Current Research (2012) Newfoundland and Labrador Department of Natural Resources
Geological Survey, Report 12-1, pages 21-38

NEW U–Pb GEOCHRONOLOGICAL CONSTRAINTS FROM MINERALIZED GRANITES IN SOUTHERN NEWFOUNDLAND

A. Kerr and V. McNicoll[1]
Mineral Deposits Section
[1]Geological Survey of Canada, 601 Booth Street, Ottawa, ON, K1A 0E8

ABSTRACT

This article reports U–Pb SHRIMP geochronological data from granitic rocks associated with W and Mo–Cu mineralization in the Grey River and Granite Lake areas of southern Newfoundland. The Grey River area hosts a vein-style tungsten deposit, and numerous minor base- and precious-metal bearing veins. A potentially large Mo–Cu deposit (Moly Brook) consisting of sheeted mineralized quartz veins is now also defined by recent exploration activity. It has long been speculated that this diverse metallogeny is genetically linked to a largely hidden younger intrusion. The granodioritic host rocks to the Mo–Cu-bearing vein system gave an age of 411 ± 4 Ma, but fine-grained alaskitic granites that contain disseminated molybdenite gave a much younger age of 378 ± 4 Ma. Field evidence suggests a contemporaneous relationship between alaskitic granites and the mineralized veins, indicating that veins also formed at ca. *378 Ma. Mineralization at Moly Brook thus postdates its immediate host rocks by >30 m.y.,* i.e.*, it is epigenetic. The age interpreted for alaskitic granites and mineralization matches that obtained from the François Granite, a geochemically evolved pluton located about 20 km to the east. The age also overlaps with ages from two other granitoid plutons associated with granophile mineralization in southern Newfoundland. At Granite Lake, Mo-bearing veins are hosted by an equigranular biotite–muscovite granite that also contains disseminated molybdenite, and locally displays intense advanced argillic alteration. The biotite–muscovite granite is thought to be contemporaneous with mineralization. The U–Pb zircon data from the granite suggest an age of 388 ± 4 Ma, and indicate inherited cores of both Silurian (427–417 Ma) and Paleoproterozoic age. If this also records the timing of mineralization, it represents a slightly older episode of metallogenesis than that at Grey River. It is possible that there is a regional age variation amongst mineralized granites from northwest to southeast, but many more data are needed to confirm this hypothesis.*

INTRODUCTION

Several granites (*s.l.*) in southern Newfoundland (Figure 1) are thought to be linked to granophile-type mineralization, including fluorite (F), molybdenum (Mo), tungsten (W) and base metals (Pb, Zn ± Cu). The granites serve either as direct hosts to disseminated mineralization, or are associated spatially with mineralized veins or replacement zones in adjoining country rocks. It is commonly considered that mineralization hosted in granites is syngenetic, but this is not necessarily so, and it can be difficult to prove. Rhenium-osmium geochrononology provides the only technique that can directly date mineralization, and it is best applied to molybdenite-bearing deposits, such as those in the Ackley Granite area (*e.g.*, Lynch *et al.*, 2009; Figure 1). Hydrothermal alteration assemblages dominated by sheet silicates can also be dated using Ar–Ar methods, but these systems are more easily disturbed by later events, and there is often a subjective link between such alteration and mineralization. For these reasons, U–Pb zircon dating of associated granites remains an important component of research on such deposits. The ages of such suites are also of regional interest because there are limited data on late-stage plutonic events in the Newfoundland Appalachians.

This article reports U–Pb geochronological data from granitic rocks associated with molybdenum mineralization near Grey River on the south coast, and from the Granite Lake area in south-central Newfoundland (Figure 1). The study represents a contribution to a wider research project on these and other granophile deposits in Newfoundland emphasizing the Re–Os technique. Preliminary results from this project are reported by Lynch *et al.* (2009, 2011a, b). There were some previous geochronological studies in the Grey River area (Higgins, 1985; Higgins *et al.*, 1990), but the results from the Granite Lake area are the first indications of the ages of magmatism.

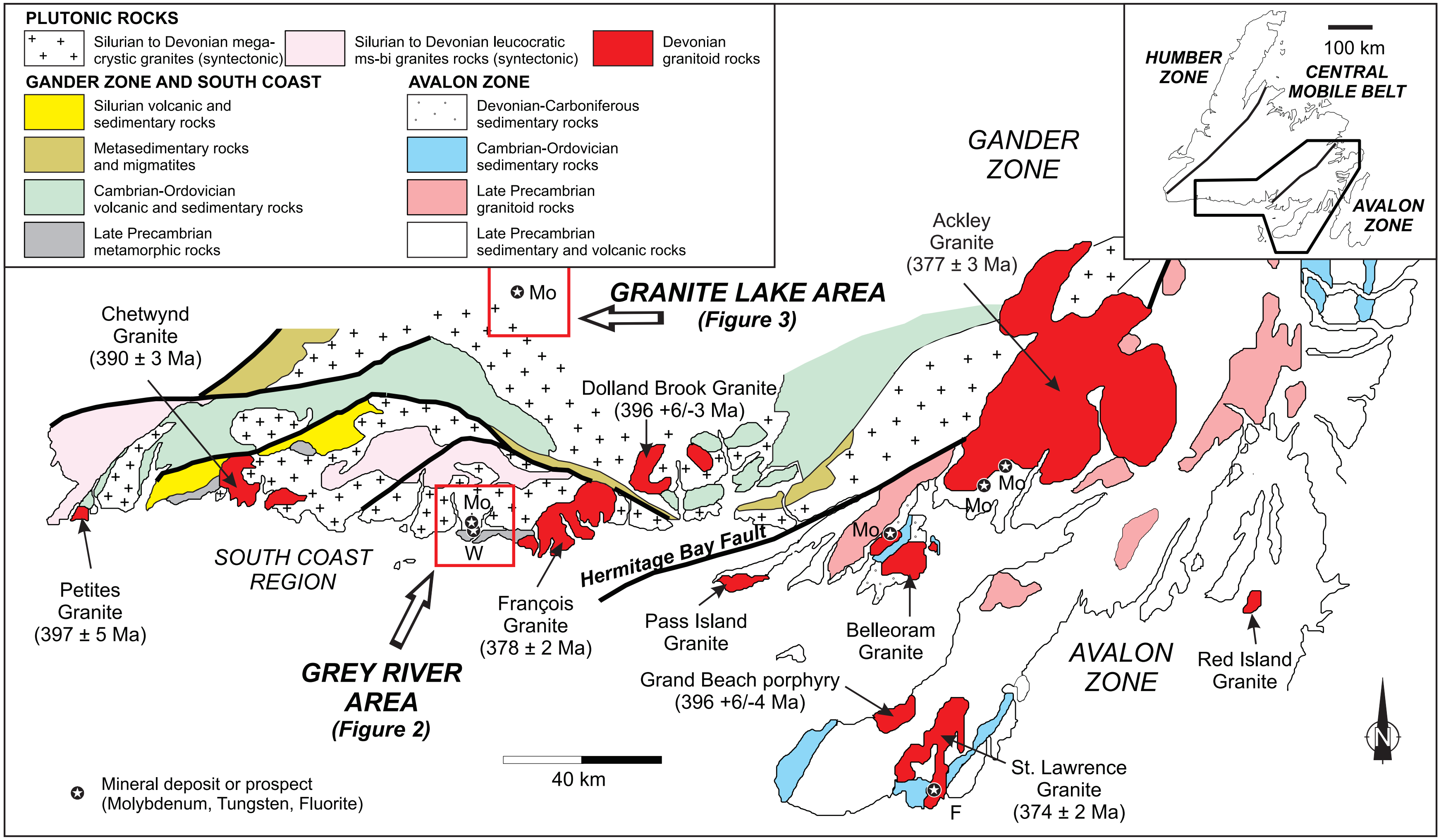

Figure 1. *Generalized regional geology of southern Newfoundland, showing the locations of granitoid intrusions and molybdenum prospects discussed in this article, and the location of more detailed figures.*

REGIONAL GEOLOGICAL AND METALLOGENIC FRAMEWORK

REGIONAL SETTING

South-central Newfoundland includes parts of the Avalon Zone and the Central Mobile Belt (Figure 1) of the Appalachian Orogenic Belt. The prominent lineament of the Hermitage Bay fault zone marks the western limit of the Avalon Zone. To the east of this line, late Neoproterozoic sedimentary, volcanic and plutonic rocks are preserved in unmetamorphosed to sub-greenschist-facies condition. However, these rocks were affected by folding during the Devonian Acadian Orogeny, and are intruded by granitoid rocks thought to be Devonian, although many remain undated. West of the Hermitage Bay fault zone, the south coast of the Island is dominated by complex and multiphase granitoid rocks of both Silurian and Devonian age but local remnants of a late Precambrian basement similar in age to the Avalon Zone remain (Dunning and O'Brien, 1989). There are also greenschist- and amphibolite-facies metasedimentary and metavolcanic rocks of probable Cambrian–Ordovician depositional age. The metasedimentary rocks are generally considered to be higher grade equivalents of the Gander Group of northeast Newfoundland. The south coast of Newfoundland was originally placed in the Gander Zone by Williams (1979) but it was later suggested that it should instead be considered an extension of the Avalon Zone (*e.g*., Dunning and O'Brien, 1989). Isotopic data from granites suggest that it has a distinct older heritage (Kerr *et al*., 1995), and this led to the current concept that it belongs to a separate peri-Gondwanan microcontinental domain termed 'Ganderia', which underlies the eastern part of the Central Mobile Belt (van Staal *et al*., 1998). The area around Granite Lake was always considered part of the Gander Zone, and is dominated by granitic plutonic rocks (as the name suggests), but also includes some older metasedimentary rocks.

GREY RIVER AREA

Local Geology

The Grey River area consists of late Precambrian metamorphic rocks and Paleozoic granitoid rocks (Figures 1 and 2), separated by a prominent zone of deformation and shearing (Figure 2). The Precambrian rocks (Grey River Enclave) consist of orthogneisses, psammitic metasedimentary rocks, and variably migmatized amphibolites; their complex evolutionary history lies beyond the scope of this article, and readers are referred to Blackwood (1985), Higgins *et al*. (1990) and Dickson *et al*. (1996) for details. Paleozoic granitoid rocks dominate the area to the north, and their internal geology remains poorly known. The most abundant rocks are coarse-grained, K-feldspar megacrystic biotite–hornblende granites, which are cut by finer grained leucocratic granites. Both variants are locally foliated, and both are affected by shearing along their boundary with the Precambrian rocks. Contact metamorphism of the latter was reported adjacent to this zone implying an original intrusive relationship prior to deformation (Higgins *et al*., 1990). Undeformed, posttectonic plutonic rocks underlie a small area near the mouth of Grey River (Figure 2). East of Grey River, the François Granite (Figure 1) comprises two overlapping ring-complexes, one of which (the eastern part) was dated at 378 ± 2 Ma (Kerr *et al*., 1993b). This is one of the most geochemically evolved granites in Newfoundland (Dickson *et al*., 1996), and is marked by prominent radiometric and geochemical anomalies.

Mineralization

The Grey River area has been a focus for mineral exploration since the discovery of vein-hosted tungsten mineralization (Bahyrycz, 1956). These quartz–wolframite veins were studied in detail by Higgins (1985) and were more recently explored by Playfair Mining, who estimate a resource of 0.85 million tonnes at 0.86 % WO_3 (Playfair Mining, www.playfairmining.com, viewed as of December 29, 2011). In the 1980s and 1990s, exploration focused on gold and base-metal showings north of Grey River (Figure 2). Royal Oak Mines discovered molybdenite- and chalcopyrite-bearing quartz veins in a brook, and these proved to be regionally extensive (*e.g*., Mercer, 1996; Lendrum and Mercer, 1997). The waterway in which the initial find was made (by prospectors Bill and Hiram Barter of Grey River) was christened 'Moly Brook'. Some drilling was completed, but the deposit was not evaluated in detail. Activity resumed in 2007, after the area was staked by the Barter brothers and optioned to Tenajon Resources. Systematic drilling outlined an extensive mineralized sheeted-vein system hosted by granodioritic rocks, and similar vein-hosted mineralization was also outlined in two locations south of the shear zone. A preliminary resource estimate of 118 million tonnes at 0.063 % Mo was announced in 2009, of which about three-quarters falls into the indicated category (Tenajon Resources, Press Release, May 5, 2009). Kerr *et al*. (2009) provide a review of Mo and W deposits in Newfoundland, including information available at the time on Moly Brook. Exploration activity for both tungsten and molybdenum has been limited since 2010, and Tenajon Resources has since become part of Creston Molybdenum Corporation.

The Moly Brook deposit is hosted within variably foliated, heterogeneous granitoid rocks (Figure 2). Mercer (1996) termed the host unit the 'Moly Brook stock' and described it as composite, ranging from diorite to syenite and granite. This variation represents gradational (but local-

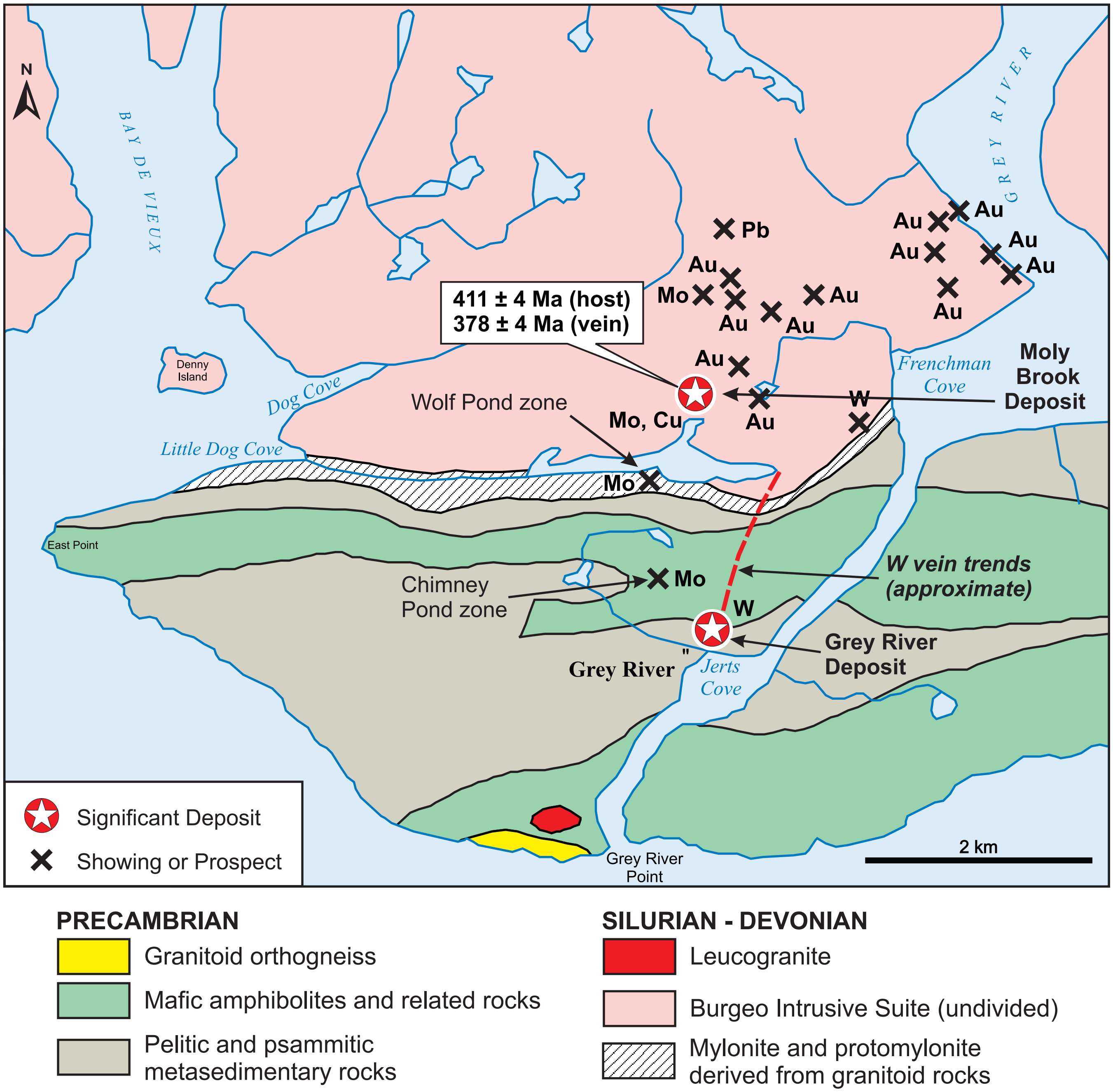

Figure 2. *Simplified geological map of the Grey River area, southern Newfoundland, showing mineral occurrences, and the locations of the Grey River (tungsten) deposit, and the Moly Brook (Mo–Cu) deposit. Modified after Higgins (1985), Blackwood (1985) and Higgins* et al. *(1990).*

ly abrupt) variations within a single unit of broadly granodioritic composition (Kerr *et al*., 2009). The proportion of phenocrysts varies widely on a scale of metres, and a cataclastic to protomylonitic fabric is locally developed. The granodioritic host rocks display propylitic (chlorite±biotite) alteration throughout the deposit area, upon which localized potassic alteration is superimposed in areas of mineralized veins. The potassic alteration is manifested by intense reddening of K-feldspar, and by discrete muscovite-rich zones along vein margins. Differential (and sequential) alteration is everywhere superimposed upon primary lithological variations within the host rocks, and the drillcore commonly has a chaotic and disorganized appearance.

Molybdenite and lesser chalcopyrite are essentially restricted to quartz veins, occurring on their outer contacts or along internal selvages. Individual quartz veins range in width from <1 mm to 1 m, but most have widths between 0.5 and 5 cm. The Mo and Cu grades are essentially proportional to the intensity of veining in a given core interval. In trench exposures, veins are mostly oriented roughly north–south, and dip steeply, although individual vein attitudes are varied. Quartz veins are dominant, but there are also pegmatitic and aplitic varieties containing feldspar and muscovite, and late carbonate–sericite veins. Lynch *et al*. (2011b) summarize the vein parageneses and fluid inclusion results, which record a chronological progression from higher to lower temperatures. The discordant relationship between individual quartz veins and locally cataclastic fabrics argue against any syngenetic link between the sulphides and the immediate host rocks (Kerr *et al.*, 2009).

A deep drillhole completed in 2008 (Hole MB-08-18) intersected a distinct unit from about 435 m to its final depth of about 496 m. The 'Hole 18 granite' is a fine-grained, pale-pink, homogeneous alaskitic rock, containing minor muscovite (± chlorite). No sense of intrusion timing can be gleaned from its upper contact in drillcore, but it is undeformed, and contains few mineralized quartz veins compared to the dominant megacrystic host rocks. Hole MB-08-18 terminated in this fine-grained granite and so the full depth extent of this unit remains unknown. However, veins of a similar alaskitic granite were observed to cut quartz veins in some other deep drillholes (E. Lynch, personal communication, 2009). The Hole 18 granite contains disseminated pyrite and lesser disseminated molybdenite, and minor amounts of fluorite occur on fracture surfaces. It is considered to be a dyke-like satellite body from a subjacent pluton that is genetically related to (and contemporaneous with) the mineralization. The relative lack of mineralized quartz veins in the Hole 18 granite suggests that it was emplaced late in the evolution of the system, but that hydrothermal activity continued after emplacement. Examples of the typical host rocks to mineralization at Moly Brook, and the Hole 18 granite, are illustrated in Plate 1.

GRANITE LAKE AREA

Local Geology

Granite Lake is located some 80 km north of Grey River, west of the Meelpaeg Lake Reservoir, within the Meelpaeg Subzone of the Gander Zone (Figure 1). The geology of this area is summarized by Dickson (1982), but detailed interpretation is impeded by poor exposure. The geology and known mineralization are also discussed by Tuach (1996), who considered the area to have further exploration potential. The south of the area is dominated by granitoid plutonic rocks, but an area in the north consists of metasedimentary rocks (Figure 3). Two groups of granitoid rocks are defined, which are inferred to be separated by a sheared zone termed the Meelpaeg Lake fault. The granites in the west (Wolf Mountain Granite) are potassic, compositionally evolved, biotite–muscovite granites, and were considered to be younger than plagioclase- and biotite-rich tonalites and granodiorites in the east (Dickson, 1982; Tuach, 1996).

Mineralization

Molybdenum, tungsten and fluorite occurrences are scattered widely in the area, and are best exposed along a hydroelectric canal in the south of the area (Figure 3). Most occurrences are small, and were discovered in the 1980s, during follow-up work based on regional lake-sediment geochemical anomalies. Also, there are extensive soil geochemistry anomalies for both molybdenum and tungsten, and several other metals, defined by these exploration programs (Tuach, 1996). Mineralization includes disseminated molybdenite in granites (typically associated with altered zones), molybdenite in quartz veins, veinlets and pegmatites, and wolframite in quartz veins. Since 2008, Playfair Mining has explored the area, with an emphasis on a location originally known as the 'Hill showing', where molybdenite occurs in quartz-vein networks in variably altered granite. Drilling at this site shows that mineralization is extensive over an area of 600 x 100 m, and extends to depths of greater than 150 m (Briggs, 2008). No resource estimates have been released for this zone, which was predictably christened 'Moly Hill', but the mineralized intersections are wide, including 167 m at 0.054% Mo (Playfair Mining, Press Releases and website information). Unlike Moly Brook, there seems to be little associated Cu mineralization. Drillcore indicates that mineralization consists of molybdenite and pyrite associated with quartz veins from less than 1 cm to over 1 m in width. The Wolf Mountain Granite in the mineralized cores is a medium-grained equigranular muscovite-rich rock that is typically pink or red, with reddening or bleaching locally associated with the margins of mineralized veins. Diffuse zones of darker grey, biotite-rich, locally foliated granite are interpreted as enclaves of an older unit, perhaps the granodiorite mapped to the east by Dickson (1982). The host leucogranite locally contains interstitial patches and rosettes of molybdenite, and these do not appear to be spatially linked to the vein systems. Alteration along the margins of veins consists largely of secondary muscovite, but there are also zones where the core is intensely altered to a friable, green-white to buff-yellow material. Similar alteration was noted in outcrops by Tuach (1996) and considered to include clay minerals. Visible/infrared reflectance spectrometry (VIRS) data indicate the presence of kaolinite and dickite, amongst other species typical of advanced argillic alteration (Kerr *et al*., 2011). These intensely altered zones do not appear to be spa-

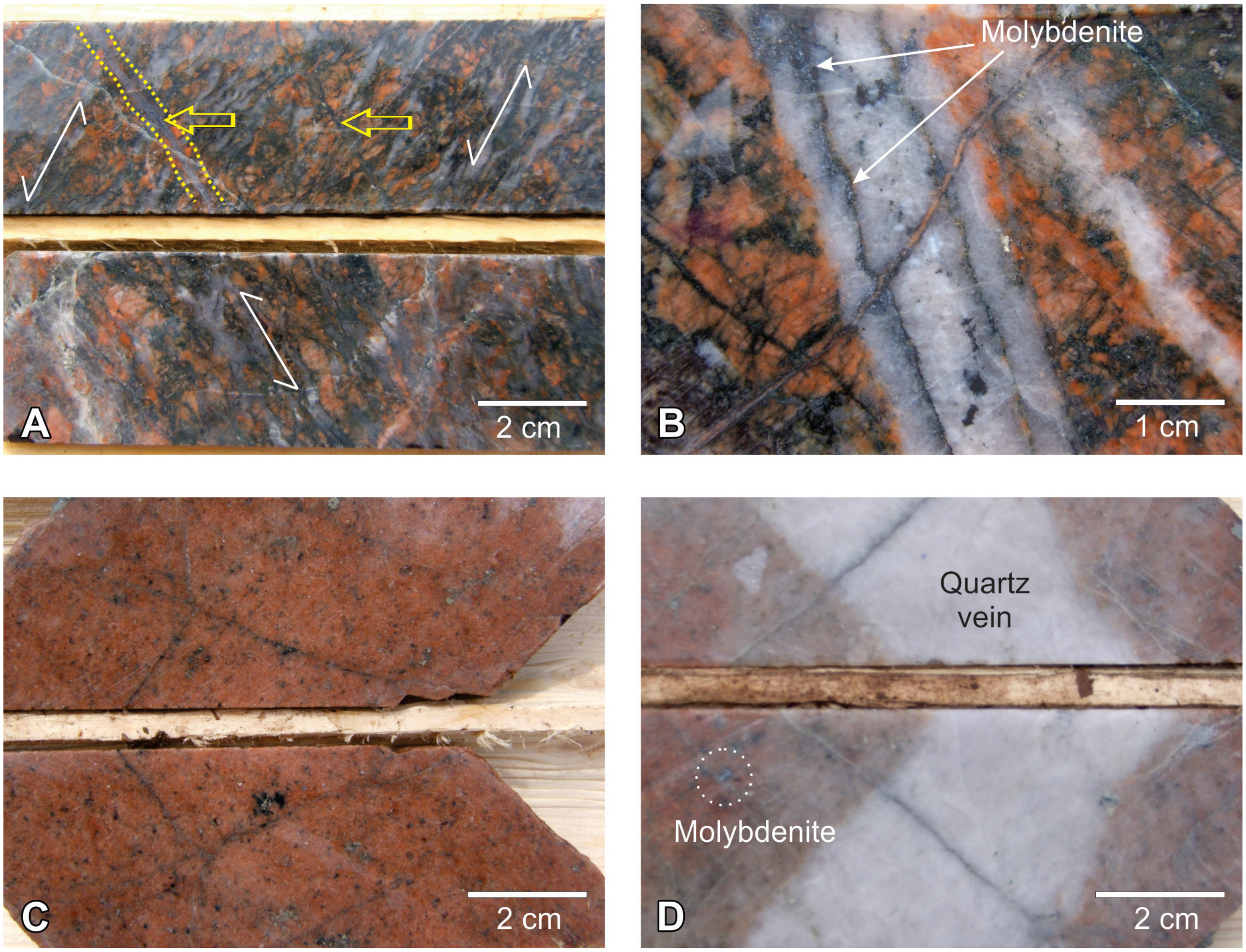

Plate 1. *Examples of the rock units at the Moly Brook deposit. A) Foliated, melanocratic hornblende–biotite granodiorite representing the regional host rocks to the Moly Brook deposit. Note the cataclastic fabric, which is cut at high angles by mineralized veinlets (indicated by yellow arrows). B) Typical mineralized quartz vein containing molybdenite and chalcopyrite along internal selvages. C) Fine-grained pink alaskitic granite from Hole MB-08-018, note minor disseminated pyrite. D) Rare example of a quartz vein cutting the Hole 18 granite. Note disseminated molybdenite in the fine-grained granite.*

tially associated with a greater density of mineralized veins, although they are cut by such veins locally. The dark chlorite-rich 'propylitic' alteration observed at the Moly Brook deposit is rarer at Granite Lake, and seen only locally in more mafic enclaves. Its absence likely reflects the generally Mg- and Fe-poor leucocratic host rocks compared to those at Moly Brook. Typical examples of mineralization and host rocks from this zone at Granite Lake are illustrated in Plate 2.

U–Pb ZIRCON GEOCHRONOLOGY

The U–Pb zircon geochronology at Moly Brook was initiated to test the model that the Hole 18 granite is a dyke related to a younger subsurface pluton and, in conjunction with Re–Os work, to establish the timing of mineralization. The objectives at Granite Lake were to determine the age of the host rocks and mineralization relative to other plutonic suites in the area. The U–Pb data from these granitoid rocks complement Re–Os geochronology by confirming links between molybdenite-rich zones and spatially associated granites (*e.g.*, Lynch *et al.*, 2011a, b).

SAMPLING, PROCESSING AND ANALYTICAL TECHNIQUES

Three samples were analyzed for this study. Sample AK-08-023 (z9746) was collected in 2008 from an outcrop on a drill access road at Moly Brook. It is a weakly altered, grey to pink, medium- to coarse-grained granodiorite con-

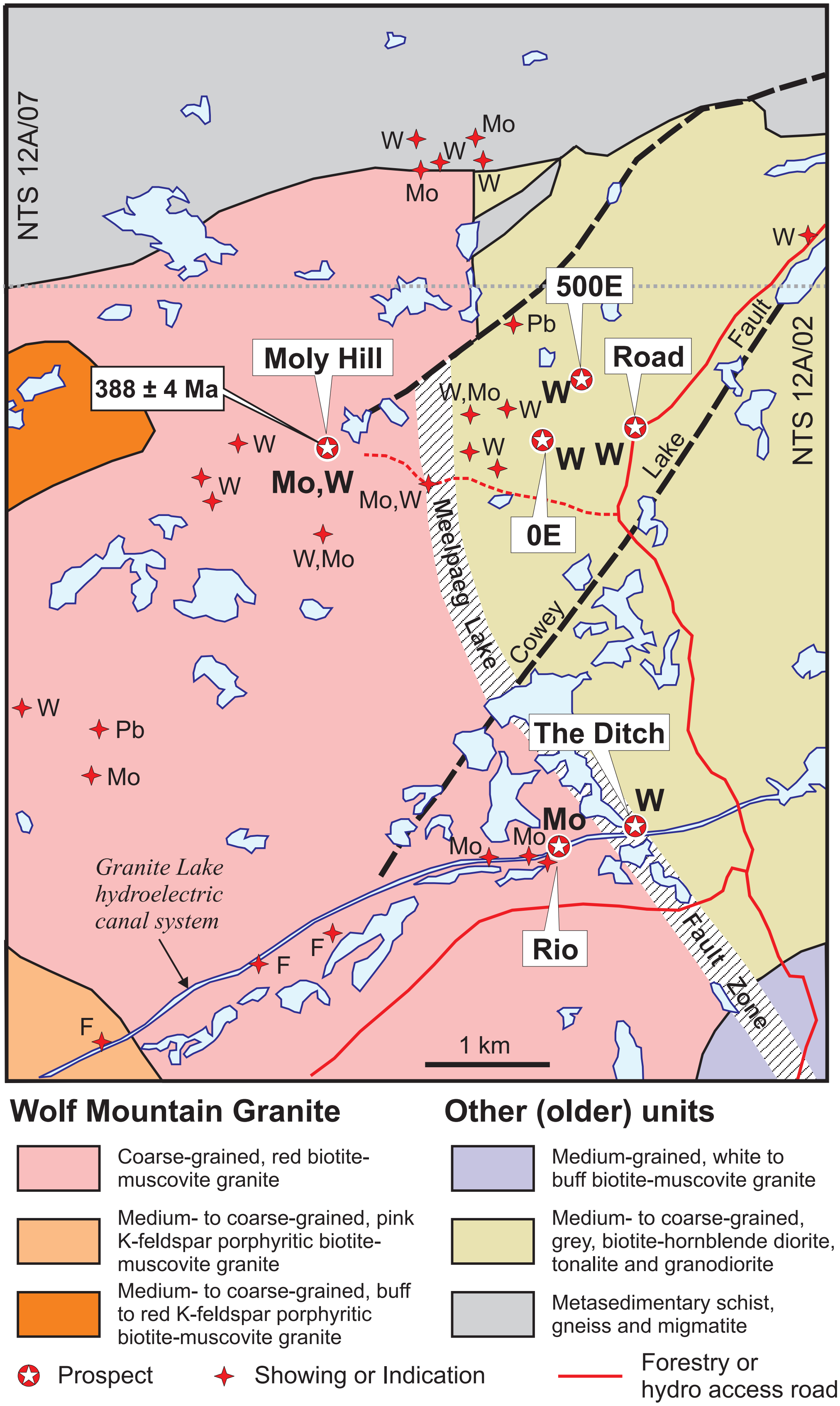

Figure 3. *Simplified geological map of the Granite Lake area, showing mineral occurrences. Modified after Tuach (1996).*

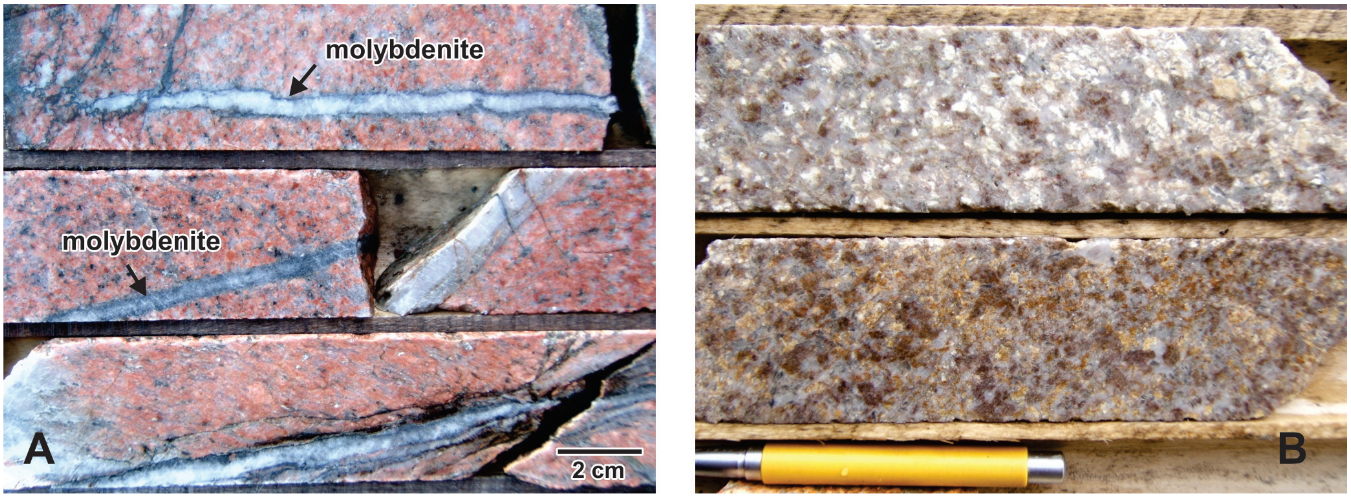

Plate 2. *Examples of the rock units from the Granite Lake area. A) Typical red biotite-muscovite granite host rock, cut by molybdenite-bearing quartz veinlets. Note that the granite also contains minor disseminated molybdenite, not visible in photo. B) Intense clay mineral alteration of the host granite, in this case without a spatial relationship to mineralized quartz veins.*

taining biotite and hornblende, and represents the host rocks to mineralization. The sample site was chosen to avoid quartz veining and is unmineralized, but it is adjacent to a zone, rich in molybdenite, which was provided for Re–Os dating by E. Lynch. Sample KC-08-013 (z9747) was collected from diamond-drill core donated by Tenajon Resources in 2008, representing the final 4.5 m of drillhole MB-08-018 (about 491.5 – 496 m) below the main mineralized zone at Moly Brook. It represents the Hole 18 granite, as described above; the sample was hand-picked to avoid two quartz veins that cut the granite and avoid fluorite-coated fractures. The rock type is a typical fine-grained alaskitic granite containing minor muscovite, pyrite and molybdenite. Sample KC-09-044 (z10411) was collected in 2009 from drillcore representing Hole GL-08-53 from the Granite Lake area, which is now stored at the Department of Natural Resources core-storage facility in Buchans. The sample consists of about 4 m of split drillcore between depths of 179.8 and 183.9 m. It is a medium-grained pink to red biotite–muscovite granite, selected because it was relatively free of mineralized veins or alteration zones. The surrounding core contains more abundant mineralized veins. The sample was handpicked to avoid some small quartz veins and altered fractures.

All processing and analysis were completed at the Geological Survey of Canada laboratories. The samples were crushed, and heavy mineral separates were obtained by standard methods, using a Wilfley table and heavy liquid separations, followed by magnetic separation using a Frantz isodynamic separator. Zircons were placed in epoxy grain mounts (GSC reference number IP509 for z9746 and z9747 and IP591 for the z10411) along with fragments of laboratory standards, and polished with diamond paste to reveal internal structure and texture. The grain mounts were evaporatively coated with 10 nm of high-purity Au. The zircons were photographed in transmitted light, and imaged using backscattered electrons (BSE) on a scanning electron microscope.

The SHRIMP II analyses used analytical and data reduction procedures described by Stern (1997) and Stern and Amelin (2003) and offline data processing was completed using in-house software programs. The GSC laboratory standard z6266 (^{206}Pb–^{238}U ages of 559 Ma) was used for calibration purposes. Analyses of a second zircon standard (Temora 2) were interspersed between the sample analyses to verify the accuracy of the U–Pb calibration. Using the calibration defined by the z6266 standard, the weighted mean ^{206}Pb–^{238}U ages of the analyses of Temora 2 zircon on the grain mounts were determined to be 415.7 ± 3.6 Ma (IP509) and 415 ± 3 Ma (IP591). The accepted ^{206}Pb–^{238}U age of Temora 2 is 416.5 ± 0.22 Ma, based on 21 isotope dilution fractions (Black *et al.*, 2005). The SHRIMP II data are presented in Table 1. The isotopic ratios and ages are corrected for common Pb and are reported at 1 sigma precision, which includes an uncertainty of ± 1.0–1.1 % in calibration of the standard (*see* Table 1). The program Isoplot v. 3.00 (Ludwig, 2003) was used to calculate weighted means and to generate concordia plots. Errors on the calculated weighted means are reported at 2 sigma, and error ellipses in concordia plots (Figures 4 to 6) are depicted at 2 sigma.

RESULTS AND CALCULATION OF AGES

Previous Geochronological Studies

Previous geochronological studies in the Grey River area by Higgins *et al*. (1990) used Rb–Sr and K–Ar methods

Table 1: U/Pb SHRIMP analytical data

Spot Name	U (ppm)	Th (ppm)	Th/U	Pb* (ppm)	^{204}Pb (ppb)	^{204}Pb/^{206}Pb	±^{204}Pb/^{206}Pb	^{208*}Pb/^{206*}Pb	±^{208}Pb/^{206}Pb	^{207*}Pb/^{235}U	±^{207}Pb/^{235}U	^{206*}Pb/^{238}U	±^{206}Pb/^{238}U	Corr Coeff	^{207*}Pb/^{206*}Pb	±^{207}Pb/^{206}Pb	Apparent Ages (Ma) ^{206}Pb/^{238}U	±^{206}Pb/^{238}U	^{207}Pb/^{206}Pb	±^{207}Pb/^{206}Pb
AK-08-023 (GSC lab# z9746): Granodiorite; GSC Mount# IP5091																				
9746-3.1	127	157	1.24	13.7	1.763	0.00024	0.00014	0.418	0.011	0.496	0.022	0.0657	0.0009	0.326	0.0548	0.0023	409.9	5.6	405	92
9746-4.1	155	218	1.40	17.1	2.341	0.00026	0.00009	0.476	0.011	0.484	0.016	0.0655	0.0008	0.356	0.0536	0.0016	409.2	4.6	355	69
9746-5.1	422	353	0.84	42.2	0.584	0.00002	0.00003	0.277	0.008	0.495	0.008	0.0659	0.0007	0.632	0.0544	0.0007	411.5	4.3	389	29
9746-6.1	265	236	0.89	26.9	1.826	0.00012	0.00001	0.308	0.007	0.491	0.009	0.0657	0.0008	0.674	0.0542	0.0007	410.1	4.9	381	30
9746-7.1	197	95	0.48	18.5	1.880	0.00017	0.00004	0.153	0.005	0.499	0.011	0.0664	0.0007	0.484	0.0545	0.0011	414.3	4.4	391	44
9746-9.1	146	74	0.51	14.0	-1.607	-0.00020	-0.00024	0.189	0.007	0.527	0.032	0.0649	0.0008	0.208	0.0589	0.0036	405.1	5.0	565	131
9746-10.1	549	492	0.90	56.4	-2.613	-0.00008	-0.00001	0.296	0.005	0.525	0.008	0.0659	0.0007	0.749	0.0578	0.0005	411.5	4.3	521	21
9746-11.1	174	273	1.56	20.2	0.854	0.00008	0.00007	0.519	0.011	0.502	0.017	0.0671	0.0007	0.339	0.0543	0.0017	418.5	4.5	384	69
9746-14.1	146	134	0.92	15.0	0.251	0.00003	0.00002	0.316	0.014	0.529	0.012	0.0649	0.0009	0.605	0.0592	0.0010	405.2	5.2	573	38
9746-15.1	262	495	1.89	31.0	2.746	0.00018	0.00016	0.627	0.009	0.477	0.023	0.0656	0.0007	0.233	0.0527	0.0024	409.6	4.4	316	105
9746-16.1	180	97	0.54	16.6	1.854	0.00018	0.00003	0.169	0.009	0.473	0.010	0.0656	0.0007	0.507	0.0523	0.0010	409.9	4.3	299	42
9746-17.1	268	261	0.97	27.4	1.786	0.00012	0.00022	0.315	0.007	0.509	0.031	0.0656	0.0008	0.191	0.0563	0.0033	409.5	4.5	463	131
9746-18.1	438	329	0.75	42.4	0.318	0.00001	0.00001	0.243	0.005	0.495	0.007	0.0650	0.0007	0.725	0.0553	0.0006	405.8	4.3	424	23
9746-19.1	352	269	0.76	34.6	1.203	0.00006	0.00010	0.242	0.005	0.502	0.016	0.0659	0.0007	0.346	0.0552	0.0016	411.6	4.4	419	67
9746-20.1	148	75	0.51	14.0	0.116	0.00001	0.00001	0.165	0.007	0.493	0.011	0.0665	0.0008	0.554	0.0538	0.0010	414.9	4.8	362	40
9746-22.1	408	254	0.62	41.3	-1.332	-0.00006	-0.00003	0.217	0.008	0.532	0.009	0.0675	0.0008	0.679	0.0571	0.0007	421.2	4.5	495	27
9746-25.1	486	401	0.83	48.6	1.658	0.00006	0.00004	0.264	0.005	0.506	0.009	0.0660	0.0007	0.614	0.0556	0.0008	412.2	4.3	436	31
9746-23.1	164	82	0.50	15.6	0.355	0.00004	0.00014	0.181	0.007	0.518	0.021	0.0653	0.0007	0.271	0.0576	0.0023	407.5	4.4	515	87
9746-24.1	76	78	1.02	8.2	0.976	0.00022	0.00020	0.358	0.013	0.532	0.030	0.0663	0.0009	0.238	0.0582	0.0032	413.7	5.5	536	122
9746-26.1	165	205	1.24	17.7	2.046	0.00022	0.00015	0.415	0.010	0.488	0.022	0.0659	0.0008	0.251	0.0537	0.0024	411.3	4.6	360	99
9746-28.1	351	249	0.71	34.6	0.572	0.00003	0.00002	0.243	0.005	0.509	0.009	0.0657	0.0008	0.681	0.0562	0.0007	410.1	4.5	459	27
9746-30.1	421	390	0.93	43.0	2.587	0.00011	0.00006	0.310	0.005	0.498	0.011	0.0660	0.0007	0.476	0.0548	0.0011	411.7	4.3	404	45
9746-31.1	131	136	1.03	13.6	0.346	0.00005	0.00022	0.352	0.010	0.512	0.031	0.0648	0.0009	0.229	0.0573	0.0034	404.7	5.5	504	131
9746-32.1	232	151	0.65	22.5	0.857	0.00006	0.00005	0.218	0.006	0.506	0.011	0.0656	0.0008	0.555	0.0559	0.0010	409.8	5.0	449	42
9746-33.1	152	81	0.53	15.3	-0.694	-0.00008	-0.00005	0.185	0.007	0.551	0.013	0.0675	0.0007	0.466	0.0591	0.0012	421.2	4.5	572	45
9746-37.1	93	112	1.20	9.9	0.925	0.00017	0.00031	0.410	0.013	0.497	0.042	0.0652	0.0008	0.145	0.0553	0.0046	407.2	4.8	426	187
9746-36.1	269	176	0.65	26.7	-2.125	-0.00014	-0.00002	0.220	0.006	0.536	0.009	0.0662	0.0007	0.642	0.0587	0.0008	413.1	4.5	556	29
9746-35.1	269	199	0.74	26.0	2.774	0.00018	0.00010	0.241	0.006	0.475	0.019	0.0658	0.0007	0.277	0.0523	0.0020	410.7	4.3	300	86
9746-38.1	272	190	0.70	26.4	-0.917	-0.00006	-0.00011	0.224	0.006	0.509	0.017	0.0654	0.0007	0.339	0.0565	0.0017	408.2	4.4	470	68
9746-39.1	107	76	0.71	10.6	-0.581	-0.00009	-0.00008	0.228	0.009	0.530	0.016	0.0658	0.0008	0.390	0.0584	0.0016	410.9	4.7	546	61
9746-40.1	384	282	0.73	38.0	-2.443	-0.00011	-0.00008	0.245	0.005	0.519	0.013	0.0654	0.0007	0.445	0.0576	0.0013	408.3	4.3	514	48
9746-41.1	204	277	1.36	22.8	-0.634	-0.00005	-0.00001	0.452	0.010	0.526	0.010	0.0658	0.0007	0.583	0.0580	0.0009	411.0	4.3	528	33
9746-43.1	130	119	0.92	12.8	1.848	0.00025	0.00016	0.294	0.009	0.491	0.024	0.0647	0.0007	0.238	0.0550	0.0026	404.4	4.5	413	105
9746-45.1	285	264	0.93	28.2	1.786	0.00011	0.00005	0.295	0.006	0.483	0.011	0.0651	0.0007	0.495	0.0538	0.0010	406.5	4.3	361	43
9746-47.1	94	89	0.95	10.3	-2.026	-0.00038	-0.00024	0.357	0.012	0.594	0.035	0.0657	0.0008	0.197	0.0656	0.0038	410.3	4.7	793	123
9746-49.1	304	957	3.15	45.7	2.700	0.00015	0.00009	1.102	0.015	0.509	0.015	0.0674	0.0007	0.374	0.0547	0.0015	420.7	4.5	400	62
9746-51.1	175	218	1.25	18.6	2.328	0.00024	0.00027	0.430	0.010	0.474	0.037	0.0651	0.0008	0.153	0.0528	0.0040	406.3	4.7	321	173
9746-52.1	433	752	1.74	52.6	0.093	0.00000	0.00005	0.580	0.007	0.532	0.011	0.0673	0.0007	0.527	0.0574	0.0010	419.8	4.4	506	38
9746-55.1	291	229	0.79	28.8	1.510	0.00009	0.00010	0.250	0.006	0.500	0.016	0.0662	0.0007	0.346	0.0548	0.0016	413.0	4.4	402	66
KC-08-013 ((GSC lab# z9747): Alaskitic Granite; GSC Mount# IP5091																				
9747-1.1	99	123	1.25	10.0	2.415	0.00044	0.00016	0.369	0.014	0.461	0.025	0.0649	0.0008	0.233	0.0515	0.0027	405.4	5.0	262	121
9747-4.1	106	234	2.21	12.2	0.463	0.00008	0.00035	0.747	0.019	0.477	0.044	0.0606	0.0011	0.189	0.0571	0.0052	379.4	6.5	496	201
9747-3.1	64	97	1.52	6.3	1.826	0.00055	0.00014	0.501	0.022	0.404	0.025	0.0604	0.0010	0.259	0.0485	0.0029	378.3	5.9	123	140

Table 1: U/Pb SHRIMP analytical data

KC-08-013 ((GSC lab# z9747): Alaskitic Granite; GSC Mount# IP5091 *(Continued)*

Spot Name	U (ppm)	Th (ppm)	Th/U	Pb* (ppm)	^{204}Pb (ppb)	^{204}Pb/^{206}Pb	±^{204}Pb/^{206}Pb	^{208*}Pb/^{206*}Pb	±^{208}Pb/^{206}Pb	^{207*}Pb/^{235}U	±^{207}Pb/^{235}U	^{206*}Pb/^{238}U	±^{206}Pb/^{238}U	Corr Coeff	^{207*}Pb/^{206*}Pb	±^{207}Pb/^{206}Pb	Apparent Ages (Ma) ^{206}Pb/^{238}U	±^{206}Pb/^{238}U	^{207}Pb/^{206}Pb	±^{207}Pb/^{206}Pb
9747-6.1	424	257	0.61	36.0	1.251	0.00006	0.00007	0.204	0.005	0.445	0.011	0.0600	0.0007	0.437	0.0538	0.0012	375.4	4.0	361	50
9747-7.1	79	160	2.03	9.1	0.151	0.00004	0.00034	0.687	0.019	0.505	0.044	0.0617	0.0008	0.143	0.0594	0.0052	385.7	4.7	580	189
9747-8.1	116	119	1.03	11.2	0.755	0.00012	0.00004	0.367	0.013	0.483	0.020	0.0609	0.0010	0.409	0.0575	0.0022	381.0	6.3	510	83
9747-5.1	329	253	0.77	29.9	-0.435	-0.00002	-0.00002	0.259	0.006	0.479	0.008	0.0611	0.0007	0.643	0.0569	0.0007	382.2	4.0	488	28
9747-12.1	243	182	0.75	21.5	0.175	0.00001	0.00013	0.253	0.007	0.461	0.018	0.0605	0.0007	0.291	0.0553	0.0021	378.4	4.3	423	85
9747-13.1	714	385	0.54	61.4	0.523	0.00001	0.00001	0.169	0.003	0.460	0.007	0.0616	0.0007	0.772	0.0541	0.0005	385.5	4.1	377	20
9747-14.1	167	124	0.74	14.2	3.255	0.00038	0.00016	0.241	0.008	0.428	0.021	0.0594	0.0007	0.244	0.0523	0.0025	372.1	4.4	298	110
9747-17.1	834	449	0.54	73.2	-2.661	-0.00006	-0.00001	0.186	0.004	0.469	0.007	0.0619	0.0007	0.729	0.0550	0.0006	387.0	4.1	411	23
9747-19.1	149	235	1.58	15.7	0.515	0.00007	0.00003	0.514	0.017	0.521	0.015	0.0608	0.0007	0.414	0.0622	0.0016	380.6	4.4	679	55
9747-22.1	64	76	1.18	7.0	3.681	0.00110	0.00102	0.480	0.028	0.634	0.127	0.0605	0.0013	0.108	0.0760	0.0151	378.4	7.9	1095	399
9747-26.1	157	209	1.33	15.1	6.282	0.00077	0.00033	0.416	0.021	0.467	0.043	0.0596	0.0007	0.137	0.0568	0.0052	373.4	4.5	485	200
9747-29.1	97	175	1.81	10.4	-0.107	-0.00002	-0.00002	0.607	0.032	0.481	0.014	0.0602	0.0008	0.473	0.0580	0.0015	376.5	4.9	528	55
9747-32.1	381	192	0.50	31.3	2.167	0.00011	0.00003	0.169	0.004	0.444	0.008	0.0594	0.0007	0.636	0.0542	0.0008	371.8	4.1	381	31
9747-35.1	177	121	0.68	15.1	1.349	0.00015	0.00003	0.220	0.008	0.441	0.011	0.0599	0.0007	0.468	0.0534	0.0012	375.3	4.2	346	49
9747-36.1	241	210	0.87	21.6	1.517	0.00012	0.00004	0.282	0.007	0.452	0.010	0.0603	0.0007	0.494	0.0543	0.0010	377.5	4.0	385	43
9747-38.1	468	284	0.61	40.7	-1.357	-0.00006	-0.00005	0.195	0.005	0.476	0.010	0.0607	0.0007	0.529	0.0568	0.0010	380.1	4.0	486	38
9747-40.1	157	336	2.13	18.3	0.152	0.00002	0.00001	0.734	0.019	0.507	0.013	0.0608	0.0007	0.459	0.0605	0.0014	380.4	4.4	620	50
9747-47.1	194	280	1.44	18.8	1.136	0.00011	0.00014	0.450	0.011	0.449	0.019	0.0593	0.0007	0.275	0.0549	0.0022	371.5	4.2	410	90
9747-46.1	192	144	0.75	16.6	0.211	0.00002	0.00028	0.247	0.016	0.456	0.035	0.0594	0.0007	0.155	0.0558	0.0042	371.8	4.3	443	169
9747-51.1	111	144	1.30	10.7	1.984	0.00035	0.00009	0.420	0.015	0.474	0.017	0.0594	0.0007	0.337	0.0578	0.0020	371.8	4.4	524	75
9747-52.1	418	203	0.48	34.9	1.182	0.00005	0.00003	0.159	0.008	0.459	0.008	0.0603	0.0006	0.579	0.0552	0.0008	377.3	3.9	420	34
9747-53.1	1440	639	0.44	123.4	2.471	0.00003	0.00001	0.146	0.004	0.467	0.007	0.0620	0.0007	0.844	0.0546	0.0004	387.9	4.5	395	17
9747-54.1	377	297	0.79	34.9	1.352	0.00007	0.00002	0.276	0.007	0.483	0.009	0.0615	0.0007	0.611	0.0570	0.0008	384.9	4.2	490	32
9747-56.1	63	139	2.21	6.9	1.481	0.00045	0.00013	0.745	0.025	0.415	0.025	0.0598	0.0009	0.265	0.0503	0.0029	374.1	5.7	210	133
9747-57.1	120	155	1.30	11.4	3.241	0.00053	0.00048	0.428	0.013	0.458	0.063	0.0593	0.0008	0.101	0.0560	0.0076	371.2	5.0	452	302
9747-64.1	211	112	0.53	17.7	-0.662	-0.00006	-0.00003	0.155	0.007	0.482	0.011	0.0598	0.0007	0.538	0.0584	0.0011	374.6	4.4	546	42
9747-70.1	310	412	1.33	30.8	1.394	0.00009	0.00002	0.441	0.009	0.471	0.009	0.0606	0.0007	0.581	0.0564	0.0009	379.1	4.1	467	34
9747-71.1	160	78	0.49	14.4	-4.006	-0.00047	-0.00015	0.181	0.008	0.543	0.021	0.0609	0.0007	0.289	0.0646	0.0024	381.3	4.1	763	78
9747-73.1	471	361	0.77	42.1	0.996	0.00004	0.00006	0.259	0.006	0.455	0.011	0.0609	0.0007	0.479	0.0542	0.0011	381.0	4.3	378	48
KC-09-044 (GSC lab# z10411); GSC mount# IP5912																				
10411-54.1	104	58	0.58	5.4	0.847	0.00049	0.00076	0.210	0.016	0.456	0.094	0.0608	0.0011	0.086	0.0545	0.0112	380.2	6.5	380.1	4.5
10411-56.1	128	177	1.43	6.7	1.031	0.00059	0.00024	0.435	0.020	0.398	0.035	0.0608	0.0007	0.135	0.0476	0.0041	380.3	4.3	383.3	4.2
10411-55.1	242	80	0.34	12.6	0.356	0.00021	0.00004	0.091	0.006	0.446	0.010	0.0608	0.0006	0.468	0.0533	0.0011	380.6	3.9	381.1	4.0
10411-43.1	310	73	0.24	16.2	0.000	0.00000	0.00000	0.085	0.006	0.473	0.010	0.0609	0.0007	0.565	0.0564	0.0009	381.3	4.2	380.4	4.3
10411-19.1	134	148	1.14	7.0	-0.352	-0.00020	-0.00055	0.399	0.019	0.500	0.069	0.0610	0.0012	0.145	0.0596	0.0081	381.6	7.4	379.3	6.6
10411-31.1	135	156	1.19	7.1	0.722	0.00042	0.00011	0.381	0.018	0.442	0.023	0.0610	0.0009	0.284	0.0526	0.0026	381.8	5.5	382.5	5.6
10411-42.1	132	186	1.46	6.9	-0.705	-0.00041	-0.00015	0.504	0.022	0.491	0.022	0.0612	0.0007	0.255	0.0582	0.0025	383.1	4.3	381.4	4.2
10411-28.1	302	174	0.60	15.9	-0.229	-0.00013	-0.00011	0.205	0.009	0.480	0.016	0.0613	0.0008	0.377	0.0569	0.0018	383.3	4.8	382.2	4.8
10411-49.1	180	162	0.93	9.5	0.209	0.00012	0.00024	0.286	0.014	0.440	0.032	0.0615	0.0007	0.159	0.0520	0.0037	384.7	4.3	385.8	4.1
10411-48.1	209	316	1.56	11.1	0.234	0.00014	0.00000	0.506	0.018	0.459	0.010	0.0616	0.0007	0.478	0.0542	0.0011	385.6	4.0	385.8	4.1
10411-2.1	550	450	0.84	29.1	0.069	0.00004	0.00010	0.263	0.008	0.469	0.014	0.0617	0.0007	0.358	0.0552	0.0015	385.8	4.0	385.5	4.0
10411-15.1	203	363	1.85	10.8	-0.090	-0.00005	0.00000	0.609	0.019	0.490	0.011	0.0619	0.0007	0.522	0.0575	0.0011	387.2	4.3	385.8	4.3
10411-13.1	370	54	0.15	19.7	0.150	0.00009	0.00004	0.053	0.004	0.462	0.009	0.0619	0.0006	0.512	0.0542	0.0009	387.4	3.9	387.5	4.0

Table 1: U/Pb SHRIMP analytical data

KC-09-044 (GSC lab# z10411); GSC mount# IP5912 *(Continued)*

Spot Name	U (ppm)	Th (ppm)	Th/U	Pb* (ppm)	^{204}Pb (ppb)	^{204}Pb/^{206}Pb	±^{204}Pb/^{206}Pb	^{208*}Pb/^{206*}Pb	±^{208}Pb/^{206}Pb	^{207*}Pb/^{235}U	±^{207}Pb/^{235}U	^{206*}Pb/^{238}U	±^{206}Pb/^{238}U	Corr Coeff	^{207*}Pb/^{206*}Pb	±^{207}Pb/^{206}Pb	Apparent Ages (Ma) ^{206}Pb/^{238}U	±^{206}Pb/^{238}U	^{207}Pb/^{206}Pb	±^{207}Pb/^{206}Pb
10411-22.1	602	345	0.59	32.0	0.048	0.00003	0.00006	0.199	0.006	0.479	0.011	0.0620	0.0006	0.465	0.0562	0.0011	387.7	3.9	387.0	3.9
10411-52.1	362	495	1.41	19.3	0.086	0.00005	0.00003	0.442	0.012	0.474	0.009	0.0620	0.0007	0.581	0.0555	0.0009	387.9	4.2	387.4	4.3
10411-44.1	277	85	0.32	14.8	-0.107	-0.00006	-0.00022	0.108	0.007	0.490	0.029	0.0622	0.0007	0.189	0.0572	0.0034	388.8	4.3	387.6	4.1
10411-40.1	120	140	1.21	6.4	-0.635	-0.00037	-0.00033	0.415	0.021	0.521	0.042	0.0622	0.0008	0.156	0.0609	0.0049	388.9	4.8	386.0	4.3
10411-27.1	122	131	1.12	6.5	0.401	0.00023	0.00001	0.321	0.018	0.464	0.014	0.0622	0.0009	0.480	0.0542	0.0014	389.1	5.4	389.3	5.5
10411-3.1	162	317	2.03	8.7	-0.161	-0.00009	-0.00006	0.700	0.023	0.509	0.014	0.0624	0.0007	0.401	0.0592	0.0015	390.4	4.3	388.3	4.3
10411-50.1	279	168	0.62	15.0	0.271	0.00016	0.00015	0.207	0.009	0.461	0.021	0.0625	0.0007	0.257	0.0536	0.0024	390.7	4.5	391.2	4.5
10411-16.1	351	36	0.11	18.8	-0.094	-0.00005	-0.00010	0.037	0.004	0.473	0.015	0.0625	0.0007	0.329	0.0550	0.0017	390.8	4.1	390.5	4.1
10411-33.1	153	137	0.92	8.2	-0.188	-0.00011	-0.00003	0.296	0.015	0.487	0.012	0.0626	0.0007	0.427	0.0565	0.0013	391.5	4.1	390.6	4.2
10411-4.1	682	295	0.45	36.7	0.125	0.00007	0.00006	0.148	0.005	0.476	0.010	0.0627	0.0006	0.475	0.0552	0.0010	391.8	3.9	391.5	3.9
10411-11.1	221	315	1.47	12.0	0.155	0.00009	0.00010	0.445	0.015	0.482	0.016	0.0632	0.0007	0.315	0.0555	0.0018	394.8	4.1	394.4	4.1
10411-1.1	259	175	0.70	14.2	-0.150	-0.00009	-0.00029	0.238	0.010	0.530	0.039	0.0636	0.0007	0.160	0.0605	0.0044	397.6	4.5	395.0	4.1
10411-57.1	530	83	0.16	29.0	0.135	0.00008	0.00010	0.047	0.003	0.474	0.015	0.0636	0.0007	0.331	0.0542	0.0017	397.7	4.1	397.9	4.1
10411-9.1	96	98	1.05	5.3	-1.952	-0.00113	-0.00051	0.382	0.023	0.654	0.065	0.0639	0.0009	0.143	0.0744	0.0073	399.2	5.5	390.1	4.4
10411-25.1	57	70	1.26	3.1	-1.409	-0.00081	-0.00038	0.426	0.032	0.584	0.052	0.0642	0.0009	0.159	0.0662	0.0058	400.9	5.5	395.6	5.0
10411-14.1	440	436	1.02	25.2	-0.296	-0.00017	-0.00005	0.346	0.009	0.524	0.011	0.0667	0.0007	0.504	0.0570	0.0010	416.5	4.2	415.7	4.3
10411-45.1	422	262	0.64	24.3	0.090	0.00005	0.00018	0.217	0.012	0.507	0.026	0.0670	0.0007	0.213	0.0550	0.0027	418.0	4.4	418.1	4.2
10411-51.1	292	131	0.46	17.0	7.538	0.00435	0.00048	0.095	0.005	0.349	0.085	0.0678	0.0012	0.071	0.0374	0.0091	423.0	7.1	431.9	6.6
10411-53.1	503	119	0.24	29.5	0.115	0.00007	0.00008	0.074	0.004	0.522	0.013	0.0683	0.0007	0.404	0.0555	0.0013	426.0	4.3	426.0	4.3
10411-47.1	97	17	0.18	11.3	0.245	0.00014	0.00004	0.106	0.007	1.519	0.031	0.1364	0.0015	0.560	0.0810	0.0014	824.0	8.8	810.3	8.9
10411-12.1	226	121	0.55	57.9	0.032	0.00002	0.00008	0.173	0.004	4.668	0.079	0.2977	0.0037	0.729	0.1139	0.0013	1680.1	18.3	1657.9	20.1
10411-6.1	121	43	0.37	36.4	-0.082	-0.00005	-0.00006	0.131	0.005	7.211	0.098	0.3519	0.0039	0.809	0.1489	0.0012	1943.8	18.5	1869.7	20.6

Notes (see Stern, 1997):
Spot name follows the convention x-y.z; where x = sample number, y = grain number and z = spot number. Multiple analyses in an individual spot are labelled as x-y.z.z
Uncertainties reported at 1sigma (absolute) and are calculated by numerical propagation of all known sources of error
$f206^{204}$ refers to mole percent of total ^{206}Pb that is due to common Pb, calculated using the ^{204}Pb-method; common Pb composition used is the surface blank (4/6: 0.05770; 7/6: 0.89500; 8/6: 2.13840)
* refers to radiogenic Pb (corrected for common Pb)
Discordance relative to origin = 100 * ((207/206 age -206/238 age)/(^{207}Pb/^{206}Pb age))
Calibration standard 6266; U = 910 ppm; Age = 559 Ma; ^{206}Pb/^{238}U = 0.09059
Standard Error in Standard calibration was 0.34% (not included in above errors but required when comparing data from different mounts).

[1] Error in ^{206}Pb/^{238}U calibration 1.1% (included) (GSC mount# IP509); Spot size is 16 x 23 mm.
[2] Error in ^{206}Pb/^{238}U calibration 1.0% (included) (GSC mount 591); Spot size is 13 x 16 mm

in an effort to determine the age of tungsten mineralization; the Moly Brook Mo–Cu deposit was at that time undiscovered, although molybdenite was known to occur locally in veins. The Rb–Sr isotopic data from granites along the shores of Grey River (Figure 2) were ambiguous. The entire dataset gave an errorchron age of *ca.* 523 Ma, but a subset of the 6 least deformed samples defined an isochron age of 412 ± 5 Ma, with an initial Sr isotope ratio of 0.7086. Foliated granite samples plotted below this isochron, suggesting loss of radiogenic Sr, during deformation. The K–Ar (biotite) ages were also obtained from several of the granite samples, but these were significantly older at *ca.* 466 to 444 Ma. The K–Ar ages from muscovites in marginal greisen-like alteration zones associated with the quartz–wolframite vein yielded ages ranging from 386 ± 12 to 352 ± 18 Ma, interpreted to indicate Devonian hydrothermal mineralization (Higgins, 1985). Attempts to obtain whole-rock Rb–Sr isochrons from the same samples gave older or younger ages than the K–Ar data. Prior to this study, no geochronological data of any type were available in the Granite Lake area.

Grey River Area

Sample z9746 contained abundant high-quality zircon. The zircon grains ranged in habit from stubby to elongate, and are generally well faceted and colourless. The BSE images of the grains indicate that most are magmatic, with well-defined growth zoning, and most lack obvious cores. A small proportion of grains contained well-defined cores, likely inherited, but these have not yet been investigated. The U–Pb isotopic data are very consistent, and the weighted average of 39 concordant or near-concordant ^{206}Pb–^{238}U ages is 411.2 ± 1.4 Ma (MSWD = 0.95). The crystallization age of the host granodiorite is conservatively interpreted to be 411 ± 4 Ma (Figure 4), corresponding to the lowermost Devonian.

Sample z9747 provided a modest yield of euhedral zircon crystals, ranging from stubby to prismatic. Most are well faceted and colourless, but their quality is variable, due to abundant fractures and inclusions. The BSE images indicate that most are magmatic zircons that display well-defined growth zoning. Inherited cores were visible in several grains, but only one of these was analyzed. With the exception of this analysis (labelled 1.1 in Figure 5), the data are again very consistent, and a weighted average of 31 concordant or near-concordant ^{206}Pb–^{238}U ages is 378.3 ± 1.8 Ma (MSWD = 1.2). The analysis from the suspected inherited core gives an age of ca. 405 Ma. The crystallization age of the Hole 18 granite is thus conservatively interpreted to be 378 ± 4 Ma (Figure 5), corresponding to the Upper Devonian.

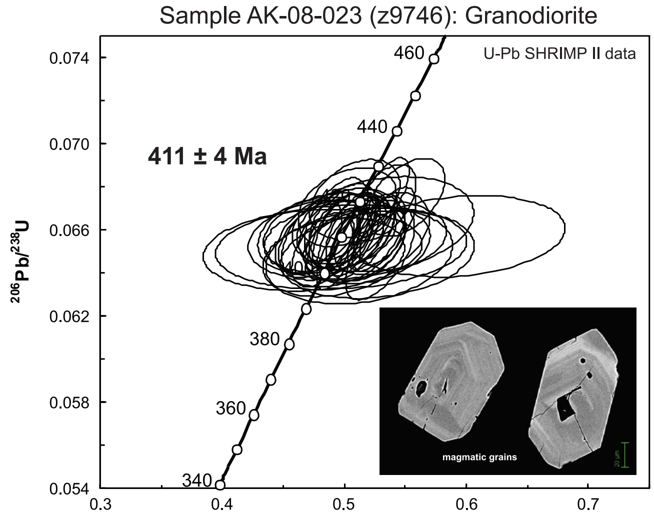

Figure 4. *U–Pb concordia diagram for sample z9746, representing the host rocks to the Moly Brook deposit.*

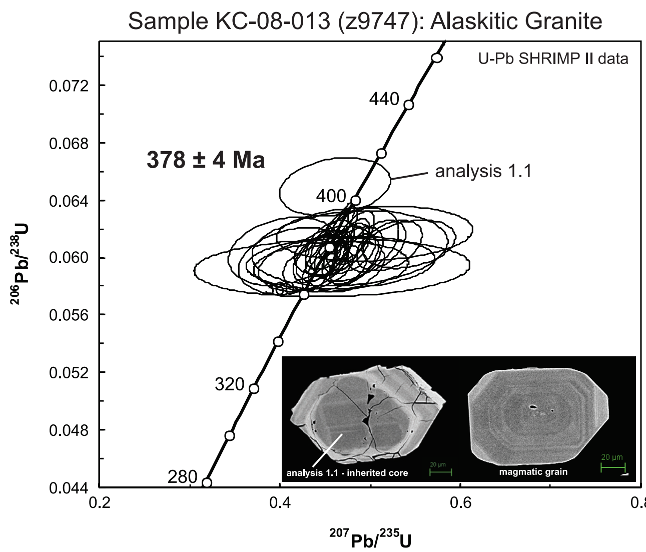

Figure 5. *U–Pb concordia diagram for sample z9747, representing the molybdenite-bearing alaskitic granite from drillhole MB-08-18.*

Granite Lake Area

Sample z10411 contained abundant high-quality zircon, ranging in habit from euhedral elongate crystals to short stubby prisms, all of which appear to be of magmatic origin. Some grains contain well-defined cores with overgrowths (Plate 3). The SHRIMP analyses reveal a wide variety of ages, but most of the analyses form a tight cluster for which the weighted average of ^{206}Pb–^{238}U ages is 388.3 ± 2.1 Ma (MSWD = 1.5, n=28). As these analyses are from grains that lack visible cores or from outer parts of composite grains, an age of 388 ± 4 Ma is interpreted as the time of crystallization of the host granite, corresponding to the Middle Devon-

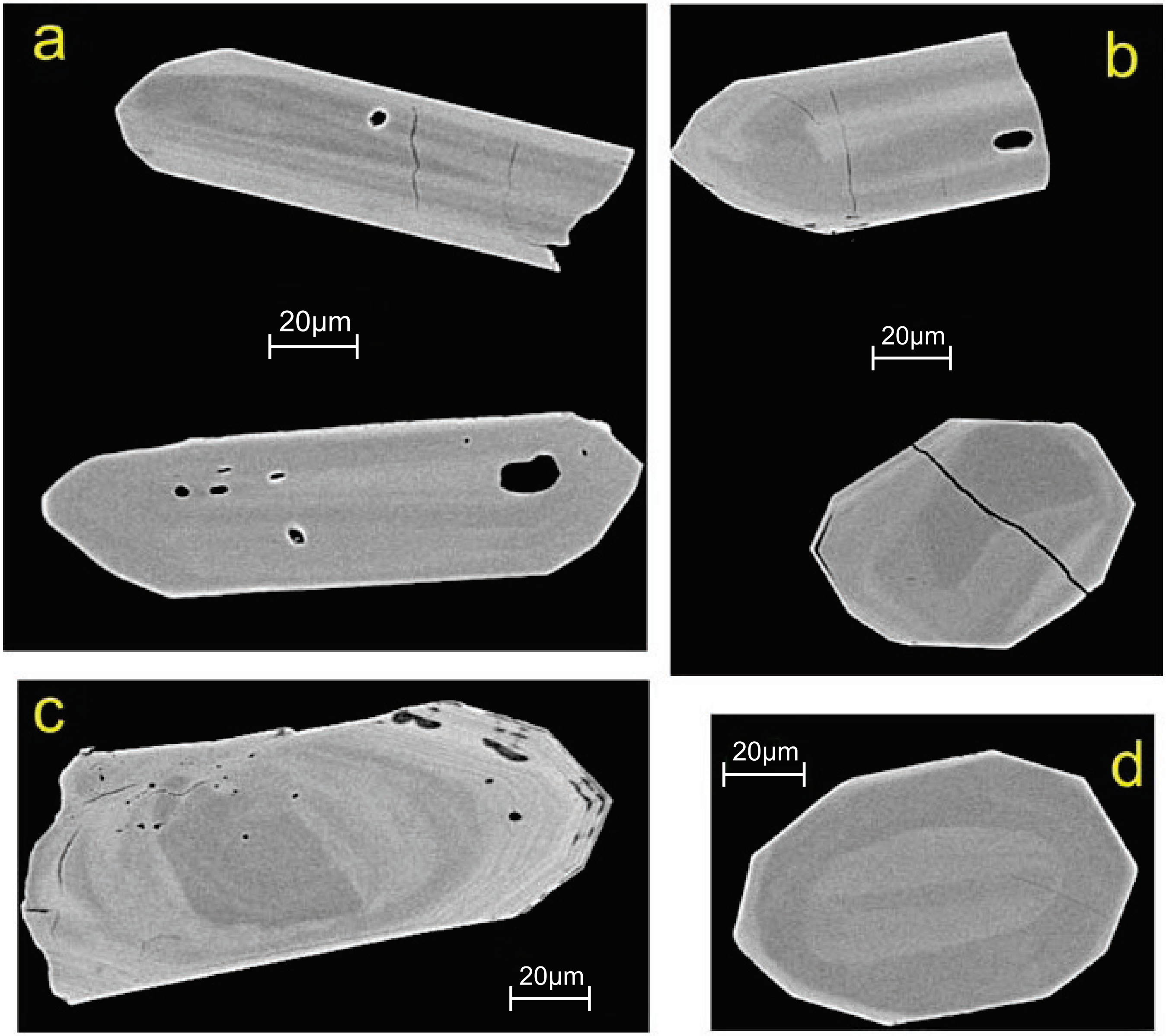

Plate 3. *Photographs of zircons from the Granite Lake sample, (z10411), showing the presence of inherited cores in some individual crystals.*

ian (Figure 6). A smaller number of analyses from cores include Late Silurian results (*ca.* 426 to 417 Ma) and some discordant Proterozoic ages (Figure 6; Table 1). These cores are likely inherited zircons derived from the source regions of the granite magma. No attempt was made to resolve the pattern of inheritance, although this is a subject of potential interest in the context of crustal source regions.

INTERPRETATION AND DISCUSSION

These new U–Pb zircon data provide valuable information about the ages of host rocks and the timing of mineralization at the Moly Brook deposit and at Granite Lake and are also of interest in the context of both local and regional correlations. These topics are addressed separately in this section. The discussion points are illustrated by a simple time-space correlation chart (Figure 7).

Age of the Host Rocks at Moly Brook

The U-Pb zircon age of 411 ± 4 Ma obtained from host rocks at Moly Brook (z9746) is within error of the previous Rb-Sr isochron age of 412 ± 5 Ma obtained by Higgins *et al.* (1990) using coastal outcrops on Grey River. However, given that this latter result represents a smaller subset from a database that did not exhibit isochron behaviour, this coin-

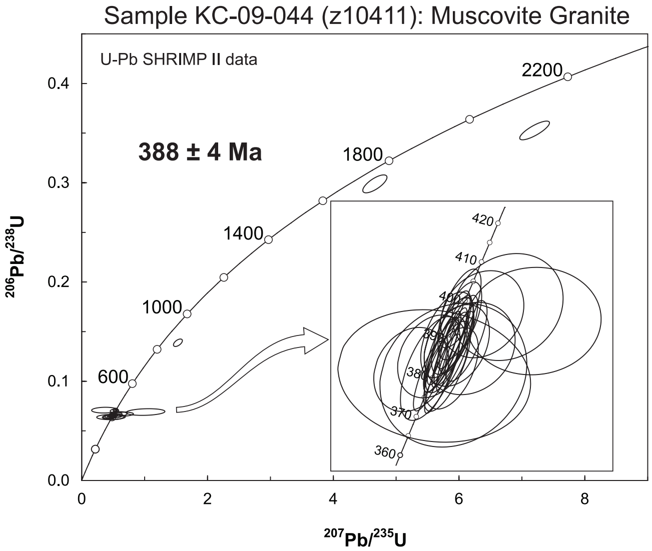

Figure 6. *U–Pb concordia diagram for sample z10411, representing the molybdenite-bearing host granite from drill-hole GL-08-53 at Granite Lake. The main diagram shows the complete range of results, and the inset those results interpreted to record the crystallization age of the rock.*

cidence may be fortuitous. The 411 Ma age lies close to the general range of ages obtained for the Burgeo Intrusive Suite to the west (428 to 415 Ma; Dunning *et al.*, 1990; Figure 2), and supports this regional correlation. However, the 411 Ma age is at the younger end of the spectrum, resembling ages from equigranular biotite–muscovite granites, rather than those from K-feldspar megacrystic granites similar to the Moly Brook host suite. The K-feldspar megacrystic granites in the Burgeo Intrusive Suite tend to be older than the biotite–muscovite granites (Dunning *et al*., 1990; Dickson *et al*., 1996). As previously noted by Higgins *et al*. (1990), this suggests that K-feldspar megacrystic biotite granites and biotite–muscovite granites overlap in age through the region (*cf.*, Kerr, 1997). The 411 Ma age also provides a maximum constraint for cataclastic deformation that affected the granodiorite, most likely related to the shear zone marking its southern contact. Latest motions on this structure are likely related to the Devonian Acadian Orogeny, rather than the widespread mid-Silurian (Salinic) event recorded across much of the Central Mobile Belt (*e.g.*, Dunning *et al*., 1990).

The Timing of Mo-Cu Mineralization at Moly Brook

The U–Pb geochronological data do not provide direct information on the timing of mineralization at Moly Brook, as they represent ages for magmatic zircon rather than hydrothermal molybdenite or chalcopyrite. The 411 ± 4 Ma age from the granodiorite host rocks clearly provides a maximum age for the mineralized quartz veins. Nevertheless, there is evidence that the Hole 18 (alaskitic) granite is contemporaneous with the mineralized vein swarm in the form of mutually crosscutting relationships, and disseminated interstitial molybdenite in the Hole 18 granite suggests that the parent magma was Mo-enriched. The 378 ± 4 Ma U–Pb age of the Hole 18 granite is thus also interpreted as the age of hydrothermal mineralization. This conclusion is broadly consistent with the preliminary Re–Os age of *ca.* 380 Ma that was reported from molybdenite at Moly Brook (Lynch *et al*., 2011a).

Granophile mineralization at Moly Brook thus likely has no temporal or genetic link to the altered granitoid host rocks, and is some 33 m.y. younger than them. Strictly, the 378 Ma age for Mo–Cu mineralization at Moly Brook cannot be extrapolated to the nearby vein-hosted W mineralization described by Higgins (1985). Nevertheless, most of the muscovite K–Ar ages from vein-related alteration (Higgins *et al.*, 1990) are within error of 378 Ma, although they are, on average, slightly younger (~369 Ma). It is hard to imagine that two temporally discrete hydrothermal systems could develop sequentially in the same restricted area, although this is possible, but the presence of molybdenite in early W-bearing veins at Grey River (Higgins, 1985) supports some linkage. Preliminary Re–Os geochrononological data from molybdenite in W-bearing vein samples also points to this conclusion (Lynch *et al*., 2011a).

Evidence for Devonian Granites in the Subsurface at Grey River

The idea that a hidden pluton was the ultimate source for hydrothermal mineral deposits in the Grey River was first suggested by Bahyrycz (1956). The results from the Hole 18 granite provide the first direct evidence for upper Devonian magmatism in the area, and support this hypothesis. The Hole 18 granite is part of the youngest magmatic pulse yet identified in the Newfoundland Appalachians (*see* below). Further inferences about a hidden pluton must come from deep drilling, and from geophysical surveys. Lendrum and Mercer (1997) commented on the presence of multiple 'bullseye' positive magnetic anomalies at Moly Brook. Given that the granodioritic host rocks are generally non-magnetic (because original magnetite was converted to pyrite during propylitic alteration), these anomalies are interpreted to have subsurface origins. Once again, developing indirect constraints on the extent and 3D geometry of this buried pluton presents an interesting research challenge, with obvious application to exploration. Local geological patterns do provide some general information. If the granitic stock near the mouth of Grey River (Figure 2) is also related to this pluton, it is clearly of regional extent, and must transect the shear north of the Grey River Precambrian enclave. Fine-grained leucocratic granites that resemble the

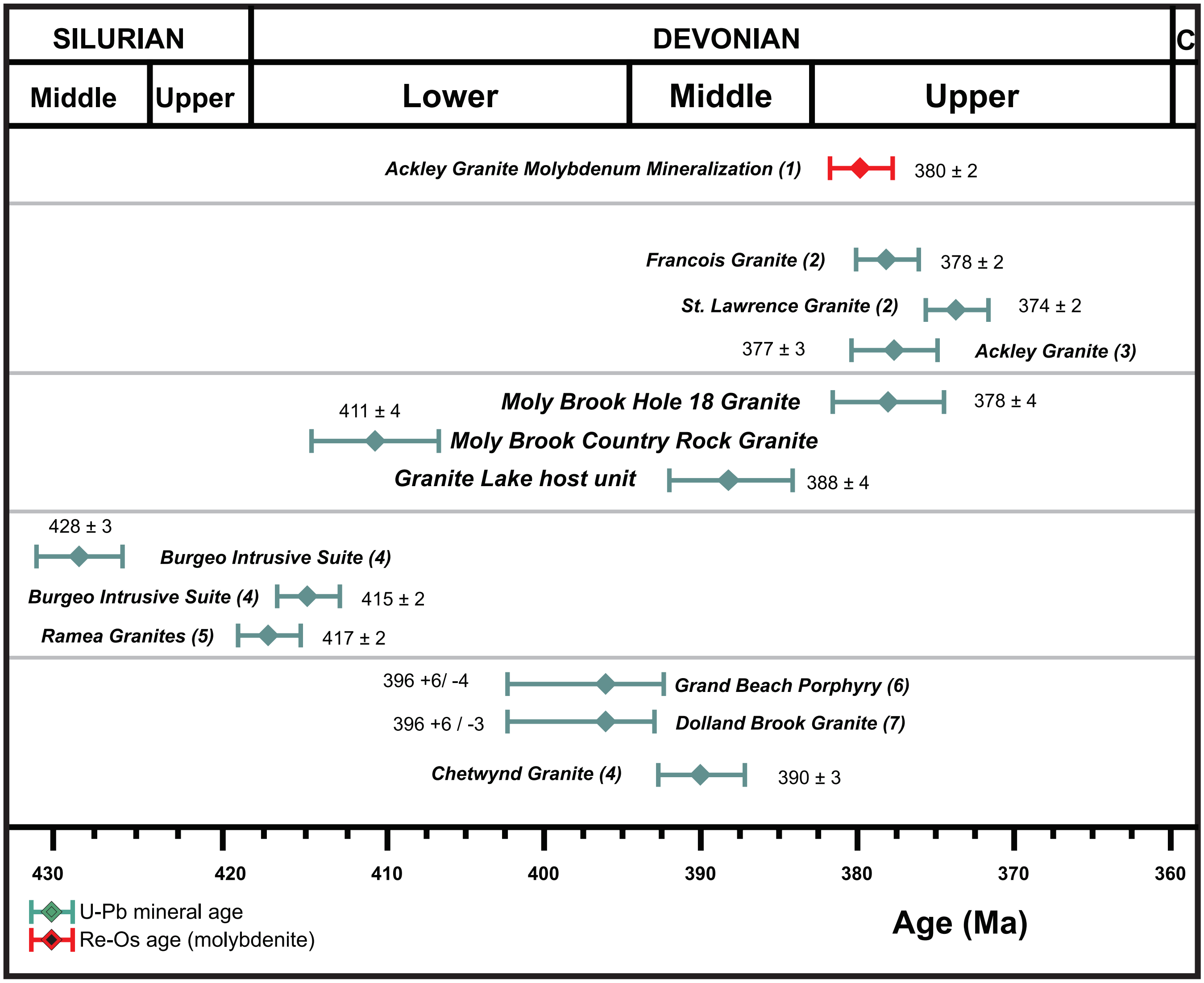

Figure 7. *Chart showing the ages obtained for granitoid rocks and associated mineralization in southern Newfoundland, illustrating possible correlations. Sources for published and unpublished ages; (1) Lynch* et al. *(2009); (2) Kerr* et al. *(1993a); (3) R. Tucker, listed by O'Brien (1986); (4) Dunning* et al. *(1990); (5) Dickson* et al. *(1996); (6) Krogh* et al. *(1988); (7) Dickson* et al. *(1996).*

Hole 18 granite outcrop, locally along drill-access roads at Moly Brook, and the largely buried pluton, may have surface expression elsewhere in the generally rugged and forested area around the deposit.

The Timing of Magmatism and Mineralization at Granite Lake

The mineralization intersected in Hole GL-08-53 and other drillholes at Granite Lake has many similarities to that encountered at Moly Brook. The presence of disseminated molybdenite in the host granite implies that it is similar in age to the mineralization, but does not prove such a relationship; this requires confirmation from direct Re–Os geochronology. The U–Pb results indicate that the host granite at Granite Lake is approximately 10 m.y. older than the Hole 18 granite at Moly Brook, so the two cannot be directly linked.

Correlation with Other Devonian Plutonic Suites

The 378 ± 4 Ma age from the Hole 18 granite at Moly Brook is identical to the 378 ± 2 Ma age of the François Granite (Kerr *et al*., 1993b), located some 30 km to the east (Figure 1). However, this does not necessarily indicate any physical connection between the Hole 18 granite and the François Granite. It is perhaps more likely that both granites are related to a deeper magma chamber of truly batholithic dimensions. There are other small bodies of undeformed posttectonic granites across the region, and they may have a similar relationship. On the scale of the Appalachian Orogen in Newfoundland, the 378 Ma age is also within error of U–Pb zircon ages from the Ackley Granite (377 ± 3 Ma; R. Tucker, quoted by O'Brien, 1998) and the St. Lawrence Granite (374 ± 2 Ma; Kerr *et al*., 1993b). The Ackley Granite is well-known for its Mo prospects (*see* Kerr *et al*., 2009 and references therein), and recent Re–Os dating confirms that the mineralization is syngenetic, as molybdenites yield an indistinguishable age of 380 ± 2 Ma (Lynch *et al*., 2009). The St. Lawrence Granite is best known for its vein-style fluorite deposits, but some veins also contain minor Mo and base metals. There are other undated granite plutons across southern Newfoundland that may also be part of this temporal grouping, *e.g*., the Pass Island Granite (Figure 1), which closely resembles the François Granite in terms of rock types. The new results from Moly Brook add weight to the concept of a discrete 'specialized granite' association emplaced shortly after 380 Ma. This apparently had varied geochemical affinities, as the St. Lawrence Granite is peralkaline, whereas others are metaluminous to weakly peraluminous (Kerr *et al*., 1993a; Kerr, 1997).

The age determined for the host granite at Granite Lake, however, is demonstrably older at 388 Ma. This age matches those obtained from some late posttectonic granites in central and southwestern Newfoundland, including the Chetwynd Granite (390 ± 3 Ma; O'Brien *et al.,* 1991). Thus, there are at least two groups of Devonian-aged granites that may have potential for granophile mineralization in southern Newfoundland or alternatively, there is a continuum of ages for such rocks. More geochronological data from both mineralized and unmineralized plutonic suites are required to properly test these alternatives, and also to better link mineralization to spatially associated granites. Some initial sampling work toward this objective was completed in the 2011 field season, in conjunction with the Geological Survey of Canada Targeted Geoscience Initiative (TGI-4) Program.

CONCLUSIONS

The U–Pb zircon geochronological data from the Grey River area largely confirm inferences based upon earlier field work and exploration. The host rocks to the Moly Brook Mo–Cu deposit are of earliest Devonian age (411 ± 4 Ma), and correlate broadly with the Burgeo Intrusive Suite. A fine-grained, undeformed alaskitic granite from a deep drillhole gave a Late Devonian emplacement age (378 ± 4 Ma). This granite appears to be contemporaneous with the mineralized veins, and contains disseminated pyrite and molybdenite, so this age is here interpreted to also record the mineralizing event, a conclusion supported by preliminary Re–Os results (Lynch *et al.,* 2011a). Porphyry-style Mo–Cu mineralization at Moly Brook is thus some 33 m.y. younger than its immediate host rocks, and is epigenetic. The data support previous inferences of a subsurface Devonian pluton beneath the Grey River area, and suggest that this largely cryptic pluton is of the same age as the nearby François Granite. The age is also within error of U–Pb and Re–Os ages from those obtained from the Ackley Granite (377 Ma, quoted by O'Brien, 1998; 380 Ma, Lynch *et al*., 2009) and the St. Lawrence Granite (374 ± 2 Ma; Kerr *et al.*, 1993b), suggesting that this period is important for the development of metallogenically specialized granites. A slightly older Middle Devonian age (388 Ma) was obtained from the host rocks at Granite Lake; if this also indicates the timing of mineralization, age cannot be the only control upon mineral potential.

ACKNOWLEDGMENTS

Field work and sampling for this project were completed with the assistance and hospitality of Tenajon Resources, who are gratefully acknowledged for permission to visit and initiate this research. Sue and Bill Scott of Geoscott Exploration Consultants are thanked for their logistical assistance, and Tom Loder and Diane Smeltzer are thanked for interesting geological discussions about the mineralization and exploration results. Playfair Resources are thanked for their interest in results from both Grey River and Granite Lake, and Stewart Cochrane is thanked for his assistance with drillcore sampling in Buchans. Edward Lynch of the National University of Ireland (Galway) is thanked for interesting discussions on the topic and on related Re-Os investigations. The manuscript was improved following suggestions from John Hinchey and Lawson Dickson.

REFERENCES

Bahyrycz, G.S.
1956: Geology and mineral deposits of the Grey River area, southern Newfoundland. Unpublished report for the Buchans Mining Company. Geological Survey File 11P/11/13.

Black, L.P., Kamo, S.L., Allen, C.M., Davis, D.W., Aleinikoff, J.N., Valley, J.W., Mundil, R., Campbell, I.H., Korsch, R.J., Williams, I.S. and Foudoulis, C.
2005: Improved $^{206}Pb/^{238}U$ microprobe geochronology by the monitoring of a trace element-related matrix effect; SHRIMP, ID-TIMS, ELA-ICP-MS and oxygen isotope documentation for a series of zircon standards. Chemical Geology, Volume 205, pages 115-140.

Blackwood, R.F.
1985: Geology of the Grey River area, south coast of

Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 84-1, pages 153-164.

Briggs, N.
2008: Granite Lake bulk tonnage molybdenum. Paper presented at Mineral Resources Review, November 2008, St. John's, Newfoundland (abstract).

Dickson, W. L.
1982: Geology of the Wolf Mountain (12A/2W) and Burnt Pond (12A/3E) map areas, Newfoundland. Newfoundland Department of Mines, Mineral Development Division, Report 82-5, 43 pages.

Dickson, W.L., Poole, J.C. and Delaney, P.W.
1996: Geology of the Silurian and Devonian granites and associated rocks in the Cape La Hune (NTS 11P/10) and Ramea (NTS 11P/11) map areas, south coast of Newfoundland. Newfoundland Department of Natural Resources, Geological Survey, Report 96-2, 137 pages.

Dunning, G.R. and O'Brien, S.J.
1989: Late Proterozoic - early Paleozoic crust in the Hermitage Flexure, Newfoundland Appalachians. Geology, Volume 17, pages 548-551.

Dunning, G.R., O'Brien, S.J., Colman-Sadd, S.P., Blackwood, R.F., Dickson, W.L., O'Neill, P.P. and Krogh, T.E.
1990: Silurian orogeny in the Newfoundland Appalachians. Journal of Geology, Volume 98, pages 895-913.

Higgins, N.C.
1985: Wolframite deposition in a hydrothermal vein system: The Grey River tungsten prospect. Economic Geology, Volume 80, pages 1297-1397.

Higgins, N. C., Halliday, A. N., and Mitchell, J. G.
1990: Age of a K-feldspar megacrystic granite from the Burgeo Intrusive Suite, and timing of tungsten mineralization at Grey River, southern Newfoundland. Canadian Journal of Earth Sciences, Volume 27, pages 893-902.

Kerr, A.
1997: Space-time-composition relationships amongst Appalachian-cycle plutonic suites in Newfoundland. Geological Society of America, Memoir 191, pages 193-220.

Kerr, A., Dickson, W.L., Hayes, J.P. and Fryer, B.J.
1993a: Devonian postorogenic granites on the southeast margin of the Newfoundland Appalachians: A review of geology, geochemistry, petrogenesis and mineral potential. *In* Current Research. Newfoundland Department of Natural Resources, Geological Survey, Report 93-1, pages 239-279.

Kerr , A., Dunning, G.R. and Tucker, R.D.
1993b: The youngest Paleozoic plutonism of the Newfoundland Appalachians: U-Pb ages from the St. Lawrence and François granites. Canadian Journal of Earth Sciences, Volume 30, pages 2328-2333.

Kerr, A., Fryer, B.J. and Jenner, G.A.
1995: Sm-Nd isotopic geochemistry of Precambrian to Paleozoic granites and the deep crustal structure of the southeast margin of the Newfoundland Appalachians. Canadian Journal of Earth Sciences, Volume 32, pages 224-245.

Kerr, A., Rafuse, H., Sparkes, G.W. and Sandeman, H.A.
2011: Visible/Infrared Reflectance Spectrometry (VIRS) as a research tool in economic geology: Background and pilot studies from Newfoundland and Labrador. *In* Current Research. Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 11-1, pages 145-166.

Kerr, A., van Nostrand, T., Dickson, W.L. and Lynch, E.P.
2009: Molybdenum and tungsten in Newfoundland: A geological overview and a summary of recent exploration developments. *In* Current Research. Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 09-1, pages 43-80.

Krogh, T.E., Strong, D.F., O'Brien, S.J. and Papezik, V.S.
1988: Precise U-Pb zircon dates from the Avalon Terrane in Newfoundland. Canadian Journal of Earth Sciences, Volume 25, pages 442-453.

Lendrum, S. and Mercer, B.
1997: Assessment report on licenses 4558 and 4586 (2nd year) and license 4476 (3rd year), at Frenchman's Cove, Grey River, Newfoundland. Unpublished assessment report for Royal Oak Mines. Geological Survey File 11P/11/0175.

Ludwig, K.R.
2003: User's manual for Isoplot/Ex rev. 3.00: A geochronological toolkit for Microsoft Excel. Berkely Geochronology Centre, Special Publication 4, 70 pages.

Lynch, E.P., Feely, M., Selby, D. and Wilton, D.H.C.
2011b: Geological, mineralogical and fluid inclusion studies of vein-hosted Mo-Cu mineralization at Moly

Brook, southern Newfoundland. Geological Association of Canada, Annual Meeting, Ottawa, ON, May 2011 (abstract).

Lynch, E.P., Selby, D., Feely, M. and Wilton, D.H.C.
2009: New constraints on the timing of molybdenite mineralization in the Devonian Ackley Granite suite, southeastern Newfoundland: Preliminary results from Re–Os geochronology. *In* Current Research. Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 09-1, pages 225-235.

Lynch, E.P., Selby, D., McNicoll, V., Feely, M., Wilton, D.H.C. and Kerr, A.
2011a: Geochronology of the Moly Brook Mo-Cu deposit, southern Newfoundland: Implications for local and regional granite-related metallogeny. Atlantic Geoscience Society Colloquium, Fredericton, NB, February 2011 (abstract).

Mercer, B.
1996: First year assessment report on licenses 4558 and second year assessment report on license 4476, at Frenchman's Cove, Grey River, Newfoundland. Unpublished assessment report for Royal Oak Mines. Geological Survey File 11P/11/0177.

O'Brien, B.H., O'Brien, S.J. and Dunning, G.R.
1991: Silurian cover, Late Precambrian-Early Ordovician basement, and the chronology of Silurian orogenesis in the Hermitage Flexure (Newfoundland Appalachians). American Journal of Science, Volume 291, pages 760-799.

O'Brien, S.J. (compiler)
1998: Geology of the Connaigre Peninsula and adjacent areas, southern Newfoundland. Newfoundland Department of Mines and Energy, Geological Survey, Map 98-02.

O'Brien, S.J., Dickson, W.L. and Blackwood, R.F.
1986: Geology of the central portion of the Hermitage Flexure area, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 189-208.

Stern, R.A.
1997: The GSC Sensitive High Resolution Ion Microprobe (SHRIMP): analytical techniques of zircon U-Th-Pb age determinations and performance evaluation. *In* Radiogenic and Isotopic Studies, Report 10. Geological Survey of Canada, Current Research 1997 Part F, pages 1-31.

Stern, R.A. and Amelin, Y.
2003: Assessment of errors in SIMS zircon U-Pb geochronology using a natural zircon standard and NIST SRM 610 glass. Chemical Geology, Volume 197, pages 111-142.

Tuach, J,
1996: Tungsten-molybdenum mineralization in the Granite Lake - Meelpaeg Lake area (NTS 12A/2, 12A/7), Newfoundland. Newfoundland Department of Natural Resources, Geological Survey Branch, Mineral Resource Report 7, 53 pages.

Williams, H.
1979: Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, Volume 16, pages 792-807.

van Staal, C.R., Dewey, J.F., Mac Niocaill, C. and McKerrow, W.S.
1998: The Cambrian - Silurian tectonic evolution of the northern Appalachians and British Caledonides: history of a complex west- and southwest-Pacific type segment of Iapetus. Geological Society, London, Special Publication 143, pages 199-242.