ULTRAMAFIC ROCKS IN BRITISH COLUMBIA: DELINEATING TARGETS FOR MINERAL SEQUESTRATION OF CO_2

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KEYWORDS: CO_2 sequestration, ultramafic, mineral potential, serpentinite, dunite.

SUMMARY

British Columbia has favourable geology and excellent exploration potential to host the raw materials suitable for CO_2 mineral carbonation, one of the methods considered for lowering greenhouse gas levels. British Columbia has been situated on the active, west-facing Pacific margin of continental North America for at least the last 530 million years, and subjected to a subduction zone (accretionary) tectonic setting for the last 390 million years. Due to its tectonic history, British Columbia contains numerous Alpine-type and several Alaskan-type complexes, both types rich in Mg-silicates. Dunite zones within these complexes are currently considered as the most promising sources of raw materials for the mineral sequestration process, since they contain the most Mg by weight, the component necessary for binding with CO_2 to form stable carbonates. In addition, stock piles containing short fibre chrysotile mined from serpentine-rich zones in ultramafic complexes may provide a source of starting material, thereby simultaneously disposing of CO_2 as well as potentially hazardous materials. British Columbia's ultramafic rocks were studied previously as possible hosts of base metals, precious metals and gemstones. This study draws relevant information from that research and utilizes the database originally designed to evaluate mineral potential for the province. From this database a map depicting dunite- and serpentinite-bearing ultramafic rocks has been produced. Several targets have been selected, relying on preliminary data including mineralogy, geochemistry, potential size of the resource, accessibility and proximity to major CO_2 point sources. These include the dunite zone of the Alaskan-type Tulameen Complex near Princeton and the Cassiar Chrysotile tailings in northern British Columbia. These targets are the subject of current detailed research.

INTRODUCTION

A number of carbon dioxide (CO_2) sequestration methods, including geological storage, ocean storage and mineral sequestration have been proposed worldwide, and methods conceivably applicable to British Columbia (BC) were listed and reviewed by Voormeij and Simandl (2003a). Mineral carbonation is considered to be the only method that truly disposes of CO_2 on a geologic time-scale and with minimum risk of leakage (Lackner *et al.*, 1997; O'Connor *et al.*, 2000). Although Ca-silicates (e.g. wollastonite) may also have potential for mineral carbonation (Wu *et al.*, 2001; Kakizawa *et al.*, 2001), Mg-silicates are more common in high concentrations and as large deposits (Goff and Lackner, 1998). Mg-silicates also contain more reactive material per tonne than Ca-silicates (Lackner *et al.*, 1997). The mineral carbonation concept is based on the natural weathering process of Mg-olivine (forsterite) and serpentine, which carbonate by the following reactions:

$$\underset{\text{[olivine]}}{Mg_2SiO_4} + 2CO_2 \Rightarrow \underset{\text{[magnesite]}}{2MgCO_3} + \underset{\text{[silica]}}{SiO_2} \qquad (1)$$

$$\underset{\text{[serpentine]}}{Mg_3SiO_3(OH)_4} + 3CO_2 \Rightarrow \underset{\text{[magnesite]}}{3MgCO_3} + \underset{\text{[silica]}}{2SiO_2} + H_2O \qquad (2)$$

This process is thermodynamically favoured in near surface environments and its products are stable on a geological time scale. The concept was first proposed by Seifritz (1990) and considered in more details by Lackner *et al.* (1997), O'Connor *et al.* (1999; 2000) and Kohlmann and Zevenhoeven (2001; 2002).

The mineral carbonation process, as considered in this paper, is envisioned in an industrial setting (*ex situ*). Geographical location, proximity to infrastructure, the size of dunite and serpentinite resources and their physical and chemical properties are some of the important factors determining the potential viability of mineral sequestration in BC. Ideal sites should be located close to both the Mg-silicate deposit and a major CO_2 emission point source to minimize transportation costs of the CO_2 and raw materials. Geographic distribution of major stationary CO_2 point sources in BC has been completed (Voormeij and Simandl, 2003b). In order to match sinks to these point sources, areas with the potential to host raw material for mineral CO_2 sequestration need to be identified. Dunite zones of ultramafic complexes are preferred over the serpentinite zones, since they contain the most magnesium by weight. Serpentinite zones are more common and for this reason are also considered as candidates. Detailed methodology proposed for systematic evaluation of the ultramafic materials for use in mineral carbonation is outside of the scope of this study and is covered by Voormeij and Simandl (in preparation).

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ULTRAMAFIC ROCKS

Petrology and Mineralogy

Serpentine and forsteritic olivine are common silicates with high magnesium contents. There are three principal forms of serpentine: lizardite, antigorite and chrysotile (Deer, Howie and Zussman, 1978), all with the approximate composition $Mg_3Si_2O_5(OH)_4$. The most abundant is lizardite, whereas the fibrous chrysotile is relatively rare. The latter is perhaps best known since it had many industrial applications including fireproofing insulation, specialty paints, brake pads, gaskets, etc. (Virta and Mann, 1994). It has also been used extensively in construction materials such as cements and tiles. However, the use of chrysotile was severely curtailed due to health regulations associated with its use (Hamel, 1998) and banned in several European countries.

Olivine exists as a solid solution series between the Mg_2SiO_4 (forsterite) and Fe_2SiO_4 (fayalite) end members. The monomineralic rock of olivine is called dunite (Figure 1). Forsteritic olivine is currently the favoured mineral for the carbonation process because it does not require the energy-intensive pre-treatment that serpentine needs (Lackner *et al*., 1997; O'Connor *et al*., 2000). However, research into optimization of energy used in the pre-treatment of serpentine is still ongoing (McKelvy *et al.*, 2002; O'Connor *et al*., 2000). Furthermore, serpentine-rich rocks are more widespread than those rich in olivine. Thus both have to be considered. Some selected chrysotile-bearing stockpiles sites are also investigated because in addition to sequestering CO_2, the mineral carbonation method may also aid in the disposal of unwanted asbestos waste (Huot *et al*., 2003).

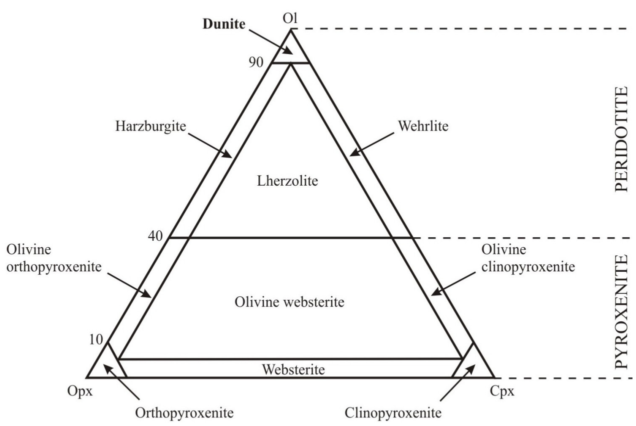

Figure 1. IUGS classification scheme for ultramafic rocks (after Le Maitre, 1989). Ol-olivine; Opx-orthopyroxene; Cpx-clinopyroxene. The general term "peridotite" is used when the olivine content is 40-100%, whereas "pyroxenite" refers to an olivine content of 0-40%. For example, "dunite" is a peridotite containing 90-100% olivine.

ULTRAMAFIC COMPLEXES

Ultramafic complexes can be divided into three major categories: Alpine, Alaskan and Layered intrusive types. Their geographic distribution is restricted by tectonic setting, which also indirectly influences the physical and chemical characteristics of dunite and serpentinite rocks within these complexes. These characteristics include relative position of the dunite and serpentinite bodies, structural control, variation in mineralogy, and mineral composition. Table 1 lists well-documented examples of these categories and describes their geological setting.

Alpine-Type Complexes

Alpine-type ultramafics are the most voluminous and widespread of all ultramafic bodies (Coleman, 1977) and are interpreted as forming the basal part of an ophiolitic suite (Dewey, 1976 and Moores, 1982; 2002). A complete ophiolite sequence, tectonically emplaced over crystalline basement (Figure 2), consists of (from bottom to top): tectonic mélange, metamorphic sole, deformed mantle tectonite, cumulate peridotite (alternately layered olivine and pyroxene), cumulate gabbros grading upwards into massive gabbros and plagiogranites, overlain and partially intruded by sheeted dike swarms, followed by pillow basalts, capped by deep-sea and/or pelagic or, in some cases, volcaniclastic turbidites, all overlain by shallow water sediments. This sequence is thought to represent an analogue for oceanic crust formed at fast spreading centres as exemplified by the Juan de Fuca Ridge situated off the coast of BC.

Dunitic rocks of ophiolitic sequences are divided into two broad categories based upon their texture and petrography, tectonite and cumulate. Dunites within the tectonite section generally occur as lenses within harzburgite or lherzolite, ranging from 1 metre to hundreds of meters in size. In most cases the tectonite is gradational into the cumulate sequence, where forsteritic olivine is the dominant cumulate phase (Coleman, 1977; Moores, 2002). Podiform chromitite is commonly associated with the tectonite zone; stratiform or thin chromitite accumulations are typical of the cumulate zone (Coleman, 1977). During the serpentinization of the alpine peridotites, fibrous chrysotile veins and stockworks may be formed. Where chrysotile-filled fractures constituted 3-10 % of the rock and formed long fibres of high quality, it was economically mined (Hora, 1999).

Alaskan-Type Complexes

Alaskan-type complexes (also called Alaskan-Ural, Uralian and concentric or zoned complexes) are mafic and ultramafic intrusions. Their type locations are in a narrow, northerly trending belt, 600 kilometres long, in southeastern Alaska (Irvine, 1967).

Geological Setting	Complex Type	Description	Distribution of dunite and/or serpentinite zones	Examples
Syn-orogenic ultramafic bodies	***Alpine-Type***	Tectonically emplaced ultramafic complex that makes up the basal section of an ophiolite (ocean-crust) sequence	Mantle tectonite section contains pods of dunite. Cumulate section contains layers of dunite. Dunite variably serpentinized. Tectonic melange is typically rich in serpentinite.	Nahlin UMF Complex (BC); Cache Creek UMF complex (BC); Shulaps UMF Complex (BC)
	Alaskan-Type	Podiform intrusions of mafic to ultramafic magmas into accreted island arcs.	Concentrically zoned. Successive zones of wehrlite, clinopyroxenite and orthopyroxenite around a dunite core. Dunite variably serpentinized, increasing outwards from core.	Duke Island (Alaska); Polaris (BC); Tulameen (BC); Turnagain (BC)
Intracratonic	***Layered Intrusion-Type***	Large, often funnel-shaped sill-like intrusions. Layering formed partly as a result of fractional crystallization of the primary melt	Laterally extensive, alternating layers of dunite/peridotite and pyroxenite.	Muskox (NWT), Bushveld (RSA), Great Dyke (Zimbabwe), Stillwater (MT), Windemurra (AUS)

Table 1. Characteristics of the three main types of ultramafic complexes containing significant deposits of dunite and/or serpentinite.

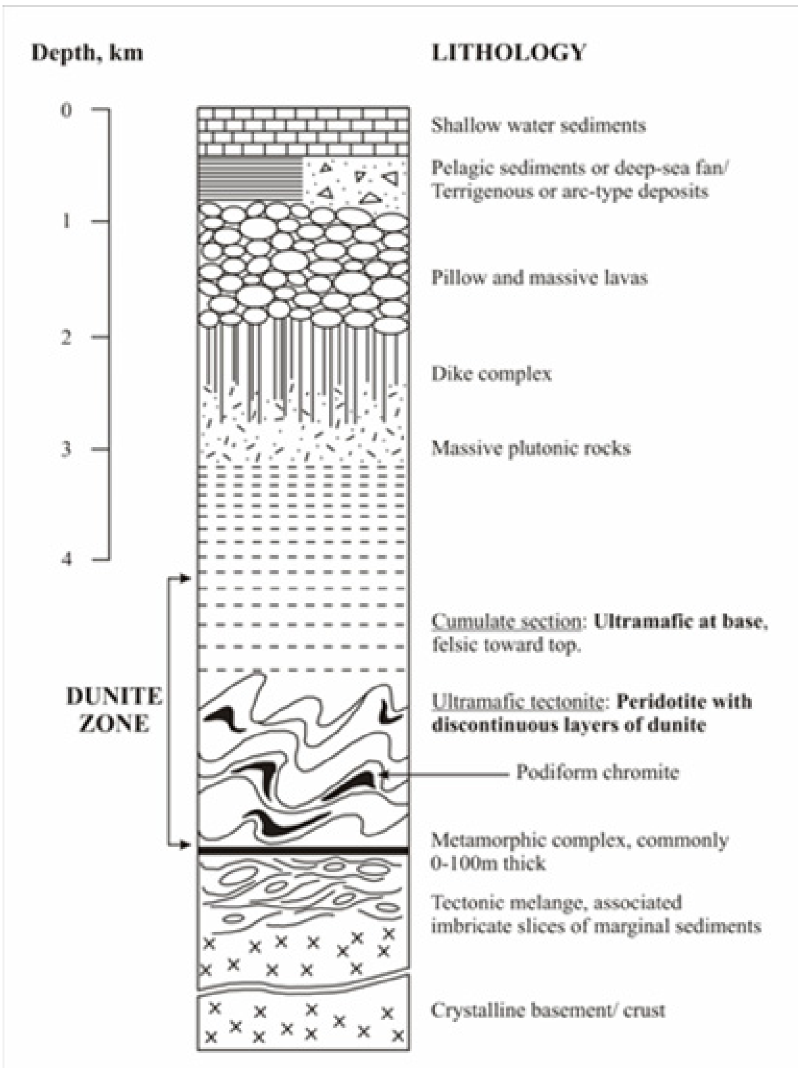

Figure 2. Cross-section of a "complete" ophiolite complex. Few ophiolite complexes contain all of these units; most contain only part(s) of the entire complex (source: Moores, 2002).

Similar ultramafic bodies are found in belts along the central Ural Mountains of Russia (Irvine, 1987) and through the interior of BC (Findlay, 1963, Irvine, 1976, Clark, 1980 and Nixon, 1990). Idealized Alaskan-type complexes are characterized by the crude zonation of successive wehrlite, clinopyroxenite and hornblende-rich lithologies around a dunite core (Irvine, 1987). In many of the well-documented examples any one of these zones may be missing or discontinuous (Nixon, 1990). Massive dunite cores, consiting primarily of forsteritic olivine (Irvine, 1987), may be exposed over large areas and in many cases dunite is well preserved.

Layered-Intrusive Complexes

Layered mafic-ultramafic intrusions are either sill-like (e.g. Stillwater) or funnel shaped (e.g. Skaergaard and Great Dyke). They are typically intruded into rifted cratons and may be associated with tholeitic flood basalt provinces. A good example of this is the Muskox intrusion, which is intimately associated with Coppermine River basalts (Baragar, 1969, Kerans, 1983).

As magma crystallizes and differentiates, cyclically layered sequences form. An ideal cycle consists of basal dunite followed upward by a harzburgite and an uppermost orthopyroxene layer (Naslund and McBirney, 1996). These cyclic units vary in thickness. For example, in the Bushveld complex they are present on a millimetre scale (Eales and Cawthorn, 1996), at Great Dyke on centimetre scale (Naslund and McBirney, 1996) and at Muskox intrusion on metre scale (Irvine and Smith, 1967). Olivine composition in a typical layered ultramafic intrusion trends from forsterite-rich olivine towards fayalitic olivine upwards in succession (Table 2).

Name, locality	Olivine composition in lower zone	Olivine composition in upper zone	References
Bjerkreim-Sokndal, Norway	Fo77-74	Fo50-19	Wilson *et al.* (1996)
Bushveld, RSA	Fo85-88	Fo63-35	Eales and Cawthorn (1996)
Great Dyke, Zimbabwe	Fo92	Fo91-87	Wilson (1996)
Skaergaard, Greenland	Fo74-68	Fo10-5	McBirney (1996)
Windimurra, Australia	Fo90-50	Fo35	Mathison and Ahmat (1996)

Table 2. Olivine composition changes from Mg-rich (forsterite) to Fe-rich (fayalite) from lower to upper zones within layered intrusive complexes.

The layering is commonly laterally continuous for hundreds of square kilometres (Eales and Cawthorn, 1996) and the ultramafic sequence can be up to several kilometres in thickness. For example, the Windimurra Complex has a 0.5 kilometre thick ultramafic section (Mathison and Ahmat, 1996), the Muskox Intrusion has ultramafic layers that total 1.5 kilometres in thickness (Irvine and Smith, 1967) and the Great Dyke has an ultramafic sequence several kilometres in thickness (Wilson, 1996).

TECTONIC SETTING OF BC

Since the breakup of the Rodinia supercontinent, British Columbia has been located on a continent-ocean boundary for at least 530 million years (Monger, 1997). As a result of subduction-related activity, which started approximately 390 million years ago, the Canadian Cordillera is commonly described as an orogenic collage made up of intra-oceanic arc and subduction complexes accreted to the craton margin, and of arcs emplaced in and on the accreted bodies. The Canadian Cordillera has been subdivided into 'terranes' (Figure 4), each consisting of characteristic assemblages (Monger and Berg, 1984).

Assemblages within the *Slide Mountain*, *Cache Creek* and *Bridge River* terranes (Figure 4) are of oceanic affinity, representing the deformed sequences of ocean basins that closed in the Mesozoic during the accretion of offshore island arcs to the North American Craton. The *Slide Mountain* terrane is composed of ultramafic rocks, gabbro, pillow basalt and chert, which formed in a back-arc ocean basin (Figure 5). The ultramafic rocks in the *Cache Creek* and *Bridge River* terranes are associated with a mélange of marine sediments with blocks, lenses and slivers of ophiolitic origin, often in a serpentine matrix, representing an accretionary/ subduction complex (Figure 5). These oceanic affiliated terranes contain numerous Alpine-type complexes (Evenchick *et al.*, 1986). The *Stikinia* and *Quesnellia* terranes are composed of arc-related volcanic and sedimentary rocks and coeval intrusions (Evenchick *et al.*, 1986). BC's Alaskan-type complexes are found in these terranes (Figure 5) and represent the high-level magma chambers of Late Triassic to Middle Jurassic arc volcanoes (Nixon, 1990). There are no large layered intrusive ultramafic complexes known in British Columbia, as they are believed to be restricted to an intra-cratonic tectonic setting.

ULTRAMAFIC ROCKS IN BC

The geographic distribution of ultramafic rocks in British Columbia, with emphasis on those Alpine and Alaskan-type complexes, which contain known dunite and/or serpentinite zones, are depicted in Figure 6. This map was derived from the database developed for the mineral potential assessment of British Columbia (Kilby, 1994) and was originally introduced in a Geofile (Voormeij and Simandl, 2004).

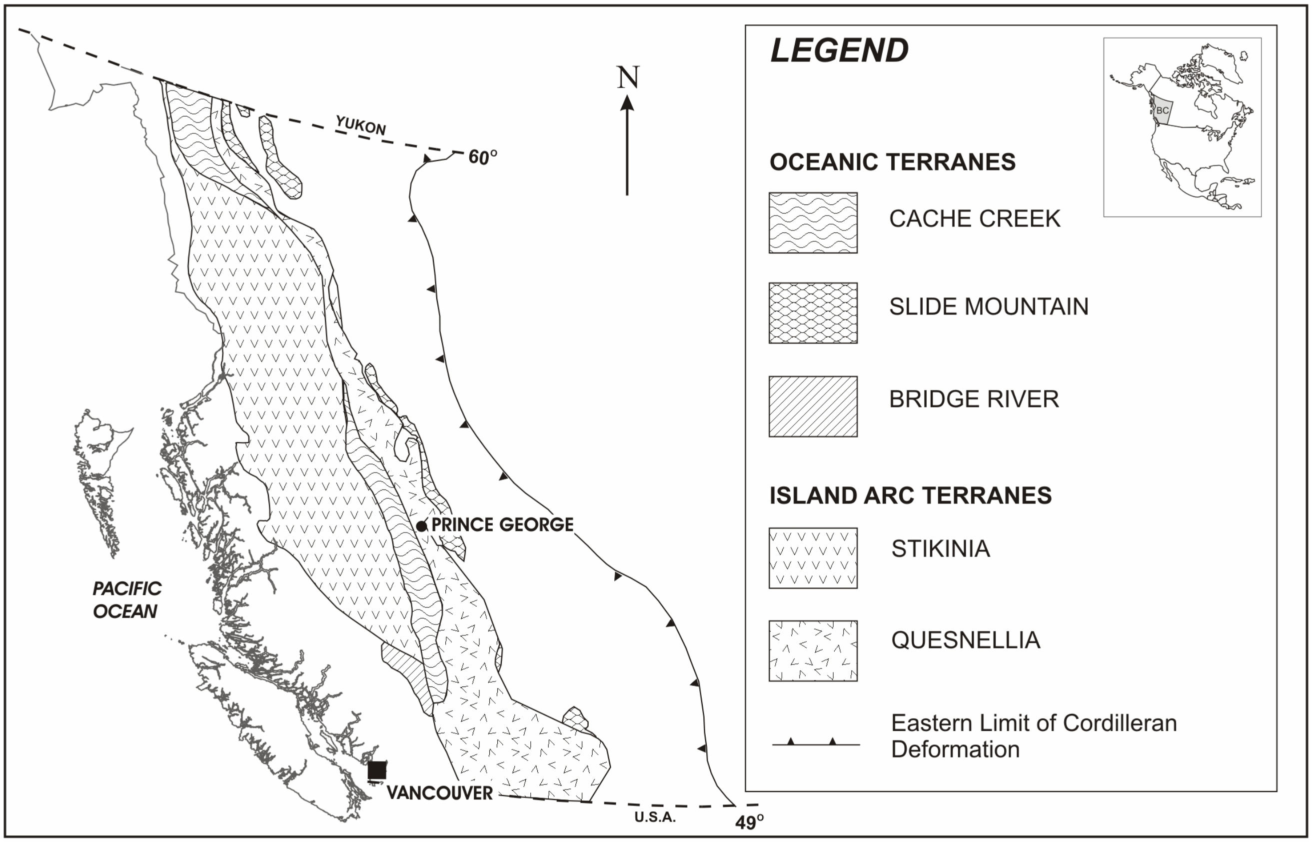

Figure 4. Distribution of major ultramafic-bearing terranes in British Columbia (based on Gabrielse *et al*., 1991). The Alpine-type ultramafic complexes are confined primarily to the Cache Creek, Slide Mountain and Bridge River oceanic-affiliated terranes, whereas the Alaskan-type ultramafic bodies are associated with the Stikinia and Quesnellia island-arc terranes.

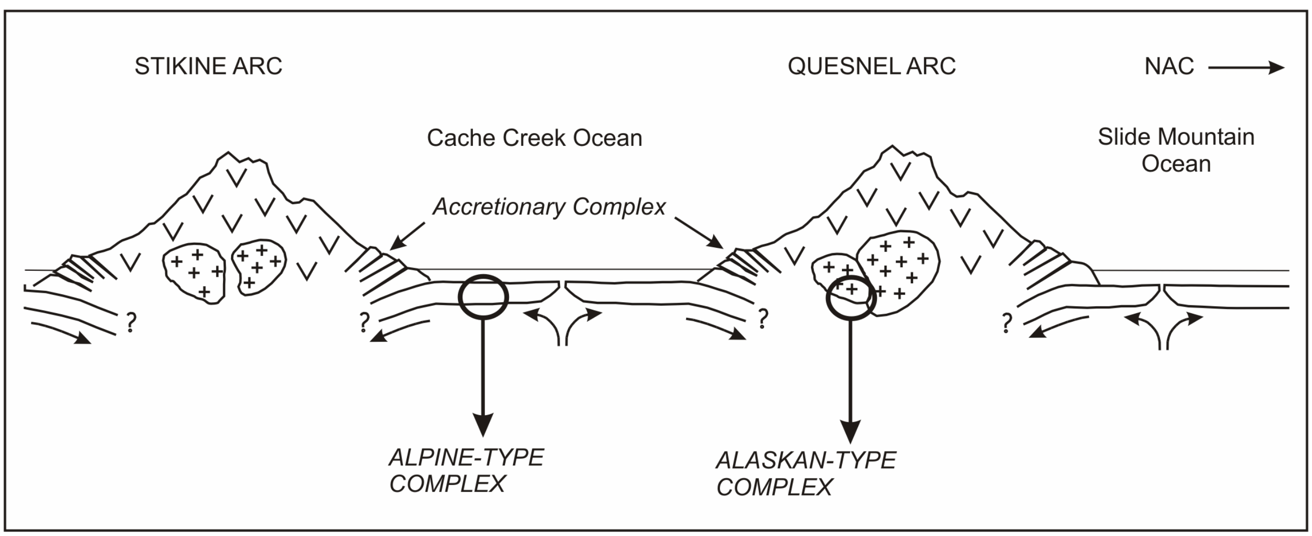

Figure 5. Simplified diagram depicting the different tectonic settings for the oceanic affiliated, subduction-related and island arc terranes in British Columbia and the origin of their ultramafic complexes (based on Monger and Journeay, 1994). NAC= North American Continent.

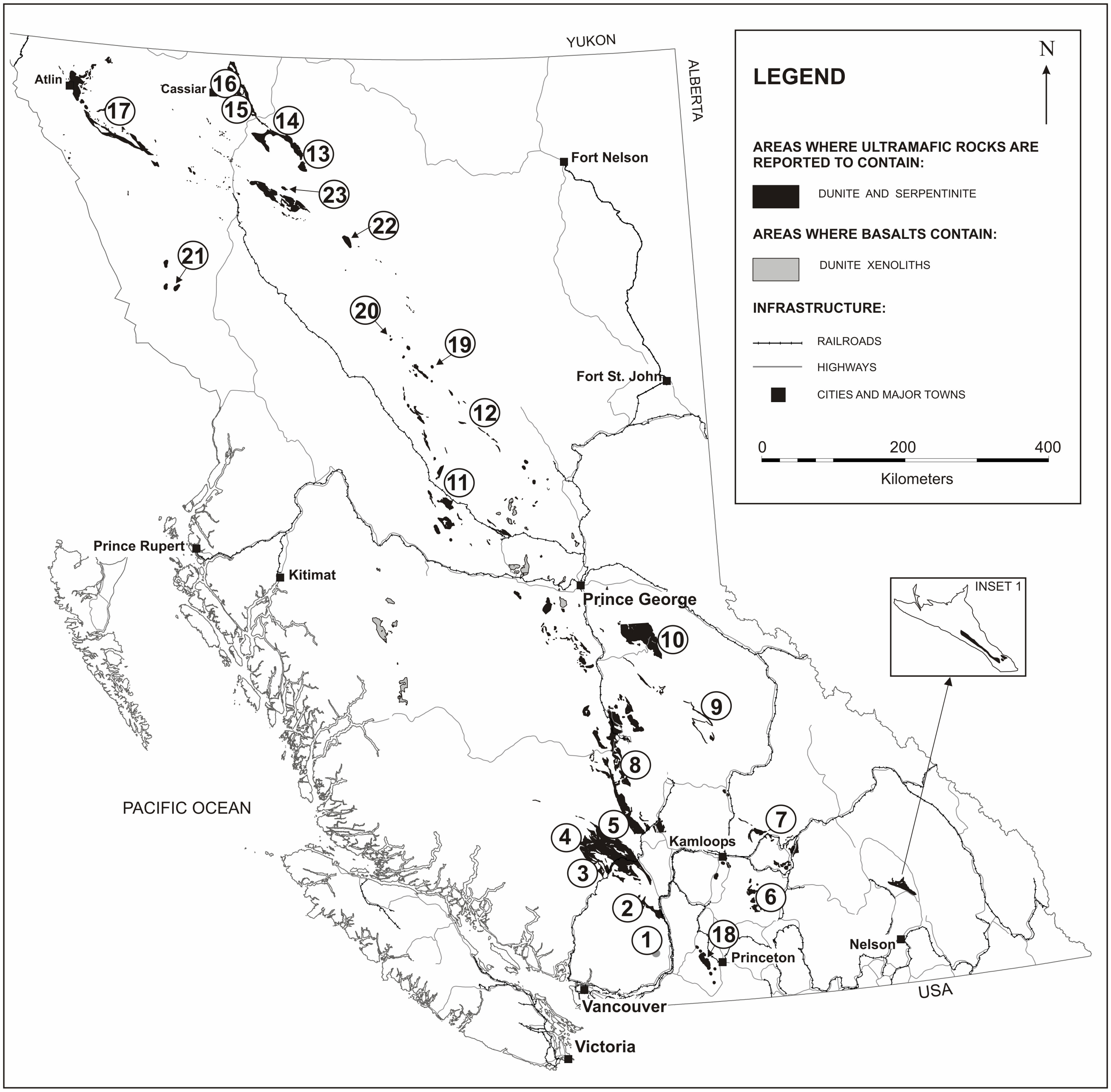

Figure 6. Distribution of dunite and serpentinite-bearing rocks in British Columbia. Alpine-type ultramafic complexes include: 1. Cogburn Emory Zone, 2. Coquihalla Serpentine Belt, 3. Bralorne-East Liza, 4. Bridge River Complex, 5. Shulaps, 6. Chapperon Group, 7. Mount Ida Assemblage, 8. Southern Cache Creek Complex, 9. Crooked Amphibolite, 10. Antler Formation, 11. Central Cache Creek Complex, 12. Manson Lake Complex, 13. Blue Dome Fault Zone, 14. Sylvester Allochthon, 15. Cassiar and McDame, 16. Zus Mountain, 17. Northern Cache Creek Complex (includes Atlin and Nahlin complexes). Alaskan-type ultramafic complexes include: 18. Tulameen, 19. Polaris, 20. Wrede, 21. Hickman, 22. Lunar Creek, 23. Turnagain.

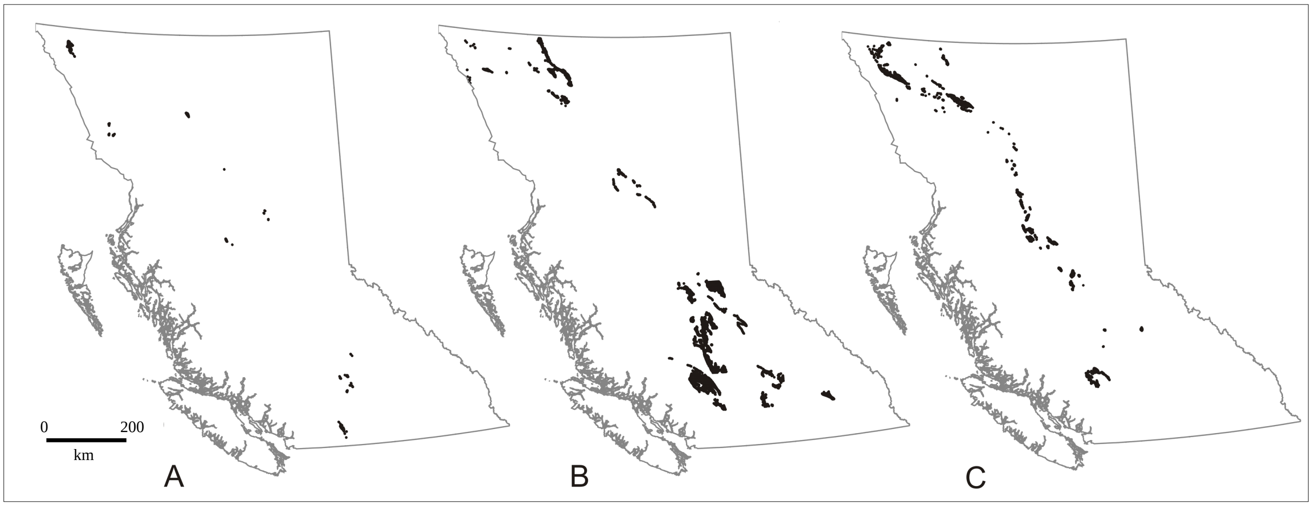

Figure 7. Separating out the dunite and serpentinite zones associated with ultramafic rocks: A. Areas where ultramafic rocks are reported to contain dunite only. B. Serpentinite only. C. Dunite and serpentinite are reported together.

The compiled geology used in Figure 6 has been captured in digital form at a scale of 1:250,000, by means of GSB Open File series releases (Massey, 1994); (Schiarizza *et al*., 1994); (Höy *et al*., 1994); (MacIntyre *et al*., 1994); (Bellefontaine and Alldrick, 1994); (MacIntyre *et al*., 1995); (Bellefontaine *et al*., 1995); (Mihalynuk *et al*., 1996) and (Schiarizza and Church., 1996). From this electronic database, units containing the words "dunite" and "serpent-" were extracted, thereby assembling a digital file of zones that contain the words "dunite", "serpentinite", "serpentinized", or "serpentine" in their original description. Figure 6 shows the resulting zones.

Extraction of areas that contain the terms "dunite" and "serpent-" from the database does not discriminate between minor and major amounts of dunite and/or serpentinite present. Thus, most of the zones are overestimates of actual area underlain by dunites and/or serpentinites. For example, Figure 6 shows a zone in southeastern BC, ~120 km north of Nelson. This area appears approximately 100 km long by 50 km wide on the map. However, a more detailed map (Figure 6, Inset 1) shows the presence of serpentine-magnesite-talc related rocks only a few km across (source: Read and Wheeler, 1977). Although the approach used to construct Figure 6 results in overestimating the areas underlain by ultramafic rocks, it is a preferred preliminary approach because large portions of BC have not been mapped in detail and may contain more ultramafic rocks than expected. Several potential dunite and serpentinite tracts shown on this map are abruptly terminated along straight lines that correspond to map boundaries. This happens where a geological unit extends across two or more 1:250 000 map sheets. This unit may have the same name on several of the mapsheets, but ultramafic rocks are not present in all of them.

Our approach also delineated areas that contain ultramafic xenoliths. For example, numerous zones within central BC correlate to spinel peridotite xenoliths described by Canil *et al.* (1987), many of which are hosted in the alkali basalts typical of the Chilcotin Group plateau-lavas (Dostal *et al*., 1996). The olivine-rich xenoliths are not significant as a potential source of raw material for the *ex situ* mineral carbonation process. However, recent studies have shown the mineral trapping potential of injected CO_2 into deep saline aquifers located within thick sequences of flood basalt provinces (O'Connor *et al*., 2003). For this reason, the distribution of British Columbia's flood basalts that contain olivine xenocrysts and dunite xenoliths is included in Figure 6.

Ultramafic rocks containing dunite zones but not serpentinite (Figure 7a) are not common. These zones are mostly restricted to Alaskan-type complexes. In contrast, ultramafic rocks containing serpentine but not dunite, are relatively abundant (Figure 7b). As expected from the distribution of ultramafic rocks in Alpine-type complexes, dunite and serpentinite are commonly associated together (Figure 7c).

Alpine-Type Complexes in BC

Most of BC's Alpine-type complexes are located within the *Cache Creek, Slide Mountain* and *Bridge River* terranes. The *Cache Creek* terrane forms a long narrow tract that extends within the Intermontane belt from southern BC to central Yukon Territory (Figure 4). The larger complexes of the *Cache Creek* terrane include the Southern Cache Creek Ultramafic Assemblage in southwestern BC and the Nahlin Ultramafic Complex near Atlin, northwestern BC (Figure 6). The *Slide Mountain* terrane forms a narrow, discontinuous belt extending 2000 km from southeastern BC to northwestern Yukon Territory (Figure 4). Alpine-type ultramafics are located in the Antler Formation in central BC, the Redfern and Crooked Amphibolite in east-central BC and the

Sylvester Allochthon in north-central BC (Figure 6). The Cassiar and McDame asbestos deposits are located in Sylvester serpentinites (Figure 6). Zus Mountain, located in the Sylvester Allochthon, is known to contain intact oceanic upper mantle and ultramafic cumulate material (Nelson and Bradford, 1993). *Bridge River* is a small terrane, situated near latitude 52^{o}N, just west of the *Cache Creek* terrane. The Bridge River Complex, with the associated Shulaps and Bralorne-East Liza complexes (Figure 6), the Coquihalla Serpentine Belt and the Cogburn body are probably the southern extent of the Cache Creek terrane (Schiarizza *et al.*, 1997).

Alaskan-Type Complexes in BC

In British Columbia, Alaskan-type complexes are found in the *Stikinia* and *Quesnellia* terranes. However, only those with a recognized dunite zone are discussed and their geographical distribution is given in Figure 6. Table 3 gives the major Alaskan-type complexes for BC that contain known dunite cores. *Stikinia* is the largest terrane in the Canadian Cordillera. It extends more than 1700 km from eastern Alaska to south-central BC (Figure 4). The Hickman complex is an Alaskan-type ultramafic within *Stikinia*. The Lunar Creek Complex is located on the boundary between *Quesnellia* and *Stikinia* terranes (Figure 6). *Quesnellia* forms an orogen-parallel belt that extends from south-central BC into the Yukon Territories (Figure 4). Complexes of the Alaskan type that are located in this terrane include the Tulameen (Figure 3), Polaris, Wrede and Turnagain complexes. Tulameen is the largest Alaskan-type body in BC (Table 3).

Economic Potential of Ultramafic Rocks in BC

Up to now, BC's ultramafic complexes were primarily of interest to economic geologists in terms of associated metals, traditional industrial mineral deposits and gemstones. These complexes are known to host Cyprus-type massive sulphide (Höy, 1995), Au-quartz veins (Ash and Alldrick, 1996), silica-carbonate mercury deposits (Ash, 1996a), podiform chromite (Ash, 1996b), stratiform chromite (Nixon *et al*., 1997), talc and magnesite (Simandl and Ogden, 1999), chrysotile asbestos (Hora, 1999), nephrite jade (Simandl *et al*., 2000), vermiculite (Simandl *et al*., 1999a), emeralds (Simandl *et al*., 1999b) and corundum group gemstones (Simandl and Paradis, 1999). Also, they are known to host platinum group elements (Rublee, 1986; Evenchick *et al*., 1986; Nixon, 1990; Nixon, 1996; Nixon *et al*., 1997), Ti and Fe oxide deposits (Gross *et al*., 1999) and nickel (Hancock, 1990). Olivine may be used as a foundry and blasting sand (White, 1987) as well as a raw material in the manufacture of refractories (Henning, 1994). In the past, most of the complexes were assessed with these commodities in mind, however, should mineral sequestration of CO_2 emissions become a reality, then these complexes will also become essential as sources of high magnesia silicates. The synergy between the development of some of the traditional metal, industrial mineral and gemstone commodities and magnesium silicates for CO_2 sequestration may be possible.

Complex Name	Terrane	Aerial Extent of Complex	Surface Area of Dunite zone	References
Hickman	**ST**	~11 km^2	< 1 km^2	Nixon *et al*. (1997)
Lunar Creek	**QN**	~45 km^2	~ 1.5 km^2	Nixon *et al*. (1997)
Polaris	**QN**	~50 km^2	~8-9 km^2	Nixon *et al.* (1997)
Tulameen	**QN**	~ 60 km^2	~ 6 km^2	Findlay (1963); Nixon *et al.* (1997)
Turnagain	**QN**	~25 km^2	~ 5 km^2	Clark (1980); Gabrielse
Wrede	**QN**	~10 km^2	~ 5km^2	Hammack *et al.* (1990)

Table 3. Surface area of dunite zones in Alaskan-type complexes. Arc-related tectonostratigraphic terranes within which these complexes are located: QN= Quesnellia; ST= Stikinia.

Targets for Mineral Sequestration of CO_2

Figure 6 also marks the following specific areas considered for detailed study as part of the M.Sc. Thesis of the senior author: The Tulameen site was chosen because it contains a well-exposed, large (6 km^2), relatively unserpentinized dunite body, and is located within the vicinity of several major point sources of CO_2 (Voormeij and Simandl, 2003b). Cassiar Asbestos tailings, currently owned by Cassiar Resources Inc., are investigated because the waste piles have potential as raw material for the mineral carbonation process, since the serpentine has already been milled and therefore may lower the sequestration costs. The site contains 5,457,000 tonnes of broken rock, 17,021,000 tonnes of tailings and 48 millions of tonnes of *in situ* serpentine-rich rock (Budinski, 2000). The fibrous nature of this variety of serpentine, which is considered a health concern (Hamel, 1998), may be effectively destroyed during the mineral carbonation process.

CONCLUSIONS

Should the mineral carbonation process be considered as a form of sequestering CO_2 emissions in British Columbia, an overview of locations of raw material within the vicinity of major CO_2 point sources is an important parameter in conceptual modeling. The distribution of ultramafic rocks in British Columbia, with emphasis on those complexes containing dunite and/or serpentinite zones is depicted in Figure 6. Based on this map, less than 3% of BC's surface is underlain by ultramafic rocks containing dunite and/or serpentinite. Of this 3%, less than 1% corresponds to areas where dunite is reported without serpentinite, approximately 2% is related to areas where serpentinite occurs without dunite and 1% of BC is underlain by ultramafic rocks where dunite and serpentinite are reported together. Because of the methodology used to construct the map, surface areas corresponding to ultramafic rocks are overestimates.

Due to the subduction-related tectonic setting, Alpine-type and Alaskan-type ultramafic complexes are more common along the western margin of North America than, for example, in areas located on the stable craton or passive margin. With this in mind, claims made by Goff et al. (1997) and Goff and Lackner (1998), in which they state that "abundant resources of Mg-rich peridotite [dunite] and serpentinite exist within the United states and many other countries" should be questioned and follow-up is needed.

Ultramafic complexes may host a wide variety of economic minerals. Thus, the geographic distribution of dunites and serpentinites can be used as a metallotect in exploration for a variety of metallic, industrial mineral and gemstone deposits. In a number of specific cases, serpentine- and olivine-bearing rocks contain chromite, Ni, Co and platinum group elements. If these commodities can be recovered at profit as a by-product of mineral sequestration, then costs of the CO_2 disposal may be substantially reduced.

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