

CHROMIAN DRAVITE ASSOCIATED WITH ULTRAMAFIC-ROCK-HOSTED ARCHEAN LODE GOLD DEPOSITS, TIMMINS-PORCUPINE DISTRICT, ONTARIO

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ABSTRACT

In most instances, tourmaline associated with Canadian Archean lode gold deposits belongs to the schorl-dravite solid-solution series; Fe-rich compositions tend to predominate. However, at the Beaumont property and the Buffalo Ankerite mine in the Timmins-Porcupine district, Ontario, tourmaline is found whose elevated Cr and Mg contents warrant classification as chromian dravite (0.42-1.52 wt. % Cr₂O₃, 8.08-8.74 wt. % MgO). These tourmaline compositions show Mg > Fe > Cr and Na > Ca. Relatively high Al contents (>6 atoms per formula unit) suggest Cr substitution for Mg in the Y site rather than for Al in the Z site. Both occurrences are spatially associated with serpentinized peridotite bodies and komatiitic flows.

Keywords: tourmaline, chromium, dravite, schorl, gold deposit, Abitibi greenstone belt, komatiite, tholeiite, peridotite, Ontario.

SOMMAIRE

Dans la plupart des cas, la tourmaline associée aux gisements d'or en "veines" d'âge archéen au Canada fait partie de la solution solide schorl - dravite. Sa composition tend à être riche en fer. Toutefois, dans le cas de l'indice de Beaumont, aussi bien qu'à la mine de Buffalo Ankerite, dans le camp minier de Timmins-Porcupine, en Ontario, la tourmaline possède une teneur élevée en Mg et Cr (0.42-1.52% de Cr₂O₃, 8.08-8.74% de MgO par poids) et justifie le terme *dravite chromifère*. Les compositions montrent Mg > Fe > Cr et Na > Ca. Une teneur relativement élevée en aluminium (plus de 6 atomes par unité formulaire) fait penser que le Cr remplace le Mg dans la position Y plutôt que l'aluminium dans la position Z. Les deux exemples sont associés dans l'espace avec un massif de péridotite serpentinisé et des coulées de komatiite.

(Traduit par la Rédaction)

Mots-clés: tourmaline, chrome, dravite, schorl, gisement d'or, ceinture de roches vertes de l'Abitibi, komatiite, tholéite, péridotite, Ontario.

INTRODUCTION

Tourmaline is one of the characteristic gangue minerals in lode gold deposits of the Archean Superior Province (Bain 1933, Boyle 1979). The tourmaline mostly belongs to the schorl-dravite series,

with Fe-rich compositions predominating (King & Kerrich 1986, King *et al.* 1986, 1988, King 1988). Two occurrences of Cr-rich dravite have been identified in the course of a systematic study of the chemical and isotopic properties of tourmaline paragenetically associated with precious metal mineralization in the Abitibi greenstone belt. This paper describes mode of occurrence, geological setting, and microprobe compositions of chromian dravite from the Beaumont property and the Buffalo Ankerite mine, Timmins, Ontario, and compares them with tourmaline from other gold deposits in the Timmins-Porcupine district specifically, and the Abitibi greenstone belt in general.

GEOLOGICAL SETTING

Both the Beaumont property and Buffalo Ankerite mine are located within the Timmins-Porcupine gold district, which is one of the largest producing Archean lode gold areas in the world. The geology of the Timmins-Porcupine area has been reviewed by Dunbar (1948), Ferguson *et al.* (1968), Pyke (1975, 1982), Davies (1977), and Hodgson (1983). Volcanic and sedimentary rocks in the study area have been folded into a major west-plunging synform (Pyke 1982) called the Porcupine Syncline. The majority of gold deposits in the Timmins-Porcupine district are confined to Formation IV of the Upper Supergroup, close to the boundary between the two volcanic cycles (Pyke 1982). Most of the gold-bearing quartz - ferroan dolomite - tourmaline veins are located in brittle-ductile shear zones that crosscut the stratigraphy.

Geology of the Beaumont property

The Beaumont property lies at the base of the Upper Supergroup (Formation IV) on the north limb of the Porcupine Syncline. In the vicinity of the Beaumont property, Formation IV consists predominantly of basaltic and ultramafic flows. Gold mineralization is associated with quartz-carbonate veins emplaced along carbonatized zones that trend northeast, in general conformity with the strike of the volcanic stratigraphy. The veins are discontinu-

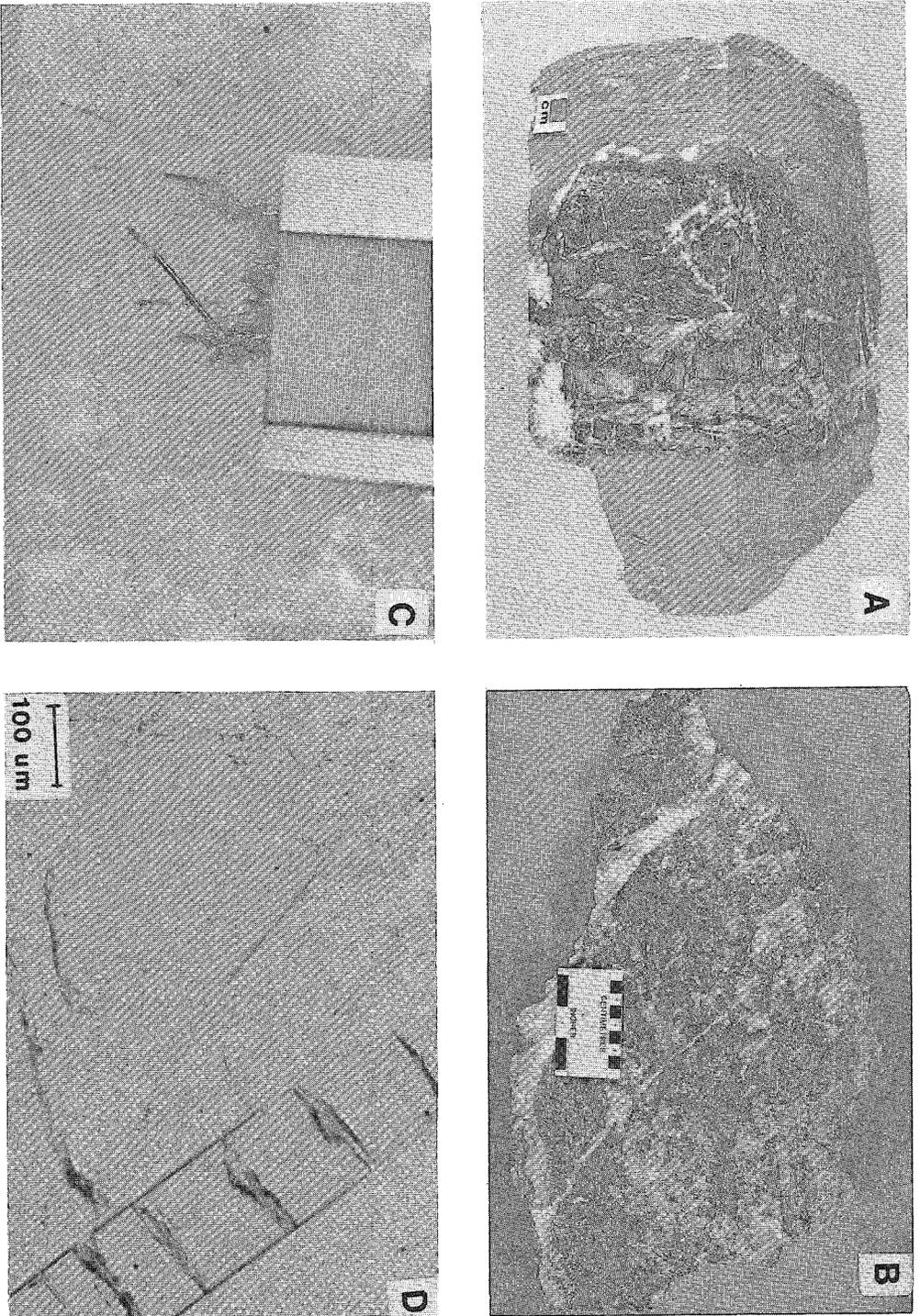


FIG. 1. A. Stratabound quartz - ferroan dolomite - tourmaline vein from the Buffalo Ankerite mine. Photograph taken on an angle to emphasize boudinaged appearance of the vein. B. Ore-bearing stockwork quartz-tourmaline vein, Buffalo Ankerite mine. C. Slender prisms of chromian dravite in quartz vein from the Beaumont property. Chromium-rich tourmaline at the Buffalo Ankerite mine occurs in the same manner (scale bar = 1 cm). D. Euhedral chromian dravite needles in a quartz vein (Beaumont property). Note the lack of optical zonation in the needles and the intense cross fracturing in longitudinal section (plane-polarized light).

ous lenses, composed mainly of quartz, many of which have flat-dipping branches (Ferguson *et al.* 1968). Pyrite and tourmaline are the only accessory minerals associated with the gold-bearing quartz veins of this deposit. No significant gold reserves have been proven despite historical underground development (1927–1928), and recent (1980s) diamond drilling.

Geology of the Buffalo Ankerite mine

Gold mineralization at the Buffalo Ankerite mine occurs at the base of the Upper Supergroup (Formation IV), on the south limb of the Porcupine Syncline. The ultramafic and Fe- and Mg-tholeiitic basalt flows exposed in the mine area are interpreted (Pyke 1982, Fyon *et al.* 1986) to be stratigraphically equivalent to flows at the Beaumont property, and to those in the area of the Pamour No.1, Bell Creek, Owl Creek, and Hoyle Pond mines on the north limb of the syncline. Basaltic and ultramafic komatiitic flows crop out at the base of the section and are overlain by Mg-rich tholeiitic basalt.

Auriferous veins in this mine differ in character from those in the remainder of the Timmins–Porcupine district in terms of the greater abundance of tourmaline (up to 65 modal %), carbonate (up to 15 modal %), and pyrite (Kinkel 1948) relative to quartz. Gold occurs predominantly as inclusions in pyrite or, less commonly, as visible gold in late-stage extensional quartz veins.

Tourmaline at the Buffalo Ankerite mine is present in three distinct generations of veins: (1) stratabound quartz – ferroan dolomite – tourmaline veins (Fig. 1A), (2) stockwork quartz–tourmaline veins (Fig. 1B), and (3) late extensional quartz veins. All three generations of tourmaline-bearing veins contain gold, but only the stockwork quartz–tourmaline veins were mined as gold ore. The tourmaline in both the stratabound and stockwork veins occurs as ultrafine-grained ($\leq 200 \mu\text{m}$), dark brown to black aggregates, layered to somewhat massive in configuration.

The third generation of tourmaline in the Buffalo Ankerite mine is a distinctive emerald green variety that occurs in zones of quartz flooding within the carbonatized ultramafic flow unit, which forms the stratigraphic footwall to the main mineralized zone. These veins, which grade $<3 \text{ g/t Au}$ (Fyon *et al.* 1986), consist largely of milky white quartz with minor amounts of acicular tourmaline and visible gold (Fig. 1C).

The Beaumont and Buffalo Ankerite study areas are characterized by their common stratigraphic position within a sequence of ultramafic to mafic volcanic flows. There is a significant difference, however, in that felsic rocks and chemical and volcanoclastic sediments only occur in the latter area.

PHYSICAL AND OPTICAL CHARACTERISTICS OF THE TOURMALINE

Chromium-rich tourmaline at both the Beaumont property and the Buffalo Ankerite mine is characterized in hand specimen by distinctive emerald green coloration. At both localities the tourmaline forms long, slender, hexagonal, prismatic, translucent crystals up to 3 cm long, with good rhombohedral terminations (Fig. 1C). Like most members of the tourmaline group except buergerite (Dietrich 1985), the chromium-rich tourmaline shows no cleavage. In thin section, the euhedral acicular tourmaline is colorless to pale green, and lacks optical zonation (Fig. 1D). This absence of optical zonation is a characteristic feature of tourmaline associated with gold deposits of the Superior Province, and contrasts with the strongly zoned tourmaline typical of pegmatites and massive sulfide deposits (Manning 1982, Taylor & Slack 1984).

In longitudinal section, the tourmaline needles show variable intensities of cross-fracturing, with some displacement along the fractures (Fig. 1D); however, no alteration occurs along the fractures. Microprobe traverses from core to rim and from core to fracture boundaries verify this observation (see below). In both occurrences, the chromium-rich tourmaline generally coexists with calcite and ferroan dolomite, albite, Cr-bearing muscovite, pyrite and gold.

TABLE 1. COMPOSITION OF TOURMALINE FROM THE BEAUMONT PROPERTY AND BUFFALO ANKERITE MINE

Location	Beaumont		Buffalo Ankerite	
	Cr-rich dravite	Cr-rich dravite	Qtz-Ank vein	stockwork vein
SiO ₂	37.33 (0.32)	37.22 (0.20)	37.19 (0.05)	37.18 (4.89)
Al ₂ O ₃	33.97 (0.60)	33.14 (0.32)	33.86 (1.06)	34.64 (1.69)
TiO ₂	0.04 (0.00)	0.08 (0.02)	0.14 (0.04)	0.25 (0.10)
FeO*	2.67 (0.28)	3.33 (0.02)	2.77 (0.24)	4.69 (2.78)
MnO	0.02 (0.00)	0.04 (0.00)	0.02 (0.00)	0.00 (0.00)
MgO	8.59 (0.02)	8.33 (0.08)	8.21 (0.10)	6.95 (0.23)
Cr ₂ O ₃	0.61 (0.03)	1.33 (0.02)	0.26 (0.02)	0.15 (0.02)
CaO	0.01 (0.00)	0.01 (0.00)	0.02 (0.00)	0.25 (0.27)
Na ₂ O	1.89 (0.25)	2.06 (0.08)	2.56 (0.08)	2.29 (0.13)
K ₂ O	0.02 (0.00)	0.01 (0.00)	0.00 (0.00)	0.02 (0.00)
Total	86.15	85.55	85.03	86.42
Structural formulae on the basis of 29 oxygen atoms				
B**	3.000	3.000	3.000	3.000
Si	6.000	6.000	6.000	5.956
Al	0.000	0.000	0.000	0.044
VI _{Al} Z	6.000	6.000	6.000	6.000
VI _{Al} Y	0.437	0.298	0.441	0.498
Ti	0.005	0.010	0.017	0.030
Fe	0.359	0.449	0.374	0.628
Mn	0.002	0.004	0.002	0.000
Mg	2.058	2.001	1.974	1.659
Cr	0.078	0.169	0.033	0.019
Y site	2.939	2.931	2.841	2.834
Ca	0.002	0.002	0.003	0.043
Na	0.589	0.644	0.801	0.711
K	0.004	0.002	0.000	0.004
X site	0.595	0.648	0.804	0.758

Notes: * Total Fe reported as FeO; ** Boron assumed to be present in amount needed to satisfy stoichiometry. Symbols: Qtz quartz, Ank ankerite.

MICROPROBE ANALYSES

The tourmaline crystals were analyzed by wavelength-dispersion techniques with an automated MAC three-channel electron microprobe at an operating voltage of 15 kV and a current of 0.25 μA . Standards included tourmaline for Si and Al (analyzed independently by wet-chemical means), kaersutite for Ti, orthopyroxene for Fe and Mg, rhodochrosite for Mn, chromite for Cr, diopside for Ca, albite for Na, and orthoclase for K. Calibration checks on standardizations were made against well-characterized homogeneous minerals, including tourmaline, kaersutite and diopside. Corrections and data reduction were conducted according to the methods of Bence & Albee (1968).

A number of core-to-rim traverses were made, using closely spaced spots 10 μm apart. The formula for tourmaline was calculated on the basis of 29 oxygen atoms, assuming three boron atoms per formula unit. Once normalized against oxygen for charge balance, if the formula showed an excess Si over six atoms per formula unit, the composition was normalized to six silicon atoms. Although such excesses

are small, they are difficult to explain in terms of the structure of tourmaline (see also Jolliff *et al.* 1986, Ethier & Campbell 1977). Average compositions with standard deviations at the 2σ level are given in Table 1.

COMPOSITION OF THE TOURMALINE

Compositions of the emerald green tourmaline from the Beaumont property and the Buffalo Ankerite mine correspond to the schorl-dravite solid-solution series, and have elevated contents of chromium (Table 1). The Buffalo Ankerite tourmaline averages 8.33 ± 0.08 wt. % (2σ) MgO, and 3.33 ± 0.02 wt. % (2σ) FeO. Accordingly, Fe/Mg values are relatively low, and compositions show 73 to 75% of the dravite component (Fig. 2). The low calcium contents (0.01 wt. % CaO) indicate a negligible uvite component. Tourmaline compositions for Beaumont are closely comparable to those from Buffalo Ankerite (Table 1). Stage-three tourmaline at the Buffalo Ankerite mine averages 1.33 wt. % Cr_2O_3 , whereas counterparts at the Beaumont property average 0.61 wt. % Cr_2O_3 .

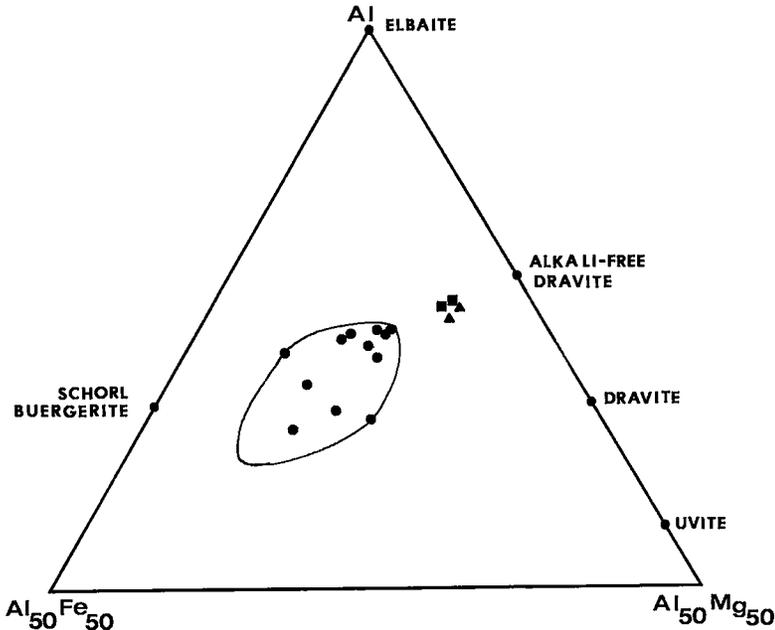


FIG. 2. Average composition of tourmaline found in Timmins gold deposits, plotted in terms of Al, Mg, and Fe. Solid triangles represent chromian dravite compositions from the Buffalo Ankerite mine and Beaumont property. Solid squares represent other generations of tourmaline at the Buffalo Ankerite mine. Solid circles represent tourmaline compositions from other gold deposits in the Timmins camp. Solid line represents boundary of tourmaline compositions from Archean lode gold deposits throughout the Superior Province (King & Kerrich 1986, King 1988).

Extensive microprobe analyses reveal that Cr ranges from 1.00 to 1.52 wt. % Cr₂O₃ for tourmaline from the Buffalo Ankerite mine, and between 0.42 and 0.79 wt. % Cr₂O₃ for the Beaumont tourmaline. This variation in Cr apparently is not due to chemical zonation of individual tourmaline grains, which are optically uniform and compositionally homogeneous with respect to Cr (see below); the variation is due to variable Cr contents from grain to grain. Only subtle chemical zonation of Cr and Mg is present, with maximum identified variations from core to rim only of about 0.2 wt. % for each element (Table 1). The remainder of the major elements have uniform concentrations in all of the seven sections analyzed. For a total of 48 analyzed spots, the range of FeO/(FeO + MgO) values is 0.22 to 0.29, and the Na₂O/(Na₂O + CaO) values span 0.98 to 1.00 (Table 1).

DISCUSSION

The ideal formula for schorl is NaFe₃⁺Al₆B₃Si₆(O,OH)₃₀(OH,F), which grades continuously, without a miscibility gap, to dravite NaMg₃Al₆B₃Si₆(O,OH)₃₀(OH,F). Although microprobe analyses of tourmaline cannot provide sufficient data to completely characterize site occupancies in the tourmaline structure, it seems that the composition of the emerald green chromian dravite conforms to the ideal formula for a tourmaline lying in the schorl–dravite series. The high Al content in the chromian dravite (> 6 atoms per formula unit) is consistent with the substitution of Cr³⁺ for Mg²⁺ in the Y site. According to Dunn (1977), Cr³⁺ may occupy either or both the Y and Z sites in tourmaline, substituting for Mg²⁺ and Al³⁺, respectively. The substitution of trivalent elements in the normally divalent (Y) site of tourmaline has been well established, as in elbaite and buergerite (Mason *et al.* 1964). However, the substitution of Cr³⁺ for Mg²⁺ in the Y site instead of for Al³⁺ in the Z site results in a charge imbalance that must be compensated for in the structural formula of the tourmaline. This charge imbalance can be rectified either by dehydroxylation or by the creation of vacancies in the alkali site, as described by Foit & Rosenberg (1977).

In both studied occurrences of chromian dravite (Table 1), the total number of cations in the Y site does not total 3, implying vacancies in the Y site. Since structural determinations of tourmaline indicate a lack of Y-site vacancies in the schorl–dravite series (Foit & Rosenberg 1977, Rosenberg & Foit 1979), it is assumed that there are no Y-site vacancies and that charge balance is maintained by substituting O²⁻ for (OH)⁻. This substitution results in the formation of a proton-deficient end-member component as described by Foit & Rosenberg (1977), which may be related in chromian dravite to vacancies in the X site.

Influence of Cr on coloration

Available microprobe data for the chromian dravite are insufficient to fully assess the importance of Cr³⁺ in producing the green coloration. Studies by both Lum (1972) and Dunn (1977) indicate that even small quantities of Cr can produce green coloration in tourmaline (see also Dietrich 1985). Manning (1969) concluded that the color of chromium-bearing green tourmaline is strongly influenced by the ⁴A_{2g} – ⁴T_{2g} – and ⁴A_{2g} – ⁴T_{2g} transitions at the two prominent absorption bands, at 17000 and 24000 cm⁻¹. The same two transitions are observed at 17800 and 24000 cm⁻¹ in chromium-bearing pyrope (Manning 1967), and at 16700 and 23000 cm⁻¹ in uvarovite (Manning 1968). The green color may also result from the presence of Fe³⁺ (Taylor & Terrell 1967), or from Fe²⁺ – Ti⁴⁺ charge transfer (Faye *et al.* 1974).

Comparison with tourmaline from other Archean gold deposits

Both occurrences of emerald green tourmaline are enriched in Cr compared to the ≤0.15 wt. % Cr₂O₃ typical of tourmaline associated with lode gold deposits of the Abitibi Subprovince specifically, and with those of the Superior Province in general (King & Kerrich 1986, King *et al.* 1986, 1988, King 1988).

Compositionally, the two other generations of tourmaline at the Buffalo Ankerite mine also are Mg-rich members of the schorl–dravite solid-solution series (Table 1) and plot close to the dravite end-member on an Al–Mg–Fe triangular diagram (Fig. 2), within the same field as the chromian dravite. Chromium abundances for both generations of tourmaline range between 0.04 and 0.27 wt. % Cr₂O₃. Although these levels of chromium are somewhat higher than the values reported for tourmaline in other gold deposits of the Abitibi greenstone belt (King & Kerrich 1986, King *et al.* 1986, 1988, King 1988), they are significantly lower than those of the chromian dravite discussed above.

In the Abitibi lode gold deposits, tourmaline with a high dravite component is known only at the Beaumont property and the Buffalo Ankerite mine. It does not occur at other gold deposits in the Timmins camp, many of which lie in the same stratigraphic sequence of volcanic units. As demonstrated on the Al–Mg–Fe diagram (Fig. 2), hydrothermal tourmaline associated with gold-bearing veins in the Timmins–Porcupine district generally plot in the schorl–dravite solid-solution series, with a tendency for Fe-rich members to predominate. This Fe-rich field identified for the Timmins–Porcupine samples also is typical of tourmaline associated with gold deposits of the Abitibi Subprovince, and the Superior Province in general (King & Kerrich 1986, King *et al.* 1986, 1988, King 1988).

In the Fe-rich compositional field shown in Figure 2, several of the data points fall below the schorl-dravite join. Some authors (*e.g.*, Henry & Guidotti 1985) infer this to mean the presence of substantial Fe^{3+} in the tourmaline. Work currently in progress, however, suggests that this does not apply to tourmaline associated with Superior Province gold deposits.

Comparison with other occurrences of chromian dravite

Relatively few occurrences of tourmaline having significant concentrations of Cr have been described in the literature, and to our knowledge none have been reported from the Superior Province. The earliest to be described, and apparently the richest in chromium, is a chromiferous dravite from the Systerter district in the Urals, identified by Cossa & Arzruni (1883). Their analysis, which shows 10.86 wt. % Cr_2O_3 , suggests substitution of Cr for Mg, rather than for Al. Since the composition has $\text{Cr} > \text{Mg} > \text{Fe}$, it might have been considered a new species within the tourmaline group. However, a re-examination of that tourmaline by Dunn (1977) showed that the material essentially has $\text{Mg} > \text{Cr} > \text{Fe}$ and is thus only a chromian dravite. Table 2 lists some published Cr-rich tourmaline occurrences with location, geological setting, Cr_2O_3 content, and inferred site-occupancy of the Cr.

Geological control on Cr-rich dravite

Provided that no crystal-chemical barriers exist, bulk composition and geochemical environment seem to be the most important factors affecting the composition of tourmaline. Both the Beaumont property and the Buffalo Ankerite mine are spatially associated with serpentinized peridotite bodies and komatiitic flows, both of which have intrinsically elevated Cr and Mg-rich bulk compositions that may have provided some of the necessary components to form the chromian dravite.

TABLE 2. COMPILATION OF PUBLISHED DATA ON CHROMIAN DRAVITE

Location	Cr_2O_3 wt. %	Cr site occupancy	References
Urals, USSR	10.86 (5.96)*	Y	1,2
Etchison, Maryland	4.32	Y	3
Krivoi Rog, USSR	1.60	Y	4
Outokumpu, Finland	9.60	Z + Y	5
Kaavi, Finland	8.87	Z + Y	5
Swat, Pakistan	8.50	Z + Y	6
Orissa-Nausahi, India	22.85-17.84	Z + Y	7,8,2
Line Pit, Pennsylv- vania-Maryland	2.60-5.40	Z + Y	9
Zimbabwe	2.26-4.93	Y	10

* re-examined by Dunn (1977). References: 1 Cossa & Arzruni (1883), 2 Dunn (1977), 3 Gill (1889), 4 Shenderova (1955), 5 Peltola *et al.* (1968), 6 Jan *et al.* (1972), 7 Mukherjee (1968), 8 Nuber & Schmetzer (1979), 9 Foord *et al.* (1968), 10 Schreyer *et al.* (1981).

Given the proximity of the three generations of tourmaline-bearing veins at the Buffalo Ankerite mine, it is unclear why only the third generation of tourmaline is enriched in Cr, whereas the first two are relatively low in Cr. The three generations have markedly different initial $^{87}\text{Sr}/^{86}\text{Sr}$ values, with the chromian dravite being the least radiogenic; this relationship suggests their precipitation from separate pulses of hydrothermal fluid, each of which equilibrated with a distinct reservoir (Kerrick *et al.* 1987). Possibly the chromian dravite formed from hydrothermal solutions that had selectively interacted with the ultramafic komatiite flows or peridotite, or that contained ligands appropriate to Cr complexation in solution. An alternative is that chromian dravite is associated with intrusion and alteration of the peridotite body in the vicinity of the Buffalo Ankerite mine, and that intrusion postdated the first two generations of tourmaline-bearing veins.

Another factor that must be taken into consideration is Cr partitioning among coexisting mineral phases. Many of the gold-bearing veins in the Timmins-Porcupine district that are hosted by ultramafic rocks are characterized by Cr-rich muscovite. Where such Cr-rich muscovite is abundant, coexisting tourmaline is not notably enriched in Cr. The hydrothermal muscovite presumably is stabilized by appropriate aqueous K-activities; accordingly, the dravite at the Buffalo Ankerite and Beaumont deposits may be Cr-rich owing to the absence of abundant coexisting muscovite. Cr partitioning in these assemblages is the subject of current studies.

Many of the reports of Cr-rich dravite in the literature do not give a full account of the geological setting. However, in all instances where the host rocks are described, Cr-rich dravite is spatially associated with ultramafic lithologies (*e.g.*, Peltola *et al.* 1968, Lum 1972, Foord *et al.* 1981). Elevated Cr contents of the host rocks thus appear to be a first-order control on the formation of chromian tourmaline.

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