PROPERTY DESCRIPTION

The Tsa da Glisza (Regal Ridge) emerald occurrence, Finlayson Lake district (NTS 105G/7), Yukon: New results and implications for continued regional exploration

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ABSTRACT

Emerald at the Tsa da Glisza property in southeast Yukon is associated with abundant quartz-tourmaline veins within chromium-rich mafic metavolcanic rocks. A genetic model for the emerald mineralization has been formulated: vein fluids were mixtures of fluids from both magmatic and metamorphic sources. Beryllium derived from an adjacent Cretaceous granite pluton travelled as both hydroxide and fluoride complexes within dominantly magmatic fluids. Emerald crystallized during cooling, after the magmatic fluids mixed with hydrothermal fluids that had scavenged chromium from the surrounding mafic schist. Property-scale exploration targets the permeable, high-chromium mafic schists as potential hosts (rather than nearby chromium-rich, but impermeable, serpentinized ultramafic rocks). Soil geochemistry, drilling and prospecting are used to locate emerald mineralization. Based on the genetic model, further exploration in the Finlayson Lake region should focus on areas where permeable, high-chromium host rock (schist, rather than serpentinized ultramafic) is in close proximity to evolved felsic intrusive rocks.

RÉSUMÉ

À la propriété Tsa da Glisza au sud-est du Yukon, l'émeraude est associée à d'abondantes veines de quartz avec tourmaline dans des métavolcanites mafiques riches en chrome. On a établi un modèle génétique pour la minéralisation en émeraude : les fluides présents dans les veines étaient des mélanges de fluides provenant de sources magmatiques et météoriques. Le béryllium, dérivé d'un pluton de granite adjacent du Crétacé, s'est déplacé sous forme de complexes avec hydroxydes et fluorures dans des fluides à prédominance magmatique. L'émeraude s'est cristallisée pendant le refroidissement, après que des fluides magmatiques se sont mélangés à des fluides hydrothermaux qui avaient extrait du chrome du schiste mafique environnant. L'exploration à l'échelle de la propriété vise les schistes mafiques perméables à haute teneur en chrome comme roches hôtes possibles (plutôt que les roches ultrabasiques serpentinisées, riches en chrome mais imperméables, qui se trouvent à proximité). Les levés géochimiques, des forages et la prospection servent à situer les minéralisations en émeraude. S'appuyant sur le modèle génétique, la future exploration dans la région du lac Finlayson devrait se concentrer sur des zones où la roche hôte perméable (schiste plutôt que roche ultrabasique serpentinisée), riche en chrome, se trouve à proximité immédiate de roches intrusives felsiques évoluées

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INTRODUCTION

The Tsa da Glisza (previously known as Regal Ridge) emerald occurrence is centered at 61°16.6' N latitude, 133°5.5' W longitude on NTS map sheet 105G/7, in the Finlayson Lake district within the Pelly Mountains of southeastern Yukon (Fig. 1). Emerald is an extremely valuable gemstone and is rare because the required elements beryllium and chromium (with or without vanadium) are geochemically incompatible, and therefore are rarely found together in environments in which beryl is stable. The Tsa da Glisza occurrence hosts the only known chromium-bearing emerald in the Canadian Cordillera. The definition of "emerald" is still under considerable debate (e.g., Schwartz and Schmetzer, 2002). In this paper, emerald is defined as bright green, clear, gem-quality beryl, which is distinct from opaque white to medium green beryl and clear beryl that is less than bright green.

This paper compiles results from both field and laboratory research on the Tsa da Glisza emerald occurrence since 2003, develops a genetic model for the formation of emerald at Tsa da Glisza based on the results of this research, and outlines an updated exploration model to develop targets for emerald mineralization similar to that found at Tsa da Glisza.

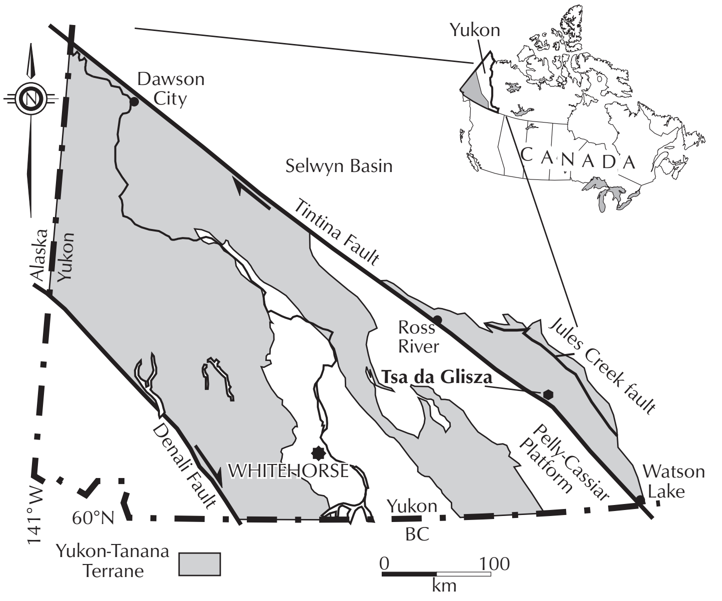


Figure 1. Map of southern Yukon showing the Yukon Tanana Terrane and the location of the Tsa da Glisza emerald occurrence.

REGIONAL GEOLOGY

The Tsa da Glisza study area is located in the Finlayson Lake district of the Yukon. The area was mapped most recently by Murphy (1997), Murphy and Piercey (1999), Murphy et al. (2001) and Murphy et al. (2004). The geologic setting of the region has been described in detail by Murphy (2004) and Murphy et al. (2002). Neufeld et al. (2004) discussed the geological setting of the Tsa da Glisza emerald occurrence in some detail, and in this paper we provide a brief review of the lithologies that are present within the immediate vicinity of the Tsa da Glisza property and highlight recent changes in the geological interpretation.

The Finlayson Lake district consists of rocks of the Yukon-Tanana Terrane (Fig. 1), which is regionally bounded to the west by the Tintina Fault, and to the east by the Jules Creek fault (Murphy, 2004). The structurally deepest rocks are contained within the Big Campbell thrust sheet, which is composed of the Upper Devonian Grass Lakes group, and the Lower Mississippian Wolverine Lake group. The Tsa da Glisza occurrence is hosted within the Grass Lakes group, which consists of mafic and felsic metavolcanic rocks and dark clastic rocks of the Fire Lake, Kudz Ze Kayah and Wind Lake formations. The Fire Lake Formation is a mafic metavolcanic package composed mainly of chloritic phyllite, and is spatially associated with mafic and ultramafic plutonic rocks (Murphy, 2004; Piercey et al., 2004). The Kudz Ze Kayah Formation stratigraphically overlies the Fire Lake Formation and consists of carbonaceous phyllite and schist, felsic metavolcanic rocks and rare quartzofeldspathic metaclastic rocks (Murphy, 2004). The rocks in the Finlayson Lake district are intruded by several ca. 112 to 110 Ma granitic bodies of the Cassiar-Anvil plutonic suite (Mortensen, pers. comm., 2004). The intrusions are syn- to post-kinematic with respect to the main Cretaceous deformation in the area.

A recent structural interpretation of the Finlayson Lake region (Murphy, 2004) suggests that the rocks in the Finlayson Lake district were strongly deformed during the Cretaceous. As the numerous felsic plutons in the region were emplaced, the east-trending North River normal fault moved to accommodate uplift and cooling of rocks in the footwall of the fault. Movement of the hanging wall of the fault was broadly north to south. Rock units in the footwall have mid-Cretaceous Ar-Ar cooling ages, and were ductily deformed prior to and during the emplacement of mid-Cretaceous granite plutons.

Tsa da Glisza occurs within the footwall of this fault, within 10 km of the present-day fault trace. The Tintina Fault lies 14 km southwest of the Tsa da Glisza property (Fig. 1). Early Tertiary volcanic rocks occur adjacent to the Tintina Fault, and faults and porphyritic dykes, likely related to Tertiary movement along the Tintina Fault, occur throughout the Finlayson Lake district (Jackson et al., 1986).

PROPERTY GEOLOGY

Neufeld et al. (2004) described the geology associated with mineralization at the Summit Zone (Regal Ridge proper). This area is underlain by rocks of the Fire Lake Formation, as well as Cretaceous and Eocene intrusive rocks. A two-week mapping program conducted in July 2004 covered the entire claim block, and resulted in a 1:10 000-scale geologic map (Fig. 2). A brief description of the rock units is given below, along with some new observations. Rock unit nomenclature is from previous mapping (Murphy et al., 2001).

The Tsa da Glisza property is mainly underlain by rocks of the Fire Lake Formation, a suite of Devonian mafic metavolcanic rocks and associated mafic and ultramafic plutonic rocks. The emerald occurrence is mainly hosted within the Fire Lake mafic metavolcanic unit (DF; Fig. 2). This rock unit was studied extensively by Piercey (1999, 2000, 2004; Murphy and Piercey 2000). It occurs as dark to medium green plagioclase-chlorite schist to phyllite, with common biotite and actinolite porphyroblasts. Greenschist facies metamorphism resulted in replacement of most primary mafic minerals with chlorite and actinolite. The finer-grained groundmass consists mainly of quartz, chlorite and actinolite with less abundant muscovite, biotite and rare carbonate. At Tsa da Glisza, the composition of the chlorite schist is equivalent to that of high-calcium boninite, which is geochemically distinct from other mafic metavolcanic rocks within the Fire Lake Formation because of high MgO, intermediate SiO_2, and anomalous Cr, Ni, Co and Sc (Table 1; Piercey et al., 2004). Chlorite alteration likely occurred prior to the Cretaceous deformation event, during which some of the chlorite schist was altered to jarosite- and mica-rich schist, while scheelite and tourmaline formed close to quartz vein contacts. This altered schist occurs mainly at the top of Regal Ridge.

Red-weathering, moderately serpentinized ultramafic rock (unit Dum) and actinolite-plagioclase-biotite leucogabbro to pyroxenite (unit Dmi) occur mainly to the west of the mineralized areas (Fig. 2). Average geochemical analyses for these ultramafic units are given in Table 1. Quartz-tourmaline veins within these units are very rare, likely due to the extremely competent nature of the rock type and the distance from the granite. Geological mapping of the property suggests that the ultramafic unit is not present at depth between the granite and unit DF (Fig. 2).

Carbonaceous phyllite (unit DKcp) occurs over much of the southeastern part of the property, and makes up the upper part of the stratigraphy in this area. A thin band of rusty quartzite marks the contact between the chlorite schist and carbonaceous phyllite units. The rusty quartzite was included within unit DKcp by Murphy et al. (2001), but was mapped separately in this study as unit DKq. Neither the carbonaceous phyllite nor the quartzite within the Kudz Ze Kayah Formation host quartz-tourmaline or emerald-bearing veins.

A biotite-muscovite granite to muscovite leucogranite, previously called a quartz monzonite by Neufeld et al. (2004), crops out in the valley between the two mineralized ridges (unit Kg; Fig. 2). This 112.2 ± 0.5 Ma pluton (Neufeld, 2004) contains rare garnet, and does not contain miarolitic cavities. The geochemistry of the granite is discussed in Neufeld et al. (2004) and average results from analyses of this rock type are presented in Table 1. A contact aureole extending approximately 500 m from granite contacts is defined by the presence of biotite and tourmaline within the surrounding schist.

Numerous leucogranite and aplite-pegmatite dykes and sills (unit Ka, not mapped separately by Murphy et al., 2001) from 30 cm to ten metres in width are present on the property. The aplite dykes consist of plagioclase, quartz, muscovite, and minor potassium feldspar, tourmaline and garnet. Pegmatite is rare, and has the same mineralogy as aplite, but with increased amounts of muscovite. Both white and green beryl occur in quartz-rich segregations within at least two of the aplite dykes. Some of the aplite and pegmatite dykes are altered, and contain albite, intergrowths of albite and muscovite, and rare interstitial calcite and sulphides. The geochemistry of the aplite dykes is discussed in Neufeld et al. (2004) and average results from analyses of this rock type are presented in Table 1.

Beige-, purple-grey-, and pink-weathering feldspar- and quartz-phyric porphyry dykes and sills (unit Eq) of inferred Eocene age occur throughout the property, and intrude along the same zones of weakness exploited by the Cretaceous aplite and leucogranite dykes and sills, or

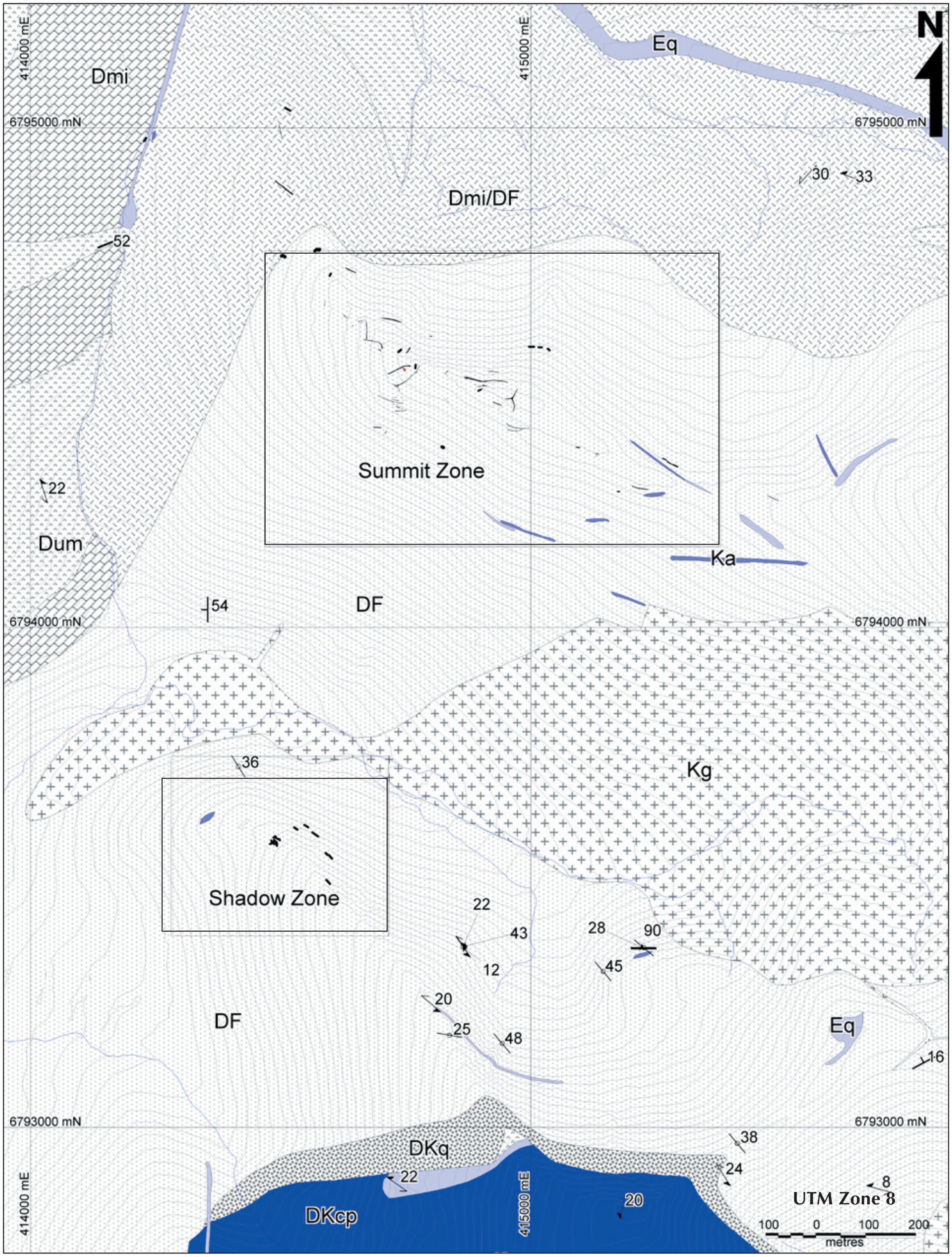
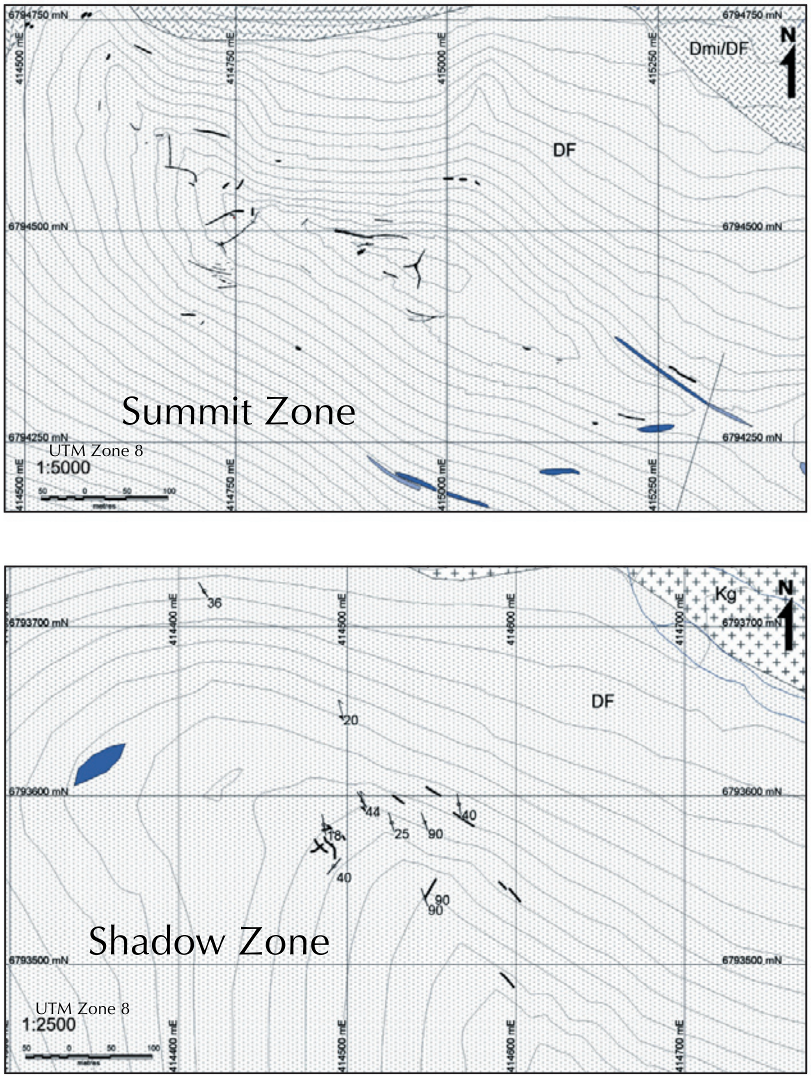


Figure 2. *Geological map of the Tsa da Glisza property, adapted from Neufeld (2004). The property occurs in NTS map sheet 105G/7. Rock unit nomenclature is mainly from YGS mapping (Murphy et al., 2001).*



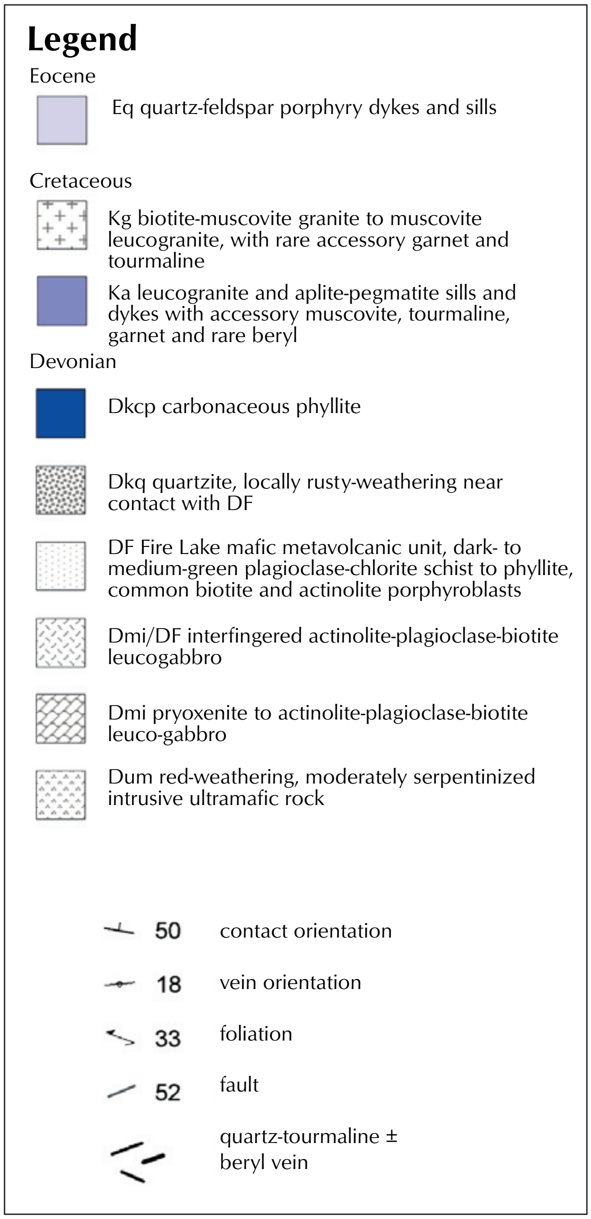


Figure 2. *continued. Inset maps of the Summit and Shadow zones.*

along geologic contacts. The porphyry intrusions are approximately 5 to 50 m thick, and are commonly intensely altered to brown rounded pebbles. Some late faulting and alteration of host rocks and emerald at Tsa da Glisza are attributed to this Eocene event.

MINERALIZATION AND ALTERATION

At Tsa da Glisza, emerald occurs: (1) in the altered selvages of quartz-tourmaline veins; (2) within quartz-tourmaline veins; and (3) in linear zones of highly altered schist, with no quartz-tourmaline veins immediately adjacent to the emerald. The formation of the quartz veins is interpreted to be syn- to late-tectonic, and coincided with the waning stages of granite emplacement (Neufeld et al., 2004). No distinct preferred orientation of emplacement for the veins is evident, and the degree of deformation is variable; some veins appear relatively linear and tabular, whereas others are extensively boudinaged. Emerald is associated with both extremes of vein type, and the crystals show no preferred growth orientation relative to either the schist foliation or to tourmaline-filled fractures within the quartz veins. Alteration of the quartz-tourmaline vein selvages consists of jarosite, tourmaline,

	ultramafic (Dum)	leuco-amphibolite (Dmi)	chlorite schist (DF)		granite (Kg)		aplite (Ka)		aplite containing qtz-beryl veinlets (Ka)	
			average n=3	std dev	average n=5	std dev	average n=8	std dev	average n=3	std dev
P_2O_5 (wt.%)	0.01	<0.01	0.02	0.01	0.1	0.02	0.05	0.02	0.02	0.01
SiO_2	42.02	49.6	51.34	1.85	72.51	1.39	73.98	0.62	74.92	4.46
TiO_2	0.03	0.1	0.25	0.06	0.23	0.07	0.06	0.03	0.04	0.02
Al_2O_3	1.65	2.03	11.42	2.44	14.96	0.55	15.02	0.6	15.04	2.9
Cr_2O_3	0.43	0.37	0.13	0.11	0.02	0.01	0.01	0	0.02	0
Fe_2O_3	9.75	7.51	9.98	1.49	1.24	0.31	0.59	0.15	0.3	0.11
MgO	35.99	25.03	13.13	3.04	0.41	0.11	0.14	0.1	0.07	0
CaO	0.04	9.51	8.23	1.48	0.98	0.24	0.85	0.37	2.14	1.05
MnO	0.08	0.19	0.18	0.04	0.02	0.01	0.03	0.03	0.06	0.03
FeO	3.6	3.29	7.6	1.13	0.89	0.18	0.36	0.15	0.26	0.04
Na_2O	0.13	0.07	1.29	0.71	3.22	0.28	3.8	0.44	4.93	1.36
K_2O	0.03	0.03	0.17	0.11	4.7	0.36	4.05	0.62	0.75	0.64
BaO	<0.01	<0.01	0.01	0	0.04	0.01	0.01	0	0.02	0
SrO	<0.01	0.01	0.02	0.01	0.02	0.01	0.01	0	0.02	0.02
LOI	9.53	4.15	2.73	0.98	1.07	0.19	0.87	0.29	0.88	0.14
Total	**99.67**	**98.62**	**98.9**	**0.33**	**99.61**	**0.31**	**99.44**	**0.37**	**99.15**	**0.53**
Li (ppm)	7.1	1.4	58.9	21	143.4	43.5	61.6	21.9	14.7	10.5
Be	1.24	0.25	0.29	0.22	11.65	1.36	14.41	3.31	145.05	74.89
B	30	<20	–	–	33	5	42	26	20	0
C	<0.05	0.08	0.08	0.02	–	–	–	–	0.05	0
F	430	<20	69	54	974	268	460	138	83	40
Cl	<50	<50	253	99	–	–	100	0	–	–
Sc	5.7	24.2	44.4	8.8	4.2	0.7	2.4	1	0.3	0.2
V	23	35	237	45	14	6	–	–	–	–
Cr	3080	2460	964	767	102	56	123	14	140	25
Co	120	54.2	49.9	12	7.1	7.7	0.8	0.3	1.1	0.6
Ni	1635	303	284	223	8	2	7	1	7	<1
Cu	18	<5	63	64	17	12	61	29	8	0
Zn	57	33	65	14	54	23	16	5	8	3
Ga	4	2	11	2	30	2	32	37	31	11
Rb	1	0.3	10.3	10.6	397	16.7	340	26.2	134.2	142.5
Sr	2.5	11.2	65.2	57.2	111.8	43.4	25.1	16.3	108.5	106.8
Y	<0.5	2.2	6.2	1.3	10.5	1	16.6	6.7	8.1	5.2
Zr	1.5	2.1	13.2	11.9	195.1	170.2	101.2	107.2	35.2	3.5
Nb	<1	<1	–	–	13	2	9	2	34	33
Mo	3	3	3	1	3	1	4	0	4	0
Ag	<1	<1	–	–	1	0	–	–	–	–
Sn	5	<1	1	0	23	13	27	11	35	31
Cs	4.3	0.1	6.5	8.2	23	6.9	12.9	1.6	12.3	7.9
Ba	2.4	15.4	77	61.8	345.38	140.3	30.3	24.8	88.8	51.3
La	0.6	1	1.5	0.3	34.5	9.2	7.3	4	2.1	0.1
Ce	0.6	0.7	1.8	0.3	73.8	23.1	15.6	8.4	4.2	0.6
Pr	<0.1	0.1	0.2	0.1	8	2.2	1.8	0.9	0.5	0.1
Nd	<0.5	<0.5	1.1	0.2	26.5	7.3	6.6	3.4	1.8	0.4
Sm	<0.1	0.1	0.4	0.1	4.8	1.1	2	0.5	1.1	0.2
Eu	<0.1	0.1	0.2	0.1	0.5	0.2	0.1	0.1	0.1	0
Gd	<0.1	0.2	0.6	0.1	3.6	0.9	1.9	0.4	0.8	0.5
Tb	<0.1	<0.1	0.1	0	0.5	0.1	0.4	0.1	0.4	0.1
Dy	<0.1	0.4	1	0.2	2.1	0.2	2.4	0.7	1.3	0.8
Ho	<0.1	0.1	0.2	0.1	0.4	0	0.5	0.2	0.3	0.1
Er	0.1	0.3	0.8	0.1	1	0.1	1.5	0.7	0.5	0.3
Tm	<0.1	<0.1	0.1	0	0.1	0.1	0.1	0	0.1	0
Yb	<0.1	0.3	0.9	0.2	0.9	0.1	1.6	0.8	0.7	0.5
Lu	<0.1	0.1	0.1	0.1	0.1	0	0.2	0.1	0.1	0
Hf	<1	<1	1	0	5	3	3	2	6	<1
Ta	<0.5	<0.5	–	–	4.2	3.7	1.4	0.3	17.5	14.4
W	31	16	12	4	64	84	6	3	15	9
Tl	<0.5	<0.5	–	–	1.2	0.2	1	0	1	0
Pb	<5	<5	5	0	47	4	31	7	9	3
Th	<1	<1	–	–	21	5	6	3	3	1
U	<0.5	<0.5	–	–	8.7	3.4	11.8	5.9	8.1	3.5
CO_2	<0.2	0.3	0.3	0.1	–	–	–	–	0.2	0
H_2O-	0.38	0.07	0.14	0.07	0.1	0.03	0.03	0.01	0.06	0.02
H_2O+	9.61	4.16	3.22	1	0.72	0.1	0.56	0.22	0.45	0.29

Note: Most major elements were analyzed using XRF and most trace elements by ICP-MS or ICP-ES. Li, Be, Cr and Mo were determined by AAS, B and Cl by INAA, FeO by titration, CO_2 and H_2O by infrared spectroscopy, and F by specific ion potentiometry.

Table 1. *(facing page) Whole-rock geochemistry of selected rock types present at the Tsa da Glisza emerald occurrence. Analyses represent average values for each rock type and are from samples collected from different locations on the property.*

lepidolite (fluorine- and lithium-rich mica), scheelite and fluorite, in order of abundance. Scheelite and fluorite crystals are less than 1 mm in size. Tourmaline and mica are most abundant within 10 cm of the vein-host contact, whereas more distal alteration consists mainly of jarosite within foliation planes of the chlorite schist. Whole-rock geochemistry of samples taken across numerous mineralized veins shows a consistent enrichment of lithium, tin, and fluonne within the vein selvages, and rare enrichment of beryllium, bismuth and tungsten within the vein itself (Fig. 3; Table 2). This is consistent with the abundant lepidolite in vein selvages. Boron is enriched in both the veins and selvages relative to unaltered chlorite schist, likely reflecting the abundant tourmaline in both veins and selvages.

Beryl and rare emerald are found in quartz-rich segregations within two albitized aplite dykes at Tsa da Glisza. Beryl within the aplite dykes may have formed from late-crystallizing fluids trapped within the aplite. These residual fluids are expected to have been rich in Be. Alternately, these occurrences may indicate that some Be was sourced from plagioclase, which, when altered by sodium-rich fluids to a more albitic composition, released the minor amount of Be that was originally incorporated into the plagioclase structure (cf. Charoy, 1999). It is highly unlikely that all of the Be within the mineralizing fluids was sourced from the aplites after they had crystallized, since most mineralized quartz vein selvages are anomalous in several magmatic-associated elements (B, W, Bi, F, Sn, Li) and it is unlikely that all of these were remobilized from aplite during a later metasomatic event.

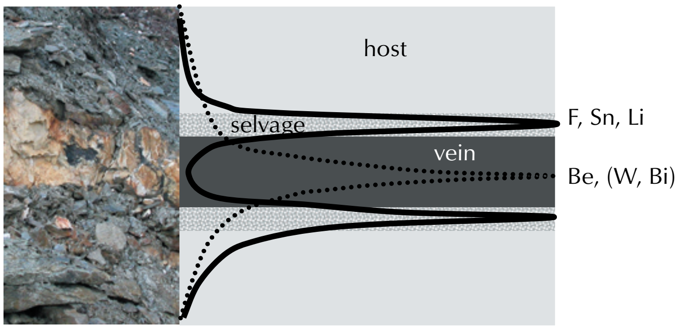


Figure 3. *Typical geochemical trend across a mineralized quartz vein. Based on data from 94 whole rock geochemical samples, from 11 different mineralized veins. Geochemical data for each of the six elements of interest were normalized to the highest values of that element. Elements consistently partition into the area around the vein (Li, F, Sn), or peak within or in the immediate selvage of the vein (Bi, W, Be). The photo shows a quartz-tourmaline vein approximately 1 m in width.*

Table 2. *Selected element geochemistry from samples taken across a mineralized quartz vein at the Tsa da Glisza emerald occurrence.*

Element (ppm)	Bottom host (DF)	selvage	qtz vn	qtz vn	selvage	host (DF)	Top host (DF)
Ag	0.04	0.18	0.02	0	0.06	0.05	0.15
As	0.6	0.2	0.6	0.7	0	0.4	0
Ba	280	370	30	20	30	40	40
Be	6.75	32.4	145.5	65.2	21.2	34.5	19.5
Bi	0.58	9.68	2.37	0.64	1.64	2.17	1.87
Cd	0.1	0.12	0	0	0.1	0.14	0.14
Ce	1.29	1.13	0.22	0.28	1.22	1.27	1.52
Co	53.8	51	4.8	3	30.8	37.4	42.6
Cr	564	574	224	184	243	281	262
Cs	245	211	14.3	15.9	52.2	32.5	22.1
Cu	22.6	188.5	25.6	10.7	77.2	59.4	175.5
F	1140	4450	1480	1190	2340	4390	2250
Ga	8.24	10.9	8.75	6.17	19.2	13.35	17
Ge	0.26	0.28	0.07	0.05	0.24	0.24	0.24
Hf	0.2	0.2	0	0	0.3	0.3	0.3
In	0.031	0.027	0	0	0.058	0.042	0.048
La	0.5	0.5	0	0	0.5	0.5	0.6
Li	177.5	204	25.1	21.7	32.2	57.6	41.7
Mn	1490	1360	160	135	1200	1330	1185
Mo	0.32	1.2	1.72	1.86	0.38	0.67	0.28
Nb	0.5	1.4	0.1	0.1	1.1	1.2	2.2
Ni	321	300	18.4	9.5	76.4	91.3	94.2
P	40	20	10	20	90	70	110
Pb	2.1	1.9	1.4	1.2	3.5	3.1	4.5
Rb	273	371	20.8	29.7	97.8	56.5	35.1
Re	0.003	0.006	0.009	0.003	0.006	0.005	0.005
Sb	0.09	0.05	0	0	0.06	0.07	0.05
Se	0	1	0	0	0	0	1
Sn	14.5	45.2	8.8	6.7	53.1	35	33.1
Sr	31.9	17.3	9.6	7.3	125.5	64.3	115.5
Ta	0.07	0.2	0	0	0.07	0.17	0.11
Te	0	0	0	0	0	0	0
Th	0	0	0	0	0	0	0
Tl	1.91	2.42	0.17	0.16	0.59	0.35	0.21
U	0.1	0.1	0	0	0.2	0.1	0.1
V	227	202	24	15	304	237	258
W	2.8	78.1	233	50.3	111	112.5	69.2
Y	5.7	5.8	1.2	0.7	8.2	7.7	8.7
Zn	87	112	36	34	59	83	64
Zr	2.2	2.7	1.4	0	4.2	3.6	4

Note: Most major elements were analyzed using XRF, and most trace elements by ICP-MS or ICP-ES. Li, Be, Cr and Mo were determined by AAS, and F by specific ion potentiometry.

GENETIC MODEL

Emerald formation at Tsa da Glisza was associated with the interaction of magmatic and hydrothermal fluids within the actively deforming zone in relatively close proximity to a peraluminous granite (Neufeld et al., in press). The mineralizing event was mainly syn- to late-tectonic, and coincided with the waning stages of granite emplacement and peak metamorphic (upper greenschist) conditions (Neufeld et al., 2004). The Tsa da Glisza deposit best fits a deposit model for beryl proposed by Barton and Young (2002) in which mineralization is related to magmatic-hydrothermal fluids that originate from strongly peraluminous W-Mo (biotite-muscovite) granites. Any genetic model for emerald mineralization must account for the incompatibility of two necessary elements for emerald formation, Be and Cr, which are rarely found together in environments in which beryl is stable.

The genetic model we propose for emerald mineralization at Tsa da Glisza is shown in schematic form in Figure 4 (modified from Neufeld et al., in press). Be, together with other magmatic elements such as B, W, Li, Bi and F, moves out from the granite within highly evolved magmatic fluids. Be is increasingly mobile in fluids containing B and phosphate, and may complex with F, chlorine, and hydroxyl ions. The high F content within mineralized vein selvages suggests that Be most likely travelled as a fluoride or possibly hydroxide complex. Aplite and pegmatite dykes formed with the onset of cooling. Although the dykes locally contain Be concentrations of up to 100 ppm, little Be was incorporated into the aplite-forming minerals, and the beryllium continued to move through the host rocks, within dominantly magmatic fluids (Neufeld, 2004).

A hydrothermal fluid cell was initiated in the host rocks with emplacement of the granite. These fluids percolated through the chlorite schist, and leached Cr from the mafic groundmass. Geochemical transects from unaltered chlorite schist through altered schist, to quartz-tourmaline veins give no indication of how far Cr may have travelled within these fluids (Table 2, Neufeld, 2004). Cr may have been directly sourced from host rock within centimetres of quartz-tourmaline veins through contact metasomatism, or may have travelled some distance along hydrothermal fluid pathways.

The following scenarios could have triggered beryl crystallization: (1) mixing of the Be-rich magmatic fluid with cooler hydrothermal fluids; (2) crystallization of tourmaline, which would have removed boron and possibly some Li and F and/or lowered the aluminium activity of the Be-rich fluid, thereby reducing the solubility of Be (cf. London and Evensen, 2002); (3) an increase in the Ca content of the fluid due to interaction with the host schist; (4) an increase in host-rock permeability or porosity due to either rock type differences or fracture propagation related to deformation; (5) precipitation of lepidolite within the vein selvage, removing fluorine (ligand) and lithium (buffer) from the fluids; and/or (6) a decrease in pressure and/or temperature. Likely all of these factors played some role in initiating beryl precipitation, particularly where mineralization is contained within highly altered vein selvages. Where emerald occurs solely within the quartz veins, factors (3) and (5) above are probably not involved, and where emerald occurs within linear zones of alteration away from quartz-tourmaline veins, low silica activity may also be a factor in prompting precipitation of beryl (London and Evensen, 2002).

EXPLORATION MODEL

Emerald exploration in the Yukon has been ongoing since at least 1999, and has resulted in the 2003 discovery of aquamarine at the True Blue occurrence (Deklerk, 2003; Turner, this volume). Emerald mineralization was also discovered one kilometre away from known mineralization at the Tsa da Glisza property in 2004 (Shadow Zone; Fig. 2). Walton (1996) first discussed the possibility of gem mineralization in Yukon, and the various models for emerald formation worldwide as applicable to Yukon exploration are discussed by Walton (2004). In this paper, we discuss an exploration model based solely on the style of emerald mineralization at the Tsa da Glisza occurrence. Such a model may be applicable to much of the Canadian Cordillera, but is specifically aimed at the Finlayson Lake district of the Yukon-Tanana Terrane. Key aspects of the model are discussed below.

HOST ROCK

Geochemistry

The amount of emerald mineralization within quartz-tourmaline veins is limited by the availability and transport of Cr from the host rock (Laurs et al., 1996). The main host rock for emerald mineralization at Tsa da Glisza is a fine-grained chlorite schist (unit DF) of boninitic composition, with an average Cr content of 800 ppm, which is higher than any other mafic metavolcanic rocks

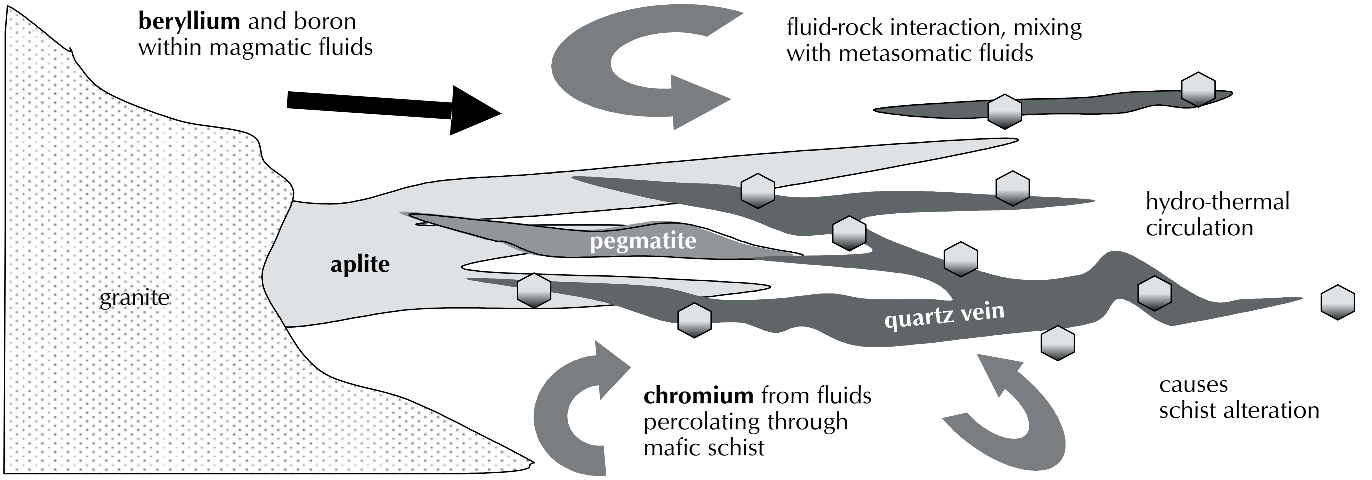


Figure 4. *Proposed genetic model for emerald mineralization at Tsa da Glisza.*

in the Finlayson Lake district, including other rock compositions within unit DF (Table 1; Neufeld et al, 2004; Piercey et al., 2004). This suggests that emerald exploration within the Finlayson Lake district should focus on host rocks of boninitic composition, which are found regionally within unit DF. Although the Cr content of the ultramafic unit is much higher than that of the chlorite schist (Table 1), two factors argue against it being the source of Cr in the mineralizing fluids. Firstly, geological mapping of the property indicates that the ultramafic unit is not present at depth beneath the deposit (i.e. between the granite and the mineralized region; Fig. 2). Secondly, aplite and quartz veins within the ultramafic unit generally display little or no surrounding alteration, suggesting limited interaction between the host and the hydrothermal fluids. The more likely source of the Cr in the Tsa da Glisza occurrence is the chlorite schist, which, due to its schistosity and high mica content, is both highly permeable and reactive. Therefore, exploration should target high-Cr content, permeable mafic schist hosts rather than ultramafic rock. Data available from the Yukon Geological Survey website* can be used to produce maps that show the locations of intermediate to mafic volcanic and metamorphic rocks in Yukon that may help in targeting appropriate host lithologies.

Alteration

Emerald mineralization at Tsa da Glisza is commonly associated with narrow, highly altered vein envelopes and selvages, and zones of less-altered host rock that extend up to several metres away from the quartz veins. This style of alteration indicates that the host rocks were permeable, and if present, increases the potential for emerald mineralization within a prospective area.

RELATED INTRUSIVE ROCKS

Close proximity of an evolved felsic intrusion is obviously implicit in the model for magmatic-hydrothermal emerald deposits. Tsa da Glisza is one of numerous emerald deposits worldwide that are closely associated with peraluminous granite (Guiliani, 1990; Barton and Young, 2002). In addition, the presence of aplite and pegmatite dykes outside of the pluton indicates that not only did the magma produce evolved fluids, but also that at least some of those fluids moved out into the surrounding rocks, rather than cooling and crystallizing within the pluton itself. While beryl is a common component of pegmatites within granitic plutons, emerald will not form unless some amount of mixing of the magmatic fluids with a Cr- or V-bearing source has occurred.

Age

At Tsa da Glisza, the 112.2 ± 0.6 Ma biotite-muscovite granite underlying the deposit is part of the Anvil plutonic suite (Mortensen et al., 2000). The Cretaceous age of the related intrusive is not a restrictive factor of the model; however, it is a good "rule of thumb" for emerald exploration within the Yukon, as the Cretaceous Cassiar and Tungsten magmatic suites also contain evolved, felsic granites (L.L. Lewis, pers. comm., 2003).

**www.geology.gov.yk.ca*

Mineralogy

The mineralogy of a granitic pluton can be used to determine whether Be was likely a component of the evolved magmatic fluids, or was accommodated into the structure of common minerals within the pluton itself. Cordierite, muscovite and plagioclase can all accommodate some Be into their structure during crystallization. Cordierite has by far the highest Be partition coefficient of these three minerals, but plagioclase of composition An_{30} (oligoclase-andesine) can also remove substantial amounts of Be from the magmatic fluids. A pluton that contains cordierite or abundant oligoclase-andesine is unlikely to have produced Be-rich residual fluids during crystallization.

The mineralogy of associated aplite dykes provides important information for the exploration model. For example, aplite dykes that contain white beryl reveal that Be moved out of the pluton, but suggest limited mixing of fluids with host rocks. In general, aplite bodies with more albite than potassium feldspar (Laurs et al., 1996) and those that contain tourmaline are increasingly likely to be associated with emerald mineralization.

Geochemistry

The Be content of the granite at Tsa da Glisza averages 12 ppm (Table 1), which is relatively high compared to crustal values (3 ppm, Wedepohl, 1995) but at the low end of the global average Be-content of granites (1 to 160 ppm, London and Evensen, 2002). Yukon granites with associated beryl tend to have between 12 to 20 ppm Be (L.L. Lewis, pers. comm., 2003). Lithium, fluorine, phosphorous and boron contents are also high in the granite at Tsa da Glisza (Table 1). As discussed previously, high concentrations of these potential ligands and buffers within a fluid increase the mobility of Be within that fluid.

The geochemistry of aplite dykes is unlikely to assist in assessing a target for emerald potential, although high sodium to potassium ratios and Be contents greater than 30 ppm may indicate the presence of Be-F within a sodium-rich fluid during crystallization of the aplite (Neufeld, 2004).

STRUCTURAL ENVIRONMENT

As discussed above, the Tsa da Glisza occurrence lies in the footwall of the Cretaceous North River fault, within 10 km of the present-day fault trace. This indicates that unloading of the rock units at Tsa da Glisza was relatively late in the local tectonic regime. The structural geology at Tsa da Glisza is complex and deserves further study; however, the Cretaceous structural setting as discussed by Neufeld et al. (2004) clearly shows a re-orientation of the shear system late in the Cretaceous event. Emerald mineralization was syn-to post-tectonic, and possibly coincided with this environment of rapid unloading, which would have decreased lithostatic pressure and increased the permeability of the host rocks to fluids.

Cretaceous granites within the Finlayson Lake district show a moderate emplacement depth (Mortensen et al., 2000). The quartz-tourmaline veins at Tsa da Glisza were emplaced into greenschist facies rocks near the brittle-ductile transition (Marshall et al., 2003; Neufeld et al., 2004). Be saturation, although dependent on alumina activity, commonly occurs at temperatures of 450 to 550°C (e.g., Barton, 1986). Mineralization has thus far been found within 800 m of outcropping granite, and between 200 and 500 m above granite that is not exposed at the surface.

GEOCHEMICAL INDICATORS

Preliminary element correlation studies on soil geochemical data from the Tsa da Glisza property highlight a correlation of Be, W, Sn and Bi anomalies near emerald mineralization (Neufeld, 2004). Different analytical methods, however, give drastically varying results for Be concentrations (L.L. Lewis, pers. comm., 2004). New soil geochemical data from the Tsa da Glisza property are pending, and are expected to more clearly delineate element correlations. In general, Be values greater than 10 ppm in soil are considered anomalous. High Be values, however, do not necessarily indicate the presence of beryl. During regional exploration for emerald at various locations throughout the Yukon in 2004, several Be soil geochemistry anomalies were caused by Be-rich mica occurring on pegmatite selvages, or by clay minerals, rather than by the presence of beryl. Conversely, the soil that overlies some mineralized areas at Tsa da Glisza is not anomalous in Be. This is observed in some of the areas where emerald occurs within relatively impermeable quartz veins, rather than on altered selvages where it is more susceptible to weathering and mobilization. Although they don't conform to this model, areas with Be-rich clays might be considered for Colombian-style emerald mineralization, where emerald forms within thrust faults and shear zones. Areas with abundant Be-rich micas are relatively unlikely to contain beryl mineralization, since beryl will typically form prior to mica, and remove Be from the residual fluid. Many of the elements that are strongly correlated with mineralized quartz veins and selvages (e.g., B, F, Li) in geochemical transects across the veins, are relatively mobile elements and do not correlate well with Be in soil geochemistry.

Regional soil geochemistry can be used to distinguish rock types with high Cr contents. However, as mentioned above, ultramafic rocks, which give the highest regional Cr values, are unlikely to host emerald mineralization similar to Tsa da Glisza. By correlating regional geophysical data with Cr soil geochemisty (e.g., Bond et al., 2002), high-Cr rocks with lower magnetic susceptibilities (therefore not likely to be ultramafic) can be identified. Since regional geochemical coverage may be scarce, this method likely will require some scavenging through old assessment reports for results from property-scale soil geochemistry programs.

GEOPHYSICAL INDICATORS

The quartz-tourmaline veins associated with emerald at Tsa da Glisza do not produce magnetic anomalies on any scale. They occur within a mafic metavolcanic host rock that is neither a magnetic high nor low on regional geophysical maps (Bond et al., 2002). The associated pluton produces a distinct magnetic low, attesting to its S-type, peraluminous nature (lack of magnetite or hornblende). The nearby ultramafic unit is regionally a strong magnetic high. As mentioned above, a correlation between magnetic highs and high Cr soil geochemistry may help to narrow the target zones, since ultramafic rocks are not a requirement of the exploration model. Areas with a medium magnetic response and medium to high Cr in soil geochemistry are viable targets because mafic metavolcanic rocks can host emerald mineralization, particularly where they occur near a felsic pluton.

CONCLUSIONS

The coincidence at Tsa da Glisza of the many necessary factors for emerald formation is fortuitous, but it is not necessarily unique. Many of the factors commonly occur together, such as granitic plutons and the deformational environment above and adjacent to them, or mafic host rocks with schistose, and therefore permeable, textures. Emerald typically occurs over small areas that are difficult to find using typical exploration methods such as soil geochemistry and geophysical surveys. Highly prospective targets can be identified using the exploration model outlined above, which constrains host rocks, associated intrusive rocks, structural environments, and geochemical and geophysical indicators. Detailed prospecting of those specific targets is the most effective method of exploration for emerald.

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