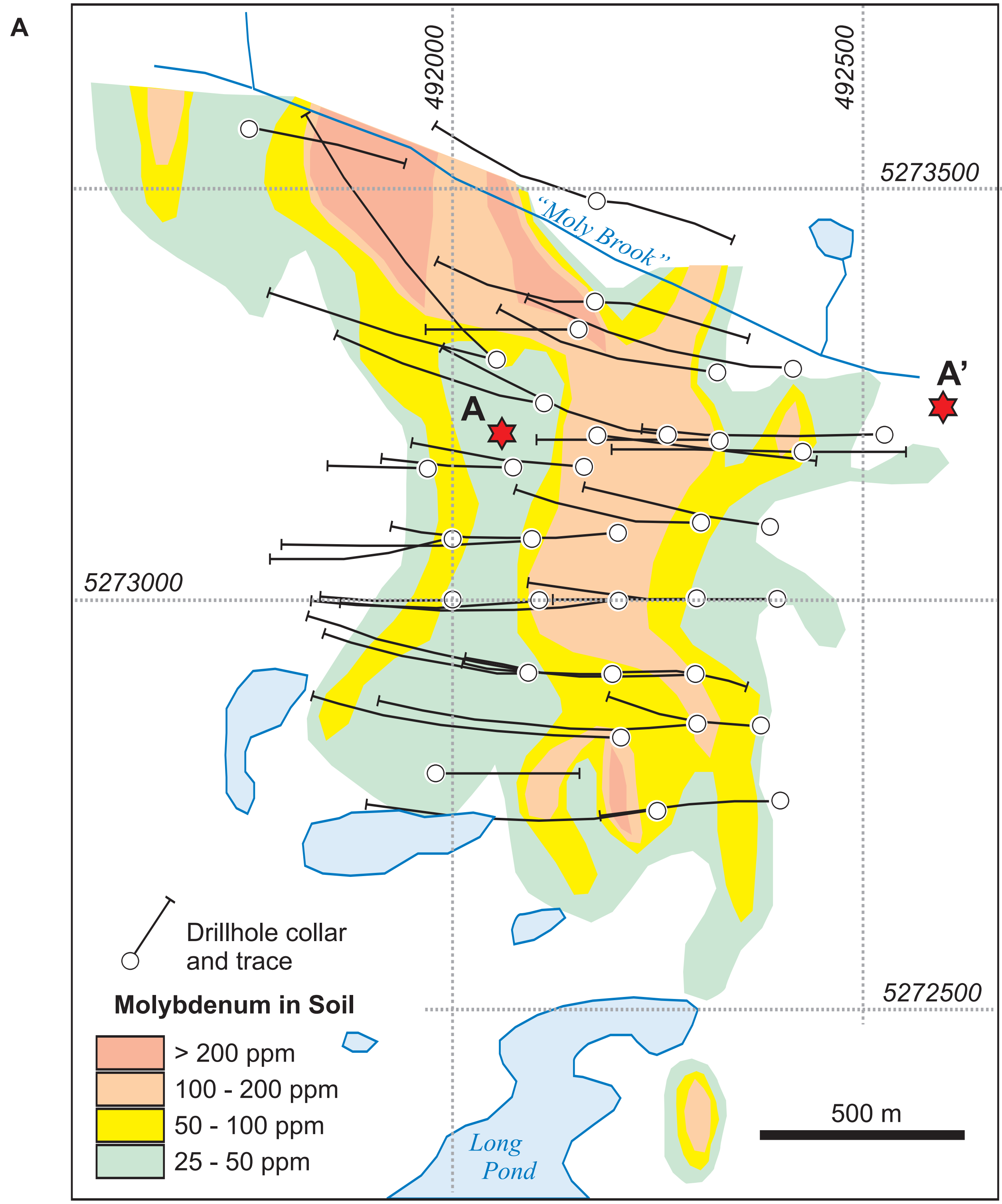

Figure 7. *A). surface map of the area of the Moly Brook deposit, showing drillhole locations and distribution of Mo in soils. Modified after information published on the Tenajon Resources website.*

than any motions on the fault zone that runs through Long Pond. Higgins (1985) noted the presence of leucocratic granitoid rocks in drillcore at Grey River, and similar rocks are represented by the Hole MB-08-18 granite at Moly Brook. The paucity (but not absence) of mineralized veinlets in this rock type, compared to surrounding rocks, and the presence of disseminated and likely syngenetic molybdenite, indicate that it is synchronous with vein swarm develop-

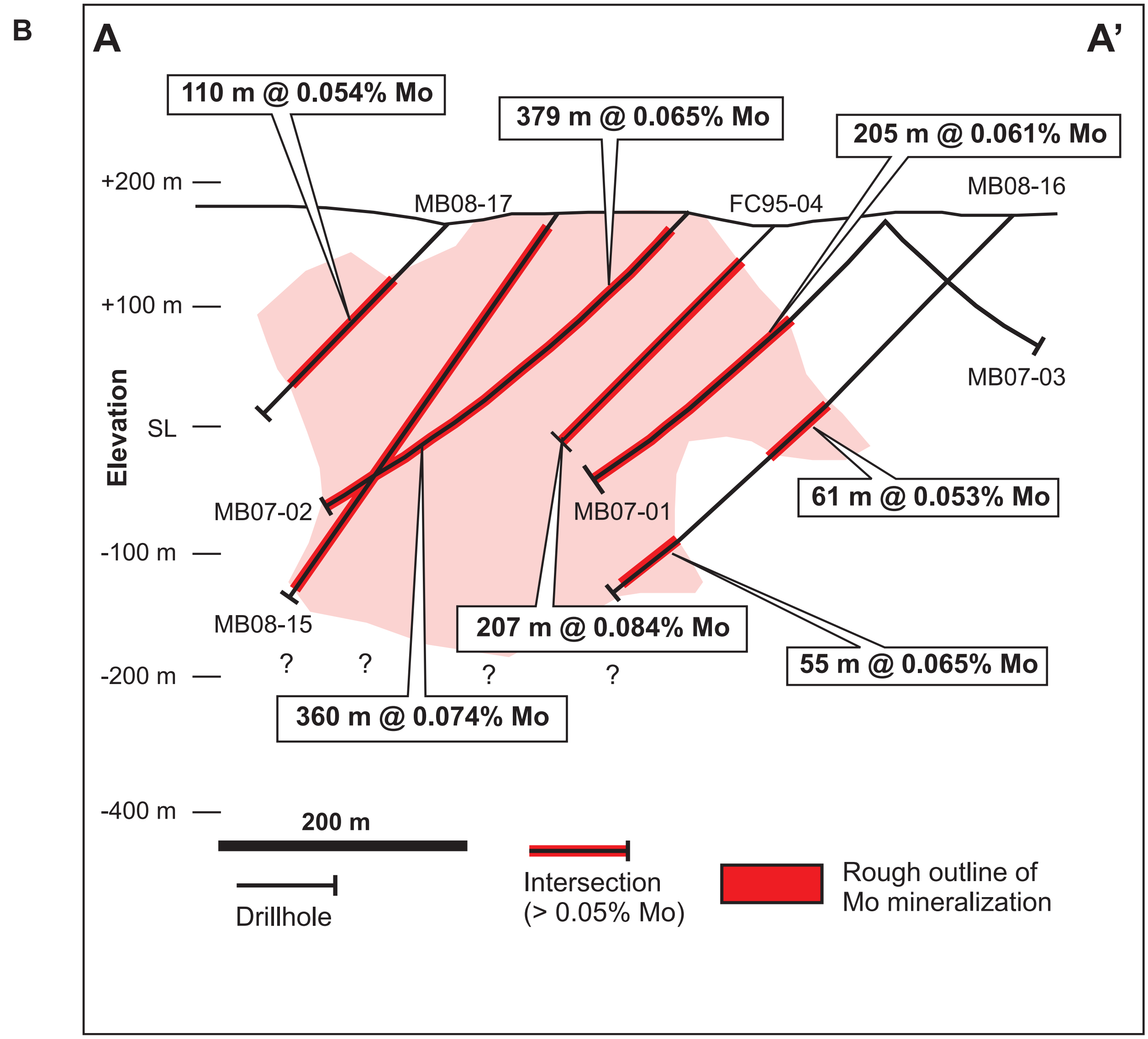

Figure 7. Continued *B). Generalized cross-section through the defined portion of the deposit, indicating rough outline of mineralized zones averaging more than 0.05% Mo. Modified after information published on the Tenajon Resources website.*

ment. It is a small step in reasoning from this to conclude that it has a genetic relationship, in that these represent local offshoots from a larger buried plutonic body. This likely extends across the fault zone through Long Pond, which might itself have provided controls on magma emplacement and ascent. Figure 8 shows the inferred relationships at Moly Brook in a schematic manner.

The general features of mineralization at Moly Brook are consistent with its interpretation as a Mo–Cu 'porphyry' system, although in this case the bulk of the mineralization is situated within sheeted quartz veins above some sort of cupola-like feature (Figure 8). The widespread chloritic alteration observed in the host rocks is consistent with 'propylitic' alteration, which typically forms the outer shell in porphyry systems, as first outlined by Lowell and Guilbert (1970). For a more recent summary of porphyry systems with an emphasis on the Canadian context, see Sinclair (2007). The potassic alteration associated with the Mo–Cu mineralization is also characteristic of the cores of such porphyry systems. The disseminated Mo mineralization observed in the Hole MB-08-18 granite, although very low grade, is in some senses akin to the richer endocontact mineralization near the fossil roof of the Ackley Granite (*see* earlier discussion, page 48). Although there can be no direct connection between the two, the Ackley Granite may represent a more deeply eroded analogue of the largely unseen batholith that may lurk beneath the Grey River area. The initial discovery and eventual delineation of the Moly Brook deposit is regionally significant, because it indicates the

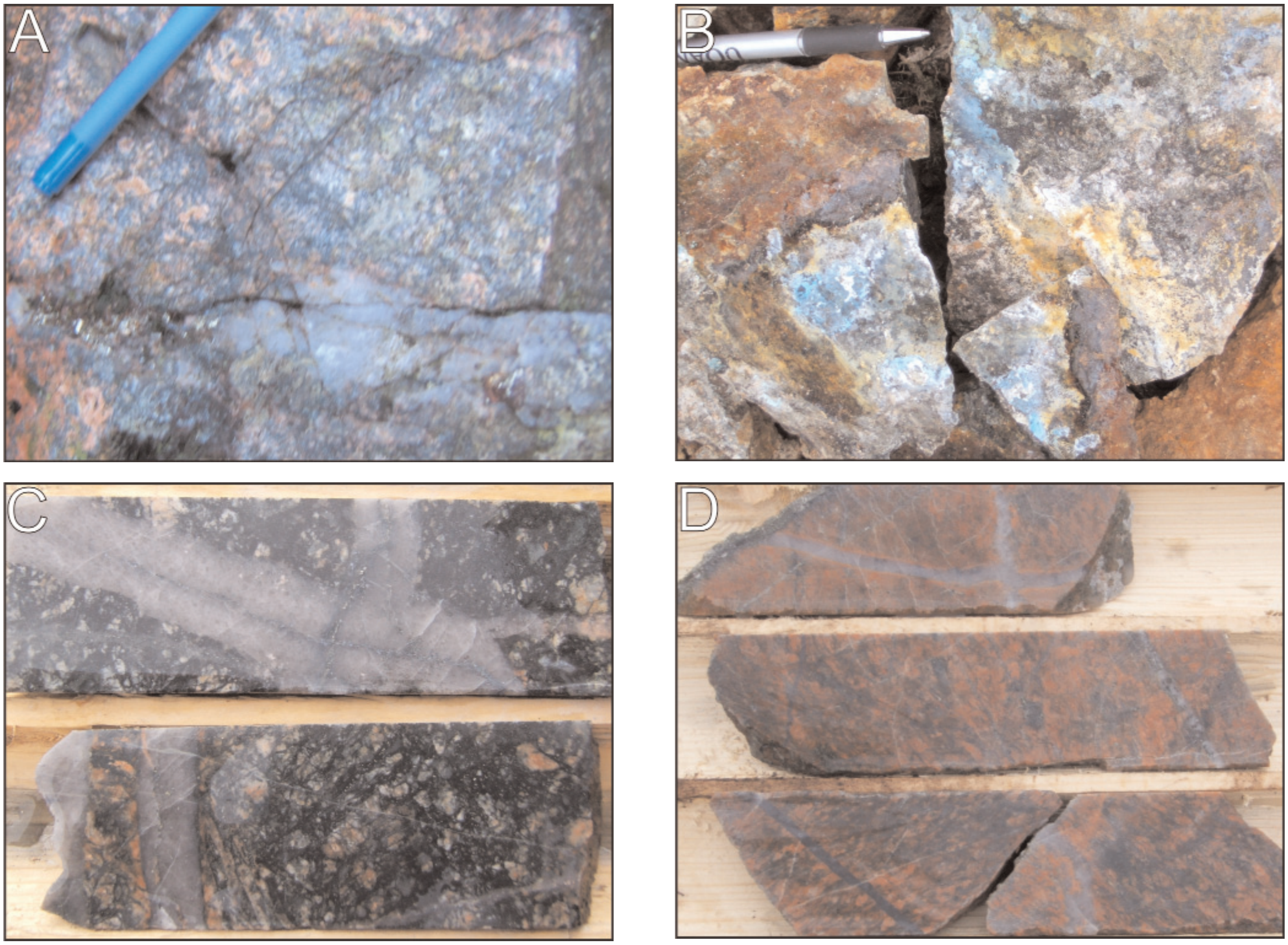

Plate 5. A*) Altered and mineralized granodiorite cut by quartz veins associated with molybdenite and chalcopyrite in surface exposures at Moly Brook. B) Malachite staining on fracture surfaces in mineralized outcrop; the yellowish stain may be molybdite, a common alteration product of molybdenite. C) Typical drillcore from Moly Brook, showing variably porphyritic melanocratic granodiorite cut by molybdenite-bearing quartz veins. D) Intense, brick-red, potassic (?) alteration in leucocratic host rocks cut by mineralized veinlets; note that veinlets cut the weak cataclastic fabric in the host rock. E) Pervasive dark (biotite ± chlorite) alteration developed around discrete dark veinlets in unmineralized host rocks. F) Example of com-*

potential for prospective magmatic systems to lie in the shallow subsurface across southern Newfoundland. The Granite Lake area (*see* pages 64-67) may perhaps be an example of another such mineralizing system with similar origins.

GRANITE LAKE AREA

Regional and Local Setting

The Granite Lake area is in south-central Newfoundland, within the Meelpaeg Subzone of the Gander Zone (Figure 2). The area was mapped in the 1970s and 1980s, and the regional geology is described by Dickson (1982). The known granite-related mineralization, and the exploration potential, are discussed by Tuach (1996). The oldest rocks exposed at surface in this area are metasedimentary gneisses, considered to represent the equivalent of the Gander Group in northeastern Newfoundland (Figure 2). There are three groups of plutonic rocks in the area, *i.e.*, equigranular tonalite to granodiorite, biotite–muscovite granites, and coarse-grained, equigranular, biotite–muscovite granite. The latter is termed the Wolf Mountain Granite (Dickson, 1982; Figure 9). The area is poorly exposed, and intrusive relationships are hard to establish, but the Wolf Mountain Granite is considered to be the youngest component. There are no reliable radiometric ages from this area, but the Wolf Mountain Granite is considered to be equivalent to the Dolland Brook Granite, dated at 396 +6/-3 Ma (Dunning *et al.*, 1990). The area is transected by some important fault zones, most notably the Meelpaeg Lake Fault Zone, which is a 400-m-wide deformation zone that separates the Wolf Mountain Granite from tonalites and granodiorites to the east (Figure 9). This zone, and a related fault zone known as the Cowey

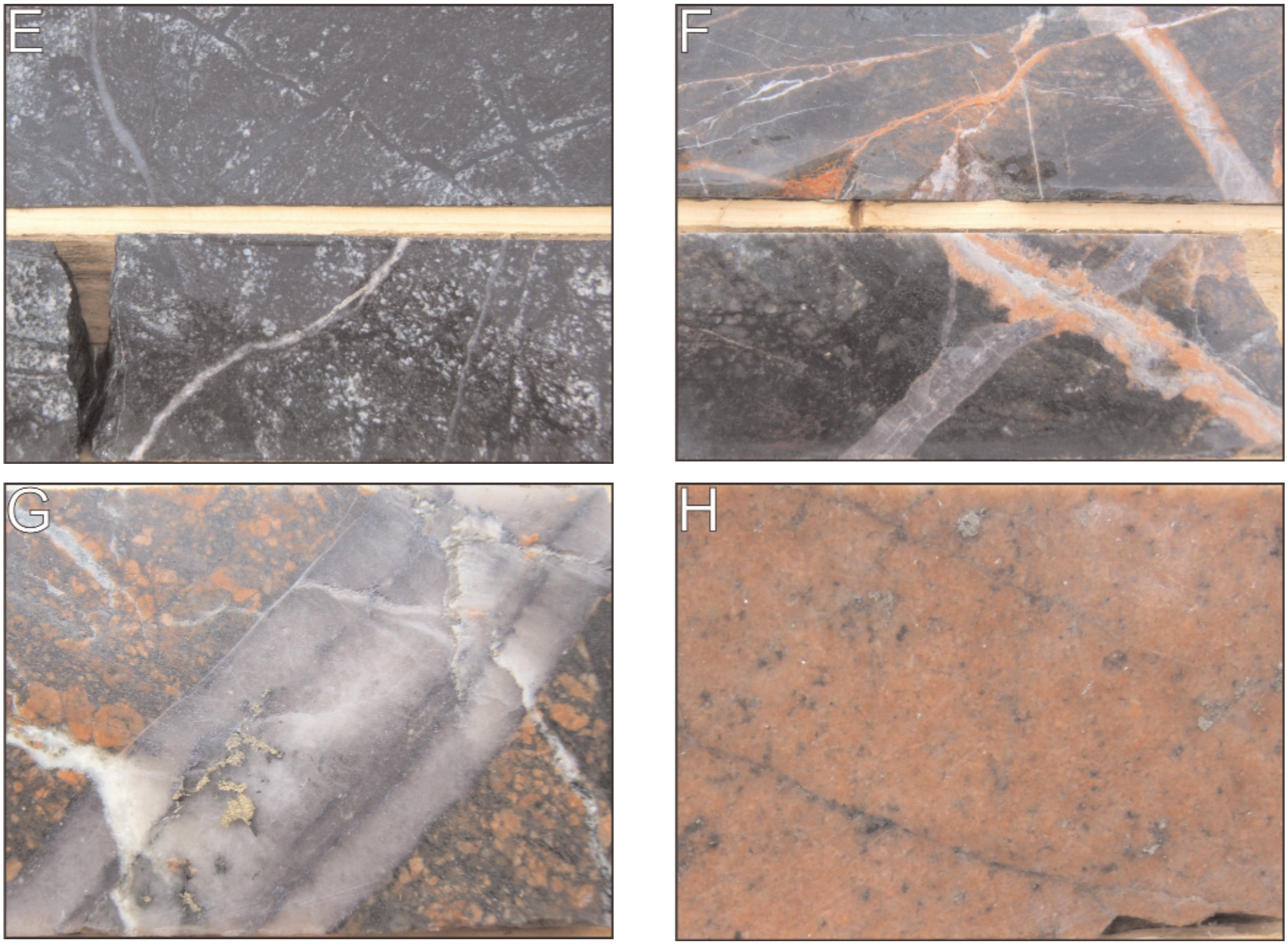

Plate 5. *(*Continued) *plex timing relationships, in which a molybdenite-bearing quartz vein is cut by a later composite aplitic-quartz vein, and both are cut by late carbonate-rich veins. G) Composite mineralized vein with molybdenite developed along outer contacts and along internal boundaries, where it is associated with coarse chalcopyrite. Note late veins, with variable offset along vein contacts. H) Fine-grained, equigranular leucogranite from hole MB-08-18, possibly representing an offshoot from a buried pluton; the sample contains disseminated pyrite and molybdenite, although the latter is not visible in the photo.*

Lake Fault, are well-defined by surficial (lake-sediment and soil) geochemical anomalies, and, where exposed, exhibit widespread quartz-veining and alteration (Tuach, 1996).

Tungsten and Molybdenum Mineralization

The locations of the main W and Mo showings and prospects in the Granite Lake area are indicated in Figure 9; typical features of the mineralization are shown in Plate 6. The best-known zone occurs along a hydroelectric canal that exposes a nearly continuous section of altered and veined granites, described by Dickson (1982) and Tuach (1996). Molybdenite mineralization occurs in granitic dykes, pegmatite and quartz veins, and is also present widely on fracture surfaces. Scheelite and/or wolframite mineralization appears to have a broadly similar form (Dickson, 1982), and is best known at the Ditch showing (Figure 9). The best-known molybdenum showing is the Rio showing (Figure 9) but reported grades from here are low (0.1% Mo). Elsewhere, tungsten mineralization is best known at the Road showing, which comprises a well-defined vein containing up to 2.4% WO_3, and at the Line 500E and Line 0E showings, where similar mineralization occurs in quartz stringers and pods. Small showings in the same general area have returned significant amounts of bismuth (up to 1.9% Bi). Most of the mineralization known until recently is dominated by wolframite and scheelite with quartz, and contains only minor amounts of molybdenite; most of these sites are listed in the MODS system as W occurrences (Figure 9; Table 1). The host veins include pure quartz veins, greisen (muscovite-rich) and also quartz–feldspar veins of pegmatitic or aplitic aspect.

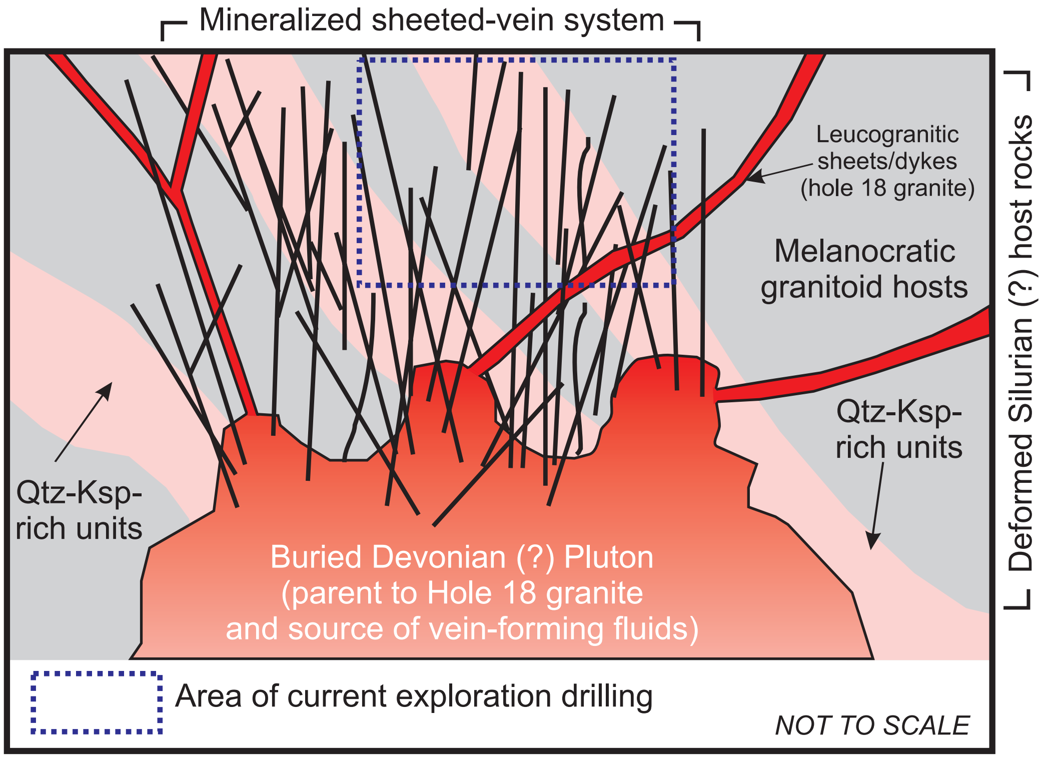

Figure 8. *Schematic diagram illustrating the inferred regional configuration of mineralization at Moly Brook, and its possible relationship to a subsurface plutonic body represented only by dykes and sheets at the present level of exploration. The heterogeneity of the plutonic host rocks to the deposit is also indicated in a general way, but does not relate to any mapping observations.*

Recent exploration by Playfair Mining has focused on an area located to the west of the Meelpaeg Lake Fault Zone, near to a location known as the Hill showing (Figure 9), which was previously known for W associated with lesser Mo. At the Hill showing, mineralized and altered float is more abundant than outcrop, and mineralization is associated with quartz vein networks. The main area of interest lies a few hundred metres west of the original showing, and is now known as the Moly Hill prospect (Figure 9). Drilling in this area has defined a 'corridor' of low-grade Mo mineralization in an area of about 600 by 100 m, to vertical depths of about 125 m (Briggs, 2008). The results suggest that low-grade mineralization is widespread, and this prospect has now returned some notable intersections including one hole that assayed 0.054% Mo over 167 m, and ended in mineralization (Playfair Resources, website information, 2008). The longest intersection was some 250 m at 0.03% Mo, and high-grade sections in individual holes contain up to 0.09% Mo. Molybdenum mineralization is associated with sheeted to stockwork-style quartz veining, and with varied alteration, including clay minerals (presently unidentified) and potassic alteration manifested by reddening of drillcore and greisen development (Briggs, 2008). A regional magnetic low associated with the mineralized zone is interpreted to reflect this alteration and the transformation of magmatic magnetite into pyrite. These results are, in many respects, similar to those obtained from the Moly Brook deposit near Grey River (*see* page 60). The extent and depth of the mineralized zone are not fully defined by the existing data, and it remains open in most directions.

Mineralization at Granite Lake is present over an area of about 25 km^2, and it appears to have a broad spatial relationship to the Meelpaeg Lake Fault Zone. The host rocks include both the Wolf Mountain Granite and the adjacent tonalites and granodiorites. The most obvious alteration consists of reddening (hematization) in the granitoid rocks, which is interpreted as potassic alteration. Sericitic alteration is also widespread, and local kaolinite alteration is reported. Tuach (1996) noted that surficial geochemical patterns (from stream sediments and soils) indicated a broad zonation in this area, where there is a W-rich central zone surrounded by a zone anomalous in Mo.

Discussion and Interpretation

Mineralization in the Granite Lake area appears to have much in common with that seen in the Grey River area, although its extent and potential is presently less well defined. The style of mineralization is one of sheeted vein

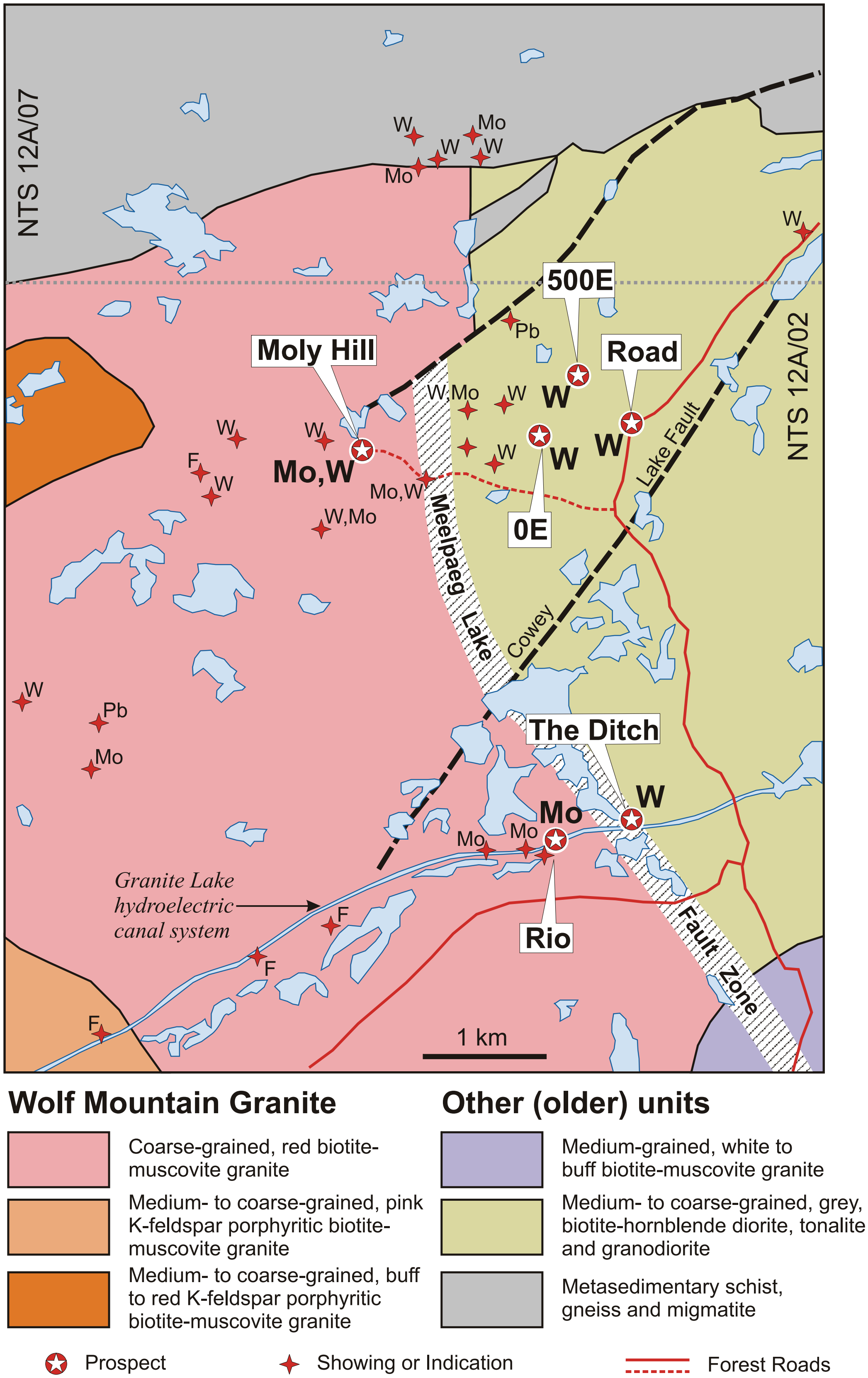

Figure 9. *Simplified geological map of the Granite Lake area, showing the distribution of mineralized zones. Modified after Dickson* et al. *(1982) and Tuach (1996).*

Plate 6. *Features of mineralization in the Granite Lake area. A) Typical outcrop of the red-weathering Wolf Mountain granite. B) Drillcore from the Moly Hill prospect showing quartz veining and alteration of the host granite. C) Molybdenite and chalcopyrite in quartz vein from drillcore. All drillcore has a diameter of about 4 cm. D) Coarse wolframite in quartz veins at the Road showing; hammerhead approximately 2 cm wide. Plates B), C) and D) kindly provided by Playfair Resources.*

systems, developed over a wide area, and the temporal and genetic connections between alteration, mineralization and the rocks are not entirely clear. Dickson (1982) noted that most mineralization is concentrated within coarse-grained biotite–muscovite-granite, or near its contact with other units, suggesting a possible connection to this unit. Mineralization is present in two different granitoid units whose ages are interpreted on the basis of regional correlations as Silurian and Devonian, respectively, but it is entirely possible that it is younger than both. At this point, there is no direct evidence of a discrete granitic unit containing disseminated, syngenetic molybdenite, as represented by the Hole MB-08-18 granite at Moly Brook. Given the very poor exposure in this area, it is hoped that recent drilling by Playfair Mining will provide data that will allow a better understanding of the timing of and controls upon mineralization.

OTHER AREAS OF INTEREST

Molybdenum occurrences are scattered across parts of Newfoundland other than those discussed specifically above, *e.g.*, in the northeastern Gander Zone and also in the western White Bay area (Figure 4). The present information on these occurrences from the MODS system suggests that all are small concentrations within, or adjacent to, granitic rocks, and some amount to little more than a few scattered flakes of molybdenite. It is unlikely that these have any significance for exploration, although they do provide a generalized indication of the potential for specific granitoid units. The largest concentration of such small molybdenite showings is in the Bay d'Espoir area. One occurrence on the Baie Verte Peninsula (the Parrell prospect), differs from the norm, and is covered briefly here. Several W showings in southern

Newfoundland (Figure 3) appear also to be very minor, and most of these contain only a few hundred ppm W. Tungsten mineralization in the Great Gull Lake area and at Charles Cove may attract further exploration interest, although these sites are presently dormant.

Bay d'Espoir Area Molybdenite Occurrences

There are numerous small molybdenite occurrences in the area around Bay d'Espoir, most notably northwest of Lampidoes Passage and Bois Island. The dominant host rocks in this area are metasedimentary units of the Baie d'Espoir Group, close to the rather diffuse eastern contact zone of the North Bay Granite. These occurrences are described in assessment reports, and summarized by Colman-Sadd and Swinden (1982). In the area around Northwest Cove, molybdenite occurs in pegmatites, aplites and quartz veins; elsewhere it occurs mostly in quartz veins. Attempts to relocate many of these smaller occurrences were unsuccessful, and they are believed to be of minor extent (Colman-Sadd and Swinden, 1982). Commodities associated with Mo in this area include Cu, Bi and Au, with reports of up to 6.5 ppm Au locally. Geographically, there appears to be a transition from Mo and Cu, in the west, to Ba, Pb, Sb and As in the east. Colman-Sadd and Swinden (1982) suggested that this reflected increasing distance from the contact of the North Bay Granite. Although there is presently no indication of mineralization that has significant extent, this area stands out by virtue of the number of occurrences, and there has been little exploration.

Great Gull Lake Area Tungsten Prospects

Two prospects adjacent to the Bay d'Espoir highway in central Newfoundland are the only presently known instances of possible skarn-related W mineralization. At the Great Gull Lake #1 and #2 showings, tungsten is hosted not by granitoid rocks or quartz veins, but rather by sedimentary rocks of the Baie d'Espoir Group, consisting of cleaved shale and thin-bedded greywacke. Mineralization occurs in narrow calc-silicate bands, which contain variable amounts of scheelite, clinopyroxene, garnet and chlorite. These are well exposed in a small aggregate quarry beside the highway. The Great Gull Lake area was explored in the early 1980s, initially by Shell, and then by Kidd Creek Mines (Robertson, 1985; Kohlsmith, 1986), but there has been little subsequent activity. Channel sampling suggested grades of 0.29 to 0.55% WO_3, with enrichment in Sn (116 ppm). Drilling completed in 1985 at Great Gull Lake #1 intersected 27 narrow zones of mineralization, from which the best assay was 1.5% WO_3 over 0.2 m; the wider intervals of mineralization generally returned values <1% WO_3. A single hole completed at Great Gull Lake #2 intersected 11 mineralized zones, from which the best assay was 2.7% WO_3 over 0.2 m (Kohlsmith, 1986). In both cases, the host rocks showed signs of contact metamorphism, and are cut by leucocratic granite veins and pegmatites, possibly related to the nearby Middle Ridge Granite (Robertson, 1985).

A third zone of W mineralization, located about 3 km north along the road is also hosted regionally by the Baie d'Espoir Group, but here the mineralization is mostly in the form of scheelite and fluorite occurring in the narrow leucocratic granite veins within the metasediments. The veins are locally tourmaline-bearing (Blackwood and Green, 1983; Robertson, 1985). Samples from surface mineralization are reported to contain up to 0.53% WO_3. Drilling in this area did not reveal interesting mineralization, but it did indicate significant units of limestone, which may represent a potential host to skarn-type mineralization. The granitic veins are interpreted to be linked to the Middle Ridge Granite, an evolved leucocratic pluton that lies a short distance to the east, which was dated at 410 ± 3 Ma using monazite (R. Tucker, unpublished data, quoted by Kerr, 1997). The Great Gull Lake prospects also lie within a few kilometres of the western contact of the Middle Ridge Granite, and contain discrete granite veins. They may thus also have a genetic link to magmatic fluids derived from this source.

Charles Cove Tungsten Prospect

The Charles Cove prospect is located in northeastern Newfoundland, close to Gander Bay (Figures 2 and 4), and is hosted within the Charles Cove granodiorite, a small undated granitic unit. It was initially discovered in 1953 during GSC mapping (Patrick, 1953), and was explored in the late 1950s and 1960s (O'Toole, 1970), with emphasis on tungsten. Subsequent exploration at the site was by Noranda and Copper Hill Resources (Green, 1989; Wilton and Taylor, 1999; Wilton, 2005), but this work was aimed almost entirely at gold, rather than tungsten. Most of the exploration work has been reviewed by Evans (1996). The early work was the most comprehensive, including trenching and packsack drilling (O'Toole, 1970). Mineralization is confined to a north- to northwest-trending quartz vein that ranges from 0.6 to 4.5 m in width, and has been traced over a strike length of approximately 1 km. The quartz vein consists of several discrete phases, and contains scheelite, tungstite, pyrite, arsenopyrite, galena, chalcopyrite and molybdenite. Initial sampling of the vein returned assays up to 2.81% WO_3, and a drillhole intersection gave 1.02% WO_3 over 0.3 m. The scheelite has an irregular distribution within the vein, and many parts of it do not reveal any significant W enrichment. O'Toole (1970) considered the tungsten to be restricted to a very narrow zone on the footwall of the vein, where it is discontinuous. However, there is gold and silver enrichment in many other areas. Other quartz veins are reported, and some of these have given assays ranging up to

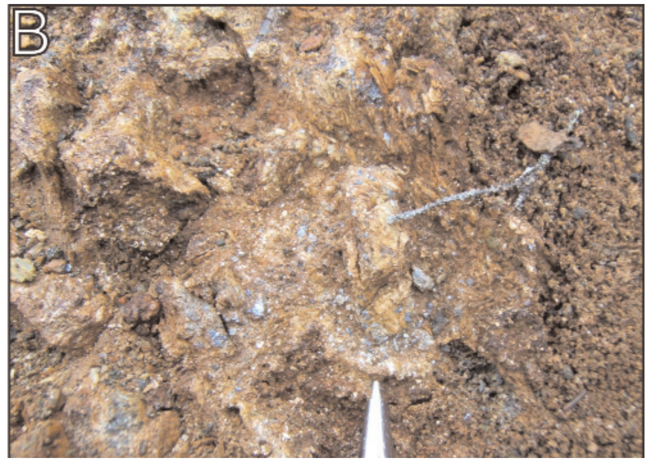

Plate 7. A*) Mineralization at the site of the Parrell prospect. Upper part of photo is altered serpentinitic ultramafic rock, lower part is intensely faulted zone marking its contact with adjacent metasedimentary rocks. B) Close-up of high-grade molybdenite mineralization (blue) in the friable material within the fault zone.*

6 ppm Au and 4% Ag (Evans, 1996). The mineralization is clearly epigenetic with respect to the surrounding granodiorite, but its precise origins remain unknown.

Parrell Molybdenite Prospect

The Parrell prospect, located in the town of Fleur-de-Lys on the Baie Verte Peninsula (Figures 2 and 4) is perhaps the most curious of all the occurrences discussed in this report, and also may have the distinction of being the only past-producer of molybdenum in the province. It was reportedly discovered around 1900, but was originally thought to be a galena prospect, as this mineral also occurs in the Fleur-de-Lys area. The earliest description is by Hatch (1924), but the most detailed information is provided by the subsequent account of Fuller (1945). Around 1915, the Harbour Grace Shipping Company sank a shaft to a depth of about 17 m, and mined about 18 tons containing as much as 10% MoS_2 (6% Mo) and a further 100 tons containing about 1.5% MoS_2 (0.9% Mo). Most of this material remained at the site, according to later accounts. Hatch (1924) reports assay results from later sampling of dumps and within the shaft; these contained from 0.25 to 10.6% MoS_2, with the best results from the dump. Between 1935 and 1938, there was some further assessment and prospecting, and four drillholes were completed in search of additional material, but nothing came of this effort. The high-grade mineralization appears to be very restricted in extent. There is now no trace of the shaft or ore dumps, for it seems that straightening of a nearby road many years later created a roadcut right through the original site of the deposit. Geological relationships and mineralization can now be observed on the walls of this roadcut, but it is hard to relate observations to the detailed descriptions of Fuller (1945).

Molybdenite mineralization at the site appears to be confined to a zone of intense fracturing and fault gouge development localized along the contact between high-grade metasedimentary rocks of the Fleur-de-Lys Supergroup, and a serpentinized ultramafic unit, believed to be allochthonous. The latter unit is also the location of the historic Dorset Eskimo Soapstone Quarry, one of the oldest mining excavations known in North America, and this historic site lies just a few hundred metres from the Parrell prospect. Apart from any geological considerations, this would appear to place significant limits on any development potential.

On a visit in 2008, the only place where molybdenite was observed was in a friable fault gouge developed along the contact between these ultramafic rocks and dolomite–actinolite schist in the wall of the roadcut. The material is so soft that it can easily be removed by hand, and the content of molybdenite is locally very high (Plate 7). No molybdenite was observed in the bounding units, although the ultramafic section of the outcrop does contain some pyrite and chalcopyrite. These observations are in accordance with the conclusions of Fuller (1945), who noted that the best molybdenite was always found in areas of intense faulting and fracturing. The prospect has generally been viewed as a potential skarn-type environment, based on its location at the junction of two different units, and the suggestions of Fuller (1945) that the local abundance of talc, dolomite, actinolite and biotite recorded the interaction between these host rocks and hydrothermal fluids. However, Fuller (1945) also suggested that "acidic hydrothermal solutions derived from an underlying batholithic intrusion" were the ultimate source of the molybdenum. The mineral assemblages developed in the bounding host units may thus have existed long before Mo was introduced.

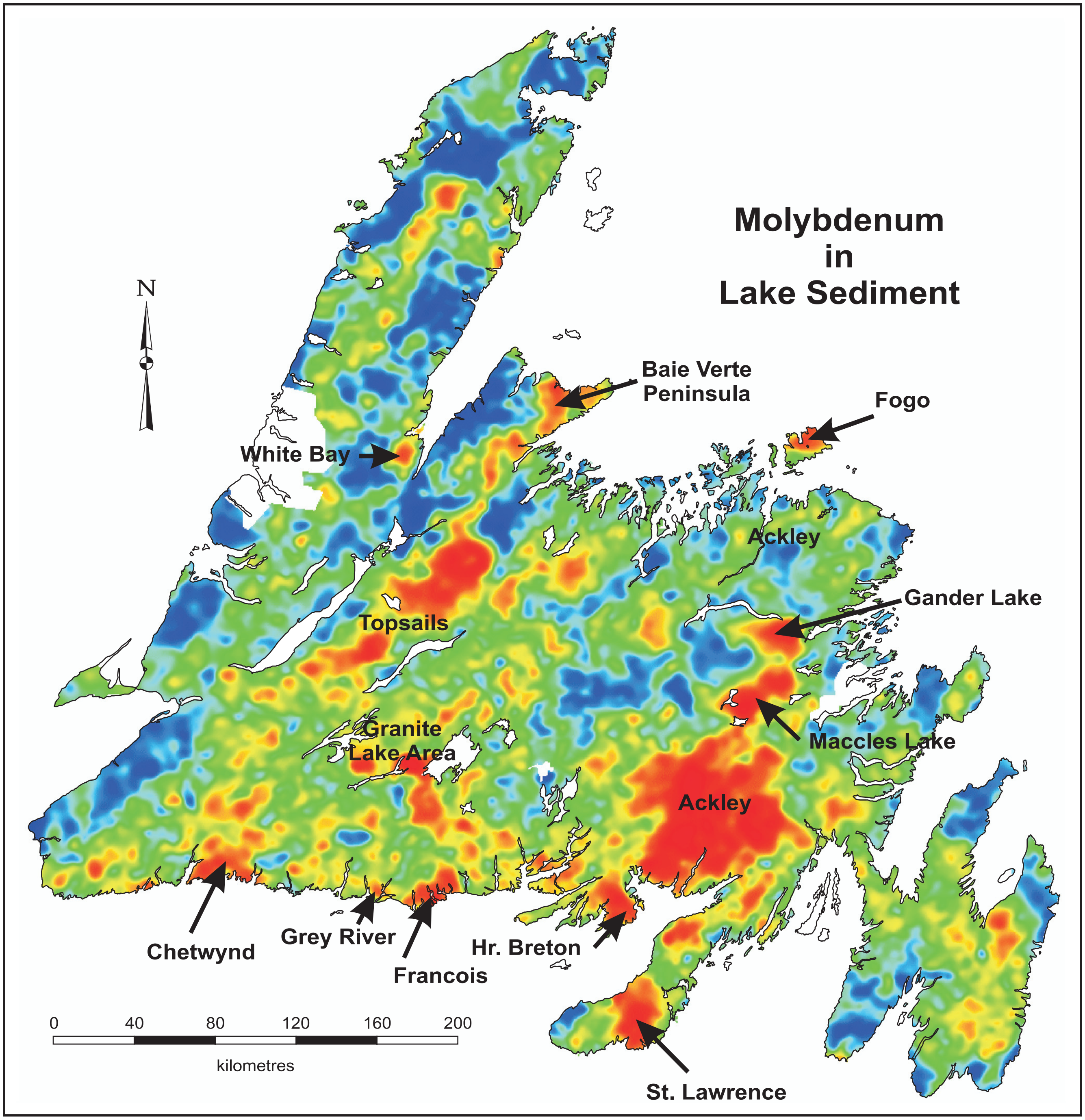

Figure 10. *Regional distribution of molybdenum in lake sediment across Newfoundland. Data from the Geological Survey Resource Atlas.* http://gis.geosurv.gov.nl.ca/

EXPLORATION METHODS AND STRATEGIES

SURFICIAL GEOCHEMICAL PATTERNS

In many of the areas discussed, there are well-developed surficial geochemical anomalies defined by lake-sediment, lake-water and soil sampling. In some cases, such as the Granite Lake area, these anomalies were instrumental in the initial discovery of Mo–W mineralization. Although they may not have provided the initial pathway to discovery in all instances, such patterns have proved useful in the delineation of high-priority areas prior to drilling. There is no doubt that surficial geochemistry methods are likely to be of value in both regional and property-scale exploration.

Regional Patterns for Molybdenum

The regional distribution pattern for molybdenum in lake sediments is illustrated in Figure 10, using data from the on-line Resources Atlas at GSNL. The pattern is relatively noisy, but several broad areas of enrichment are defined, and these include areas of known mineralization. The most obvious of these is the large positive Mo anomaly that provides excellent definition of the Ackley Granite and extends northwestward to define the Gander Lake Granite, another evolved pluton of probable Devonian age. The Maccles Lake Granite also forms part of this general trend, although outcrops exposed in the northwest of this body are syntectonic K-feldspar-megacrystic granodiorites that more closely resemble typical Silurian suites of the area (Kerr *et al.*, 1993b). However, the western section of this body is not well mapped, and thus perhaps deserves closer examination. The Granite Lake area is well-defined by regional lake-sediment Mo data, and several other evolved granitoid plutons also stand out, including the Chetwynd Granite, the Francois Granite and the St. Lawrence Granite. Of these, only the latter is presently known to be associated with mineralization that includes molybdenum. The second-largest contiguous lake-sediment Mo anomaly is associated with the Topsails Intrusive Suite in west-central Newfoundland, which is similarly not known to contain significant Mo or W mineralization, although it is presently a target for uranium. There are some small molybdenite indications on the west side of the body (Figure 4).

Other regional lake-sediment anomalies for Mo are relatively small, and their significance is not obvious other than that most of them are associated with areas underlain by granitic rocks. The Grey River area, site of the Moly Brook deposit, does not present an obvious regional Mo geochemical anomaly, but this is, in part, a function of sampling density, as there is a local lake-sediment geochemistry Mo anomaly at Long Pond, and also in soil geochemistry (*described below*).

Regional Patterns for Tungsten

The regional distribution pattern for W in lake sediments is shown in Figure 11, using data from the Resources Atlas at GSNL. Compared to Mo (Figure 10), the W pattern is more focused and less noisy, at least on a regional scale. It mostly defines a broad swath of W enrichment that extends from southwestern Newfoundland, along the south coast, and then northeastward into the Gander Zone. The pattern defines the main areas in which Mo and/or W mineralization is presently known, and also provides good definition of the Ackley Granite and other evolved plutons within this general area. It also defines the Grey River area much better than does the regional Mo data.

There are some important differences between the Mo and W patterns (Figures 10 and 11). The most striking is that several areas defined by Mo in lake sediments are not defined by the pattern for tungsten. These include the Topsails area, Fogo Island, and other locations. However, the W pattern does highlight an area north of Deer Lake, where the underlying bedrock consists of Carboniferous sedimentary rocks rather than granites. There is no obvious cause for this latter anomaly, but it may merit examination in the context of ongoing uranium exploration in the Deer Lake Basin.

Deposit or District-Scale Surficial Geochemical Patterns

Two areas containing advanced projects illustrate the value of stream-sediment and soil geochemistry in later stages of exploration, once a generalized target area has been defined. In the Granite Lake area, the distribution in stream sediments and soils of Mo and W, and several other elements, provides a good definition of the Meelpaeg Lake Fault Zone, which appears to be a primary control on the mineralization. These patterns were discussed by Tuach (1996) and also appear to be effective in locating mineralization. The pattern for Mo, coupled with geophysical data (*described below*) was instrumental in the discovery of the new Moly Hill prospect. At the Moly Brook deposit near Grey River, which was not indicated as clearly in regional lake-sediment patterns, the distribution of Mo, W and also Cu are useful in delineating the main zone of mineralization, and perhaps indicating its extensions in the surrounding area (Figure 7a). The data have been used in targeting drilling locations during the 2008 exploration program (*e.g.*, Visagie, 2008).

GEOPHYSICAL TECHNIQUES

The choice of geophysical techniques in exploring for Mo or W deposits in Newfoundland depends on the exact nature of the deposit model. Given that the porphyry-type environment (as exemplified by Moly Brook) or endocontact disseminated deposits in granitoid rocks likely have the greatest tonnage potential, the following discussion emphasizes these settings. Clearly, exploration and delineation methods for a rectilinear vein-style deposit such as the Grey River or Charles Cove veins would be very different.

Regional Geophysical Exploration

Most sheeted-vein style deposits, or disseminated deposits, would not likely have electrical connectivity, and large-scale airborne resistivity surveys, such as those used routinely in exploration for magmatic sulphides or VMS deposits, would likely not be effective. The capacity of such systems to detect disseminated sulphides more amenable to

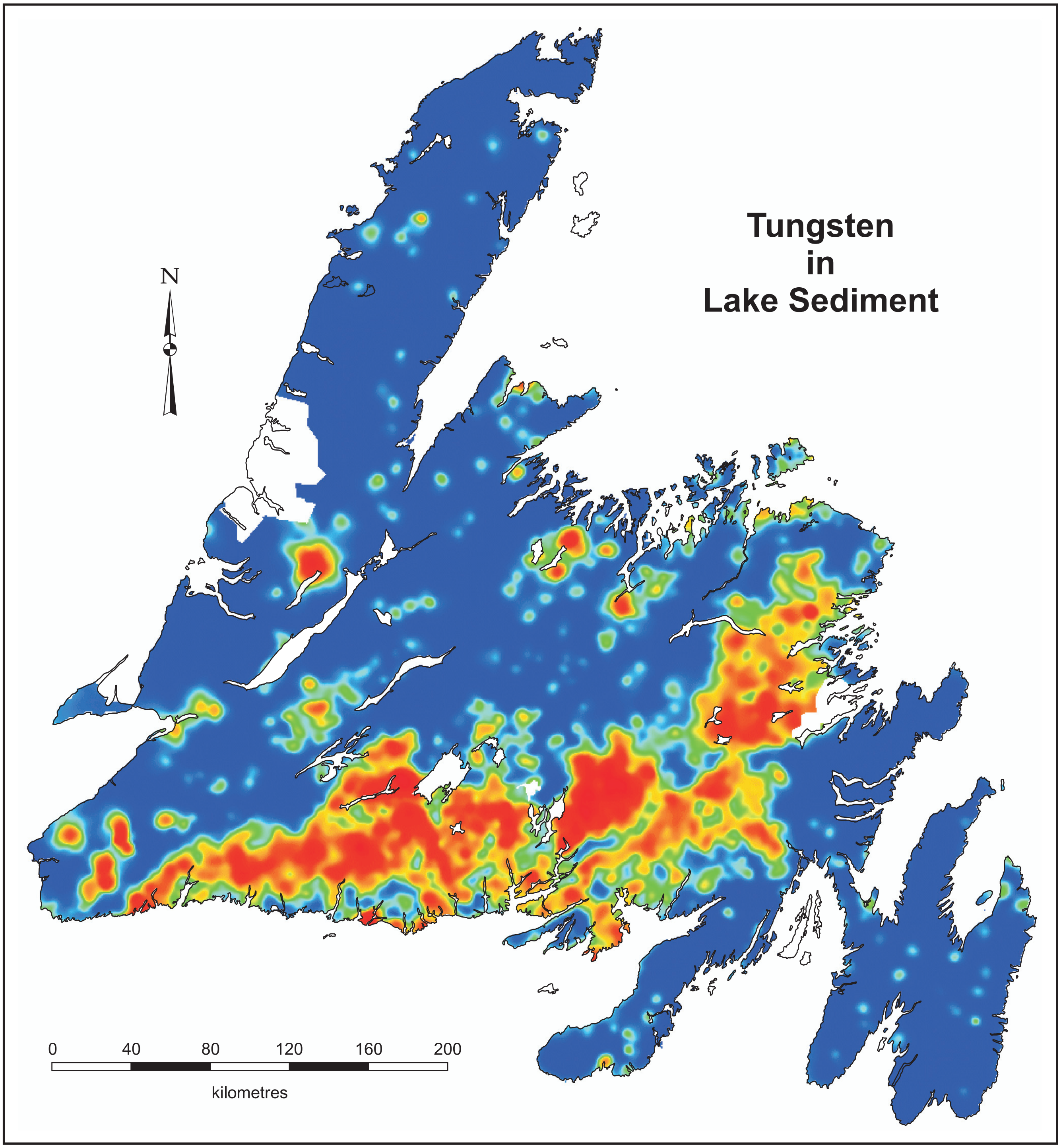

Figure 11. *Regional distribution of tungsten in lake sediment across Newfoundland. Data from the Geological Survey Resource Atlas,* http://gis.geosurv.gov.nl.ca/, *accessed 2008.*

ground-based techniques such as Induced Polarization (IP) is limited.

Given the association between Mo–W mineralization and geochemically evolved or specialized granitoid rocks, and the common prevalence of potassic alteration in the cores of hydrothermal systems, it follows that airborne radiometry could be useful on a variety of scales. The three-component (ternary) radio-element maps that are available from existing regional data show excellent definition of evolved, mineralized plutons such as the Ackley Granite (*e.g.*, Figure 12), and could be useful in defining smaller

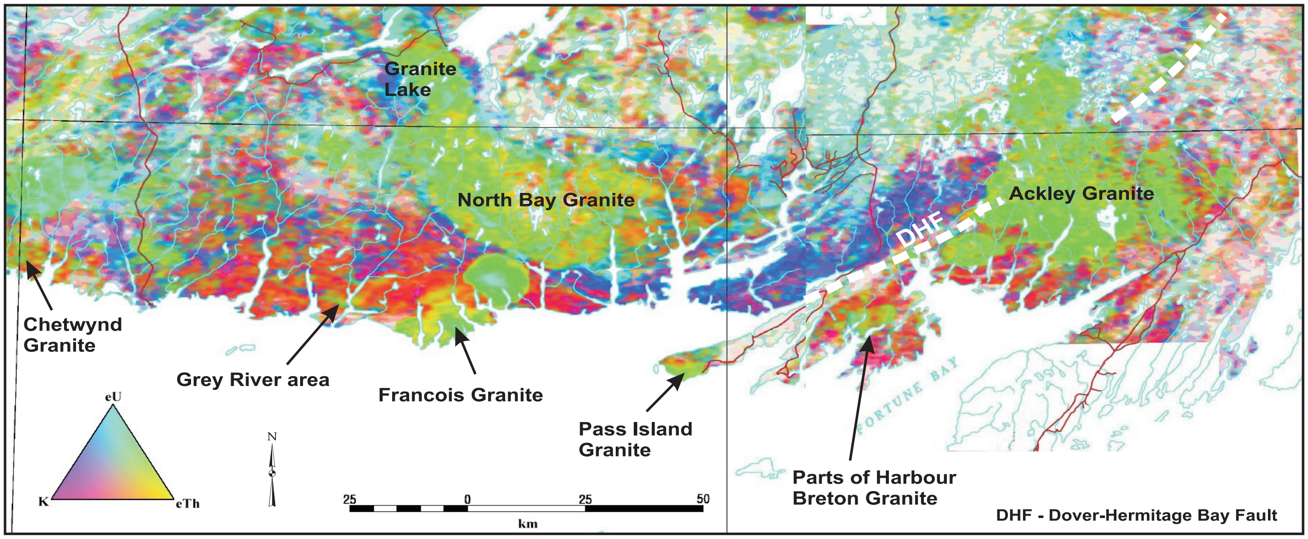

Figure 12. *Ternary airborne radiometric image of the southcoast of Newfoundland, derived from regional Geological Survey of Canada data. Image file prepared by Gerry Kilfoil at GSNL. Red areas are dominated by potassium response, blue by uranium response, and yellow by thorium response. Late, evolved granites are defined exceptionally well by their combined U–Th response, and such data may also be useful in delineating potassic alteration linked to magmatic hydrothermal systems.*

bodies of similar type, or in recognizing spatial-compositional trends without the need for bedrock sampling. Examination of data from the perspective of potassium enrichment may be useful in delineating the hydrothermal alteration systems related to these deposits, which are likely several times larger than the mineralized zones.

Deposit or District-Scale Exploration

The character of mineralization developed as sheeted-vein systems or disseminated sulphides suggest that Induced Polarization (IP) methods are the most effective second-stage geophysical technique. The IP method has proved useful at the Moly Brook, and the best grades of mineralization have typically been proven in areas of strong IP response (Visagie, 2008). Another method that may be useful in more detailed delineation of alteration systems is the total field magnetic response, because intense alteration commonly involves the destruction of primary magnetite, which is, in many cases, replaced by pyrite. However, magnetic surveys detect sources at various depths, so complexities in the 3D geological pattern may mask such effects. For example, at the Moly Brook deposit, prominent 'bulls-eye' magnetic highs (Lendrum and Mercer, 1997) may reflect a buried plutonic body that has retained primary magnetite, whereas pervasive propylitic alteration has largely destroyed magnetite in the immediate host rocks to the mineralization.

Techniques discussed above are, for the most part, also applicable to skarn-type environments, although where such deposits involve carbonate rocks, the redistribution and reduction of carbon can lead to graphite formation, which can complicate interpretation of EM data. The silicate minerals in many skarn deposits are relatively dense, and gravity surveys may also provide a method of detecting larger zones in the shallow subsurface, subject to complications arising from regional geology. Some skarn-type deposits also show enrichment in U and Th, and would thus be amenable to radiometric survey methods.

DISCUSSION AND CONCLUSIONS

Molybdenum mineralization was discovered in Newfoundland 125 years ago, and tungsten was discovered over 50 years ago, but these commodities have never attracted the sustained or systematic exploration devoted to base metals or gold. This situation changed in the last few years as prices for both commodities rose, and this report attempts to take stock of what is known concerning such mineralization. Given the established links between Mo–W mineralization and granitoid magmatism, it comes as no surprise that virtually all instances are hosted by granites or indirectly linked to them. Only the Parrell Mo prospect and the Charles Cove W prospect presently lack an obvious connection, and the former appears to be a geological curiosity. Most examples of Mo–W mineralization are located in southern Newfoundland, along with other styles of granite-related mineralization such as tin-bearing greisens and fluorspar veins. The lake-sediment geochemical distribution of Mo and W clearly highlights the south coast of Newfoundland, although many other areas underlain by granites are defined by enriched Mo. Combined Mo–W anomalies have a more restricted distribution. Thus, from an empirical perspective, southern Newfoundland represents the most obvious regional target area. The available information suggests that various surficial geochemical techniques provide the most effective exploration methods on both regional and property scales. If mineralization can be convincingly linked to plutonic suites of a given age or composition, then such factors may become important in regional targeting. A connection to evolved granites of mid- to Late Devonian age is strongly suspected, but remains unproven for all but the occurrences in the Ackley Granite.

There are two main styles of Mo mineralization. The first is exemplified by prospects in the Ackley Granite, and is essentially syngenetic, believed to be genetically related to the immediate host rocks. The latter are evolved granitic rocks such as aplites, pegmatites and alaskites, commonly with greisen-style mica alteration. These deposits have the characteristics of so-called 'pegmatite–aplite' deposits considered to form when evolved, fluid-rich magmas are trapped in the roof zones of large granitic plutons, and molybdenite crystallizes, in part, with the silicate minerals. Locally, hydrothermal fluids were concentrated as a discrete phase, leading to lesser concentrations in quartz veins and crosscutting altered zones (*e.g.*, White, 1940; Whalen, 1980). These deposits are locally relatively high-grade, but appear to have limited dimensions. In the case of the Ackley Granite, there has been no deep drilling around known prospects, but models for such deposits do not suggest a high potential for better grade material at depth, and disseminated mineralization would likely only be viable if amenable to open-pit extraction. However, there may be other mineralized zones in the area south of the main part of the pluton, where the original roof of the magma chamber may lie in the shallow subsurface. The Belle Island showing hints at this possibility.

The second style of Mo mineralization is exemplified by the Moly Brook deposit, and perhaps also by the Granite Lake area. At Moly Brook, the mineralization is likely epigenetic, and there is no clear genetic link to its immediate host rocks. Virtually all the molybdenite is hosted in sheeted- to stockwork-style quartz veins within a wider envelope of strong, largely potassic, alteration. The overall Mo grades in these examples are lower than in first type, but they are much larger systems, potentially including hundreds of millions of tonnes of low-grade material. They also contain associated Cu and other elements (*e.g.*, W and Bi), which may add to their aggregate value. Such deposits are best assigned to the 'porphyry clan', within which there is a well-known continuum between Cu-rich and Mo-rich systems. Sinclair (2007) divides Mo-rich porphyry deposits into Climax-type deposits (characterized by high grades of 0.17 to 0.24% Mo) and Endako-type deposits (characterized by grades that are typically less than 0.1% Mo). Moly Brook likely belongs to the latter, although some of the higher grade intersections reported in recent drilling approach Climax-type grades.

The potential porphyry-style Mo (± Cu) deposit at Moly Brook appears to be hosted by unrelated plutonic rocks, but there is now more evidence for a genetic connection to evolved granites at depth, as originally proposed in the 1950s. The presence of disseminated molybdenite in the Hole MB-08-18 granite and similar intersections also provides a possible link between the exocontact sheeted-vein-hosted mineralization and syngenetic endocontact mineralization that is, perhaps, akin to that documented from the Ackley Granite. The relationships between Mo (± W) mineralization, of similar style, at Granite Lake and its host rocks are presently equivocal, but the fact that mineralization occurs in at least three different lithological units suggests that it may be related to none of them. A 'buried pluton' model of the type proposed for Moly Brook is possible, although direct evidence is lacking. If two such systems exist in this wide area, within which surficial geochemical patterns indicate pervasive Mo–W enrichment, there may well be other examples waiting to be found.

In contrast, much of the W mineralization known in Newfoundland is associated with discrete larger veins, of which the best known is the Grey River vein # 10. This is just one of a large number of polymetallic veins documented in this area. Although this is small in terms of tonnage, it is significant in that such deposits are rare and typically have interesting grades. Given its proximity to a large porphyry-style Mo system, a wider connection between the W deposits and a largely unseen granitic pluton is logical. This is consistent with the views of Bahyrycz (1956) and Higgins (1985), who suggested that the small leucogranite stock a short distance west of the veins might be a representative of such a body.

To prove such a connection is not a simple matter, but the most obvious route is through precise geochronology. Efforts are currently underway to date the mineralization at Moly Brook using Re–Os methods, which opens the possibility for direct correlation with units such as the Hole MB-08-18 granite. The latter is presently a target for U–Pb geochronological studies. Early phases of the Grey River # 10 W vein contain molybdenite, and are thus possibly amenable to Re–Os dating, and correlation with other styles of mineralization.

Skarn-type mineralization is also a common feature of porphyry-style metallogenic systems developed in favourable country rocks, notably those that contain carbonate sedimentary rocks. This geological scenario is uncommon in Newfoundland, and there are no clear examples of Mo-rich skarns. Although the Parrell prospect, near Baie Verte, has been placed in this category, there is no clear evidence supporting such an origin. However, the W mineralization reported in the Great Gull Lake area does have some of the characteristics of skarn-type mineralization, and this area may now merit more detailed evaluation for such targets. The proximity of these zones to the western contact of the Middle Ridge Granite suggests that there may be a connection to this large body. Skarn-type W deposits generally tend to be larger than vein-hosted systems, although they typically have lower grades.

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