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SIGNIFICANCE OF DUMORTIERITE IN AN ALUMINOSILICATE-RICH ALTERATION ZONE, LOUVICOURT, QUEBEC

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ABSTRACT

A dumortierite-bearing, aluminosilicate-rich zone of hydrothermal alteration has been found in the northeastern sector of Louvicourt Township, in the Abitibi greenstone belt, Val d'Or area, Quebec. The affected schists (metavolcanic rocks of the Malartic Group) are andalusite-bearing; they are located near the southern contact of the Bevcon pluton. The presence of dumortierite makes the rocks pinkish. Its *a* and *b* cell parameters, 11.822(5) and 20.251(7) Å, are larger than usually reported, and may reflect the presence of ^{VI}Mg and ^{IV}Al. The *c* dimension is 4.698(1) Å. The average chemical composition of the dumortierite in two samples differs slightly: $(Al_{6.56}Mg_{0.12}Ti_{0.07}Fe_{0.006}\square_{0.25})_{\Sigma 7.01}B(Si_{2.81}Al_{0.14}P_{0.04})_{\Sigma 2.99}O_{17.09}(OH)_{0.91}$ (surface exposure) and $(Al_{6.62}Mg_{0.07}Ti_{0.05}Fe_{0.03}\square_{0.25})_{\Sigma 6.99}B(Si_{2.64}Al_{0.34}P_{0.02})_{\Sigma 3.00}O_{16.90}(OH)_{1.10}$ (subsurface). The dumortierite replaces andalusite, which formed during the metamorphism and deformation of the intensely leached metavolcanic rocks. The introduction of boron thus occurred late. The presence of dumortierite, here described for the first time in the Abitibi greenstone belt, provides a valuable target for further exploration because of the link between peraluminous altered rocks and zones of Au and Cu mineralization.

Keywords: dumortierite, cell dimensions, electron-microprobe data, andalusite, alteration zones, boron, Louvicourt, Val d'Or mining district, Abitibi belt, Quebec.

SOMMAIRE

Nous décrivons une zone d'altération riche en aluminosilicate et contenant de la dumortiérite dans le secteur nord-est du canton de Louvicourt, ceinture des roches vertes de l'Abitibi, région de Val d'Or, Québec. Les schistes affectés, à l'origine des roches métavolcaniques du Groupe de Malartic, contiennent de l'andalousite; ils sont situés près du contact avec le pluton de Bevcon. La présence de dumortiérite donne aux roches une teinte rose violacée. Les dimensions *a* et *b* de la maille de la dumortiérite, 11.822(5) et 20.251(7) Å, sont supérieures à celles qui sont documentées dans la littérature, et seraient l'expression de la présence de ^{VI}Mg et ^{IV}Al. La dimension *c* est 4.698(1)Å. La composition chimique de la dumortiérite diffère légèrement dans deux échantillons: $(Al_{6.56}Mg_{0.12}Ti_{0.07}Fe_{0.006}\square_{0.25})_{\Sigma 7.01}B(Si_{2.81}Al_{0.14}P_{0.04})_{\Sigma 2.99}O_{17.09}(OH)_{0.91}$ (échantillon de surface) et $(Al_{6.62}Mg_{0.07}Ti_{0.05}Fe_{0.003}\square_{0.25})_{\Sigma 6.99}B(Si_{2.64}Al_{0.34}P_{0.02})_{\Sigma 3.00}O_{16.90}(OH)_{1.10}$ (carotte). La dumortiérite remplace l'andalousite, qui s'était formée par recristallisation métamorphique de roches métavolcaniques lessivées et déformées. L'introduction du bore serait donc tardive. La présence de la dumortiérite, signalée pour la première fois dans la ceinture de roches vertes de l'Abitibi, aurait une signification comme indice de cibles d'exploration à cause du lien entre les roches altérées hyperalumineuses et la minéralisation en Cu et Au.

Mots-clés: dumortiérite, dimensions de la maille, données à la microsonde électronique, andalousite, zones d'altération, Louvicourt, camp minier de Val-d'Or, ceinture de l'Abitibi, Québec.

INTRODUCTION

A dumortierite-bearing, aluminosilicate-rich zone of hydrothermally altered rocks has been found in the Abitibi greenstone belt, in the northeastern sector of Louvicourt Township, Val d'Or area, Quebec (Fig. 1). The occurrence of dumortierite sheds light on the locally intense hydrothermal transformations that affected meta-igneous rocks in parts of this belt. Our objectives in this paper are 1) to characterize the dumortierite, first

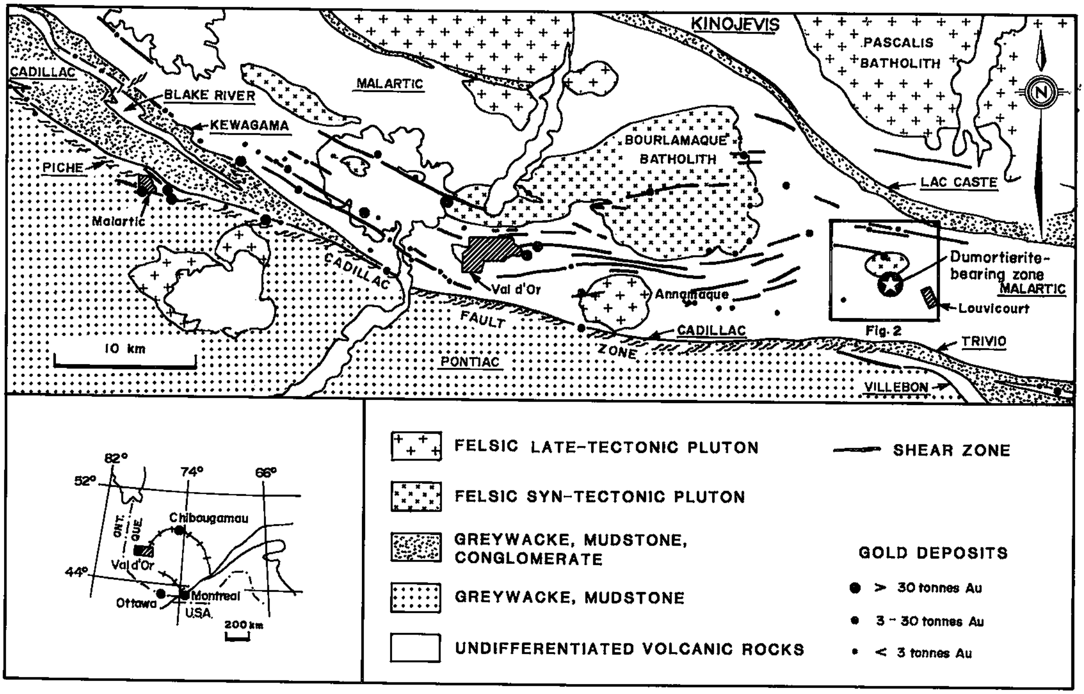

FIG. 1. Simplified geological map of the Val d'Or mining district, showing location of the dumortierite-bearing zone and of the area covered by Figure 2. The map is modified from a compilation of the Ministère de l'Énergie et des Ressources du Québec, and Imreh (1984).

noted in a fine-grained assemblage of alteration products by Taner (1984), 2) to examine its relationship with other aluminosilicate phases, and 3) to explore its possible association with Au- and Cu-bearing fluids responsible for mineralization in this part of the Abitibi belt.

GEOLOGICAL SETTING

The dumortierite-bearing zone is located in the extreme southeastern part of the Abitibi greenstone belt, in the Superior Province of Canadian Shield, about 28 km east of Val d'Or, near the junction of Highways 117 and 113 (Figs. 1, 2). The affected rocks are considered ultimately to have been volcanic in origin.

The geology of the Val d'Or mining district (Fig. 1) is dominated by suites of Archean mafic to felsic volcanic rocks, including pyroclastic facies; the major cycles of volcanic activity were separated by periods of clastic sedimentation. The volcanic sequences were intruded by several intermediate to felsic syntectonic and late-tectonic plutons of trondhjemitic to tonalitic character, of which the Bevcon pluton (Fig. 2) is considered typical. All volcanic and sedimentary rocks have been metamorphosed, generally to the greenschist facies, and locally deformed along numerous zones of mylonitization. Further information on the geological setting of igneous activity in the area is provided by Sharpe (1968), Dimroth *et al.* (1982, 1983), and Hébert *et al.* (1991).

LOCAL GEOLOGY

Several geological units can be recognized near the dumortierite-bearing zone (Fig. 2); undifferentiated mafic to felsic rocks of the Central Pyroclastic Belt of Sharpe (1968) are the most widespread. These rocks consist of 1) a complex sequence of diorites, which host the dumortierite-bearing aluminosilicate-rich assemblage, a large sericite-enriched zone (Fig. 2), and a facies containing "opalescent" quartz "eyes", such as recognized in the Dumagami mine area by Marquis *et al.* (1990), 2) undifferentiated mafic to felsic volcanic rocks of the Malartic Group, 3) a horizon of mafic volcanic rocks containing disseminated magnetite, 4) hornblende-rich diorite porphyry, similar to the diorite porphyry of the Annamaque showing (Fig. 1), and 5) a horizon of chloritoid-bearing metavolcanic rocks.

The Bevcon pluton consists of tonalite and trondhjemite, typical of the intrusive complexes in the Val d'Or mining district. It is strongly altered and locally deformed; silicification and albitization have led to the development of a micrographic intergrowth of quartz and albite (Taner 1990). The pluton hosts two gold deposits (Bevcon and Buffadisson, both former produc-

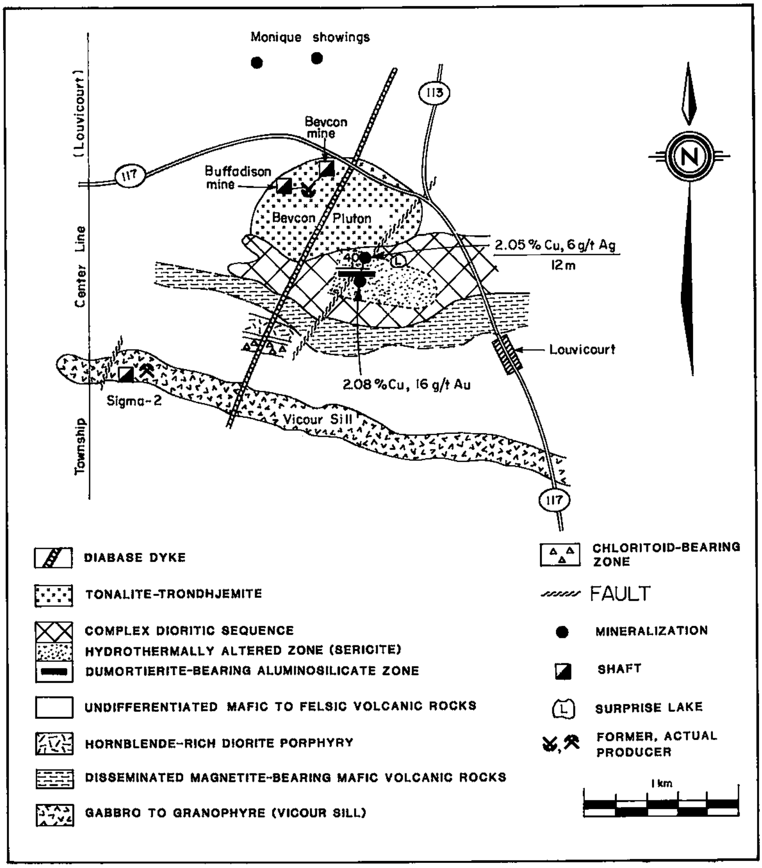

FIG. 2. Schematic local geology, from field observations and interpreted from aeromagnetic survey (Taner 1990).

ers) near its highly sheared northern border (Sauvé 1985).

To the south of the dumortierite-bearing zone, the Vicour gabbroic sill, which hosts the Sigma-2 gold mine, has local granophyric segregations (Hébert *et al.* 1988, 1991). This sill and the map-units mentioned above are cut by relatively undeformed diabase dykes.

THE DUMORTIERITE-BEARING ZONE

The dumortierite-bearing rock, an andalusite – dumortierite – rutile quartzitic schist, with local kyanite and pyrophyllite, is unevenly developed over an area of about 180 × 300 m to the south of the pluton. The same lithological unit was encountered in drill core at a depth of 275 m; on this basis, the map-unit is inferred to dip 40° to the north (Fig. 2), and seems to have a roughly constant thickness. The outcrops are mottled (Fig. 3), with the strikingly pinkish dumortierite-bearing rocks distributed over about 20% of the area. The intensity of the color varies with the proportion of dumortierite. The regionally developed schistosity strikes roughly east–west and dips steeply to the north. The axial plane of minor folds parallels the schistosity. Deformation affected a dumortierite-bearing felsic dyke whose strike is perpendicular to the schistosity.

The dumortierite-bearing schist consists of alternating grey andalusite-rich and white quartz-rich bands (Fig. 4). The grains of andalusite, 0.5 to 0.8 mm across, locally contain euhedral inclusions of dumortierite, with rare rutile. Where enriched in dumortierite, the rock is pinkish and generally contains 60% quartz, up to 20% andalusite, up to 20% dumortierite, with 2% rutile, sericite and rare epidote. Zircon and apatite are accessory phases. Kyanite occurs exclusively associated with quartz in veins. Pyrophyllite is found in the same area, in dumortierite-free rocks.

The pinkish schist is present as "knots" that range from 10 to 40 cm in diameter (Fig. 3), and as conform-

FIG. 3. Main dumortierite-rich outcrop. The purplish pink color varies in intensity with abundance of dumortierite.

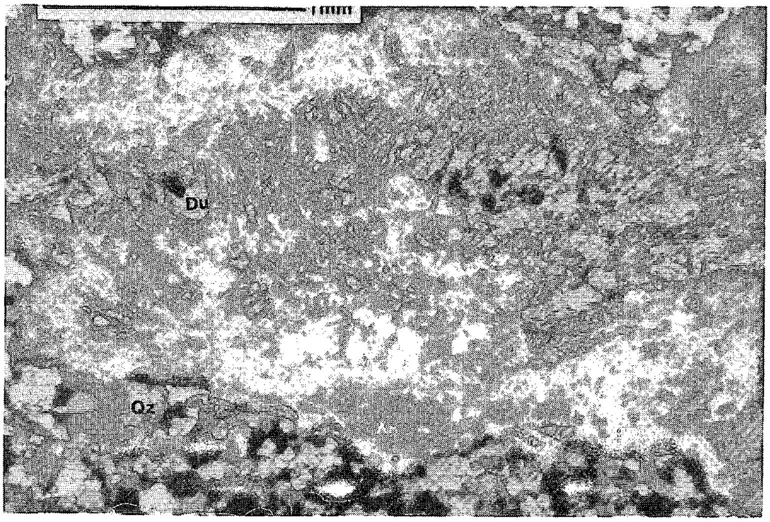

FIG. 4. Andalusite (An) phenoblast with inclusions of the euhedral, rectangular dumortierite (Du) and rutile (Ru) grains (opaque). We interpret this as textural evidence of the replacement of andalusite by dumortierite.

able layers up to one cm thick. The presence of deformed paramorphs after β-quartz, with the amoeboid shape typical of phenocrysts in felsic volcanic rocks, suggests that the impure quartzite may have developed at the expense of such a rock type. A quartzofeldspathic schist containing sericite – chlorite – rutile ± andalusite, found within the andalusite – dumortierite zone, also contains bipyramidal α-quartz paramorphic after β-quartz phenocrysts, still visible in spite of the deformation. This rock thus also is of probable felsic volcanic origin.

MINERALOGY

The dumortierite and andalusite were first identified using optical properties, and their presence later was confirmed by X-ray diffraction (powder method), first with a Gandolfi camera (diameter: 114.6 mm), then with a Guinier–Hägg focusing camera (Cu$K\alpha_1$ radiation, synthetic spinel added as internal standard).

Dumortierite, an aluminum borosilicate, consists mostly of acicular crystals (Fig. 5) 100–200 μm in length, generally radially disposed in andalusite (Fig. 6) and fibrous in quartz grains (Fig. 7). It also occurs as rectangular euhedra 100 μm across in andalusite (*e.g.*, Fig. 5). It is characterized by a distinct pleochroic scheme: X pink to purple, $Y = Z$ colorless, with a parallel extinction in the longitudinal section and a negative elongation, which distinguishes it from fibrous sillimanite. Dumortierite is biaxial negative; its $2V$ is about 40° with strong dispersion ($r > v$). Indices of refraction were measured at room temperature: α 1.670(2), $\beta \approx 1.684$ (estimated), γ 1.686(2). These values are somewhat lower than those given by Alexander *et al.* (1986). Rutile invariably lies close to the dumortierite grains (Fig. 4).

Powder-diffraction maxima from the polycrystalline dumortierite + andalusite mixture were corrected and indexed according PDF 7–71 and 13–122. On the basis of ten corrected and indexed peaks, the Louvicourt dumortierite has the following unit-cell parameters: a 11.822(5), b 20.251(7), c 4.698(1) Å. Whereas the c dimension matches the values reported for twelve natural specimens by Alexander *et al.* (1986) and seventeen examples of dumortierite synthesized at low pressure (Werding & Schreyer 1990), both the a and b dimensions of our sample exceed significantly the ranges in a and b encountered by them (11.781 – 11.802 and 20.177 – 20.222 Å, respectively: Alexander *et al.* 1986; 11.790 – 11.811 and 20.218 – 20.243 Å, respectively: Werding & Schreyer 1990). The larger unit-cell volume that results (1124.8 Å^3 compared to 1115.4 – 1122.2 Å^3) is consistent with the incorporation of a larger cation in a tetrahedrally or octahedrally coordinated position that affects the X–Y plane of this orthorhombic mineral (see Discussion). Interestingly, the cell dimensions reported by Moore & Araki (1978) for the crystal from Saharina (Madagascar) that they selected for structure analysis, a 11.828(1), b 20.243(3), c 4.7001(5) Å, resemble ours closely; unfortunately, they did not characterize its chemical composition.

The unit-cell dimensions of the andalusite, based on 22 indexed peaks, are: a 7.7967(15), b 7.8988(16), c 5.5529(11) Å, V 341.97(8) Å^3. The observed a and b values are within 1σ of those found for reference

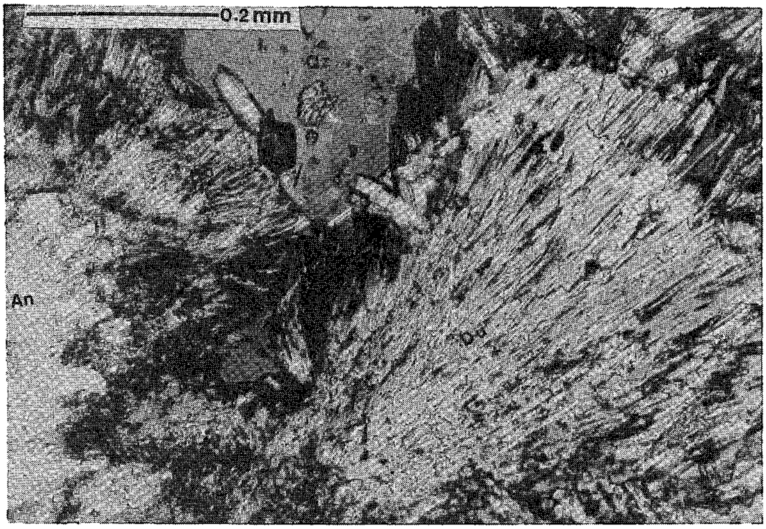

FIG. 5. Typical sheaf of radially disposed euhedral dumortierite (Du) crystals; these crystals likely did not arise by replacement, but are an overgrowth at the border of an andalusite (An) grain.

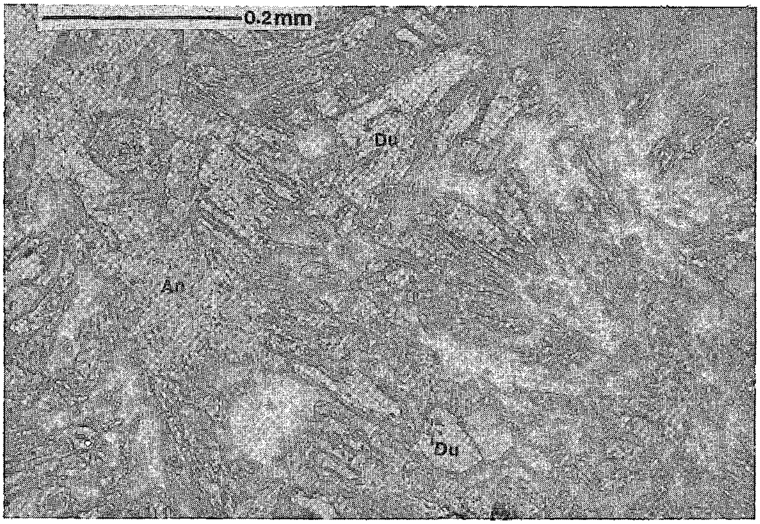

FIG. 6. Detail of replacement of andalusite (An) by dumortierite (Du).

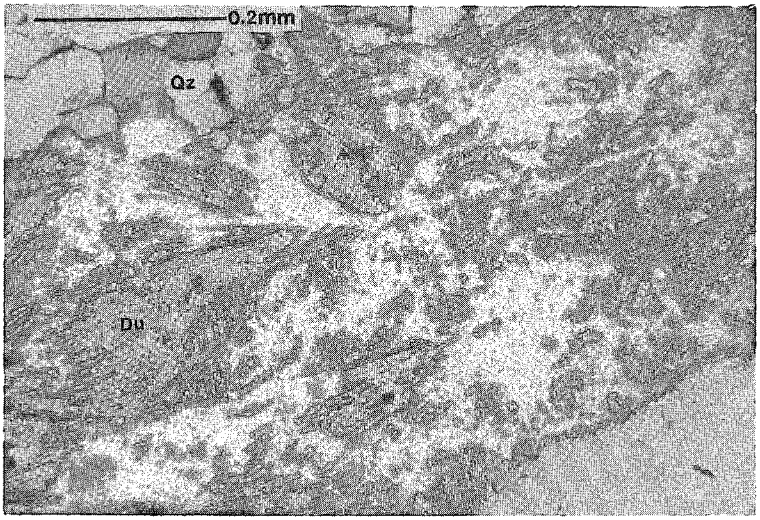

FIG. 7. Typical occurrence of fibrous dumortierite (Du) within a quartz-rich zone (Qz).

andalusite from Minas Gerais, Brazil (PDF 13–122); its *c* dimension is 5.5580 Å. The unit-cell dimensions of the kyanite, based on 42 indexed peaks, are: *a* 7.1193(8), *b* 7.8453(8), *c* 5.5696(10) Å, α 89.973(15), β 101.135(14), γ 106.004(13)°, *V* 292.93(5) Å^3. These cell parameters are very close to those of reference kyanite (PDF 11–46).

COMPOSITION OF THE DUMORTIERITE

Two different samples of dumortierite-bearing andalusite schist were studied, one from a surface exposure and one from a section of drill core (Table 1). We used using a Cameca CAMEBAX electron microprobe operated at 15 kV, 7 nA and a counting time of 30 seconds. The following standards were used: orthoclase (Al, Si in a first session), kyanite (Al, Si in a second session), diopside (Mg), andradite (Fe), manganiferous ilmenite (Mn, Ti), apatite (P) and LiF (F). The data were corrected using a ZAF program. The presence of boron as a major element was confirmed in an energy-dispersion spectrum; no element other than those reported in Table 1 is present in significant amounts. The low analytical totals

TABLE 1. COMPOSITION OF DUMORTIERITE FROM LOUVICOURT

	1	2	3	4	5
SiO_2 wt.%	29.25	29.81	27.45	27.95	31.85
TiO_2	0.89	0.92	0.67	0.68	-
Al_2O_3	59.13	60.26	61.51	62.62	60.81
FeO	0.07	0.08	0.04	0.04	-
MgO	0.81	0.83	0.51	0.52	-
P_2O_5	0.52	0.53	0.30	0.30	-
B_2O_3		6.14		6.14	6.15
H_2O^+		1.44		1.74	1.19
Total	90.67	100.00	90.48	100.00	100.00

Compositions determined by electron microprobe (see text for conditions of analysis and standards used). Columns 1 and 3 represent the average result of four spot-analyses of dumortierite from a sample of schist collected from an outcrop and from a piece of drill core, respectively. Columns 2 and 4 represent those compositions recast according to four assumptions [full occupancy of the tetrahedrally coordinated site and the boron site, presence of 0.25 vacancy in the Al(1) octahedrally coordinated site, and electrostatic neutrality] and summed to 100%. Structural formulae are reported in the text. Column 5 reports the ideal composition of the Ti-, Mg-, P-, and Fe-free end member that has the same 75% occupancy in the Al(1) site as assumed here (Moore & Araki 1978, Table 6). Mn and F were sought, but not found. Total iron is expressed as FeO. As pointed out by Alexander et al. (1986), both Fe^{2+} and Fe^{3+} likely are present.

(allowing for the presence of B and H_2O^+) encountered in a first session motivated a second round of analyses. We contend that the presence of boron as a major element, not taken into account in the ZAF correction procedure, accounts for these low totals. Totals obtained on andalusite in the same sessions are fine.

The following structural formulae were calculated on the basis of four assumptions: 1) full occupancy of the tetrahedrally coordinated site, 2) full occupancy of the boron site (both assumptions rest on refinements of the crystal structure of dumortierite: Moore & Araki 1978, Alexander *et al.* 1986), 3) 75% occupancy of the Al(1) site, as proposed by Moore & Araki (1978), and 4) electrostatic neutrality. The resulting structural formulae are $(Al_{6.56}Mg_{0.12}Ti_{0.07}Fe_{0.006}\square_{0.25})_{\Sigma 7.01}B(Si_{2.81}Al_{0.14}P_{0.04})_{\Sigma 2.99}O_{17.09}(OH)_{0.91}$ for the sample collected from the surface exposure, and $(Al_{6.62}Mg_{0.07}Ti_{0.05}Fe_{0.003}\square_{0.25})_{\Sigma 6.99}B(Si_{2.64}Al_{0.34}P_{0.02})_{\Sigma 3.00}O_{16.90}(OH)_{1.10}$ for the sample from the subsurface. Both compositions compare favorably with the end-member Ti-, Mg-, P, and Fe-free composition calculated with the same set of assumptions (Table 1, column 5), and with those reported by Alexander *et al.* (1986). The Mg content of the first sample is high, relative to most samples of dumortierite, and matches in this respect sample 7 of these authors, from the Virgin Mountains, Nevada, the most Mg-rich in their collection of twelve analyzed samples. However, such Mg contents are only one tenth the value recently documented for dumortierite in pyrope–coesite rocks from the Dora Maira massif, Western Alps (Schertl *et al.* 1991). The Ti contents encountered are in the low part of the range reported by Alexander *et al.* (1986), and Fe contents are as low as in their most iron-poor specimen. Our data and compositions quoted by Willner & Schreyer (1991) show that phosphorus is an important minor constituent of dumortierite; it should be routinely sought in future studies on this species.

A minor extent of OH-for-O substitution is required in the Louvicourt material to insure electrostatic neutrality. The importance of OH-for-O substitution was established by Moore & Araki (1978). Alexander *et al.* (1986) reported results of an infrared absorption (IR) study of three of their twelve samples, which reveals "small OH absorption bands of similar intensities"; they assumed these bands to be indicative of 0.6 wt.% H_2O, and this amount was added to the composition of each of their twelve specimens. Beukes *et al.* (1987) cautioned that moisture in the KBr pellet could be expected to mask such low concentrations of H_2O. Werding & Schreyer (1990) showed that the water in the IR spectrum is indeed structurally bound by synthesizing dumortierite with deuterium in the place of hydrogen. They found that without traces of water in their experiments, no dumortierite could be synthesized. They established that OH is an essential constituent of natural and synthetic dumortierite.

The pinkish color of the Louvicourt dumortierite stems from the relative concentration of Fe and Ti. The atomic ratio 100Fe/(Fe+Ti) is in the range 6–8, which is typical of "pale red" dumortierite, and far removed from the cutoff value between pale red and blue dumortierite [20 according to Alexander *et al.* (1986), possibly as low as 13 according to Beukes *et al.* (1987)].

COMPOSITION OF THE HOST ROCKS

Representative bulk compositions of the dumortierite-bearing schist from Louvicourt (Table 2) reflect the

TABLE 2. COMPOSITION OF DUMORTIERITE-BEARING SCHIST

	1	2	3
SiO_2 wt.%	78.50	78.44	81.03
TiO_2	0.56	0.56	0.46
Al_2O_3	19.01	18.71	15.49
Fe_2O_3	0.11	0.11	0.01
MnO	0.01	0.01	0.01
MgO	0.07	0.04	0.02
CaO	0.03	0.06	0.08
Na_2O	0.02	0.03	0.04
K_2O	0.11	0.13	0.43
P_2O_5	0.05	0.07	0.05
LOI	0.19	1.96	0.64
Total	98.65	100.11	98.24

Samples 1, 2 and 3 contain approximately 15, 10 and 40% of dumortierite by volume, respectively. Samples were analyzed by the inductively coupled plasma (ICP) technique by Chimitec Ltée, Québec. B_2O_3 not reported; total iron is reported as Fe_2O_3.

simple mineralogy of the rocks. Their composition can be explained almost entirely by the four constituents SiO_2, Al_2O_3, TiO_2 and B_2O_3. The concentration of the latter was not determined; the importance of boron in these rocks was established early by DCP emission spectrometry. A representative sample was found to contain 3000 ppm B (semiquantitative result). The rocks contain very low levels of Fe, Mn, Mg, Na, K and Ca.

Chemical data also have been acquired on other rock types exposed in the study area (Fig. 2) and mentioned above, all ultimately of igneous origin. Their bulk composition is expressed in terms of normative quartz, orthoclase, albite + anorthite, and corundum in Figure 8. The dumortierite-bearing rocks are seen to form part of a hydrothermally affected suite of meta-igneous rocks that have become highly siliceous by a combination of 1) addition of quartz and 2) efficient leaching of virtually all other constituents. Aluminum has been largely conserved in the leaching process, leading to the strongly peraluminous bulk compositions whose mineralogical expression is andalusite, pyrophyllite, sericite, and, as a result of the late addition of boron, dumortierite.

DISCUSSION

Crystal chemistry

From the work of Moore & Araki (1978), one could conclude that the extent of OH-for-O substitution in dumortierite is fixed owing to crystal-chemical considerations. In fact, the compositions synthesized hydrothermally in the simple system $Al_2O_3 - B_2O_3 - SiO_2 - H_2O$ by Werding & Schreyer (1990) contain quite variable proportions of OH and O. For example, the seven samples of single-phase dumortierite synthesized at 3 or 5 kbar described in their Table 2 contain between 1.32 and 2.30 wt.% H_2O, which works out to between 0.85 and 1.47 OH per formula unit. The amounts of H_2O^+ inferred to be present in our material (Table 1) fall in this range; the values are not firmly established, but follow from the four assumptions made in reducing the analytical data. The fact that they agree with the range of measured values of Werding & Schreyer (1990) lends credibility to our claim that the extent of OH-for-O substitution is greater than that inferred in the structural studies quoted above.

The slightly larger *a* and *b* cell dimensions of the dumortierite from Louvicourt most likely reflect the combined influence of Mg, Ti and Fe substituting for Al in the Al(2), Al(3) and Al(4) sites, and Al and P substituting in the Si(1) and Si(2) sites. Although the influence of Ti and Fe is here very small, the combined influence of ^{VI}Mg and ^{IV}Al, both at relatively high levels, is likely to be more important in affecting *a* and *b*; also, their influence likely is additive.

Significance of dumortierite at Louvicourt

We consider the feldspar-free andalusite – dumortier-

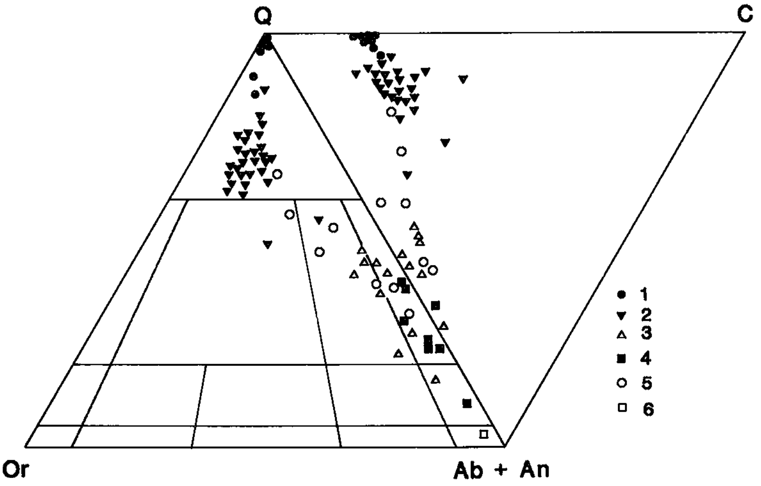

FIG. 8. Plot of normative Q, Or, Ab+An, and C (molar basis) of a suite of rocks sampled from study area (Fig. 2). Symbols: 1 dumortierite-bearing aluminosilicate-rich zone (*n* = 9), 2 hydrothermally altered zone (*n* = 33), 3 dioritic rocks with opalescent quartz "eyes" (*n* = 11), 4 Bevcon pluton (*n* = 7), 5 disseminated magnetite-bearing volcanic rocks (*n* = 7), 6 sample of the mafic dyke that cross-cuts the dioritic rocks (*n* = 1). The latter plots in the expected position for a basalt, and is unaffected by the metasomatic overprint that transformed the other rocks.

ite – rutile schist to represent the end stage of locally intense hydrothermal alteration of a meta-igneous suite of rocks. Geochemical studies of zones of modern geothermal activity (*e.g.*, Henley & Ellis 1983) and of ancient analogues (*e.g.*, Barrett & MacLean 1991, Taner & Trudel 1991) provide examples of buildup of Al by intense leaching of protoliths, presumably as a result of interaction with a low-pH fluid (*cf.* Ririe 1990). No evidence of the former presence of clay minerals and alunite expected in the original leached zone has survived in the Louvicourt suite. Deformation and regional metamorphism of the leached rocks in the field of stability of andalusite and chloritoid led to the near-complete recrystallization of the Al-enriched suite of rocks; the local preservation of relict quartz phenocrysts provides the only clear evidence that some rocks at least were rhyolitic. Boron was probably introduced late in the episode of deformation and metamorphism, as the dumortierite replaced deformed grains of andalusite. The presence of Ti in the dumortierite suggests that rutile also was a reactant in the replacement reaction.

Assemblages of peraluminous minerals are known to be spatially associated with some deposits of gold and the base metals (Ririe 1990). In two examples, the Chetwynd mine, in southwestern Newfoundland (McKenzie 1986) and the Big Bell mine, in Western Australia (Chown *et al.* 1984), the gold deposit contains a dumortierite-bearing aluminosilicate horizon. Additional examples in the Abitibi belt are provided by the sericite-rich schist horizon (ore-bearing felsic unit) of the Doyon, Bousquet and Dumagami gold deposits (Valliant *et al.* 1983, Savoie *et al.* 1986, Stone 1989, Tourigny *et al.* 1989, Marquis *et al.* 1990), which contains several Al-silicates, *e.g.*, pyrophyllite, andalusite, kyanite, Mn-rich garnet and diaspore, as well as wavellite and vivianite. Some of these minerals have been identified at or near the contact between the host rocks and mineralized quartz veins. These horizons are interpreted as a result of the metamorphism of rocks enriched in Al and Mn during the concentration of Au (Stone 1989, *cf.* Ririe 1990), and as an example of metamorphism of a zone of advanced argillic alteration (Marquis *et al.* 1990).

Tourmaline has been found to be an important gangue mineral in the lode gold deposits in the Abitibi greenstone belt. For example, it occurs in the Bevcon mine (Fig. 2; Sauvé 1985), the Sigma-2 (Fig. 2; Hébert *et al.* 1988, 1991), Sigma (Robert & Brown 1984), and Belmoral (Vu *et al.* 1987) gold mines in the Val d'Or mining district. Its presence indicates an important role for boron in rocks that show signs of hydrothermal alteration and mineralization. Presumably, dumortierite developed here instead of tourmaline because of the marked depletion of the bulk compositions in Fe, Mg, Ca and Na prior to the addition of boron. We contend that the development of dumortierite is a mineralogical expression of the association of acid metasomatism with precious-metal and base-metal mineralization (*cf.* Ririe 1990).

The Louvicourt dumortierite-bearing andalusite schist is the manifestation of a zone of aluminosilicate-rich alteration; as in other occurrences, we consider it to be the result of hydrothermal alteration and subsequent metamorphism and deformation of the Al- and Si-rich leached protolith. The assemblage is a mineralogical anomaly, and has the same importance as a geophysical or geochemical anomaly. It may, therefore, constitute a reliable target for exploration of Cu and Au deposits in the Val d'Or mining district and in analogous settings elsewhere.

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REFERENCES

ALEXANDER, V.D., GRIFFEN, D.T. & MARTIN, T.J. (1986): Crystal chemistry of some Fe- and Ti-poor dumortierites. *Am. Mineral.* **71**, 786-794.

BARRETT, T.J. & MACLEAN, W.H. (1991): Chemical, mass, and oxygen isotope changes during extreme hydrothermal alteration of an Archean rhyolite, Noranda, Quebec. *Econ. Geol.* **86**, 406-414.

BEUKES, G.J., SLABBERT, M.J., DE BRUIYN, H., BOTHA, B.J.V., SCHOCH, A.E. & VAN DER WESTHUIZEN, W.A. (1987): Ti-dumortierite from the Keimoes area, Namaqua mobile belt, South Africa. *Neues Jahrb. Mineral. Abh.* **157**, 303-318.

CHOWN, E.H., HICKS, J., PHILLIPS, G.N. & TOWNEND, R. (1984): The disseminated Archean Big Bell gold deposits, Murchison Province, Western Australia: an example of premetamorphic hydrothermal alteration. *In* Proceedings of Gold '82: the Geology, Geochemistry and Genesis of Gold Deposits (R.P. Foster, ed.). *Geol. Surv. Zimbabwe, Spec. Publ.* **1**, 305-324.

DIMROTH, E., IMREH, L., GOULET, N. & ROCHELEAU, M. (1983): Evolution of the south-central segment of the Archean Abitibi belt, Quebec. III. Plutonic and metamorphic evolution and geotectonic model. *Can. J. Earth Sci.* **20**, 1374-1388.

______, ______, ROCHELEAU, M. & GOULET, N. (1982): Evolution of the south-central part of the Archean Abitibi Belt, Quebec. I. Stratigraphy and paleogeographic model. *Can. J. Earth Sci.* **19**, 1729-1758.

Hébert, R., Gaudreau, R., Perrier, B., Giguère, C., Rocheleau, M. & Lacoste, P. (1988): Le gisement aurifère de Sigma-2 – région de Val d'Or. *Ministère de l'Énergie et des Ressources du Québec, rapp.* **MB–88–17.**

______, Rocheleau, M., Giguère, C., Perrier, B. & Gaudreau, R. (1991): Pétrologie et gîtologie d'un filon-couche différencié et minéralisé archéen: le gisement aurifère Sigma-2, canton de Louvicourt, Québec. *Can. J. Earth Sci.* **28**, 1731-1743.

Henley, R.W. & Ellis, A.J. (1983): Geothermal systems ancient and modern: a geochemical review. *Earth Sci. Rev.* **19**, 1-50.

Imreh, L. (1984): Sillon de La Motte – Vassan et son avant-pays méridional: synthèse volcanologique, lithostratigraphique et gîtologique. *Ministère de l'Énergie et des Ressources naturelles du Québec, rapp.* **MM82–04.**

Marquis, P., Hubert, C., Brown, A.C. & Rigg, D.M. (1990): Overprinting of early, redistributed Fe and Pb–Zn mineralization by late-stage Au–Ag–Cu deposition at the Dumagami mine, Bousquet district, Abitibi, Quebec. *Can. J. Earth Sci.* **27**, 1651-1671.

McKenzie, C.B. (1986): Geology and mineralization of the Chetwynd deposits, southwestern Newfoundland, Canada. *In* Proceedings of Gold '86: an International Symposium on the Geology of Gold (A.J. MacDonald, ed.). Konsult International Inc., Willowdale, Ontario (137-148).

Moore, P.B. & Araki, T. (1978): Dumortierite, $Si_3B[Al_{6.75}\square_{0.25}O_{17.25}(OH)_{0.75}]$: a detailed structure analysis. *Neues Jahrb. Mineral. Abh.* **132**, 231-241.

Ririe, G.T. (1990): A comparison of alteration assemblages associated with Archean gold deposits in Western Australia and Paleozoic gold deposits in the southeast United States. *Can. J. Earth Sci.* **27**, 1560-1576.

Robert, F. & Brown, A.C. (1984): Progressive alteration associated with gold–quartz–tourmaline veins at the Sigma mine, Abitibi greenstone belt, Quebec. *Econ. Geol.* **79**, 393-399.

Sauvé, P. (1985): Géologie de la mine Bevcon, Val-d'Or, Québec. *Ministère de l'Énergie et des Ressources du Québec, rapp.* **MB 85–04.**

Savoie, A., Perrault, G. & Filion, G. (1986): Geological setting of the Doyon gold deposits, Bousquet Township, Abitibi, Quebec, Canada. *In* Proceedings of Gold'86: an International Symposium on the Geology of Gold (A.J. MacDonald, ed.). Konsult International Inc., Willowdale, Ontario (77-107).

Schertl, H.-P., Schreyer, W. & Chopin, C. (1991): The pyrope – coesite rocks and their country rocks at Parigi, Dora Maira Massif, Western Alps: detailed petrography, mineral chemistry and PT-path. *Contrib. Mineral. Petrol.* **108**, 1-21.

Sharpe, J.I. (1968): Canton de Louvicourt, comté d'Abitibi-Est. *Ministère de l'Énergie et des Ressources du Québec, Rapp. Géol.* **135.**

Stone, W.E. (1989): Significance of metamorphism to gold distribution, Bousquet district, Abitibi greenstone belt, Canada. *In* Precious and Rare Metal Technologies (A.E. Torma & I.H. Gundiler, eds.). Elsevier, New York (29-41).

Taner, M.F. (1984): Dumortiérite dans le canton de Louvicourt, Québec; rapport d'identification. *Institut de Recherche en Exploration Minérale, projet* **84–07.**

______ (1990): Final Report on the 1990 Diamond Drilling Program, Courageous Property, Louvicourt Township, Quebec. Aur Resources Inc., Toronto (unpubl. report).

______ & Trudel, P. (1991): Gold distribution in the Val d'Or Formation and a model for the formation of the Lamaque–Sigma mines, Val-d'Or, Quebec. *Can. J. Earth Sci.* **28**, 706-720.

Tourigny, G., Hubert, C., Brown, A.C. & Crépeau, R. (1989): Structural control of gold mineralization at the Bousquet mine, Abitibi, Quebec. *Can. J. Earth Sci.* **26**, 157-175.

Valliant, R.I., Barnett, R.L. & Hodder, R.W. (1983): Aluminum silicate-bearing rock and its relation to gold mineralization, Bousquet mine, Bousquet Township, Quebec. *Can. Min. Metall. Bull.* **79**(850), 81-90.

Vu, L., Darling, R., Béland, J. & Popov, V. (1987): Structure of the Ferberger gold deposit, Belmoral Mines Ltd., Val d'Or, Quebec. *Can. Inst. Min. Metall.* **80**(907), 68-77.

Werding, G. & Schreyer, W. (1990): Synthetic dumortierite: its PTX-dependent compositional variations in the system $Al_2O_3 - B_2O_3 - SiO_2 - H_2O$. *Contrib. Mineral. Petrol.* **105**, 11-24.

Willner, A.P. & Schreyer, W. (1991): A dumortierite – topaz – white mica fels from the peraluminous metamorphic suite of Bushmanland (South Africa). *Neues Jahrb. Mineral. Monatsh.*, 223-240.