

Vermiculite in the Blue River Area, East-Central British Columbia, Canada (NTS 083D/06)

by G.J. Simandl^{1,2}, S. Paradis^{2,3}, L. Simandl⁴ and J. Dahrouge⁵

KEYWORDS: vermiculite, market, deposit, exfoliation, physical properties, carbonatite, rare earth elements, economic potential

ABSTRACT

There is currently no vermiculite produced within the Province of British Columbia. Only four localities in the BC MINFILE list vermiculite as a commodity. High concentrations of vermiculite were encountered in semiconsolidated outcrops during a hike to examine the Hodgie rare earth zone in the Blue River area. Follow-up bibliographic research indicates that this is probably a new occurrence, although similar occurrences were described in the Blue River area by McCammon (1950). Based on our observations and on the data of McCammon (1950), the occurrences located in the Blue River area have above-average vermiculite content and are certainly of higher grade than other known vermiculite occurrences in the province. Reconnaissance-level field observations, in-house particle-size analyses and rudimentary laboratory-scale exfoliation tests are encouraging. They indicate that detailed chemical and mineralogical studies are the next logical step in the assessment of this and other vermiculite occurrences in the Blue River area. Chemical analyses are required to establish trace-element levels of vermiculite-bearing material, to ensure that it does not contain elevated levels of environmentally sensitive substances. Mineralogical follow-up should establish the absence or presence of asbestiform particles. The presence of such particles would negatively impact the development of this vermiculite resource. If the outcomes of the above-recommended tests justify more rigorous laboratory and field investigations, then these occurrences of the Blue River area have the potential to become significant commercial sources of vermiculite. The closest operating vermiculite exfoliation plant is in Edmonton, Alberta, a relatively good location. This plant belongs to Grace Canada Inc.

INTRODUCTION

Vermiculite is a sheet silicate with variable chemical composition. The following formula is considered representative: $\text{Mg}_{1.8}\text{Fe}^{2+}_{0.9}\text{Al}_{4.3}\text{SiO}_{10}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. Vermiculite is commonly bronze coloured, but it can be grey-white, greenish, brown or colourless. It is characterized by a scaly appearance, low density (2.3–2.7 g/cm³), a micaceous habit and perfect basal cleavage. Individual flakes split with ease, are soft (1.5 to 2 on the Mohs scale of hardness) and pliable, but inelastic.

Vermiculite has a high total water content that can reach up to 20%, but commercial products contain from 6 to 17 wt. % H₂O. When heated to temperatures not exceeding 500°C, the water can be driven out from the vermiculite, but the mineral rehydrates readily on exposure to humidity in the air. When heated quickly to temperatures in the 870–1100°C range, vermiculite particles exfoliate by expanding at right angles to their basal cleavage. The increase in volume expected from commercial products is 8 to 12 times the original volume. On a laboratory scale, selected individual flakes may expand up to 30 times their original volume. This expansion is believed to result from the separation of the layers due to the conversion of contained interlaminar water into steam. Expanded vermiculite is a pale-coloured, low-density, porous material that is chemically inert and adsorbent. It has excellent thermal and acoustic insulation properties and high fire resistance.

Vermiculite Deposits

Economic concentrations of vermiculite are believed to form by weathering or near-surface alteration of biotite or phlogopite minerals within carbonatite bodies, ultramafic complexes or mafic gneiss units. They may also form residual deposits associated with these rock types (Birkett and Simandl, 1999; Simandl et al., 1999). Given favourable physical and chemical conditions, vermiculite also forms within a variety of intermediate and felsic rocks; however, in these settings, mafic minerals (vermiculite precursors) are present in lower concentrations. It is therefore less likely that the vermiculite occurrences hosted by intermediate and felsic rocks will have grades of economic interest. Typical vermiculite ore grades range from 20% to 35%, and processed products consist of 90% vermiculite (Hindman, 2006).

Carbonatite complexes may also contain niobium, rare earth elements (REE), phosphate, fluorite, zirconium, uranium, thorium, titanium, copper and iron mineralization (Mariano, 1989; Modreski et al., 1995; Armbrustmacher et al., 1996; Richardson and Birkett, 1996; Birkett and Simandl, 1999; Simandl et al., 1999; Simandl, 2002). With the exception of copper, these commodities have been previously reported in the Blue River area.

¹ British Columbia Ministry of Energy Mines and Petroleum Resources, Victoria, BC

² Centre for Earth and Ocean Sciences, University of Victoria, Victoria, BC

³ Geological Survey of Canada–Pacific, Sidney, BC

⁴ St. Michaels University School, Victoria, BC

⁵ Commerce Resources Corp., Vancouver, BC

This publication is also available, free of charge, as colour digital files in Adobe Acrobat® PDF format from the BC Ministry of Energy, Mines and Petroleum Resources website at <http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/Fieldwork/Pages/default.aspx>.

Market

Vermiculite is used as a lightweight aggregate in concrete; as an additive in a variety of acoustic, thermal and fire insulation products; in soil conditioning; as a fertilizer or insecticide carrier; and in absorbent packing, paints and sealants (Simandl et al., 1999; Hindman, 2006; Potter, 2009). It is also used in refractory gunning and castable mixes, in vermiculite dispersions and in replacing asbestos in brake linings, primarily for the automotive market. Recent interest in vermiculite-related nanotechnology (e.g., Weiss et al., 2006) may ultimately result in new, highly specialized but significant vermiculite markets.

Vermiculite substitutes in lightweight concrete and plaster are expanded perlite, clay, shale, slag and slate. In loose-fill thermal and fireproofing insulations, competing materials are fibreglass, perlite and rock wool. Peat, perlite, sawdust, tree bark and synthetic soil conditioners compete with vermiculite as soil-enhancement products.

World vermiculite annual production (Figure 1) is approximately 500 000 tonnes (t; Simandl et al., 1999; Potter, 2009). In 2008, the main vermiculite-producing countries were South Africa (200 000 t), China (110 000 t), United States (100 000 t), Russia (25 000 t), Brazil (15 000 t), Australia (15 000 t) and Zimbabwe (15 000 t). All remaining countries combined to account for the balance, which is less than 30 000 t (Potter, 2009).

American imports, excluding any material from Canada and Mexico, were about 54 000 tonnes for the first 8 months of 2008. China provided 70% and South Africa provided 25% of these exports (Potter, 2009).

Vermiculite concentrate (before exfoliation) is a moderately priced product that is shipped close to the market before being expanded. During 2008, depending on specifications, prices for American vermiculite concentrate, ex-plant (i.e., cost not including transportation and insurance; in bulk) ranged from US\$95 to US\$180 per tonne (Moeller, 2008). The average unit value of exfoliated vermiculite in the United States for 2008 was estimated at US\$430 per tonne (Potter, 2009).

Because most vermiculite production is confined to only three countries, transportation costs may represent a large proportion of the selling price. For example, the June 2009 prices of South African vermiculite concentrate (FOB, bulk, Rotterdam) ranged from US\$280 to US\$450 per tonne (Anonymous, 2009).

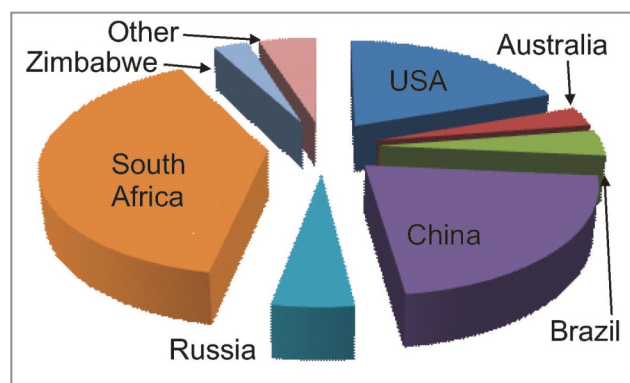


Figure 1. Main vermiculite-producing countries; total production for 2008 is approximately 510 000 tonnes (Potter, 2009).

Mining and Processing Market

Vermiculite is normally mined by open pit and, in some cases, blasting may be required. Processing of primary vermiculite ores consists of screening, blending and dry or wet beneficiation. Beneficiation may involve crushing; air classification or other methods sensitive to particle density/morphology (such as winnowing); electrostatic or high-intensity magnetic separations; and, in some cases, even flotation (Hindman, 2006). Concentrates are typically transported as close as possible to markets before being thermally or chemically exfoliated.

Vermiculite in British Columbia

There is currently no vermiculite production within the province and there are only four occurrences listed with vermiculite as a commodity in the BC MINFILE database (BC Geological Survey, 2009). Two of these occurrences were described by White (1990) and tested by Morin and Lamothe (1991). The Joseph Lake occurrence (MINFILE 093K 077) has very low vermiculite content (5.6%) and is of no of economic interest (Morin and Lamothe, 1991). The Sowchea Creek showing (MINFILE 093K 083) has a slightly higher vermiculite content; however, it does not exfoliate enough to be of economic interest (Morin and Lamothe, 1991). At the Shuttleworth Creek occurrence (MINFILE 082ESW110), vermiculite is reported to be associated with asbestiform anthophyllite. Based on this association, it is unlikely that this occurrence would be considered for follow-up work as a source of vermiculite in the foreseeable future. The Verity occurrence, in the Blue River area (MINFILE 083D 005), is carbonatite related. There is no detailed description of the vermiculite mineralization in MINFILE, but brief descriptions of vermiculite-bearing outcrops were provided by McCammon (1950). One of these occurrences could correspond to the coarse mineralization (vermiculite flakes reaching more than 15 cm across) associated with the Upper Fir carbonatite, as described by Simandl et al. (2007).

VERMICULITE IN THE BLUE RIVER AREA

During a hike to examine the newly discovered Hodgie rare earth zone in the Blue River area, anomalous concentrations of vermiculite were encountered along the access road. The fine-grained, unconsolidated vermiculite-bearing exposures, containing flakes less than 6 mm across, are the main subject of this paper. They were most likely exhumed during construction of the access road to the Hodgie rare earth zone. They may represent a new discovery, but there is a possibility that this occurrence coincides with one of the showings described by McCammon (1950).

Location

The carbonatite-related tantalum, niobium, REE and vermiculite deposits of the Blue River area (McCammon, 1953; Dahrouge, 2002; Simandl et al., 2002; Commerce Resources Corp., 2008) are spatially and genetically associated. Most of them are accessible by an extensive network of logging roads that connect to Highway 5 at the Lempriere train station, and are located approximately 40 km

north of the municipality of Blue River (Simandl et al., 2002).

The vermiculite occurrence described in this paper is located adjacent to the three diamond-drill holes that intersected the Hodgie rare earth zone, investigated for its REE content by Commerce Resources Corp. (2008). The Hodgie zone itself is located approximately 2 km southeast and uphill from the Fir carbonatite (Commerce Resources Corp., 2008). The Fir carbonatite is the main target of drilling and bulk-sampling efforts carried out by Commerce Resources

(Figure 2). The UTM (Zone 11, NAD 83) co-ordinates of the main vermiculite occurrence, sampled and described in this document, are 354137E and 5795372N at an elevation of approximately 1760 m above sea level.

Geological Setting of Blue River Carbonatites and Fenites

Vermiculite was discovered in the Blue River area in 1950 (McCammon, 1950), before the carbonate rocks

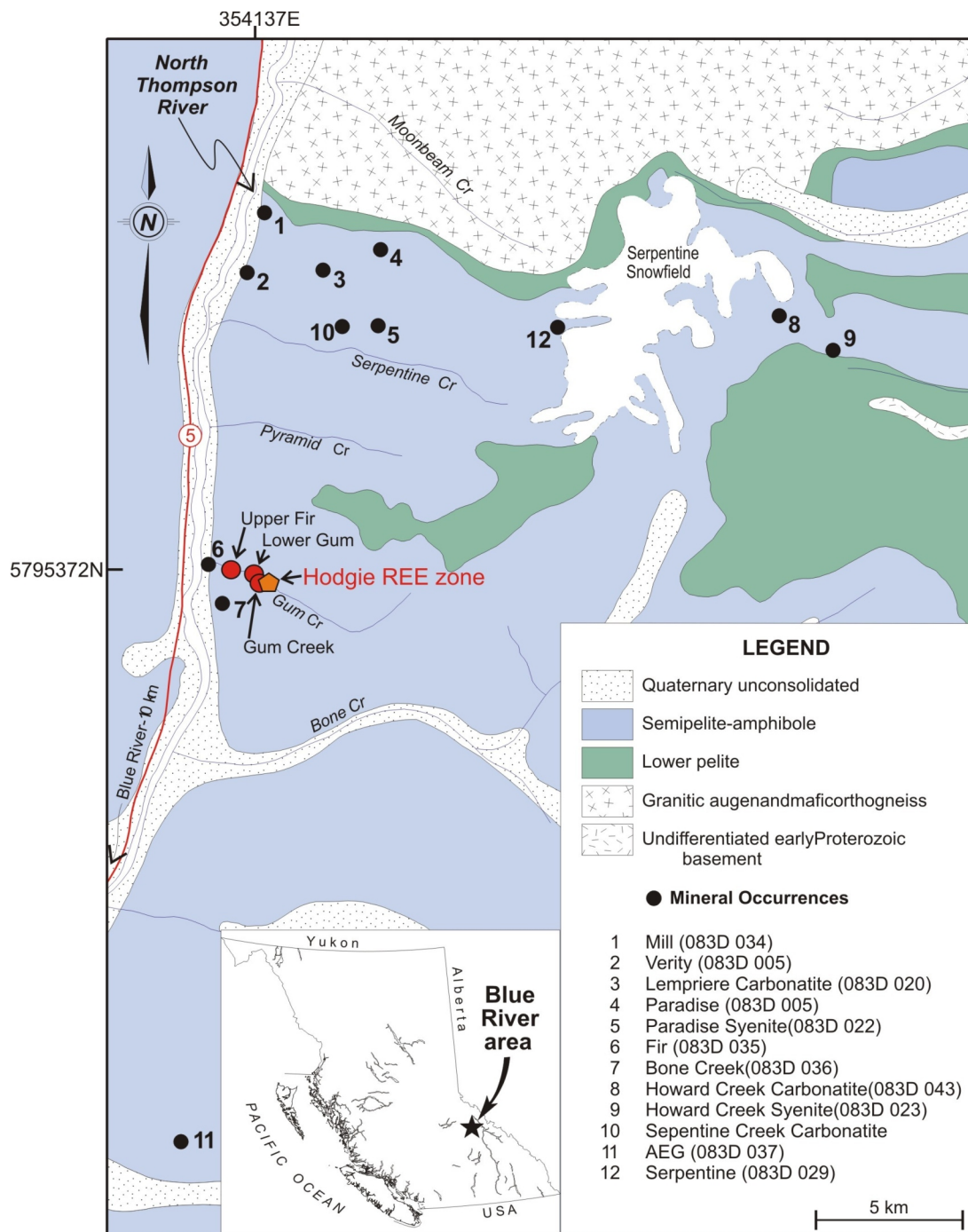


Figure 2. Location of vermiculite and carbonatite occurrences in the Blue River area, east-central British Columbia (modified from Simandl et al., 2002).

closely associated with vermiculite occurrences were recognized to be carbonatites. The carbonatites with associated fenite zones, and the related vermiculite occurrences, are part of a broad alkaline belt that follows the Rocky Mountain Trench (Pell, 1994). The Blue River carbonatites are part of the central portion of this belt and are located within the northeastern margin of the Shuswap Metamorphic Complex mapped by Campbell (1967). These carbonatites are hosted by the semipelite-amphibolite unit (Figure 1) of the Hadrynian Horsethief Creek Group (Mountjoy, 1992). Dominant rock types in the area that host carbonatites are amphibolite and biotite-feldspar-quartz (\pm garnet \pm kyanite) gneiss. Rocks within the semipelite-amphibolite unit have reached amphibolite-facies metamorphism. Sillimanite and kyanite are reported to coexist in some of the metapelite layers in this area (Campbell, 1967; Digel, 1989). The carbonatites are deformed and locally mylonitized, and appear to follow general trends observed in the hostrocks. The potassium-argon dates (White, 1982; Pell, 1994) obtained on richterite from the dolomitic Verity carbonatite are probably metamorphic (92.5 ± 3.2 and 80.2 ± 2.8 Ma). Uranium-lead dating on zircon from the same deposit indicates 325 Ma, probably the emplacement age of the carbonatite. This zircon date is more compatible with the slightly older dates from the nearby Mud Lake carbonatite and Paradise Lake syenite (363–340 Ma), also obtained on zircons (Pell, 1994). Gneisses and amphibolites host numerous crosscutting or concordant pegmatites. A number of these pegmatites are exposed in roadcuts of the deactivated access road leading to the Hodgie rare earth zone.

Vermiculite Mineralization

Vermiculite is exposed in a roadcut (break in slope) for nearly 80 m from the road fork that leads to three drillholes intersecting the Hodgie rare earth zone (Figure 3), approximately 2 km southeast and upslope of the Upper Fir carbonatite. The company reported that 84 grab samples were collected from float and outcrops in the area. Seven

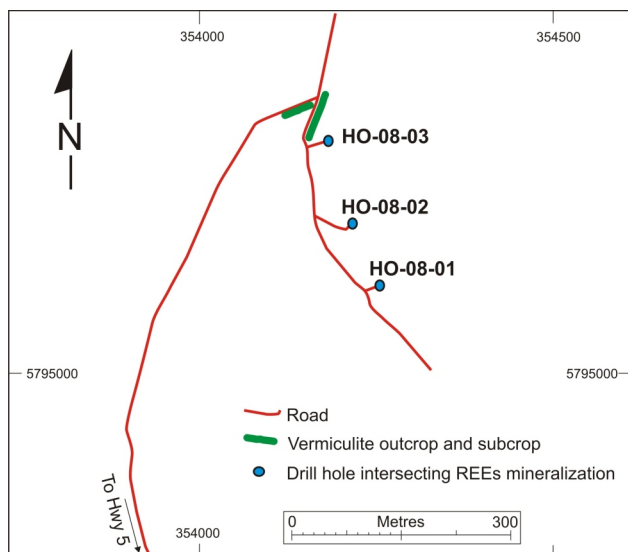


Figure 3. Sketch showing the position of the vermiculite occurrence relative to diamond-drill holes HO-08-01, HO-08-02 and HO-08-03, which intersected the Hodgie rare earth zone, Blue River area, east-central British Columbia.

samples returned total REEs + yttrium greater than 2.0%, with a high value of 11.1% (Commerce Resources Corp., 2008). The main vermiculite exposure is vertical, 0.5–3 m in height and continuous for 80 m (Figure 4). It is heterogeneous, highly friable to semiconsolidated and characterized by a layered texture that represents the original gneissic layering of the protolith (Figures 5, 6). The mineralization is unconformably overlain by overburden containing clasts of local and exotic rock types. The unconformity is sharp and irregular, and the bottom portion of the overburden has some regolith-like characteristics. The size of the vermiculite particles is equivalent to the size of the biotite flakes in the surrounding gneiss.

Unconsolidated, soil-contaminated subcrop material within the ‘lower’ roadcut (Figure 3) also contains some vermiculite. This material does not show the well-preserved primary textural features that were observed within the upper roadcut, raising the possibility that it may have slumped to its current position from the upper roadcut area.



Figure 4. An 80 m long vermiculite-bearing outcrop, adjacent to the Hodgie rare earth zone, Blue River area, east-central British Columbia.

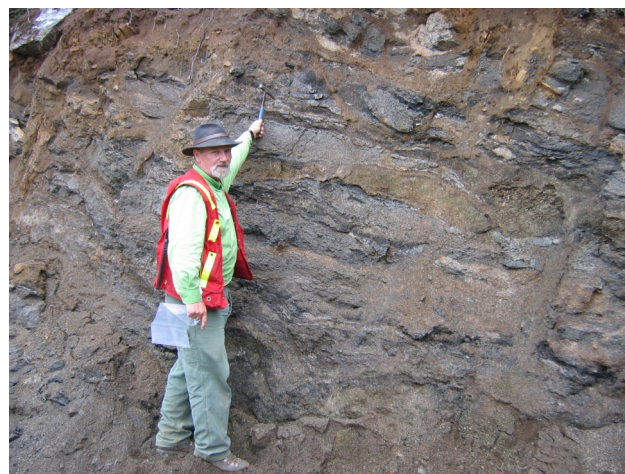


Figure 5. Vermiculite zone showing layering inherited from the protolith (mafic biotite gneiss/amphibolite), adjacent to the Hodgie rare earth zone, Blue River area, east-central British Columbia; layers dominated by amphibole are dark grey and those dominated by vermiculite are greenish and pale brown.

SAMPLING PROCEDURE AND LABORATORY WORK

Reconnaissance-type laboratory examination covers two vertical channel samples (2 and 1.5 m in length, weighing 912 and 610 g, respectively) and a grab sample (weighing 492 g) of unconsolidated, vermiculite-bearing material. Channel samples 09-SP-306 and 09-SP-307 were taken perpendicular to the layering and are considered to be representative. Grab sample 09-SP-305 represents one of the soft, high-grade mineralized layers, approximately 30 cm thick.

The samples were air dried (24 hours at 40°C) in a Despatch Industries (USA) LLB Series bench oven, weighed and screened for 2 minutes using a CE Tyler Combustion Engineering Inc. portable sieve shaker (model RX). No crushing, attrition milling or other processing-enhancing vermiculite particle liberation was done.

Grain-Size Distribution and Mineralogy

Most of the particles within the three samples that were collected are finer than 2 mm (Table 1). Macroscopic examination indicates that the main constituents of the unconsolidated mineralization are vermiculite, medium and dark green amphiboles (possibly richterite and hornblende), and feldspar (probably plagioclase). A green, vitreous, translucent mineral (probably clinopyroxene) and white, translucent, glassy mineral (most likely apatite) are the less common constituents. These minerals are present in all size fractions, but their proportions vary from sample to sample. Variations are also observed from one size fraction to the next within individual samples. Dark amphibole is most abundant in sample 09-SP-307, where the green pyroxene and plagioclase are minor non-vermiculite constituents. The dark green amphibole is also the main non-vermiculite constituent of sample 09-SP-306; however, the feldspar and the green pyroxene are significant constituents in this sample. The green, vitreous, semitransparent mineral, tentatively identified as clinopyroxene, is the main non-vermiculite constituent of sample 09-SP-305.



Figure 6. Sharp, irregular contact between amphibole-rich (dark green-grey) and vermiculite-dominated (beige to pale brown) semiconsolidated layers, vermiculite zone adjacent to the Hodgie rare earth zone, Blue River area, east-central British Columbia.

Table 1. Description and grain-size fractions of vermiculite-bearing samples from outcrop adjacent to the Hodgie rare earth zone, Blue River area, east-central British Columbia.

Sample number	Sample type	Sample weight (g)	Fraction	
			Size (mm)	Weight (g)
09-SP-305	Grab	491.7	> 4	6.6
			2–4	59.3
			1–2	122.5
			<1	298.8
09-SP-306	Channel (2 m)	911.8	> 4	98.3
			2–4	107.6
			1–2	307.4
			<1	389.6
09-SP-307	Channel (1.5 m)	609.4	> 4	3.1
			2–4	35.6
			1–2	290.7
			<1	280.0

Biotite or phlogopite appears to have been the main vermiculite precursor in all samples. Vermiculite and amphibole occur mainly as individual grains; however, depending on the sample and size fraction, up to 20% of the grains may be a compound consisting of distinct (but attached) vermiculite-amphibole grains. Textural evidence suggests that limited direct conversion of amphibole or pyroxene to very fine grained vermiculite did take place, but it does not explain the origin of the vermiculite stacks 2 mm or coarser in size. Magnetite, ilmenite, pyrrhotite, zircon, ferrocolumbite, pyrochlore and olivine were identified in the Blue River carbonatites and fenites (Simandl et al., 2002), so it is possible that they could be present as minor or trace constituents. Mineralogical studies, involving polarizing microscope, x-ray diffraction and scanning electron microscope or electron microprobe, are needed. Careful study would also be required to confirm that no asbestiform minerals are present in the vermiculite-bearing raw materials.

Exfoliation Tests

All major uses of vermiculite involve expanded products; therefore, when possible, exfoliation tests are performed during the grass-roots stage of exploration. The exfoliation of vermiculite can be achieved using a number of methods, including the insertion of organic compounds (e.g., butylammonium) into vermiculite interlayers; the decomposition of H_2O_2 (hydrogen peroxide) that penetrates between vermiculite interlayers (Obut and Girgin, 2002); microwave treatment of the concentrate (Obut et al., 2003); or thermal exfoliation (Hindman, 2006). Thermal processing remains a workhorse of the vermiculite industry for high-volume markets; therefore, thermal testing remains the most popular approach used by the industry during grass-roots mineral exploration and during the screening of development projects.

Laboratory-scale thermal-exfoliation tests have been carried out on two subeconomic, very low grade BC occurrences by Morin and Lamothe (1991). While it is not entirely clear why such low-grade deposits were tested, the document provides good examples of the methodology used. The BC Ministry of Energy, Mines and Petroleum Re-

Table 2: Results of the rudimentary laboratory-scale, thermal-exfoliation tests on raw materials (without vermiculite pre-concentration) and vermiculite grade estimates, based on samples.

Sample number	Particle size (mm)	Pre-exfoliation		Post-exfoliation		Volume increase (raw; factor)	Estimate of vermiculite content (raw; wt. %)
		Volume ($\pm 0.2 \text{ cm}^3$)	Weight ($\pm 0.05 \text{ g}$)	Volume ($\pm 0.2 \text{ cm}^3$)	Heavy fraction ($\pm 0.05 \text{ g}$)		
09-SP-305	>4						
	2–4	2	2.15	7.2	0.9	3.6	58
	1–2	2	2	6.3	0.95	3.2	52
	<1	2	2.2	5.7	1.25	2.9	43
09-SP-306	>4						
	2–4	2	2.5	2.7	2.4	1.35	4
	2–4 duplicate	2	2.3	2.4	2.1	1.2	9
	1–2	2	2.7	3.7	2.15	1.85	20
	<1	2	2.65	4.3	1.9	2.15	28
09-SP-307	>4						
	2–4	2	2.8	4	2.3	2	18
	1–2	2	2.7	4.3	1.7	2.15	47
	<1	2	2.5	5	1.1	2.5	56

sources does not have the equipment required to carry out such tests. Some of the handheld, portable propane torches (air only) are able to reach an adiabatic flame temperature of 1995°C. A propane torch is not a substitute for the tests described in the previous paragraph, but it is used in the early screening of potential perlite or vermiculite ores. Rudimentary qualitative to semiquantitative expansion tests were carried out on the <1 mm, 1–2 mm and 2–4 mm size fractions of raw samples (consisting of vermiculite and gangue minerals). The results of these tests are described in Table 2.

Mini-samples of the individual size fractions, measuring 2 cm³ in volume, were weighed and then deposited in a



Figure 7. Crude laboratory set-up used to exfoliate vermiculite-bearing rock samples taken from the outcrop adjacent to the Hodgje rare earth zone, Blue River area, east-central British Columbia.

red-hot crucible. The temperature was maintained using a propane torch (Figure 7). Heating of the container continued for 3 minutes, or until the expansion ceased. When the sample cooled, the volume of the exfoliated material was measured (Figure 8; Table 2, column 5). The volume of the mini-sample after exfoliation divided by its original (pre-exfoliation) volume, in this case 2 cm³, is indicative of volume increase (Table 2, column 7).

The expanded vermiculite had a very low density and was simply floated using water (Figure 9). The floated expanded vermiculite component from each size fraction of a given sample was collected and examined under binocular microscope. It consistently exceeded 99.5% per volume. The ‘heavy minerals component’ of the same size fraction (particles denser than expanded vermiculite) was air dried and weighed (Table 2, column 6). This component consisted mainly of gangue minerals, but the fine size fractions (<1 mm in diameter) of each sample contained up to 20% of expanded vermiculite by volume. The coarse (2–4 mm) and medium (1–2 mm) size fractions of the heavy mineral component contained consistently less than 5% expanded vermiculite per volume.

A semiquantitative estimate of the vermiculite grade of specific fractions of the three samples (Table 2, column 8) was determined by subtracting the heavy mineral component after exfoliation (Table 2, column 6) from the weight of the mini-sample prior to exfoliation (Table 2, column 4).

Trace-element chemical analyses of the vermiculite raw material and/or vermiculite concentrate are required. Excessive concentrations of base metals or radioactive elements could reduce the marketability of the product. Similarly, a detailed mineralogical study would be required to ensure that no asbestiform minerals are present in the vermiculite-bearing raw materials.

Summary of Laboratory Work

No attempt was made to upgrade the unconsolidated to weakly consolidated vermiculite-bearing samples prior to testing. Results shown in Tables 1 and 2 are useful for preliminary assessments of the occurrence, in relation to other BC occurrences.

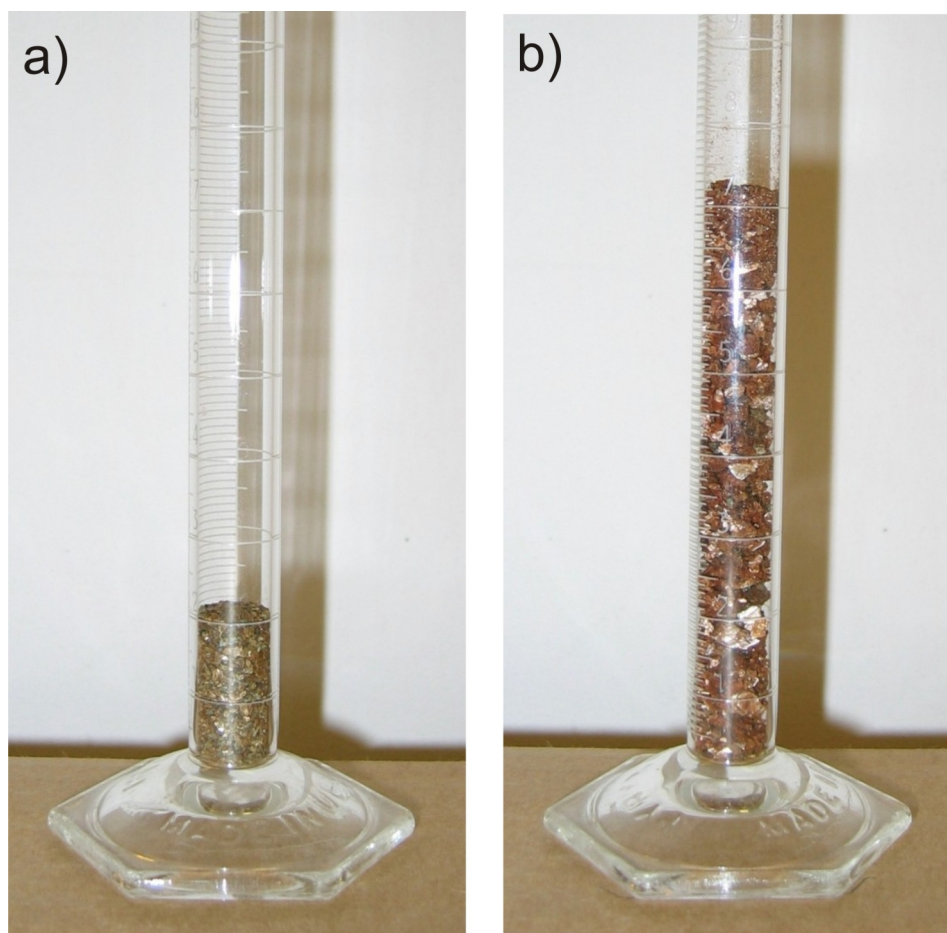


Figure 8. Change in volume caused by vermiculite exfoliation, 2–4 mm fraction of sample 09-SP-305, outcrop adjacent to the Hodgie rare earth zone, Blue River area, east-central British Columbia: **a)** pre-exfoliation, and **b)** after exfoliation.

The data confirm the following:

Vermiculite is present within the three samples.

Vermiculite grades are higher than grades reported elsewhere in the province and could locally exceed 50 wt. %.

Most of the particles composing the three samples are smaller than 2 mm.

Vermiculite content varies from sample to sample.

Vermiculite is most abundant in the coarse fraction of sample 09-SP-305 and lowest in the finest fraction. The opposite is true for samples 09-SP-306 and 09-SP-307, which have higher amphibole content than sample 09-SP-305. This is a reflection of the mineral composition of the protolith.

Mineralogical composition of each of the three samples varies according to size fraction.

Raw samples of vermiculite-bearing rock from the Blue River area exfoliate to a significant extent (Figure 10a–c); however, it is unlikely that optimal operating conditions were achieved for vermiculite exfoliation during our exfoliation experiments using the propane torch. Better results are expected if the tests are performed to the standards of the Vermiculite Institute.

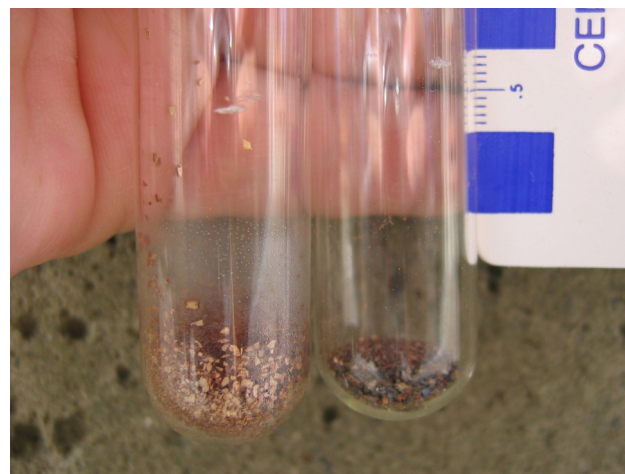


Figure 9. Separation of expanded vermiculite particles from the gangue and vermiculite-gangue composite grains of samples from outcrop adjacent to the Hodgie rare earth zone, Blue River area, east-central British Columbia; expanded vermiculite grains (left test tube) were separated by flotation (using water); composite grains, where vermiculite is attached to amphibole or other particles, have a tendency to remain within the gangue fraction (right test tube).

DISCUSSION

The vermiculite occurrence discussed in this paper may prove to be economically significant because 1) it has a relatively high vermiculite content, 2) related rudimentary exfoliation studies are encouraging, 3) there is currently no vermiculite (or perlite, the main substitute for vermiculite) production in British Columbia, and 4) the size of the surface exposure is encouraging. Evidence from the roadcuts indicates that, at least locally, carbonatites and fenites are heavily weathered (or otherwise altered) to depths in excess of 3 m. Since vermiculite is chemically inert, residual unconsolidated deposits may be found in other parts of the Blue River property. The discovery of this occurrence led to bibliographic research, which indicates that other vermiculite occurrences were reported and relatively well described in the Blue River area by McCammon (1950). These occurrences should be located and examined.

Detailed mineralogical and geochemical investigations are needed in the next stage of the investigation. Trace-element chemical analyses are required because excessive concentrations of base metals or radioactive elements could reduce the marketability of the product. Similarly, a detailed mineralogical study would be required to ensure that no asbestiform minerals are present in the vermiculite-bearing raw materials. Depending on the outcome of these mineralogical and chemical studies, more rigorous tests involving vermiculite pre-concentration and exfoliation tests may be justified and would be recommended prior to drilling or trenching.

Since the vermiculite-rich outcrops are located near the three diamond-drill holes (HO-08-1, HO-08-2 and HO-08-3) that intersect the Hodgie rare earth zone in the Blue River area, vermiculite occurrences should be analyzed for REEs. A detailed description of core (including mineralogy and geochemistry) from holes intersecting the Hodgie rare earth zone has not yet been released, and there is a possibility that it is also vermiculite rich. Vermiculite is considered by many researchers as a variety of clay. It has cation exchange capacity (CEC) in the range 100–150 milliequivalents per 100 g, more than most common clay varieties. Therefore, the remote possibility that this vermiculite mineralization also contains some REEs adsorbed (loosely bound) to the surfaces of the vermiculite laminae (analogous to the REE-bearing ionic adsorption halloysite-kaolinite ores of China) should also be investigated.

CONCLUSION

Vermiculite occurrences in the Blue River area have higher vermiculite content than any other vermiculite occurrences in British Columbia. These concentrations are comparable to the vermiculite grades in currently producing mines in other parts of the world. The response of raw vermiculite-bearing material to the exfoliation tests is encouraging. The next step should include detailed mineralogical and chemical studies. Excessive levels of base metals or radioactive elements may significantly reduce the range of potential uses for the expanded vermiculite. Similarly, detailed mineralogical study is required to establish that no asbestiform minerals are present in the vermiculite-bearing raw materials. If the outcome of these studies is positive, then rigorous metallurgical testing (vermiculite pre-concentration followed by standard exfoliation tests), mapping, trenching and drilling to establish the size and

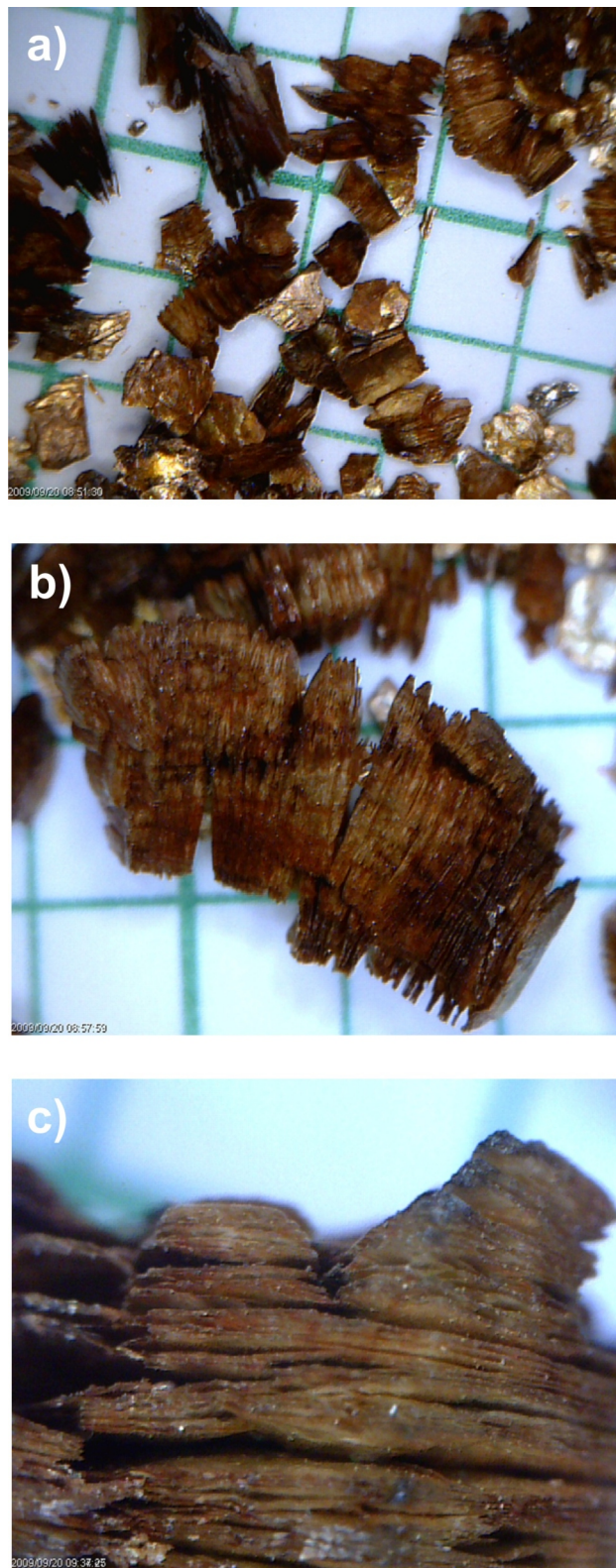


Figure 10. a) Exfoliated vermiculite-rich material derived from 2–4 mm size fraction of sample 09-SP-305, Blue River area, east-central British Columbia. b) Vermiculite particles expanding at right angles to their basal cleavage. c) Close-up of expanded vermiculite. In all three cases, the 2 mm grid is used for scale.

grade of the deposit may be warranted. Vermiculite-bearing samples should be also analyzed for REEs.

ACKNOWLEDGMENTS

The co-operation of Commerce Resources Corp. and manuscript reviews by Kirk Hancock are greatly appreciated. Ray Lett is thanked for the use of his digital microscope.

Natural Resources Canada, Earth Science Sector contribution 20090304.

REFERENCES

- Anonymous (2009): Industrial minerals; *Metal Bulletin Ltd.*, Number 501, page 69.
- Armbrustmacher, T.J., Modreski, P.J., Hoover, D.B. and Klein, D.P. (1996): Th-rare earth element vein deposits; in Preliminary Compilation of Descriptive Geoenvironmental Mineral Deposit Models, du Bray, E.A., Editor, *United States Geological Survey*, Open-File Report 95-831, pages 50–53.
- BC Geological Survey (2009): MINFILE BC mineral deposits database; *BC Ministry of Energy, Mines and Petroleum Resources*, URL <<http://minfile.ca>> [November 2009].
- Birkett, T. and Simandl, G.J. (1999): Carbonatite-associated deposits (magmatic, replacement and residual); in Selected British Columbia Mineral Deposit Profiles, Volume 3: Industrial Minerals, Simandl, G.J., Hora, Z.D. and Lefebure, D.V., Editors, *BC Ministry of Energy, Mines and Petroleum Resources*, Open File 1999-10, pages 73–76.
- Campbell, R.B. (1967): Canoe River, British Columbia; *Geological Survey of Canada*, Map 15-1967.
- Commerce Resources Corp. (2008): Development and exploration update for Blue River tantalum and niobium project in British Columbia; *Commerce Resources Corp.*, news release, December 4, 2008, 4 pages.
- Dahrouge, J. (2002): The Fir carbonatite, a potential tantalum-niobium resource; in Exploration and Mining in BC; *BC Ministry of Energy, Mines and Petroleum Resources*, pages 83–88.
- Digel, S.G., Ghent, E.D. and Simony, P.S. (1989): Metamorphism and structure of the Mount Cheadle area, Monashee Mountains, British Columbia; in Current Research, Part E, *Geological Survey of Canada*, Paper 89-1E, pages 95–100.
- Hindman, J.R. (2006): Vermiculite; in Industrial Minerals and Rocks; Kogel, J.E., Trivedi, N.C., Barker, J.M. and Krukowski, S.T., Editors, *Society for Mining, Metallurgy and Exploration Inc.*, pages 1015–1026.
- Mariano, A.N. (1989): Nature of economic mineralization in carbonatites and related rocks; in Carbonatites, Bell, K., Editor, *Unwin Hyman*, London, pages 149–176.
- McCammon, J.W. (1950): Vermiculite; in Minister of Mines, Annual Report, 1950; *BC Ministry of Energy, Mines and Petroleum Resources*, pages 229–230.
- McCammon, J.W. (1953): Lempriere; in Minister of Mines, Annual Report, 1952; *BC Ministry of Energy, Mines and Petroleum Resources*, pages 115–119.
- Modreski, P.J., Armbrustmacher, T.J. and Hoover, D.B. (1995): Carbonatite deposits; in Preliminary Compilation of Descriptive Geoenvironmental Mineral Deposit Models, du Bray, E.A., Editor, *United States Geological Survey*, Open-File Report 95-831, pages 47–49.
- Moeller, E. (2008): Vermiculite; *Mining Engineering*, Volume 60, Number 6, page 64.
- Morin, L. and Lamothe, J.-M. (1991): Testing on perlite and vermiculite samples from British Columbia; in Geological Fieldwork 1990, *BC Ministry of Energy and Mines and Petroleum Resources*, Paper 1991-1, pages 265–268.
- Mountjoy, K.J. (1992): MINFILE NTS 083D – Canoe River area and part of 083C – Brazeau; British Columbia; *BC Ministry of Energy, Mines and Petroleum Resources*, MINFILE, 133 pages.
- Obut, A. and Girgin, I. (2002): Hydrogen peroxide exfoliation of vermiculite and phlogopite; *Mineral Engineering*, Volume 15, pages 683–687.
- Obut, A., Girgin, I. and Yörükoğlu (2003): Microwave exfoliation of the vermiculite and phlogopite; *Clays and Clay Minerals*, Volume 51, pages 452–456.
- Pell, J. (1994): Carbonatites, nepheline syenites, kimberlites and related rocks in British Columbia; *BC Ministry of Energy, Mines and Petroleum Resources*, Bulletin 88, 133 pages.
- Potter, M.J. (2009): Vermiculite; in Mineral Commodity Summaries, *United States Geological Survey*, pages 182–183.
- Richardson, D.G. and Birkett, T.C. (1996): Carbonatite associated deposits; in Geology of Canadian Mineral Deposit Types, Ecstrand, O.R., Sinclair, W.D. and Thorpe, R.I., Editors, *Geological Survey of Canada*, Geology of Canada, Number 8, pages 541–558.
- Simandl, G.J. (2002): Tantalum market and resources: an overview; in Geological Fieldwork 2001, *BC Ministry of Energy and Mines and Petroleum Resources*, Paper 2002-1, pages 315–320.
- Simandl, G.J., Birkett, T. and Paradis, S. (1999): Vermiculite; in Selected British Columbia Mineral Deposit Profiles, Volume 3: Industrial Minerals, Simandl, G.J., Hora, Z.D. and Lefebure, D.V., Editors, *BC Ministry of Energy, Mines and Petroleum Resources*, Open File 1999-10, pages 69–72.
- Simandl, G.J., Jones, P.C. and Rotella, M. (2002): Blue River carbonatites, British Columbia – primary exploration targets for tantalum; in Exploration and Mining in British Columbia – 2001, *BC Ministry of Energy and Mines and Petroleum Resources*, pages 73–82.
- Simandl, G.J., Irvine, M.L., Grieve, D., Lane R., Wojdak, P., Madu, B., Webster, I., Northcote, B. and Schroeter, T. (2007): Industrial minerals in British Columbia – 2006 review; *BC Ministry of Energy, Mines and Petroleum Resources*, Information Circular 2007-2, 14 pages.
- Weiss, Z., Valaskova, M., Seidlerova, J., Supova-Kristkova, M., Sustai, O., Matejka, V. and Capkova, P. (2006): Preparation of vermiculite nanoparticles using thermal hydrogen peroxide treatment; *Journal of Nanoscience and Nanotechnology*, Volume 6, pages 726–730.
- White, G.P.E. (1982): Notes on carbonatites in central British Columbia (83D/6E); in Geological Fieldwork 1981, *BC Ministry of Energy and Mines and Petroleum Resources*, Paper 1982-1, pages 68–69.
- White, G.V. (1990): Perlite and vermiculite occurrences in British Columbia; in Geological Fieldwork 1989, *BC Ministry of Energy and Mines and Petroleum Resources*, Paper 1990-1, pages 481–487.

