Geology and structural setting of the Regal Ridge emerald property, Finlayson Lake district, southeastern Yukon

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ABSTRACT

Emerald at the Regal Ridge property in the Finlayson Lake district of southeastern Yukon is hosted within mid-Paleozoic mafic metavolcanic and metaplutonic rocks. These rocks overlie the shallowly dipping western edge of a 112 Ma quartz monzonite body, and aplite dykes associated with the intrusion locally contain beryl. Beryl-bearing aplites chemically differ from non-mineralized intrusions by having lower potassium and fluorine, and higher beryllium contents. The main host rocks for the mineralization are high-calcium boninites (high-magnesium basalt to andesite) with anomalously high chromium contents. Beryl occurs either within quartz-tourmaline veins or in highly altered schist zones adjacent to the veins. Several generations of syn- to late-tectonic quartz veins are present at Regal Ridge, and emerald appears to be mainly associated with the latest vein set, especially near the intersection between these and older veins. All of the quartz veining is thought to be related to progressive Cretaceous deformation and the relatively late emplacement of the quartz monzonite intrusions.

RÉSUMÉ

L'émeraude dans la propriété de Regal Ridge du disctrict de Finlayson Lake dans le sud-est du Yukon est encaissée dans des roches métavolcaniques et métaplutoniques mafiques du Paléozoïque moyen. Ces roches reposent sur un massif de monzonite quartzique de 112 Ma à faible pendage vers l'ouest, et les dykes d'aplite associés à l'intrusion renferment ici et là du béryl. Les aplites à béryl diffèrent par leur composition chimique des intrusions non minéralisées : elles ont une teneur plus faible en potassium et en fluor mais plus élevée en béryllium. Les principales roches encaissantes pour la minéralisation sont des boninites à haute teneur en calcium (basalte à andésite à haute teneur en magnésium) dont les teneurs en chrome sont atypiquement élevées. Le béryl est présent soit dans des filons de quartz-tourmaline ou dans les zones schisteuses altérées jouxtant les filons. Plusieurs générations de filons de quartz syntectoniques à tarditectoniques sont présents dans la propriété de Regal Ridge et l'émeraude semble principalement associée aux filons les plus tardifs, en particulier près de l'intersection entre ces filons et les plus anciens. Tous les filons de quartz serait liés à une déformation progressive au Crétacé et à la mise en place relativement tardive d'intrusions de monzonite quartzique.

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INTRODUCTION

The Regal Ridge property is 100% owned by True North Gems, Inc. It is located in the Finlayson Lake district of southeastern Yukon within the Pelly Mountains. The property consists of 93 quartz mining claims covering a total of 18 km^2, centred at 61°16.6' north latitude, 133°5.5' west latitude on NTS map sheet 105G/7 (Fig. 1).

This paper reports on new field work by the authors during 2003. Our three-week program focussed on producing a detailed (1:2500 scale) geological map of the

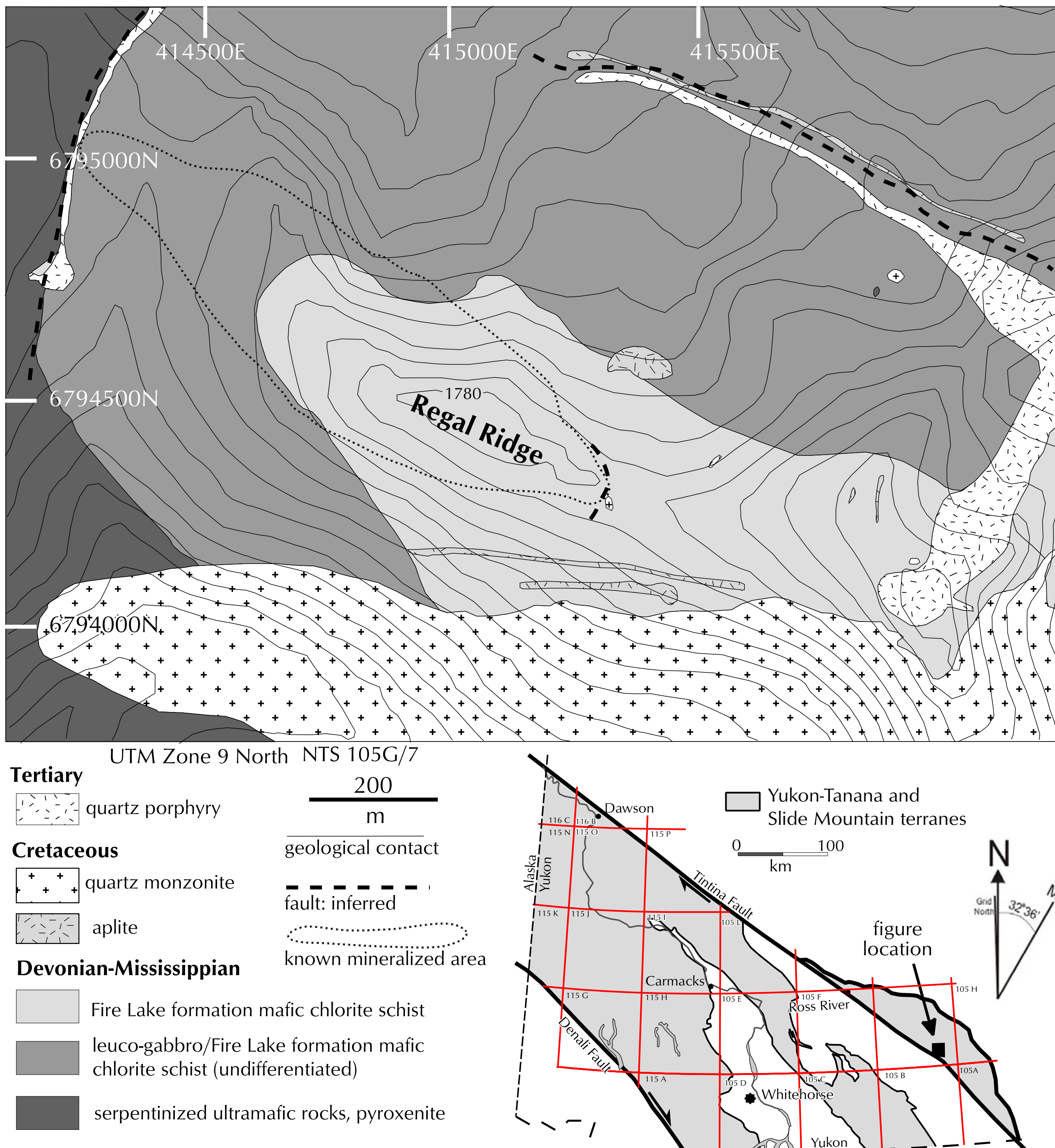

Figure 1. Geological map of the Regal Ridge property. Location map modified from Murphy, this volume. Contour interval = 20 m.

Regal Ridge property. We also carried out structural studies to better understand the structural evolution of the area and possible structural controls on the localization of emerald mineralization.

PROPERTY EXPLORATION HISTORY

Chevron Canada first explored the area from 1978 to 1980, carrying out a regional stream sediment sampling and prospecting program on the Howdee claims, 1 km southwest of the Regal Ridge property (Yukon MINFILE 2002, 105G 147, Deklerk, 2002).

With the discovery of the Kudz Ze Kayah volcanogenic massive sulphide (VMS) deposit in the early 1990s, the Finlayson Lake district saw renewed exploration interest. Expatriate Resources carried out exploration targeting VMS mineralization on the Goal claims (claims now including Regal Ridge) in 1995 and 1996, with a program involving geological mapping, prospecting, soil sampling and hand trenching.

While prospecting for Expatriate Resources in September, 1998, geologist W. Wengynowski discovered a showing of green beryl and emerald on Expatriate's GoalNet property (Goal claims). Detailed work on the property began in July, 1999; by late August, numerous green beryl- and emerald-bearing float trains and six main sources had been discovered in a 900 by 400 m area on both sides of the ridge (Groat et al., 2002).

In mid-2001, True North Gems, Inc. entered into an option agreement with Expatriate Resources Ltd. to acquire a 50% interest in the property. True North carried out an evaluation program in 2001, trench mapping and sampling over the property. In March of 2002, True North purchased Expatriate's remaining 50% interest in the Regal Ridge property. Later that year they carried out more extensive fieldwork, consisting of a small drilling program which resulted in the discovery of new mineralized zones. A small processing mill was also constructed.

Results of reconnaissance investigations of the geology and emerald occurrences of Regal Ridge carried out by the authors during the 2002 field season were summarized in Neufeld et al. (2003).

REGIONAL GEOLOGY

The Regal Ridge area is located within Yukon-Tanana Terrane (Fig. 1). Rocks in this area are composed of mainly pre-Late Devonian quartz-rich metaclastic rocks and carbonates and Late Devonian and Mississippian meta-volcanic and -plutonic rocks which are inferred to have formed in continental magmatic arc (Mortensen and Jilson, 1985; Mortensen, 1992; Murphy, 1998; Murphy and Piercey, 2000) and back-arc settings (Piercey et al., 2000a,b). The oldest rocks are in the pre-Late Devonian to earliest Mississippian Grass Lakes succession. The Fire Lake unit, a mafic meta-volcanic unit composed mainly of chloritic phyllite (Murphy et al., 2002), is the second-oldest unit within the Grass Lakes succession. The Kudz Ze Kayah unit in the footwall of the Money Creek thrust stratigraphically overlies the Fire Lake unit; and the Wolverine succession unconformably overlies the Kudz Ze Kayah unit (Piercey et al., 2001). The rocks were thrust onto the North American miogeocline between Late Triassic and earliest Cretaceous time.

All rocks are intruded by several ca. 112 Ma quartz-monzonite to granite intrusions of the Cassiar-Anvil suite. In the Finlayson Lake district these Cretaceous intrusions form a 25-km-long northerly trend, with the Regal Ridge property located at the approximate mid-point. The intrusions are late- to post-kinematic with respect to the main Cretaceous deformation, which in this area was orogen-parallel, with a northwest rather than northeast transport direction (D. Murphy, pers. comm., 2003).

The Tintina Fault lies 14 km southwest of the Regal Ridge property, and possibly related faults run through the Finlayson Lake district.

PROPERTY GEOLOGY

The main host rock for the emerald-bearing veins at Regal Ridge is green-grey chlorite-plagioclase schist that locally contains biotite and actinolite porphyroblasts. This schist forms part of the Upper Devonian Fire Lake mafic metavolcanic unit (Fig. 1; unit DF of Murphy et al., 2002). At Regal Ridge, this rock is invariably foliated and lineated, and in some areas has a waxy phyllitic texture. Despite the pervasive deformation that the unit has experienced, some quartz amygdules are still locally recognizable. Piercey et al. (1999) have shown that unit DF regionally consists of rocks with geochemical signatures ranging from boninites (high-magnesium andesite to basalt) through island arc tholeites, calc-alkaline and non-arc volcanic rocks. Geochemical analyses of the Regal Ridge mafic schist all fall in the range of high-Ca boninites (high-magnesium basalt to andesite; Fig. 2). The mafic schists on Regal Ridge have anomalously high chromium contents

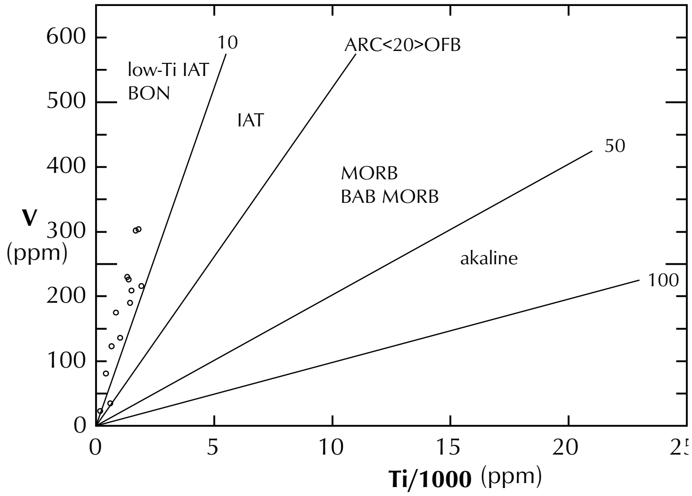

Figure 2. *Vanadium versus titanium/1000 diagram of mafic chlorite schist at Regal Ridge. The schist plots as low-titanium boninite, a high-magnesium andesite-basalt. Modified from Shervais (1982). Abbreviations: BON – boninite; IAT – island arc tholeite; MORB – mid-ocean-ridge basalt; BAB – back-arc basin; ARC – arc basalt; OFB – ocean floor basalt.*

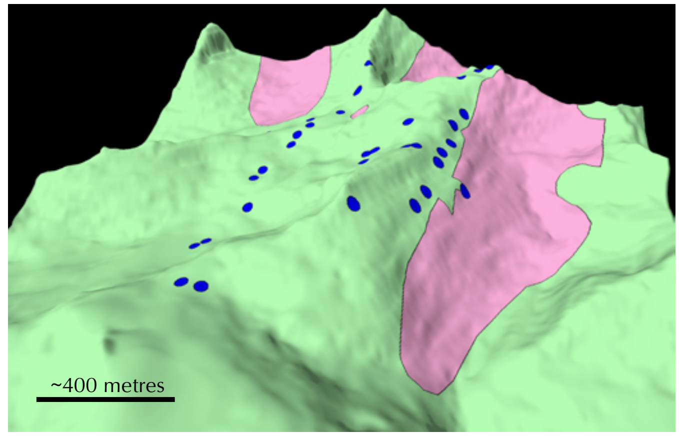

Figure 3. *Three-dimensional map looking to the east over the Regal Ridge property, showing the quartz monzonite intrusion (the darker grey) and location of aplite dykes (black circles). The mineralized area sits on the ridge, above and between protruding 'fingers' of the quartz monzonite's western edge.*

(average 960 ppm Cr), and these local host rocks are likely the source of chromium necessary for the emerald chromophore.

A biotite-actinolite-plagioclase leuco-gabbro unit (correlated with unit Dmi of Murphy et al. 2002) is closely interfingered with the mafic schist and could not be mapped separately at the scale of our mapping (Fig. 1). In hand sample, the leuco-gabbro is distinctly mottled green and white in colour, with millimetre-scale actinolite and plagioclase crystals causing the mottled texture. It is a more competent rock than the chlorite schist and is generally less altered by quartz veining.

The irregular contacts between the two units likely reflect primary interlayering (the leuco-gabbro forming synvolcanic feeder dykes and/or sills to the Fire Lake unit volcanic rocks) which has been further complicated by subsequent transposition of the original contacts.

Brown-weathering, dark green to black, variably serpentinized ultramafic rocks occur in the western and northern parts of the map area (Fig. 1). Murphy et al. (2002) suggest that the ultramafic bodies represent intrusive sills that fed the overlying Fire Lake volcanic rocks (DF) via gabbroic dykes (Dmi). Alteration of the ultramafic rocks where they are cross-cut by younger aplitic dykes and sills is highly variable, and much less extensive than that seen in the mafic schist or leuco-gabbro units. This suggests there was a more limited interaction between the host rock and the felsic magma and associated fluids. This unit has not yet been found to host emerald-bearing quartz veins.

The pluton proximal to the Regal Ridge emerald occurrence is part of the Anvil Plutonic Suite (Mortensen et al., 2000), a 112-100 Ma suite of felsic intrusions which regionally are associated with numerous tungsten, molybdenum, gold and bismuth occurrences. The 112 Ma two-mica (biotite>muscovite) quartz monzonite extends to the east of Regal Ridge, as well as far to the north and south. It is weakly foliated to unfoliated, with shallowly dipping contacts. Regal Ridge is situated above the shallowly dipping western margin of the intrusion (Fig. 3). Mapping during the 2003 field season confirmed that the mafic host rocks for emerald mineralization at Regal Ridge are underlain by Cretaceous quartz monzonite at a relatively shallow depth (approximately 800 metres) and the emerald occurrence is considerably closer to a granite body than was previously inferred by Groat et al. (2002).

Numerous aplite dykes from 40 cm to 10 m in width are present on the property. These bodies are variably strained, ranging from massive and essentially undeformed, to strongly deformed in places. The extent of hydrothermal alteration surrounding the dykes is also highly variable.

STRUCTURAL SETTING

The Fire Lake mafic metavolcanic formation was initially deformed in the early Mississippian, at ca. 360 Ma, shortly after the unit was deposited (Murphy and Piercey, 2000). This early deformation resulted in contraction and folding, and the formation of foliation-parallel, centimetre-scale, non-mineralized quartz veins. Most of this mid-Paleozoic deformation was overprinted by deformation during Cretaceous time.

In the Early Cretaceous, rocks at Regal Ridge were subjected to non-coaxial, simple shearing as a result of major contraction related to northwest-verging, Cordillera-wide orogen-parallel deformation (D. Murphy, pers. comm., 2003). Foliation related to this deformation is generally west-northwest striking in the Regal Ridge area and dips shallowly to the north. Quartz veins were formed and deformed during the progressive movement of the shear system. This resulted in considerable variability in the amount of deformation of individual veins or portions of veins depending on their orientation within the shear system and the time when they were introduced to the system. The oldest veins in the system are typically isoclinally folded and boudinaged, whereas the youngest veins are generally planar or slightly folded. Emplacement of the large quartz monzonite body to the southeast, and subsequent intrusion of aplite dykes, appears to have coincided with a re-orientation of the shear system and the development of a new generation of veins within the system. This is shown by the presence of at least two directions of lineations that are thought to have developed within the shear system and two directions of boudinage exhibited by the most strongly deformed veins. Brittle-ductile shearing outlasted intrusion of the granite and aplite bodies, since strong ductile shear zones are present within some of the aplite dykes.

Most of the quartz veining observed at Regal Ridge is thought to be related to progressive Cretaceous deformation and the relatively late-tectonic emplacement of the quartz monzonite intrusions.

Late-stage, brittle deformation, in the form of thrust and strike-slip faults and rusty-weathering alteration zones, cross-cuts much of the earlier deformation observed on the property. This deformation could be associated with regional deformation related to movement along the Tintina Fault and emplacement of Eocene dykes and sills. These dykes and brittle faults appear to follow the same zones of weakness which were exploited by the aplite bodies.

MINERALIZATION AND DISCUSSION

Twelve mineralized zones have been found thus far at Regal Ridge, within a 900- by 450-m area.

Quartz veins are abundant throughout the property, and by far the majority of them appear to be related to Cretaceous deformation. Early veins are typically relatively thin, foliation-parallel, relatively sulphide-rich, and contain no tourmaline. All of the other quartz veins, including those that contain beryl and emerald, are associated with at least some amount of tourmaline, either within the veins themselves or in the immediate vein selvages. The younger veins are at least 10 cm wide, except where they have been boudinaged. The degree of alteration surrounding the veins varies from almost no evident alteration, to metre-wide horizons of soft, rusty-weathering, jarosite-rich schist. This rustiness is likely due to weathering of finely disseminated sulphide minerals (especially pyrrhotite) that is commonly present in the alteration envelopes on the veins. Emerald is found associated with veins of several different orientations. Mineralization appears to be particularly well developed in the area of intersection between the youngest generation of veins and older, more deformed veins. Emeralds occur along the margins of quartz veins in highly altered schist, as well as within the quartz veins themselves. The mineralizing event is therefore interpreted to have occurred over a considerable period of time, but was mainly syn- to late-tectonic, coinciding with the waning stages of quartz monzonite intrusion. Crack-seal textures are present locally within some of the quartz veins, with tourmaline filling the cracks. Late ductile deformation has also affected some of the emerald-bearing veins, as evidenced by the presence of fractures healed by emerald and micro-boudinage of tourmaline grains within vein quartz.

Most aplites are spatially associated with abundant quartz veins which either cut the aplite bodies themselves or the schists immediately adjacent to the aplites. Some of these veins locally contain emerald. At least two of the aplite dykes locally contain beryl or emerald, which confirms the authors' hypothesis that there is a continuum from the

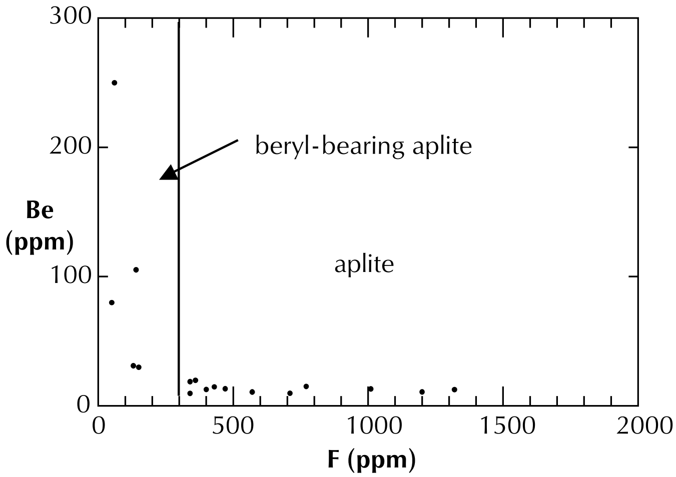

Figure 4. *Beryllium versus fluorine diagram for all Regal Ridge aplite dykes. Beryl- and emerald-bearing aplite dykes have much lower fluorine contents than aplite dykes that do not contain beryl.*

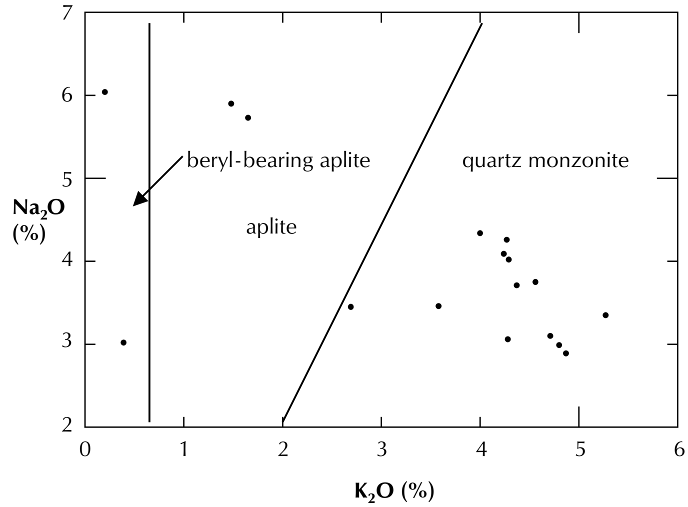

Figure 5. *Sodium- versus potassium-oxide diagram for all Regal Ridge intrusive rocks. The potassium content of beryl- and emerald-bearing aplite dykes is lower than that of non-mineralized aplite dykes. The main intrusive body has the highest potassium content.*

quartz monzonite intrusion through aplite dykes to beryl-bearing quartz veins (Neufeld et al., 2003).

Beryl-bearing aplite dykes chemically differ from non-mineralized intrusions (both aplite dykes and the main quartz monzonite body) by having lower potassium and fluorine and higher beryllium contents (Figures 4 and 5). This may provide a useful geochemical method for identifying intrusive phases elsewhere in the region that have a higher potential for being associated with emerald mineralization. The low fluorine values are surprising, however, since we hypothesize that the beryllium was transported within intrusion-derived fluids as a fluorine complex. Since an effort was made to avoid actual beryl mineralization when sampling (in order to avoid a nugget-effect chemical anomaly), it is possible that fluorine that is contained as fluorite inclusions within beryl grains was also missed. This hypothesis assumes that fluorine is intimately related to beryllium in the beryl-forming process, and only separates at the site of beryl crystallization, leaving the remainder of the intrusion relatively depleted in fluorine. However, this could alternately indicate that beryllium was transported also as a hydroxy and/or chloride complex, although there is little evidence for the latter.

CONCLUSIONS

This most recent work has resulted in a number of important findings, as listed below:

1. The discovery of emerald and beryl mineralization in the aplite dykes is more evidence for a genetic link between the quartz monzonite pluton and the emerald-bearing quartz veins.
2. The granite underlies the deposit at an estimated depth of 800 m, with depth increasing to the west-northwest.
3. The timing of deformation relative to mineralization is now understood. In particular, mineralization was syn- to late-tectonic, coinciding with the waning stages of quartz monzonite emplacement.

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