

# GEOLOGY OF THE WESTERN IDAHO ULTRAMAFIC BELT

Bill Bonnichsen  
Martha M. Godchaux

Staff Report 94-3  
September 1994

Idaho Geological Survey  
University of Idaho  
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# GEOLOGY OF THE WESTERN IDAHO ULTRAMAFIC BELT

Bill Bonnichsen<sup>1</sup> and Martha M. Godchaux<sup>2</sup>

## ABSTRACT

The western Idaho ultramafic belt stretches northward for 164 miles from Sturgill Mountain to the north end of Dworshak Reservoir. It consists of small bodies of dunite, serpentinite, metaharzburgite, and clinopyroxenite. Except at the south and north ends of the belt, the ultramafic bodies lie near the suture zone joining the accreted Blue Mountain island arc terrane on the west with the older continental crust on the east. All of the ultramafic bodies have been metamorphosed ranging from greenschist to amphibolite facies. Most appear to have been emplaced along faults. Where metamorphosed to the amphibolite facies, some appear to have been altered, having gained silica from their surroundings. Blackwall zones occur marginal to the altered ultramafic bodies. These include hornblende-garnet-spinel zones, which originally were basaltic metavolcanic rocks that lost substantial silica, and chlorite-rich zones, which initially were harzburgites that gained significant quantities of alumina from their surroundings.

There are five main occurrences of ultramafic rocks. To the southwest is the Cuddy Mountain-Sturgill Peak region, where serpentinitized harzburgite bodies lie along a major zone of high-angle reverse faulting between two subterrane within the Blue Mountain island arc accreted terrane. The southernmost occurrence associated with the island arc-continental crust suture zone is in the New Meadows area, where bodies of deformed and variably metamorphosed dunites, and associated harzburgites and chromitites, are enclosed within metamorphosed cherts, greywackes, and exhalative rocks of the New Meadows tectonic block. Farther north along the suture zone, in the Riggins region, bodies of serpentinitized harzburgite occur within the lower part of the Squaw Creek Schist and in the underlying Lightning Creek Schist of the Riggins Group. Farther north, in the South Fork of the Clearwater River region, a series of variably deformed and strongly metamorphosed harzburgites, accompanied by clinopyroxenites, and hornblende-garnet-spinel and chlorite-rich blackwall zone rocks are enclosed within quartzofeldspathic to amphibolitic schists and gneisses of the Riggins Group and associated Cretaceous, dioritic to monzonitic, plutonic rocks. In the northern part of the ultramafic belt, in the Lowell-Kamiah-Dworshak Reservoir region, metadunites and

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metaharzburgites that consist dominantly of anthophyllite, are enclosed within Proterozoic-age gneissic and schistose metasedimentary rocks and associated plutonic rocks.

Several distinct, but partially intergradational, types of ultramafic rocks occur in western Idaho. These are relatively fresh dunites, serpentinites, low-silica altered harzburgites, high-silica altered harzburgites, relatively fresh Ca-rich pyroxenites, altered Ca-rich pyroxenites, and chromitites. The original minerals for these ultramafic bodies were Mg-rich olivine, orthopyroxene, augite, and high-Cr chromite. Minerals developed during metamorphism include anthophyllite, tremolite, talc, chlorite, antigorite, magnesite, and magnetite.

The ultramafic bodies might be economically interesting for the minerals traditionally associated with these rocks, notably chromite, nickel, platinum-group elements, gold, asbestos, talc, and magnesian refractory materials. There has been, however, scant past mineral production from the western Idaho ultramafic belt, except for small-scale mining of podiform chromite deposits and massive anthophyllite.

Three episodes of geologic history -- the Early Cretaceous docking of the Blue Mountains island arc terrane against Mesozoic North America, the Late Cretaceous emplacement of the Idaho batholith, and the vertical uplift, faulting, and volcanism during the Tertiary -- have collectively obscured the earlier geologic history of the western Idaho ultramafic belt. Regardless, the ultramafic bodies probably formed initially in an oceanic environment where an upwelling of basaltic magma from the Earth's interior permitted the development of ultramafic cumulates. Later, convergent tectonic plate motions led to the obduction of the ultramafic bodies onto the pre-Blue Mountains continental margin of North America. The subsequent compressional tectonism that accompanied the docking of the Blue Mountains island arc and the emplacement of the Idaho batholith metamorphosed most of the bodies. It also remobilized them from their locations immediately after obduction into their present positions along major faults and within host rocks of widely varying ages.

## INTRODUCTION

The western Idaho ultramafic belt stretches northward about 164 miles (264 km) from Sturgill Mountain, north of Weiser, to the Breakfast Creek area near the north end of Dworshak Reservoir (Figure 1 and Table 1). For much of its length the ultramafic belt lies close to the Mesozoic-age suture zone between the pre-existing continental crust of ancestral North America and the accreted rocks of the Blue Mountains island arc terrane (Vallier and Engebretson, 1984; Vallier and Brooks, 1987). This zone is characterized by a change in the initial Sr isotope ratios of plutons, from .704 or less in the west to .708 or greater in the east (Armstrong and others, 1977; Criss and Fleck, 1987; Fleck and Criss, 1985). Small ultramafic bodies exist sporadically along the length of this belt. The bodies appear in the following regions, from south to north, near the Mesozoic continental crust-accreted terrane suture zone: New Meadows, Riggins, South Fork of the Clearwater River, and Lowell-

Kamiah-Dworshak Reservoir. Ultramafic rocks are also present in the Cuddy Mountain-Sturgill Peak area southwest of the others and somewhat west of the suture zone, well within the Blue Mountains terrane.

The ultramafic bodies and their enclosing rocks were further deformed and metamorphosed as the various plutons constituting the western part of the Idaho batholith were emplaced. This occurred after the bodies were accreted onto the Mesozoic margin of North America and the Blue Mountains island arc terrane had docked against this margin in the Early Cretaceous. The ultramafic bodies typically show close spatial relationships to major faults. Most, if not all, were likely moved along faults after they had been emplaced between the pre-existing craton and the Blue Mountains island arc terrane. The ultramafic bodies in the Cuddy Mountains-Sturgill Peak region are closely associated with a major fault boundary between two adjacent subterrane within the island arc terrane.

Several earlier studies have described the ultramafic rocks along the western Idaho belt. None, however, has developed an integrated picture of their characteristics or extent. That is the purpose of our study, which combines our own field and laboratory investigations with the work of previous investigators. Geologic mapping and other important earlier studies include Anderson (1930, 1931), Johnson (1947), and Hietanen (1963) on the northern part of the ultramafic belt; Hamilton (1963, 1969), Onasch (1977, 1987), Sarewitz (1982), and Aliberti (1986) on the Riggins area; Myers (1982) and Hoover (1986) on the South Fork of the Clearwater River region; Bonnicksen (1987) on the New Meadows region; Skurla (1974) and Mann (1989) on the Cuddy Mountain area; and Lewis and others (1992) on the Lowell area.

Several uncommon rock types are present in, or closely associated with, the ultramafic bodies of western Idaho. The following, generally standard, definitions have been adhered to in our report. Terms include **peridotite**, an ultramafic rock with greater than 10 percent of both olivine and pyroxenes and **pyroxenite**, a rock of more than 90 percent pyroxenes. More specific rock terms include **dunite**, approximately 90 percent or more of olivine and typically some orthopyroxene; **harzburgite**, olivine and 10 percent or more orthopyroxene; **clinopyroxenite**, approximately 90 percent or more of clinopyroxene and possibly some orthopyroxene; and **websterite**, principally both clinopyroxene and orthopyroxene, with neither constituting more than 90 percent. A **chromitite** has more than 50 percent of chromite. A **serpentinite** typically consists of more than 80 percent of serpentine minerals and may have substantial quantities of chlorite. The terms **metaperidotite**, **metapyroxenite**, **metadunite**, **metaharzburgite**, and **metaclinopyroxenite** define the ultramafic rocks in western Idaho that have been metamorphosed and now contain minerals other than their original olivine, pyroxenes, and chromite. Rocks whose chemical compositions have been changed significantly from their original values include **rodingite** and **metarodingite**. Rodingite is a gabbro or diabase and that underwent substantial enrichment of calcium and some loss of silica, probably shortly after it was formed; metarodingite is its subsequently metamorphosed equivalent. **Blackwall zones** refer to rocks, typically having the form of reaction zones at the margins of the ultramafic bodies, which have undergone

substantial change in their bulk composition during metamorphism, so as to become enriched in such minerals as chlorite and amphiboles.

The field work for this report has been conducted sporadically since 1978. The ultramafic and associated rocks were analyzed between 1989 and 1992 by Bill Bonnicksen at the Ronald B. Gilmore x-ray fluorescence laboratory of the University of Massachusetts at Amherst. The petrographic work was done primarily by Martha Godchaux during 1991 and 1992.

## NEW MEADOWS AREA

An area of ultramafic rocks a few miles south of New Meadows lies within a small tectonic fragment known as the New Meadows block, immediately west of the accreted terrane-continental craton suture zone (Bonnicksen, 1987). The New Meadows tectonic block contains pre-Tertiary rocks that are mostly peridotite accompanied by metachert and metagraywacke with local Mn-enriched beds and other layers of possible volcanoclastic derivation. The peridotite consists mainly of relatively fresh dunite that locally is severely deformed. The dunite masses contain harzburgite and local chromitite segregations, and serpentinite and chlorite-amphibole schist blackwall zones at their margins.

Thayer and Brown (1964) first mentioned the ultramafic rocks and associated chromitite deposits south of New Meadows, but they did not describe the rocks. Later, in a study of the Columbia River Basalt Group, Breezer (1972) included the pre-Cenozoic rocks south of New Meadows as part of a map unit consisting of metasedimentary schist and gneiss injected by quartz diorite and trondhjemite. She did not comment on the outcrops of ultramafic rocks in that area, although she did report that chromite is present.

Ultramafic rocks are abundant in a 2.5-mile (4 km)-long zone along the west side of the New Meadows block, in secs. 2, 3, 10, and 15, T. 18 N., R. 1 E., in the New Meadows 7 1/2-minute quadrangle. Although the New Meadows tectonic block has not been mapped in detail, reconnaissance traverses disclose several different ultramafic rock bodies separated by quartzose and schistose quartzofeldspathic to amphibolitic rocks. The ultramafic rocks range from nearly unaltered peridotite to schists with varying proportions of anthophyllite, tremolite, talc, serpentine (mainly antigorite and lizardite), and chlorite (probably corundophilite). These schistose rocks generally occupy the peripheral parts of the ultramafic masses and occur in zones that crosscut fresh peridotite. Mg-rich olivine, orthopyroxene, and chromite are the principal minerals in the unaltered peridotite. Clinopyroxene has not been seen, but locally abundant tremolite in hydrated zones indicate small quantities may have been present. Olivine is much more abundant than orthopyroxene, so most of the ultramafic rock is dunite. None of the peridotite examined contains plagioclase. Analyses of three relatively fresh dunite samples (W-192, W-193, and W-194) and an analysis of one low-silica altered harzburgite sample (W-68) from the New Meadows peridotite are included in Table 2.

The peridotites range from possible cumulates with equant olivine grains packed loosely in an interstitial orthopyroxene matrix to severely tectonized rocks in which large (1 cm or more across) olivine grains have been strained into sets of subparallel, curved lamellae. The small percentage of chromite consists mainly of equant grains enclosed by orthopyroxene but not by olivine, suggesting that chromite is also a cumulus mineral. The petrology, mineralogy, and structure of the peridotite bodies resemble those of alpine peridotites or fragments of ophiolite complexes, including the Canyon Mountain Complex (Thayer, 1977, Ave' Lallemand, 1976) in northeastern Oregon within the dismembered oceanic crust terrane described by Brooks and Vallier (1978) and Brooks (1979).

Chromitite has been found near prospect pits in the SW1/4 SW1/4 sec. 2, T. 18 N., T. 1 E. The chromitite probably originated as a magmatic segregation when the peridotite crystallized. It consists largely of chromite grains with an exploded texture in which the individual fragments have not been rotated, so that original grain shapes are readily discerned. The chromite grains are cut by veins of a fine-grained mixture of chlorite and serpentine and are surrounded by a matrix of the same mixture. The chromite grains typically were 1 to 3 mm across before being fragmented and serpentinized. Analyses of two chromitite samples (W-220 and W-391) are included in Table 2.

The deformed olivine and pyroxene grains in the peridotite commonly are cut by undeformed acicular anthophyllite crystals that have been largely replaced by talc. These hydrous minerals clearly grew after the olivine and pyroxene were deformed. Their presence implies a thermal metamorphic and hydration event that affected the peridotite masses after they were emplaced into their present tectonic setting. Peridotite that has been partly converted to hydrous minerals shows evidence of having undergone at least two hydration episodes, both postdating the straining of the olivine. During the first episode, numerous thin veins and local patches of very fine-grained serpentine formed throughout the rocks, cutting across olivine and pyroxene. Locally forming with this early serpentine were veins and patches of chlorite and traces of fine-grained magnetite. No amphiboles and little if any talc appeared during this early serpentinization episode.

During the second hydrous alteration episode, anthophyllite and talc formed and were accompanied locally by tremolite and additional serpentine, chlorite, and magnetite. The anthophyllite grew throughout the peridotite masses, both within olivine and pyroxene and cutting the earliest serpentine veins. Tremolite developed concurrently with anthophyllite and very likely consumed Ca that was released by the alteration of clinopyroxene or that migrated into the ultramafic bodies from the wall rocks. Following the formation of anthophyllite and tremolite, abundant talc formed both in veins and as masses replacing anthophyllite. Talc growth was an early retrograde stage of the second hydration episode. Accompanying and following the talc, additional serpentine, chlorite, and magnetite formed as a late retrograde stage.

Although anthophyllite and talc are present throughout the peridotite masses, they are much more conspicuous in some areas. Their maximum grain size is on the northwest side of Vick Creek in NE1/4 sec. 15, T. 18 N., R. 1 E., where anthophyllite occurs as sheaves and

rosettes of radiating acicular crystals, some longer than 20 cm. After they formed, the anthophyllite sheaves and rosettes were largely replaced by talc.

The nondeformed anthophyllite and talc markedly contrasts with the strongly deformed olivine in the peridotite. The nondeformed character of the secondary minerals suggests that the peridotite bodies were near their present structural positions when they were reheated, allowing the anthophyllite and talc to grow statically. The strong olivine deformation probably occurred when the peridotite masses were emplaced into their present tectonic settings, or it might have been inherited from an earlier stage.

Locally cutting the peridotite are trondhjemitic to granitic dikes of aplitic to pegmatitic texture. Their injection probably was contemporaneous with the heating event that formed the anthophyllite, tremolite, and talc.

Fine- to medium-grained, non-foliated rocks that are referred to as metarodingites and that consists predominantly of hornblende and epidote, accompanied by accessory amounts of sphene, opaque oxides, and remnants of augite within the cores of the hornblende grains, are present within the peridotite bodies. These rocks probably originated as diabase or gabbro dikes or segregations associated with the ultramafic bodies, although they have only been found as float samples. During the tectonic and metamorphic processes they underwent alteration to become rodingites, then metarodingites. Analyses of two samples (W-203 and W-205) are included in Table 2.

Thoroughly hydrated ultramafic rocks that bound or cut the peridotite masses range from almost pure anthophyllite, tremolite, talc, chlorite, or serpentine to mixtures of these minerals. Their textures vary from schistose to decussate. Inasmuch as these rocks are entirely hydrated, they probably developed because water and other constituents migrated into the peridotite. In that regard, they are blackwall zones. An analysis of one sample (W-63), composed principally of chlorite and tremolite, is included in Table 2.

Mixed with the peridotite is an assortment of thinly layered quartz-rich metasedimentary rocks varying from gneissic to hornfelsic in texture. Also present, mainly to the south, are layered rocks of quartzofeldspathic to amphibolitic compositions that originally may have been graywackes or similar clastic sedimentary rocks. In addition, bedded Mn oxide occurrences and other possible exhalatites are present in the New Meadows tectonic block. The quartz-rich and associated rocks in the New Meadows block are described by Bonnichsen (1987). Minerals reported in these rocks include quartz, hornblende, clinopyroxene, biotite, magnetite, garnet, plagioclase, epidote, zoisite, scapolite, clintonite, apatite, sphene, calcite, muscovite, tourmaline, chlorite, and hematite or rutile. The quartz-rich rocks consist of quartz layers alternating with thinner, strongly deformed layers and pods of Ca- and Mg-rich to Fe- or Al-bearing rocks. These quartz-rich metasedimentary rocks may have originated as pelagic marine cherts in which the intercalated quartz-poor layers were marl or other carbonate-rich and clay-bearing material having local ferruginous concentrations. An analysis of one sample (W-218), composed principally of biotite and accompanied by several percent of barite, is included in Table 2. This rock may be a peculiar blackwall zone rock, but it is more likely a

metamorphosed exhalatite associated with the ultramafic rocks. The metachert and other sedimentary rocks in the New Meadows block show a structural history similar to that seen in the peridotite. Locally their layering is strongly deformed, yet these rocks have hornfelsic textures indicative of reheating and annealing after emplacement into their present tectonic setting.

Gneissic rocks of mostly quartzofeldspathic and amphibolitic compositions are present to the east of the metasedimentary rocks and peridotite bodies in secs. 5 and 18, T. 18 N., R. 2 E. Most of these are strongly sheared but appear to be plutonic rocks, ranging from gabbro to tonalite in composition. They are thought to be within a major zone of faulting. Locally present in the zone are detached pyroxene- and hornblende-rich boudins of gabbroic and pyroxenitic compositions and tectonic slivers as much as a few meters across consisting of chlorite, serpentine, talc, and Ca amphibole similar to the peridotite to the west. An analysis of one of these altered metaperidotite slivers (W-114) is included in Table 2. It has the composition of a low-silica altered harzburgite.

A strongly sheared tectonic boundary separates the east side of the New Meadows block from the terrane to the east that contains metamorphic rocks resembling those in the West Mountain-Council Mountain block. The foliation in the New Meadows block trends north to north-northeast and dips moderately to steeply eastward, as in the West Mountain-Council Mountain block. Lineations in the western part of the block, however, are subhorizontal within the foliation plane. They are commonly in the form of elongate mineral streaks and shallow elongate grooves that kink the wispy to thin layers in the quartz-rich rocks. Their attitude markedly contrasts with the eastward-plunging, down-dip lineations in the West Mountain-Council Mountain block.

The shear zone at the east side of the New Meadows block is cut by many pegmatitic dikes consisting of albite, quartz, white mica, and traces of red-brown garnet. The pegmatites are foliated locally but are essentially intact. Evidently their injection largely postdated the shearing and dismemberment of their host rocks. These pegmatitic rocks along the shear zone contain tectonically derived fragments of nondeformed but partially hydrated clinopyroxenite. An analysis of one of these altered Ca-rich pyroxenites (W-107) is included in Table 2. The sheared rocks on the eastern side of the New Meadows block probably are either part of a tectonic zone between accreted terranes or part of the major tectonic zone between the North American craton and the accreted terranes to the west.

Bonnichsen (1987) postulated that the peridotite and associated metasedimentary rocks of the New Meadows block might be a melange assemblage mixed and deformed in an oceanic trench environment. He suggested that the rocks in the New Meadows block are part of the dismembered oceanic crust terrane exposed in northeastern Oregon. Although the extensive cover of Tertiary basalts obscures the older rocks, the New Meadows tectonic block is possibly part of the Blue Mountains island arc accreted terrane. However, the block may also be a fairly well-preserved part of the Mesozoic continental margin of North America that escaped some of the major deformation associated with the docking of the Blue Mountains terrane.

## RIGGINS REGION

The Riggins region contains several ultramafic bodies within the Squaw Creek Schist of the Riggins Group. The area of ultramafic rocks extends south-southwestward for 9 to 12 miles (15-20 km) from the Time Zone Bridge where highway U.S. 95 crosses the Salmon River north of Riggins. This zone of ultramafic rocks is within the Riggins, Riggins Hot Springs, Pollock, Heavens Gate, and Pollock Mountain 7 1/2-minute quadrangles. The ultramafic occurrences in the Riggins area were mapped and described in some detail by Hamilton (1963, 1969), were reexamined and remapped by Onasch (1977, 1987), were mapped in the Heavens Gate quadrangle by Sarewitz (1982) and were noted by Aliberti (1988) to lie in the southwestern part of the Riggins region. The geologic maps of Hamilton, Onasch, and Sarewitz differ considerably in the locations and outlines of the ultramafic bodies. The discrepancies result from the sparseness of outcrops in parts of the region and the structural complexity.

In the Riggins area, most of the ultramafic occurrences are at the base of or within the Squaw Creek Schist, the upper of the three formations -- the Fiddle Creek, Lightning Creek, and Squaw Creek Schists -- that constitute the Riggins Group of probable Early or Middle Mesozoic age. These three formations are composed primarily of metavolcaniclastic lithologies; minor amounts of marble, calc-silicate rock, quartz-rich rock, and amphibolite are in the upper part of the Lightning Creek Schist and in the Squaw Creek Schist. Hamilton mapped the ultramafic rocks at the contact between the Squaw Creek and Lightning Creek Schists and suggested they had been tectonically emplaced into their present stratigraphic position. He states (1963, p. 65):

The ultramafic rocks north of Riggins lie along the contact between the dissimilar Squaw Creek and Lightning Creek Schists. South of Riggins, some masses lie between the same formations, and other parallel masses are nearby. Possibly the ultramafic rocks were intruded fortuitously along a major lithologic break in a stratigraphic succession; but much more likely, the formations are separated by a thrust fault along which the ultramafic rocks were intruded, probably during thrusting. Serpentine follows thrust faults in many regions, and the position here of metaperidotite between dissimilar formations supports such an interpretation.

Onasch (1977) reexamined the stratigraphic and structural setting of the ultramafic rocks and concluded that the Lightning Creek and Squaw Creek Schists are stratigraphically gradational rather than tectonically superimposed. He described their contact as a depositional one with normal intercalations and gradations. In his mapping, Onasch (1977) concluded that the ultramafic bodies lie at two specific horizons within the lower part of the Squaw Creek Schist. He states (1977, p. 34-35):

With the exception of the body at [Time Zone] Bridge, all ultramafic bodies occur at two distinct horizons within the lower portion of the Squaw Creek



Schist. The serpentinite at [the] Bridge occurs at the contact between the Lightning Creek and Squaw Creek Schists. All occurrences, regardless of metamorphic grade or location, are associated with marbles, quartz-rich schists, and talc schists. . . . The fact that in most places the local stratigraphy around each of these bodies is identical could be explained either by emplacement into two horizons in the Squaw Creek Schist which have identical lithologies or, more realistically, emplacement along faults which carried portions of a single stratigraphic horizon along with each ultramafic body. The two levels of ultramafic bodies suggests that two faults, or perhaps an imbricate fault may be involved. These postulated faults would appear to be bedding plane faults because no large angular discordances were observed in the areas surrounding the bodies.

## TIME ZONE BRIDGE AREA

The Time Zone Bridge ultramafic body is elongate in a northwest-southeast direction and lies between the Lightning Creek Schist to the northeast and the Squaw Creek Schist to the southwest. It is mainly in sec. 34, T. 25 N., R. 1 E., and secs. 2 and 3, T. 24 N., R. 1 E., in the Riggins quadrangle. The body is 1.2 to 1.8 miles (2 to 3 km) long and 1,000-1,300 feet (300-400 m) wide. It is well exposed in the large roadcut along highway U.S. 95 on the north side of the bridge. It is the best exposed body, and one of the largest, in the Riggins area. It consists principally of serpentinite and chlorite-talc-antigorite schist, with widely varying proportions of these minerals. Only locally are remnants of original olivine preserved within the body, and orthopyroxene has not been found. Blackwall zones as much as a few cm thick of chlorite-rich and actinolite-rich are developed at its margins and at the edges of intercalated slivers of the Squaw Creek Schist. Also present are small masses of talc-rich schist and phlogopite-rich schist. Anthophyllite, magnesite, and magnetite also occur in the Time Zone Bridge ultramafic body.

Two analyses of serpentinite (W-6 and TBR-3) from the Time Zone Bridge ultramafic body and an analysis of a serpentinite (SR14-1) previously reported by Hamilton (1963) are included in Table 2. The chemical analyses and mineralogy of these rocks suggest they started as harzburgites. Also included in Table 2 are two analyses of metamorphosed basaltic rocks (TBR-10 and TBR-11) that are probably dikes in the Squaw Creek Schist immediately adjacent to the west end of the Time Zone Bridge serpentinite body.

## POLLOCK REST STOP-WHITE BIRD RIDGE AREA

The Pollock Rest Stop body is well exposed in a roadcut about 3/4 mile (1.2 km) south of the highway rest stop on U.S. 95 between Riggins and Pollock, in sec. 16, T. 23 N., R. 1 E., in the Pollock quadrangle. This ultramafic body consists principally of serpentinite and talc-chlorite-antigorite schist, with varying mineral proportions. Minor minerals in the ultramafic rock include magnetite, magnesite, tremolite, and anthophyllite; however, no remnants or original pyroxenes or olivine have been found. The enclosing rocks include

several lithologies, most notably marble, calc-silicate schist, amphibolite, quartz-rich muscovite schist, and talc schist. Analyses of a serpentinite (W-35) and of a high-silica altered harzburgite (W-36) from the Pollock Rest Stop ultramafic body are reported in Table 2, as is a previously analyzed serpentinite sample (SR37-3) reported by Hamilton (1963). Probably this ultramafic body started as harzburgite.

The Pollock Rest Stop ultramafic body is at the eastern end of a series of ultramafic outcrops that Onasch (1977) mapped as extending 2-2.5 miles (3-4 km) northwestward through an area of large landslides to an occurrence on the west side of White Bird Ridge mapped by Sarewitz (1982) in secs. 7 and 18, T. 23 N., R. 1 E., in the Heavens Gate quadrangle. The ultramafic body found by Sarewitz is within the Lightning Creek Schist, rather than within the Squaw Creek Schist. Sarewitz reports talc-serpentine, talc-tremolite, and talc-chlorite schist as rock types. Similarly, extending south-southwest from where Sarewitz (1982) found ultramafic rocks, Aliberti (1988) reports silicified talc schists appearing as small tectonic pods within the Riggins Group schists or near the contact between phyllites of the Lucile Slate and the Riggins Group schists.

## OTHER ULTRAMAFIC OCCURRENCES

The Time Zone Bridge and Pollock Rest Stop ultramafic bodies are the only ones in the Riggins area that have received detailed petrologic and structural investigations. Several other bodies in the region are thought to be very similar to the two described above.

Onasch (1977) mapped a small serpentinite body in the lower part of the Squaw Creek Schist about 0.1 mile northwest of the village of Pollock, in the SE 1/4 sec. 20, T. 23 N., R. 1 E., of the Pollock quadrangle. Hamilton did not report this occurrence.

Both Hamilton (1963) and Onasch (1977) reported serpentinite in the lower part of the Squaw Creek Schist in the North Fork of Sheep Creek area, in secs. 9, 10, and vicinity, T. 23 N., R. 1 E., in the Pollock quadrangle. Hamilton indicated this ultramafic body was almost 2 miles (3.2 km) long; however, Onasch determined it to be only about 0.1 mile long and located in the streamcourse of the North Fork of Sheep Creek.

Onasch (1977) reported three adjacent bodies of metaperidotite in the lower part of the Squaw Creek Schist in the Cat Creek-Shorts Creek area, south of the Salmon River, in sec. 24, T. 24 N., R. 1 E., and in secs. 19 and 20, T. 24 N., R. 2 E., in the Riggins and Riggins Hot Springs quadrangles. Hamilton (1963) did not include these bodies on his map.

In the Alum Gulch-Emery Creek area, Hamilton (1963) mapped a northwest-trending ultramafic zone for about 2 miles (3.2 km) along the Squaw Creek Schist-Lightning Creek Schist contact in secs. 29, 32, and 33, T. 24 N., R. 1 E., and in secs. 4 and 5, T. 23 N., R. 1 E., in the southwestern part of the Riggins quadrangle and the northwest part of the Pollock quadrangle. Onasch (1977) did not note this occurrence.

Sarewitz (1982) mapped a small body of metamorphosed ultramafic rocks about 0.8 mile (1.3 km) east-northeast of Mullin Spring, in SW1/4 sec. 19, T. 23 N., R. 1 E., in the Heavens Gate quadrangle. He refers to this occurrence, as he also did for those farther north along White Bird Ridge, as talc-serpentine, talc-tremolite, and talc-chlorite schists.

Geologists (Hamilton, 1963; Onasch, 1977, 1987) who previously reported on the ultramafic rocks in the Riggins area have concluded that the bodies were emplaced tectonically along major faults developed early in the deformational history. We believe this interpretation is quite reasonable. It is unclear whether emplacement occurred early during active subduction in a trench environment or later by tectonic forces squeezing up ultramafic bodies from the accreted prism or even from the mantle. The tectonic activity perhaps accompanied the docking of the Blue Mountains island arc terrane from the west, or even the development of the Idaho batholith. Regardless, we favor the explanation that the ultramafic bodies in the Riggins region were derived tectonically by obduction from the west during convergent plate motion, before the Blue Mountains terrane docked against North America.

## SOUTH FORK OF THE CLEARWATER RIVER REGION

A nearly linear belt of metamorphosed ultramafic rocks extends north-northeastward from Asbestos Peak, east of White Bird, for about 14 miles (22.4 km) across the South Fork of the Clearwater River to North Blacktail Butte, east of Grangeville. Several ultramafic bodies lie along this zone, and additional ones probably exist. From south to north, these bodies include Asbestos Peak, Misery Ridge, Grouse Creek, Castle Creek, and North Blacktail Mountain. In addition, the small Asbestos Point occurrence lies about 1.2 miles (2 km) east of the trend of this zone. The ultramafic rocks in the South Fork of the Clearwater region are approximately along strike northeast of the serpentinite bodies in the Riggins area, although a 24-mile (38 km)-gap lies between the two areas in which no ultramafic bodies have been reported (Figure 1).

## ASBESTOS PEAK AREA

The Asbestos Peak ultramafic body lies mainly in the southeast corner of sec. 26, T. 28 N., R. 3 E., in the Dairy Mountain 7 1/2-minute quadrangle. It is exposed for a distance of 600-700 feet (about 200 m) on Asbestos Peak and is elongate from southwest to northeast. The body probably extends southwestward into sec. 35, and additional pods of ultramafic rock lie to the northeast in sec. 25 (Paul Myers, oral commun., 1986). The main rock type on Asbestos Peak is a coarse-grained, essentially decussate-textured, anthophyllite-rich metaperidotite containing subordinate amounts of chlorite, talc, and opaque oxides, but little serpentine or Ca amphiboles. Locally, small olivine- and orthopyroxene-bearing remnants of the original harzburgite are within the anthophyllite body, but they are subordinate, even in the core of the mass. This rock shows no directional metamorphic fabric. It does show, however, what we interpret as an original layered fabric, now steeply dipping and slightly folded, that consists of approximately equant, olivine-rich crystal masses (seen on the

weathered outcrop surface as red-stained iron-oxide-rich spots typically 1 to 2 inches across) aligned in crude rows within a coarse-grained groundmass of what originally was orthopyroxene (seen as the light-colored anthophyllite- and talc-rich matrix surrounding the reddish spots). The main original ultramafic rock type at Asbestos Peak is believed to have been harzburgite. Locally, small clots up to 3 inches or so across of opaque oxides, perhaps chromite, occur in the metaperidotite. Analyses of a low-silica altered harzburgite (C-115) and two high-silica altered harzburgites (AP-3 and AP-9) are included in Table 2.

Cutting the anthophyllite-rich ultramafic body are veins ranging in width from 1/4 inch to a foot of cross-fiber asbestos, probably anthophyllite. Prospect pits on the southwest and northeast ends of the outcrop evidently were dug to examine the thickest of these asbestos veins. Exposed in the prospect pit are aplitic to pegmatitic dikes. Their compositions are tonalitic and one of the samples examined in thin section contained cordierite. The thicker veins of cross-fiber anthophyllitic asbestos probably formed because of the injection of dikes like these.

Within the Asbestos Peak ultramafic body are zones of chlorite-rich rock, generally medium- to coarse-grained and not foliated, that contain modest amounts of reddish stained opaque oxides. These zones are as much as several feet wide and 20 feet (6 m) long. They are most conspicuous at what would appear to be the northwest margin of the body. This placement and their composition suggest they are blackwall zones formed by alteration at the margin of the metaperidotite. Similar chlorite-rich zones occur inside the Asbestos Peak metaharzburgite body. Nowhere are the exposures good enough to see the exact relationships between the chlorite-rich rock and the much more abundant anthophyllite-rich metaharzburgite. Hence, it is unclear if these chlorite-rich rocks within the metaperidotite body originally were dikes, olivine segregations, wallrock inclusions, or zones of hydrothermal alteration along shears in the metaperidotite. No rocks were observed with compositions intermediate between the chlorite-rich blackwall rocks and the anthophyllite-rich metaperidotite. Two analyses of these chlorite-rich blackwall zone rocks (AP-6 and C-89) are given in Table 2.

On the southwest side of Asbestos Peak is an exposure 10 to 15 feet (3-4 m) wide of a black, generally fine-grained, nonfoliated rock consisting principally of hornblende and reddish brown garnets. In thin section the garnets are seen typically to be poikiloblastic and the hornblendes prismatic to equant. Additional minerals include green spinel, opaque oxides (probably ilmenite and magnetite), and traces of probable cordierite and possible sapphirine or idocrase. Minor amounts of chlorite and clinozoisite also are present. The garnet probably is a member of the grossularite-andradite series. Four analyses (AP-4, AP-5, C-75, and C-91) of this rock type are included in Table 2. The chemical composition, and position of this peculiar hornblende-garnet rock relative to the ultramafic body, suggests that it is a blackwall zone rock that has been significantly altered, principally by desilication. As discussed later in this report, this type of hornblende-garnet blackwall zone probably was basaltic in composition to start with.

The wall rocks enclosing the Asbestos Peak ultramafic body are not exposed near the body. Along the roads in the region are various outcrops of granitic, amphibolitic, and micaceous gneissic to schistose rocks. The Asbestos Peak body lies in an area where only reconnaissance geologic mapping has been attempted. According to the geologic compilation map of Gaston and Bennett (1979), the Asbestos Peak locality lies within a northeast-trending belt of metamorphic rocks assigned to the undifferentiated Seven Devils volcanic group and highly metamorphosed equivalents of the Riggins Group that lies between the better mapped areas around Riggins (Hamilton, 1963, 1969; Onasch, 1977) and along the South Fork of the Clearwater River (Myers, 1982, Hoover, 1986). Gaston and Bennett (1979) show a northeast-trending fault zone approximately along the southeast side of the Asbestos Peak ultramafic body. This fault may be the northeastward extension of the North Fork reverse fault of Lund and others (1993).

## MISERY RIDGE AREA

The Misery Ridge ultramafic body is about 5 miles (8 km) north-northeast of the Asbestos Peak area on the north-south-trending ridge with a top elevation of 5,460 feet in NE1/4 of sec. 1, T. 28 N., R. 3 E., of the Goodwin Meadows 7 1/2-minute quadrangle. Highly deformed and altered ultramafic rocks are exposed about 500 feet (150 m) along the top of this ridge. Also included with the Misery Ridge ultramafic locality are some very poorly exposed ultramafic rocks along the forest road leading from the south to the main exposures on the 5,460-foot-elevation ridge. These are in NE1/4 sec. 12 and along the south edge of SE1/4 sec. 1, T. 28 N., R. 3 E. As at Asbestos Peak, the rocks enclosing the Misery Ridge ultramafic body are not exposed. The ultramafic body and enclosing rocks form a continuation of the belt of metamorphic rocks generally thought to belong to the Permo-Triassic Seven Devils volcanics and the Riggins Group (Gaston and Bennett, 1979).

The ultramafic rocks on Misery Ridge vary somewhat in composition and typically are strongly deformed, with multiple stages of foliation, lineation, and folding. No dunite or harzburgite with primary olivine or pyroxenes have been found at this locality. The ultramafic rocks have been hydrated, silicified, and then altered further so that they are composed of varied mixtures of anthophyllite, chlorite, tremolite, and talc, with minor amounts of opaque oxides and serpentine. Analyses of a high-silica altered harzburgite (MR-f) and two of altered Ca-rich pyroxenites (MR-3 and MR-10) from the Misery Ridge ultramafic occurrence are included in Table 2. Also present at Misery Ridge is a mass of black, fine-grained, nonfoliated hornblende-garnet blackwall zone rock with ilmenite and spinel essentially identical to the hornblende-garnet blackwall zone rocks at Asbestos Peak. Two analyses of these blackwall zone rocks (C-137 and MR-14) are included in Table 2.

## GROUSE CREEK AREA

The Grouse Creek ultramafic occurrence, about a mile (1.6 km) northeast of the Misery Ridge body, lies along the crest and flanks of the northeast-trending ridge in the S1/2 sec. 31, T. 29 N., R. 4 E., in the Goodwin Meadows 7 1/2-minute quadrangle. Ultramafic

rocks probably extend down this ridge into the SW1/4 sec. 32, T. 29 N., R. 4 E., in the Hungry Ridge 7 1/2-minute quadrangle. The Grouse Creek body is within the area mapped by Hoover (1986). She indicates that the ultramafic rocks are a fault slice and now are enclosed in a geologic unit consisting of strongly deformed quartz-mica schist and gneiss and amphibolitic gneiss. According to Hoover (1986), the ultramafic rocks at Grouse Creek make up a small body of blocks of undeformed rocks set in a matrix of sheared gneiss and metachert lenses. She further describes the ultramafic rocks:

The predominant ultramafic lithology . . . is a talc-olivine-anthophyllite rock that crops out over most of the eastern two-thirds of the body. In the field, this rock is a mass of light gray to white talc with red-colored patches rich in olivine. In thin section, talc occurs as an intergrowth of large plates and surrounds olivine grains. Olivine occurs as masses of large hypidioblastic crystals or as idioblastic prisms and is altered to serpentine along grain margins and in cleavages. Anthophyllite is usually less than 5 percent of the mode and forms hypidioblastic prisms.

Hoover's (1986) description suggests that the principal ultramafic rock in the Grouse Creek body is harzburgite. In addition, she notes that pyroxenite, which consists of about 95 percent augite and minor olivine and chromite, crops out in the western third of the Grouse Creek locality. We also have found websterites in the Grouse Creek body. Chemical analyses of two relatively fresh Ca-rich pyroxenite samples (C-93 and C-136) and one of an altered Ca-rich pyroxenite sample (C-131) from the Grouse Creek occurrence are included in Table 2.

Associated with the ultramafic rocks in the Grouse Creek body are rocks rich in chlorite and with varied amounts of tremolite-actinolite, garnets, ilmenite, and apatite. Hoover (1986) describes these rocks as:

dark green gneisses that crop out irregularly over the western half of the unit and make up approximately 80 to 90 percent of the matrix. These rocks are about 90 percent chlorite pseudomorphed after amphibole and are strongly linedated. Plagioclase-quartz domains and minor garnet are interspersed throughout the chloritic matrix. Large, idioblastic ilmenite crystals range up to 5 cm in diameter and locally make up as much as 6 percent of the mode of these gneisses. Sheared metachert, possible metacarbonate rocks, and amphibolite gneisses make up the remaining 10-20 percent of the sheared matrix.

Some of these chlorite-rich rocks containing the large ilmenite crystals appear as dike- or vein-like masses cutting the anthophyllite-bearing metamorphosed ultramafic rocks. Chemical analyses of two chlorite-rich rocks (C-95 and C-98) from the Grouse Creek body are included in Table 2. These rocks are probably best thought of as blackwall zones, although sample C-95 is from one of the veinlike masses with ilmenite megacrysts.

## ASBESTOS POINT AREA

The Asbestos Point ultramafic rock occurrence is nearly 3 miles (4.8 km) east of the Grouse Creek body, in SE1/4 sec. 27, T. 29 N., R. 4 E., in the Hungry Ridge 7 1/2-minute quadrangle. This locality is within the area mapped by Hoover (1986). She shows the enclosing rocks as part of a porphyritic granodiorite/quartz-monzonite orthogneiss unit and that a northeast-trending fault of unspecified displacement passes near the ultramafic occurrence. Rocks in this unit range in composition from tonalitic to quartz-monzonitic. They typically have a mylonitic fabric manifested by a weak foliation and a strong lineation.

At Asbestos Point the ultramafic rocks are present only as a small area of float; we did not encounter an actual outcrop when we visited. The principal ultramafic rock is dunite that consists primarily of granular, unsheared olivine grains in a recrystallized equilibrium metamorphic fabric characterized by 120 degree grain contacts. The olivine is accompanied by minor amounts of talc, chrysotile in veinlets, and brownish opaque oxide grains (spinel?). Also present at Asbestos Point are altered ultramafic rocks that consist mainly of anthophyllite and talc, accompanied by minor chlorite and opaque oxides. Asbestos vein material cutting dunite and granitic pegmatite float is abundant near the ultramafic occurrence. An analysis of relatively fresh dunite (C-165) from the Asbestos Point ultramafic occurrence is included in Table 2.

## CASTLE CREEK AREA

The Castle Creek ultramafic occurrence lies near or along the Castle Creek fault in the NW1/4 sec. 15 and SW1/4 sec. 10, T. 29 N., R. 4 E., in the Hungry Ridge 7 1/2-minute quadrangle. The ultramafic rocks there are clinopyroxenites with high chromium concentrations. Dunite, harzburgite, or their altered equivalents have not been seen. The clinopyroxenites are not foliated. They consist principally of augite, accompanied by modest amounts of orthopyroxene, minor replacement patches of hornblende, and accessory chlorite, opaque oxides, serpentine, epidote, and possible traces of olivine. Three analyses of relatively fresh clinopyroxenite (C-151, C-161, and C-169) from the Castle Creek occurrence are included in Table 2.

Associated with the Castle Creek clinopyroxenite is altered gabbro, which can be described as rodingite. The gabbro consists of abundant augite, hornblende, and clinozoisite, minor chlorite, and possible quartz, plagioclase, and prehnite. It is not foliated, permitting the original gabbroic texture to be discerned. An analysis of rodingized gabbro (C-157) from Castle Creek is included in Table 2. Also associated with the gabbro and clinopyroxenite is chlorite-tremolite phyllite.

According to Myers (1982), the zone along the Castle Creek fault where the clinopyroxenites occur lies between the uplifted, foliated part of the Blacktail trondhjemite pluton to the west, and the biotite-muscovite schists to the east that Myers considers to be

equivalent to the Squaw Creek Schist member of the Riggins Group. Also present in this area are exposures of the calc-schist phase of the Riggins Group (Myers, 1982).

## NORTH BLACKTAIL BUTTE AREA

The North Blacktail ultramafic body is about 2 miles (3 km) long and is elongate in a generally north-south direction in secs. 21 and 28, T. 30 N. R. 4 E., in the Harpster 7 1/2-minute quadrangle, and has minor extensions into secs. 15, 16, and 27. These rocks were first noted by Anderson (1930), who concluded they were metamorphosed peridotites. Later, Myers (1982) mapped the rocks of the region in some detail and described (p. 6-7) them as follows:

A crudely stratified, strongly foliated metagabbro and metaperidotite body of lenticular form is exposed on North Blacktail Butte. . . . Its maximum thickness is about 850 feet (260 m), and it is symmetrically concordant in the hinge of the North Blacktail syncline. Its upper and lower contacts are reverse faults dipping 40 to 60 degrees eastward. From a basal layer of sheared and metamorphosed olivine-pyroxene gabbro, the rocks grade upward into a core of metaperidotite and finally to a discontinuous layer of highly altered pyroxenite. These three types of rock show considerable local variation in texture and mineral composition. . . . The metaperidotite is generally schistose or gneissic with lenticular masses of coarse magnesian amphibole porphyroblasts. Relict olivine and pyroxene have been almost completely altered to antigorite, talc, tremolite, prochlorite, zoisite, and magnetite. Accessory minerals include phlogopite and actinolite. The epidote-ferroan prochlorite-magnetite rock at the top of the metaperidotite . . . is probably a sheared and metamorphosed pyroxenite.

The rocks that bound the North Blacktail ultramafic body, according to Myers' (1982), are biotite-muscovite schist interpreted to be the Squaw Creek Schist member of the Riggins Group and minor amounts of phyllonites formed from quartz keratophyres and other lithologies of the Seven Devils volcanics. Chemical analyses of two samples of low-silica altered harzburgite, still containing substantial amounts of relict olivine (C-142 and C-146) obtained from the North Blacktail ultramafic body, are included in Table 2.

## LOWELL-KAMIAH-DWORSHAK RESERVOIR REGION

Several ultramafic bodies are in north-central Idaho near Dworshak Reservoir and the towns of Lowell and Kamiah. Some of these were discovered and described by Anderson (1930, 1931), Johnson (1947), Hietanen (1963), and Lewis and others (1992); others were found by the authors. Additional ultramafic rocks are likely present in the region. As noted on Figure 1, most of these rocks lie in a northwest-trending belt that follows the bend in the



accreted terrane-continental craton suture zone. These occurrences are described below, more or less in sequence from southeast to northwest.

## LOWELL AREA

In their recent mapping of the Lochsa River area, Lewis and others (1992) report the existence of six ultramafic bodies. We visited some of these and, in the process, found two more.

Lewis and others (1992) reported a body of ultramafic rock at Falls Point (elev. 5,069 feet) in the SE1/4, sec. 9, T. 31 N., R. 9 E., in the Selway Falls 7 1/2-minute quadrangle. This body is enclosed within a much larger unit of Cretaceous-age foliated granodiorite. We found that this rock body is a melanocratic, pyroxene- and hornblende-rich, plagioclase-bearing segregation within the enclosing more leucocratic granodiorite. There is no suggestion that it actually had an ophiolite or a mantle origin like that of the other ultramafic bodies described in this report. It probably is best considered as not belonging to the group; thus, it has not been included in Figure 1 or Table 1.

An ultramafic body, shown by Lewis and others (1992) to be about 0.25 mile wide, lies about 2 miles (3.2 km) south of Stillman Point in the NE1/4, sec. 16, T. 31 N., R. 8 E., in the Stillman Point 7 1/2-minute quadrangle. Lewis and others (1992) report that both dunite and pyroxenite are present. This body is enclosed within the quartzite and schist unit of the Syringa metamorphic sequence, of probable middle or early Proterozoic age and is adjacent to a mass of Cretaceous-age tonalite. We have not visited this locality.

A body of peridotite occurs on the west side of the Selway River at the Swiftwater Creek bridge, nearly 3 miles (4.8 km) upstream from the town of Lowell, in the NE1/4 sec. 16, T. 32 N., R. 7 E., in the Goddard Point 7 1/2-minute quadrangle. The mass stands about 100 feet (30 m) high and is about 200 feet (60 m) thick from east to west. Its length has not been determined, but it apparently does not extend south of Swiftwater Creek. In one thin section (Reed Lewis, oral commun., 1992), the peridotite contains abundant remnants of coarse-grained olivine with a nondeformed texture that has been exploded by the development of hydrous minerals along cleavages and fractures. Minerals forming at the expense of the olivine and possibly from orthopyroxene include talc, actinolite, chlorite, and carbonate. Also present are minor amounts of opaque oxides. The original texture may have been an annealed metamorphic fabric. Abundant fibrous amphibole, quite likely anthophyllite and perhaps accompanied by tremolite, occurs as very coarse-grained to pegmatitic rosettes of radiating crystals throughout much of the Swiftwater Creek ultramafic body. Next to the river alongside the ultramafic mass, and cutting it locally in vein- or dike-like tabular zones, is a green, much finer grained rock that consists predominantly of actinolite or diopside. This rock probably is an amphibole-rich blackwall zone formed by hydration and alteration of the original peridotite.

The Swiftwater Creek ultramafic body is enclosed in the schist and quartzite unit of the Syringa metamorphic sequence. This sequence is probably middle or early Proterozoic in age and is adjacent to a mass of Cretaceous-age foliated granodiorite (Lewis and others, 1992). Near to the body are outcrops of biotite-plagioclase schist and plagioclase-hornblende schist, but the marginal contacts of the peridotite are not exposed. A long north-northwest-trending fault is shown on Lewis and others' (1992) geologic map close to the Swiftwater Creek ultramafic body. This is one of several closely spaced faults in that region between the O'Hara Creek fault on the east and the Yakus Creek fault on the west.

A small peridotite occurrence, herein called the Icicle Spring peridotite body and which is identical to the Swiftwater Bridge ultramafic body, is located nearly 3 miles (4.8 km) to the north of the Swiftwater Creek body along the same group of faults. It is at approximately 1,800 feet in elevation, along an abandoned logging road near the center of sec. 33, T. 33 N., R. 7 E., in the Lowell 7 1/2-minute quadrangle. The Icicle Spring body contains rosettes of anthophyllite like many other ultramafic bodies in this region. It is enclosed by the strongly foliated, Cretaceous-age tonalite of Coolwater Ridge (Lewis and others, 1992).

About a half mile north of the Icicle Spring peridotite, near the mouth of Pete King Creek in S1/2 sec. 28, T. 33 N., R. 7 E., in the Lowell 7 1/2-minute quadrangle, Anderson (1930), reported an ultramafic body a hundred or more feet long and partially changed to asbestos. Anderson described this Pete King ultramafic occurrence as a dunite with only scattered bundles of amphibole and antigorite, talc, and chlorite. Our search for this body failed to confirm its existence. If present in the area, it would be enclosed by the schist-quartzite unit of the Syringa metamorphic sequence.

A little more than a mile northwest of the Icicle Spring peridotite near elevation point 2,802 in SE1/4 sec. 29, T. 33 N., R. 7 E., also in the Lowell quadrangle, Lewis and others (1992) reported a small ultramafic rock occurrence. We failed to find the unit at this locality as shown on their geologic map; however, about a quarter of a mile to the southeast and still in the SE1/4 of sec. 29, we found a body of talc schist just a few feet across and enclosed in plagioclase-biotite schist, in a roadcut along a logging road at about 2,650 feet in elevation. This body lies within the same zone of faults as the Swiftwater Creek and Icicle Spring occurrences. It is also enclosed by the schist-quartzite unit of the Syringa metamorphic sequence of Lewis and others (1992).

West and north of the occurrences just noted Lewis and others (1992) show two additional small ultramafic bodies on their map. These also are enclosed within the schist and quartzite unit of the Syringa metamorphic sequence and generally are associated with the northwestward continuation of the series of faults between the Yakus Creek and O'Hara Creek faults. One is on the ridge northeast of Big Hill in NE1/4 sec. 31, T. 33 N., R. 7 E., along the border of the Lowell and Syringa 7 1/2-minute quadrangles. The other is about a quarter of a mile west of Placer Creek in SW1/4 sec. 18, T. 33 N., R. 7 E. We have not visited either of these sites.

## GLENWOOD-KAMIAH AREA

Farther east, in the area west of the Maggie Butte-Woodrat Mountain ridge, Anderson (1930, 1931) described the anthophyllite deposits mined early this century. He located the principal deposit at about 3,100 feet in elevation and about 1.5 miles (2.4 km) south of Glenwood. It probably is in the NE1/4 sec. 9, T. 33 N., R. 5 E., in the Glenwood 7 1/2-minute quadrangle, according to the location given by Mitchell and others (1981). Anderson (1930, p.46), however, had placed it in sec. 10 rather than sec. 9. This is only one of several ultramafic bodies in the area. For the asbestos bodies that were mined, Anderson (1930, p.45) states:

The earliest record of development of the Kamiah deposits was shortly prior to 1909 when the Spokane Asbestos Fire Brick Company mined one of the deposits and sawed the asbestos into bricks. In 1910, the same company produced a small amount of asbestos, using it for pipe and boiler covering and for wall plaster. Whether asbestos was mined the next six years could not be learned. Some work was done in 1916 and a small shipment made in 1917 by the Kamiah Asbestos Manufacturing Company, possibly a reorganization of the earlier company. Mining was again at a standstill until 1921 when the Western Mineral Company took over the property of the Kamiah Asbestos Manufacturing Company, made repairs to equipment and mined a small amount of asbestos. Shipments were again made in 1925, this time by the Panhandle Asbestos Company. The company built storage sheds and a grinding plant on the railroad at Kamiah, and shipped some asbestos. In 1929, the deposits owned by the Panhandle Asbestos Company and the plant at Kamiah changed hands, but no mining was done.

Anderson (1931) described some of mined deposits in fair detail (p. 70):

Most of the anthophyllite deposits are in a comparatively small area of 2 or 3 square miles in the northern part of T. 33 N., R. 5 E. . . . The bodies are mainly lenticular and range from minor seams a few feet wide to dikes or lenses as much as 80 feet wide and 200 yards long. More than a dozen bodies greater than 30 feet wide and 100 feet long occur in the area. As the anthophyllite is very resistant to weathering, the bodies tend to form prominent ledges which stand from 10 to 40 feet above the more easily eroded country rock. . . . In all the deposits that were examined, the anthophyllite occurs as mass-fiber and forms essentially the whole of the body. The fibers are arranged in small bundles and generally lie in all directions through the rock, but with pronounced tendency to form radial groups which on cross-fracture yield rosettes . . . [that are] of nearly uniform size in each of the bodies, but vary in size from body to body. The largest measure 6 inches in diameter, while others measure not over 2 inches, but the average is 4 or 5 inches.

Anderson's (1930, 1931) careful microscopic examination of samples from these deposits revealed the most abundant primary mineral was olivine, of which some remains, accompanied by magnetite, chromite, and picotite spinel. He did not find enstatite but suggested it might originally have been present. Anderson thought the original ultramafic rock type was dunite, possibly accompanied by some harzburgite. The secondary minerals he reported, and which make up the bulk of the ultramafic bodies, are antigorite, kammererite? (a Cr-bearing form of chlorite), anthophyllite, talc, magnesite?, and pyrite. These minerals are listed in the order in which Anderson thought they formed. Only minor amounts of antigorite occur, principally in cleavage cracks and grain boundaries on the olivine. He found that the principal episode for the growth of serpentine minerals occurred before the extensive formation of anthophyllite and talc; this same pattern was reported at New Meadows by Bonnichsen (1987, and above). Where anthophyllite replaces olivine, Anderson (1931, p. 74) writes, it:

is not controlled in the slightest degree by the physical properties of the olivine; and thus the needles of amphibole pierce the olivine grains without regard to their boundaries, cleavages, or cracks. . . . They extend continuously from one olivine grain to another, so that a single needle or bundle of needles may pierce consecutively as many as five or six or more differently oriented olivine individuals. The development of the amphibole needles and bundles in both size and number gradually leads to the diminution in the amount of olivine until the rock is converted from a dunite into amphibolite in which olivine is entirely absent. Not only does the anthophyllite replace the olivine, but it replaces the antigorite and kammererite(?) as well, the needles and bundles of needles passing from these to the olivine with no apparent change in quantity or in ease of replacement.

Anderson (1930, 1931) notes that talc is much less abundant than anthophyllite and that generally the talc replaces both anthophyllite and the earlier antigorite. He concluded that the magnesite formed at about the same time as the talc and that the general sequence of events suggested the alteration had involved the addition of substantial quantities of water and silica. He believed that the water and silica had come from underlying parts of the Idaho batholith as it was crystallizing.

An analysis of a high-silica altered harzburgite sample (C-174), now consisting mainly of anthophyllite, from one of the old mine workings in the Glenwood area is included in Table 2. Our petrographic examination of a few samples collected in this area substantially confirms Anderson's (1930, 1931) observations that are reviewed above.

According to the summary geologic map of Rember and Bennett (1979a), the ultramafic rocks in the Glenwood area are enclosed in a metamorphic unit considered equivalent to the Precambrian-age Prichard Formation of the Belt Supergroup. More recent mapping by Lewis and others (1992), however, places the Glenwood ultramafic rocks within a hornblende gneiss unit of probable Mesozoic age and tentatively assigns them to the Riggins Group. Next to the anthophyllite deposits Anderson (1931) notes that the enclosing schists and

gneisses are highly feldspathic, with accompanying muscovite, biotite, garnet, kyanite, and accessory amounts of magnetite, pyrite, and pyrrhotite. Local granitic aplites and pegmatites cut the anthophyllite bodies as well as the enclosing schists and gneisses. Large intrusive masses of the Idaho batholith are exposed a few miles east of the Glenwood area, and equigranular biotite granodiorite occurs a short distance to the south (Lewis and others, 1992). At one locality Anderson (1930, p. 46) comments on the sharp contacts between the metamorphic country rocks (gneiss or schist, filled with seams and lenses of pegmatite and aplite) and the asbestos deposits.

Besides the deposits south of Glenwood, Anderson (1930) reports scattered small anthophyllite occurrences farther north near and in the canyon walls of Lolo Creek. He does not describe these rocks nor give an accurate location. We have not attempted to find them, so nothing is known of their nature. They probably are in either the Browns Creek Ridge or the Weippe South 7 1/2-minute quadrangle.

## OROFINO AREA

Several metamorphosed ultramafic bodies are within a few miles of Orofino. These include anthophyllite occurrences east of Orofino along Orofino Creek (Johnson, 1947), near the lower end of Dworshak Reservoir (Anderson, 1930; Johnson, 1947; Gary Davidson, oral commun., 1992), and south and east of Teakean (Anderson, 1930; Johnson, 1947). These bodies now consist mainly of anthophyllite and are thought to originally have been dunite or harzburgite. We have not visited any of the localities near Orofino.

Johnson (1947) notes that the anthophyllite deposit along Orofino Creek is about 14 miles (22.5 km) east of Orofino in a railroad cut, where a dike 10-15 feet (3-5 m) wide crops out for 1/2 mile (0.8 km) and disappears at each end under basalt and talus. Most likely this body lies in the S1/2, sec. 1, T. 36 N., R. 3 E., in the Rudo 7 1/2-minute quadrangle, considering the asbestos prospect noted at that location by Hustedde and others (1981). The metamorphic rocks associated with this occurrence, according to the summary map of Rember and Bennett (1979b), probably include amphibolite of unknown age and calc-silicate gneisses and plagioclase-quartz-biotite schists, which they assign to the Precambrian-age Wallace Formation of the Belt Supergroup. Anderson (1930) also describes an asbestos occurrence along Orofino Creek about 11 miles (17.7 km) east of Orofino. Most likely, it is at the same place as the body described by Johnson (1947). Anderson (1930) characterizes the asbestos as:

material [that] is mainly mass-fiber sparsely distributed through altered harzburgite. Several bodies are exposed in the railroad cuts. The dikes may be 40 to 50 feet wide, and intercalated with the gneiss series. In general the alteration of the olivine and enstatite has been mainly to tremolite and talc and with only a very little anthophyllite.

Near Dworshak Reservoir, about 2 miles (3.2 km) northwest of Orofino, is an ultramafic occurrence on the northeast side of the Clearwater River (Johnson, 1947). Johnson

estimates it is 10-15 feet (3-5 m) wide and 20-25 feet (6-8 m) long. This may be the same locality of Anderson (1930) in the canyon side at Ahsahka, about 3 miles (4.8 km) southeast of the Teakean asbestos deposit. It probably is in the N1/2 of sec. 1 or 2, T. 36 N., R. 1 E., in the Orofino West 7 1/2-minute quadrangle. Neither Anderson (1930) nor Johnson (1947) describes this body. According to the summary geologic map of Rember and Bennett (1979b), this body would be associated with Cretaceous-age diorite and tonalite, and with metamorphosed strata of the Precambrian-age Wallace Formation of the Belt Supergroup.

Both Anderson (1930) and Johnson (1947) considered the Teakean asbestos deposit the best exposed and largest one in the Orofino area. It probably is in the W1/2 sec. 16, T. 37 N., R. 1 E., in the Ahsahka 7 1/2-minute quadrangle. Anderson notes the occurrence is exposed on a low ridge of metamorphic rocks barely rising above the level of the basalt plateau. Anderson (1930, pp. 48-49) describes the Teakean deposits as:

asbestos bodies, apparently altered harzburgites, [that] are associated with much younger injection gneiss mainly of dioritic composition and cut by numerous pegmatites and aplites. . . . The gneissic series trends nearly east-west and dips steeply north. The asbestos-bearing rocks occur as dikes or lenses, and the major body appears to trend N. 62 degrees W. . . . Apparently, the anthophyllite occurs mainly in slip-fiber form as long woody blocks in fissures in the altered rock. The seams are irregular and pinch and swell from an inch to a foot or more. . . . Massive fiber asbestos also occurs in places, but forms a very small part of the rock, most of which has altered to talc or serpentine. . . . The relations shown in the cuts and tunnel suggest that the altered igneous rock and asbestos occurs in minor seams or lenses in the gneisses and is not in large masses like the Kamiah deposits. . . . The slip-fiber is composed of parallel fibers of anthophyllite showing replacement of altered prismatic crystals of enstatite and apparently of tremolite, the latter an alteration of olivine. . . . The original olivine and enstatite of the bodies has apparently altered in part to tremolite (coarse prismatic crystals) and to serpentine, these in turn to the . . . anthophyllite. Some of the anthophyllite replaces the olivine or enstatite directly. Talc is much more abundant in these deposits than at the Kamiah deposits and likewise serpentine. The walls of the anthophyllite seams are composed of partially altered olivine and enstatite, usually to serpentine and talc, but contains some groups of anthophyllite.

Johnson (1947) notes that the Teakean ultramafic body consists of exposures along an area about 10 feet (3 m) wide and 100 feet (30 m) long. The minerals are olivine, anthophyllite, tremolite, chlorite, talc, serpentine, quartz, apatite, magnetite, carbonate, and iddisite. Olivine is the chief mineral, ranging in abundance from 5 to 100 percent of the minerals present in individual rock samples. Johnson's petrographic descriptions resemble those of Anderson (1930) cited above. The Teakean ultramafic deposit is associated with Tertiary-age granitic dikes and metamorphosed Precambrian-age Wallace Formation sediments of the Belt Supergroup, according to Rember and Bennett (1979b).

About 2 miles east of the Teakean body is the Olsen asbestos deposit (Hustedde and others, 1981). Its location is in the SE1/4 sec. 15 or the NE1/4 sec. 22, T. 37 N., R. 1 E., in the Ahsahka 7 1/2-minute quadrangle. Logically, this would represent another ultramafic occurrence, although no description is available. If an ultramafic body exists there, it would be associated with foliated Cretaceous tonalite that intrudes metamorphosed Wallace Formation sediments of the Belt Supergroup (Rember and Bennett, 1979b).

## BREAKFAST CREEK AREA

The Breakfast Creek area is west of Dworshak Reservoir, near its northern end. A body of metamorphosed dunite was reported here on the crest of Tamarack Ridge (Hietanen, 1963). This ultramafic body is in the SW1/4 sec. 29, T. 41 N., R. 4 E., in the Township Butte 7 1/2-minute quadrangle. Hietanen (1963, p. B28) states:

Most of this body consists of fine-grained, dark greenish-gray serpentine with rust-colored specks, but a small portion contains radiating crystals of anthophyllite interleaved with chlorite. . . . [The] mesh of serpentine minerals is transected by numerous rows of tiny magnetite grains that originally crystallized along the crack of olivine. Some small specks of carbonate, talc, and a few flakes of chlorite occur as additional constituents. More chlorite and talc are in that portion of serpentine, in which anthophyllite prisms occur. Olivine with only narrow serpentinized cracks fills the interstices between the anthophyllite prisms in the fresh part of the anthophyllite-bearing outcrop. The cracks in the anthophyllite are filled by talc. Some grains of magnetite are along the cracks in the olivine and a few larger grains occur next to the anthophyllite.

Our investigation of the Tamarack Ridge ultramafic body indicates it is 0.1 to 0.2 mile (.2-.3 km) wide along the road and of indeterminate length. It appears to be elongate in a northwest-southeast direction. It is enclosed in garnet-mica schist of the metamorphosed Prichard Formation of the Precambrian-age Belt Supergroup (Hietanen, 1963). In addition to dunite and anthophyllite-rich rock at this locality, we found chlorite-rich rocks as float associated with the ultramafic mass. These rocks likely represent blackwall zones that formed at the margin, or within, the dunite body. Some rosettes of anthophyllite at this locality are several inches across. Altogether, the rocks here greatly resemble those at the Panhandle Asbestos deposit near Glenwood, discussed above, except that more primary dunite is present.

## CUDDY MOUNTAIN-STURGILL PEAK REGION

About 25 miles (40 km) southwest of the New Meadows area ultramafic rocks are associated with a zone of major faulting (Figure 1). These rocks were identified by Skurla (1974) in the Sturgill Peak area and by Mann (1989) in the Cuddy Mountain area. They are along a major zone of high-angle thrust faulting that extends northeastward from the Conner

Creek fault zone in Oregon, near the Sturgill Peak area, through the Cuddy Mountains as the Cuddy Mountain fault, and to the Lick Creek fault (Mann, 1989).

## CUDDY MOUNTAIN AREA

In the Cuddy Mountains, Mann (1989) has mapped discontinuous ultramafic bodies along the northwest-dipping Cuddy Mountain fault zone for about 6 miles (10 km), extending from SW1/4 sec. 25, T. 17 N., R. 5 W., in the Brownlee Dam 7 1/2-minute quadrangle on the southwest to SW1/4 sec. 2, T. 17 N., R. 4 W., in the Cuddy Mountain 7 1/2-minute quadrangle. The ultramafic rocks are all serpentinites with included fragments of the wall rocks. The serpentinite occurrences along the fault zone range from 50 to 500 feet (15-150 m) in width. The Cuddy Mountain fault zone is regarded by Mann (1989) to be a high-angle thrust or reverse fault separating rocks of the Paleozoic and Triassic-age Baker Terrane to the northwest that were thrust over Jurassic-age rocks of the Izee Terrane (Weatherby Formation). He suggests that the fault was reactivated during the Cenozoic as a normal fault.

We examined the ultramafic rocks along this fault zone where they are exposed in the northeast corner of sec. 10 and northwest corner of sec. 11. There, the principal rock is strongly sheared serpentinite. Locally within it are dark, nonsheared blocks that may represent an earlier stage of the serpentinite or perhaps rocks which may have primary olivine or pyroxenes. Abundant veins of quartz, typically a cm or less thick, cut the serpentinite at some places. Shearing is abundant in the serpentinite, typically with varied dips and strikes that are approximately north-south. These attitudes are at an angle to the general northeast strike of the Cuddy Mountain fault zone at this locality.

## STURGILL PEAK AREA

In the Sturgill Peak area, Skurla (1974) located a small body of ultramafic rocks along the ridge in SE1/4 sec. 17, T. 15 N., R. 5 W., in the Neil Gulch 7 1/2-minute quadrangle. This body of partially serpentinitized harzburgite is shown on his map as being along a northwest-dipping, high-angle, reverse fault separating Permian(?) -age Grassy Slope phyllites (Baker Terrane) that have been thrust over the Jurassic-age Mann Creek slates (Izee Terrane), in a fashion analogous to that described several miles to the northeast along the Cuddy Mountain fault.

The serpentinite near Sturgill Peak occupies an area perhaps 50 feet (15 m) wide along the ridge crest and extending down both slopes of the ridges as far for a few hundred feet. The serpentinite shows abundant slickensides on fracture surfaces. Skurla (1974) describes the serpentinite as having a protoclastic texture and as being composed predominately of antigorite, with subordinate chlorite and magnetite, and minor amounts of talc and chrysotile (as veinlets). Our examination of several thin sections indicates these same minerals to be present; in addition, relict olivine and orthopyroxene were found in some of the least altered samples, confirming that harzburgite probably was the original rock type. Also, minor amounts of a carbonate mineral and traces of graphite were found in some of the



serpentinites. Some rocks in the ultramafic mass probably have diabasic or gabbroic compositions, inasmuch as we found plagioclase and augite in one thin section. No anthophyllite was found in any of the ultramafic rocks. Quite likely the metamorphic grade at no time was great enough for that mineral to have formed. A serpentinite sample (W-357A) from the Sturgill Peak area that contains remnants of the original harzburgite is included in Table 2.

## GEOCHEMISTRY

We analyzed numerous rocks during this study, and the chemical data are in Table 2, along with sample locations and petrography. In the following discussion, these rocks are divided into categories of ultramafic rocks and associated metamorphic rocks.

### ULTRAMAFIC ROCKS

The mineralogy, petrography, and geochemistry of the ultramafic rocks has led us to classify them into the following seven groups: (1) relatively fresh dunites, (2) serpentinites, (3) altered harzburgites and dunites with relatively low silica contents, (4) altered harzburgites and dunites with relatively high silica contents, (5) relatively fresh Ca-rich pyroxenites and peridotites, (6) altered Ca-rich pyroxenites and peridotites, and (7) chromitites. Normalized values of the major oxides, including NiO and Cr<sub>2</sub>O<sub>3</sub>, for 32 samples are presented in Table 3, and averaged normalized compositions for the ultramafic rock groups are in Table 5. Some of the chemical characteristics of the various types of ultramafic rocks are compared in Figures 2 and 3.

Differences exist between the various ultramafic rock categories (Table 3). The alteration process, which we suggest happened during regional metamorphism, resulted in minor to significant additions of some constituents to the ultramafic bodies. These additions were superimposed on original differences between the rock types. The relatively fresh dunites and Ca-rich pyroxenites undoubtedly most closely represent the initial igneous compositions of the ultramafic rocks. The metamorphic processes of serpentinization and the higher temperature forms of alteration, especially the formation of anthophyllite, tremolite, talc, chlorite, and magnetite, were accompanied by the addition of varying amounts of H<sub>2</sub>O, CO<sub>2</sub>, O<sub>2</sub>, SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, CaO, Na<sub>2</sub>O, K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>, Zr, Sr, V, Ce, and Ba to the ultramafic rocks. The original contents of Fe<sub>2</sub>O<sub>3</sub>, MnO, MgO, Nb, Zn, and La remained essentially unchanged in all but the most extreme cases of alteration. In some rocks Ni, Cr, and perhaps even some Fe was apparently lost.

The serpentinites have more SiO<sub>2</sub> and less Fe<sub>2</sub>O<sub>3</sub> and MgO than the relatively fresh dunites. The MgO/(MgO+FeO) ratios are essentially the same for these two rock groups (Figure 2). These differences, at least in part, could be original if the serpentinites were formed from harzburgites, rather than dunites, inasmuch as orthopyroxene contains

significantly more silica and less Mg and Fe than olivine. Small amounts of  $\text{Al}_2\text{O}_3$ , which now resides mainly in chlorite, was added to some of the serpentinites.

The compositions of the low-silica harzburgites are nearly identical to those of the serpentinites. However, these altered low-silica harzburgites and dunites differ from the relatively fresh dunites by having more  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  and less  $\text{MgO}$ , in the same fashion the serpentinites differ from the fresh dunites. Again, this may mainly represent original harzburgitic rather than dunitic compositions for the low-silica harzburgite group, instead of being due to  $\text{SiO}_2$  introduced during metamorphism.

A talc-chlorite-tremolite schist sample (W-114), contains significantly greater amounts of  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{TiO}_2$ ,  $\text{Na}_2\text{O}$ ,  $\text{Fe}_2\text{O}_3$ , Zr, Ba, Ce, and Sr, less  $\text{MgO}$ , and a lower  $\text{MgO}/(\text{MgO} + \text{FeO})$  ratio than the other samples in the low-silica altered harzburgite category. Given that this sample is from a small, isolated, and completely made over ultramafic body, we suggest that the chemistry is largely the result of alteration that occurred during metamorphism, rather than being the original compositions.

The compositions of the high-silica altered harzburgites and dunites differ from those of the relatively fresh dunites, serpentinites, and low-silica altered harzburgites because of higher amounts of  $\text{SiO}_2$  and lower amounts of  $\text{MgO}$  and  $\text{Fe}_2\text{O}_3$  (Figure 2). These differences may indicate two possibilities: that substantial amounts of  $\text{SiO}_2$  were introduced into original harzburgites as anthophyllite and other hydrous minerals formed, or that the high-silica group represents rocks which initially were nearly pure orthopyroxene (bronzitites) and were metamorphosed with little or no addition of  $\text{SiO}_2$ . We suggest that substantial amounts of  $\text{SiO}_2$  has been added to rocks that originally were harzburgites to form the high-silica group. This assessment is based on the presence of relict olivine remaining in some rocks of this category, as well as textures that suggest olivine was an original constituent. Additionally, as we will discuss later, the wall rocks next to some of the altered high-silica harzburgite occurrences seem to have lost substantial amounts of the original  $\text{SiO}_2$ . Like the serpentinites and low-silica altered harzburgites, the high-silica altered harzburgites have more  $\text{Al}_2\text{O}_3$  than the relatively fresh dunites. Some of the high-silica altered harzburgites would also appear to have had  $\text{CaO}$  and  $\text{Na}_2\text{O}$  added to them.

The relatively fresh Ca-rich pyroxenite and peridotite category consists largely of clinopyroxenite, with minor amounts of orthopyroxene and olivine in some rocks. Only a few ultramafic rocks are websterites, with significant quantities of both orthopyroxene and clinopyroxene. When the Ca-rich pyroxenites are compared to the dunites, harzburgites, and their serpentinitized or otherwise altered equivalents, both groups have similar  $\text{MgO}/(\text{MgO} + \text{FeO})$  ratios and Cr contents (Figures 2 and 3). The Ca-rich pyroxenites, however, have more  $\text{Al}_2\text{O}_3$  than the relatively fresh dunites, which probably is due to significant amounts of  $\text{Al}_2\text{O}_3$  in the diopsidic augite of the Ca-rich pyroxenites. The Ca-rich pyroxenites contain only meager amounts of Ni, and less Zn than the dunite-harzburgite group. Most likely, this reflects the paucity or lack of olivine and orthopyroxene in the Ca-rich pyroxenites.

We analyzed one sample (C-93) of Ca-rich pyroxenite, a websterite, that is lower in its  $\text{MgO}/(\text{MgO} + \text{FeO})$  ratio than the other Ca-rich pyroxenites. Interestingly, this sample lacks the high Cr content that characterizes the other Ca-rich pyroxenites, and it has a much higher abundance of  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{P}_2\text{O}_5$ , and Sr than the others.

The altered Ca-rich pyroxenites and peridotites, when compared to the relatively fresh variety, have more chemical diversity. This probably reflects the introduction of  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ , Zr, Sr, Ba, Ce, and other constituents and perhaps the loss of some Cr and Fe, as amphiboles and other minerals were formed.

The two analyzed chromitite samples (W-220 and W-391) are quite similar (Tables 2 and 3). Their compositions reflect the chromite grains as well as the 20-40 percent of serpentine and other hydrous silicates they contain.

## ASSOCIATED METAMORPHIC ROCKS

The rocks associated with the ultramafic bodies seem to be primarily metavolcanics, although a few probably are extensively altered ultramafics. Most show substantial changes from their probable original compositions. The mineralogic, petrographic, and geochemical characteristics of these rocks have led us to classify them in five groups: (1) metabasalts, (2) hornblende-garnet blackwall rocks, (3) chlorite-rich blackwall rocks, (4) other blackwall and vein rocks, and (5) metarodingites. Normalized values of the major oxides for the seventeen analyzed rocks associated with the ultramafic bodies are presented in Table 4, and averaged normalized compositions for the metamorphic rock types are in Table 5. Some of the chemical characteristics of these rocks are compared with one another and contrasted with the associated ultramafic rocks in Figures 2 and 3.

Two samples (TBR-10 and TBR-11) of metabasalt are from dike-like bodies near the margins of the Time Zone Bridge serpentinite body (Tables 2 and 4). These rocks are basically spilitic in composition, with abnormally high Na and abnormally low Ca and K for basalts. Their compositions are like some of the basaltic and andesitic rocks from the Riggins Group (Table 6) reported by Hamilton (1963).

Wide variation exists in the compositions of rocks associated with the ultramafic bodies (Tables 2, 4, and 5). Most of these rocks are characterized by  $\text{SiO}_2$  contents comparable to ultramafic rocks and lower than most volcanic rocks, by higher concentrations of Al and Fe than in the ultramafic rocks, by typically only a few hundred or less parts per million of Cr and Ni, and by much lower  $\text{MgO}/(\text{MgO} + \text{FeO})$  ratios than the ultramafic rocks (Figures 2 and 3). Most of these associated metamorphic rocks have much greater abundances of many elements, including Ti, Na, K, P, Nb, Zr, Sr, V, Ce, Ba, Y, U, Rb, Th, Pb, and Ga, than do the ultramafic rocks.

The hornblende-garnet blackwall rocks typically contain abundant hornblende, accompanied by modest quantities of grossularitic garnet, varied amounts of chlorite, minor

quantities of opaque oxides (probably both magnetite and ilmenite), and traces of green spinel. Cordierite and perhaps sapphirine or idocrase were found in some of these rocks. The major element compositions of the six hornblende-garnet blackwall samples that we analyzed are quite puzzling. They do not particularly resemble normal ultramafic or mafic plutonic rocks. Even though their  $\text{SiO}_2$  contents are low enough for them to superficially resemble ultramafic rocks, their abundances of Fe, Mg, Ti, Al, Ca, Cr, and Ni do not at all suggest they are ultramafic or mafic plutonic rocks. Their modest CaO contents suggest they are not rodingites, although the general abundances of the rest of the major elements might be compatible with such an origin. Their low abundances of  $\text{SiO}_2$  and alkalis, coupled with their very high  $\text{Al}_2\text{O}_3$  contents, virtually rule out being some oddball kind of unaltered volcanic rock. Furthermore, their compositions do not suggest any particular type of sediments, although markedly desilicated mafic tuffs seem possible.

The fairly specific association of the hornblende-garnet blackwall rocks with the margins of the ultramafic bodies suggests their origin might have been related to the alteration of the ultramafic rocks that occurred during metamorphism. As noted above, evidence exists that elements such as Si, Al, and Ca were introduced into some ultramafic rocks as they were hydrated and metamorphosed. Because anthophyllite and talc developed widely at the expense of original olivine and orthopyroxene in the metaharzburgites with which the hornblende-garnet blackwall rocks are associated, the notion is attractive that considerable quantities of  $\text{SiO}_2$  may have entered these ultramafic bodies. As indicated in Table 3, we have identified a category of altered harzburgite with a higher abundance of  $\text{SiO}_2$  than normally is expected in rocks with such high  $\text{MgO}/(\text{MgO} + \text{FeO})$  ratios and Ni and Cr concentrations (Figures 2 and 3). This suggests that the  $\text{SiO}_2$  needed to form the anthophyllite and talc in the ultramafic bodies may have come from the wall rocks immediately adjacent to the ultramafic bodies, and that the hornblende-garnet blackwall rocks may be silica-depleted wall rocks. The overall characteristics of the hornblende-garnet blackwall rocks, as well as the general geologic setting of the western Idaho ultramafic belt and the abundance of metavolcanic rocks that Hamilton (1963) reported in the Riggins Group, suggested that they might have started out as volcanic or tuffaceous rocks of generally basaltic or andesitic compositions.

To further examine the proposition that the hornblende-garnet blackwall rocks might have formed by desilication from initial compositions that generally were basaltic or andesitic, we have added varying amounts of  $\text{SiO}_2$  back to their compositions. The results are given in Table 6. To develop the adjusted analyses shown in the table, enough  $\text{SiO}_2$  was added to each original analysis to bring the  $\text{Al}_2\text{O}_3$  back to reasonable values for basalts and andesites, in the 14.5 to 17.5 weight percent range, and to bring the  $\text{SiO}_2$  up to typical basalt and andesite values, in the 48 to 58 weight percent range. The results show that, with the exception of the markedly low  $\text{Na}_2\text{O}$  values, the adjusted analyses are very good matches to rocks with basaltic and andesitic compositions. For comparison, several analyses of metavolcanic rocks from the Riggins Group (Hamilton, 1963), which is the host formation for many of the ultramafic bodies, and the average of the two metabasalts associated with the Time Zone Bridge ultramafic occurrence, are included in Table 6. Although this exercise does not explicitly prove the case, our results strongly suggest that, indeed, the hornblende-garnet blackwall rocks were derived from basaltic or andesitic rocks which underwent a considerable degree of

desilication. In view of their Na<sub>2</sub>O deficit, Na<sub>2</sub>O also was likely lost from the hornblende-garnet blackwall rocks as they were metamorphosed.

The chlorite-rich blackwall rocks from the Asbestos Peak and Grouse Creek areas are dominated by chlorite and contain small quantities of oxide minerals, amphibole, apatite, and garnet. Three of these rocks (AP-6, C-89, and C-98) were analyzed and have MgO/(MgO+FeO) ratios nearly as high as in ultramafic rocks. They probably represent material from the margins of the ultramafic bodies that underwent extensive alteration during metamorphism. Aside from their higher MgO/(MgO+FeO) ratios, these rocks are similar to the hornblende-garnet blackwall rocks in their contents of SiO<sub>2</sub>, TiO<sub>2</sub>, and Al<sub>2</sub>O<sub>3</sub>. They are, however, considerably higher in their total of MgO and Fe<sub>2</sub>O<sub>3</sub> and much lower in CaO and several of the minor elements.

The fourth chlorite-rich sample (C-95) has a much lower MgO/(MgO+FeO) ratio than the others, and is very high in TiO<sub>2</sub>. It represents the rock type in vein- or dike-like chlorite-rich masses studded with irregular large ilmenite chunks (porphyroblasts?) that cut the Grouse Creek ultramafic body. These rocks also have very high contents of P<sub>2</sub>O<sub>5</sub> and several of the minor elements, in comparison to the enclosing ultramafic body or to the other blackwall rocks. Because of their chemical composition, we doubt that these vein or dike rocks originally were ultramafic, but we do not know what their protolith actually was. The substantial chemical exchange that appears to have occurred in the rocks enclosing these chlorite-rich masses suggests that marked metasomatic activity may also have been involved in their genesis.

One analyzed amphibole-rich sample (W-63) is from the margin of one of the ultramafic masses in the New Meadows area. Compared to the surrounding metavolcanic rocks, its relatively high MgO/(MgO+FeO) ratio, along with its low content of many elements that also are low in the ultramafic rocks, suggests its protolith was ultramafic. Other amphibole-rich blackwall zone rocks have been found with some of the other ultramafic masses, and their origins probably are similar. Interestingly, the composition of this amphibole-rich rock is so similar to that of one of the Ca-bearing pyroxenites, the websterite (C-93) from the Grouse Creek ultramafic mass, that it could easily represent the hydrated equivalent of a similar two-pyroxene rock.

The biotite-rich sample (W-218), is from an outcrop of biotite-rich rock associated with one of the dunite masses near New Meadows. The abundance of exposure there is insufficient to reveal if this rock is within the dunite, or occurs at its margin. Chemically, this rock is rather bizarre and does not resemble either a normal ultramafic rock or a metavolcanic rock. Its most conspicuous peculiarity is a high barium content; more than 10 percent by weight of the rock is BaO. Probably it either is a blackwall rock that has undergone profound alteration, or is a metamorphosed exhalative sedimentary deposit within the New Meadows block metasedimentary rock sequence. We prefer the latter explanation because manganiferous quartzites beds within the New Meadows block (Bonnichsen, 1987) can also be interpreted as exhalatites.

Of three metarodinites, two samples (W-203 and W-205) are from one of the dunite masses in the New Meadows area and the other (C-157) is from the metaclinopyroxenite occurrence at Castle Creek. These rocks show the geochemical pattern of rodingites: losses of  $\text{SiO}_2$  and alkalis and gains of  $\text{CaO}$  and  $\text{MnO}$ , from their probable, generally basaltic, initial compositions. The samples from the New Meadows area have been completely changed texturally and mineralogically to nonfoliated hornblende-epidote rocks with granoblastic textures. These rocks likely were diabasic dikes, emplaced within the dunite and altered before the enclosing ultramafic bodies attained their present geologic position. The Castle Creek metarodinite still shows its original gabbroic texture and some of its original augite. This rock was quite likely a gabbro that was formed when the associated clinopyroxenites were formed, and that was subsequently altered.

## ECONOMIC GEOLOGY

Various metallic and nonmetallic economic mineral deposits are associated with ultramafic rocks. Notable are the principal ores for chromium, nickel, and the platinum-group elements. Magmatic segregation deposits contain the most important metallic concentrations of these elements, but residual and lateritic concentrations are important in some regions. Some gold deposits, generally contained within or derived from veins, are associated with ultramafic rocks, although most gold is derived from other types of deposits. Significant amounts of cobalt and copper are byproducts or coproducts from some nickel mining operations. Talc, chrysotile asbestos, anthophyllite, Mg-rich olivine, and magnesite are some of the principal nonmetallic materials commonly obtained from ultramafic rock bodies.

### CHROMIUM

Chromium is obtained from the rock-type chromitite, which consists largely of the mineral chromite. Chromite is a solid solution mineral in the spinel group (mainly ranging between  $\text{MgCr}_2\text{O}_4$  and  $\text{FeCr}_2\text{O}_4$ , with substantial aluminum and ferric iron substituting for the chromium) in which the  $\text{Cr}_2\text{O}_3$  abundance reaches a maximum of about 64 weight percent. The most important chromite resources are contained within immense stratiform mafic-ultramafic igneous rock complexes, most notably the Bushveld Complex of South Africa. Small chromitite bodies in ultramafic bodies like the ones in the western Idaho ultramafic belt have been mined in the western U.S. and elsewhere. They have not, however, been the source of much of the chromite that has been mined. This type of chromite concentration is commonly referred to as a podiform chromite deposit. The ore grade in podiform deposits is higher than that in the larger stratiform deposits.

Podiform chromite deposits in the western Idaho ultramafic belt occur in the New Meadows area in the Rose Marie claims group (Thayer and Brown, 1964) in NW1/4 sec. 2, T. 18 N., R. 1 E. Hamilton (1963) noted that a small pod of fairly high-grade chromite ore in the Riggins area was mined from the NW1/4 SW1/4 sec. 8, T. 23 N., R. 1 E., during World War II. In addition, we found a small piece of probable chromitite in a thin section of

altered harzburgite from Asbestos Peak. Two chromitites from the New Meadows area (Tables 2 and 3) have bulk  $\text{Cr}_2\text{O}_3$  contents of around 40 percent, suggesting that the chromite itself probably is of the high-Cr type, which is typical of the podiform deposits. Thayer (1973) noted that the high-Cr chromites contain more than 46 percent  $\text{Cr}_2\text{O}_3$  and have Cr:Fe ratios greater than 2:1. If the silica and a nearly equivalent amount of iron plus magnesium oxides were subtracted from these analyses to account for the 20 to 40 percent of serpentine and chlorite minerals in the chromitites, then the  $\text{Cr}_2\text{O}_3$  contents probably would be in the 55-60 percent range for the remaining chromite. To get a more accurate measure of their  $\text{Cr}_2\text{O}_3$  contents, the chromites could be analyzed by electron microprobe methods, or chromite concentrates could be analyzed by other means.

The existence of the three chromitite occurrences noted above, along with the relatively high Cr contents of the western Idaho ultramafic rocks, suggests that podiform chromite deposits might occur throughout the ultramafic belt. Given the relatively small size of the ultramafic occurrences and the structural dismemberment evident in some of them, any undiscovered chromite bodies would probably be small and difficult to find. Such chromitites, judged by their Cr contents and that of some of the ultramafic rocks in the belt, could be relatively high grade, typical of the podiform type.

## NICKEL

Most nickel is mined from sulfide deposits containing Ni-bearing minerals such as pentlandite and millerite. Most nickel sulfide deposits are magmatic segregations associated with ultramafic or mafic igneous rock bodies, such as those at Sudbury, Canada. Generally, the nickel sulfide deposits associated with ultramafic rocks, like those of western Idaho, are relatively small, but they are richer in nickel than the larger deposits associated with the enormous mafic-ultramafic stratiform complexes. Nickeliferous laterite deposits in which the nickel occurs in the hydrous silicate mineral, garnierite, are a second important source of nickel. Most nickeliferous laterites are thought to have formed by deep weathering and the leaching of impurities from the exposed parts of ultramafic bodies in rainy tropical climates. An important deposit of this type, thought to have formed in the early Tertiary during a warmer, more rainy period than now has been mined at Riddle, Oregon (Cumberlidge and Chace, 1968).

To date, no nickel sulfide concentrations have been found with the ultramafic bodies in western Idaho. This is not surprising because of the extensive ground cover in the region and the small size of such deposits. A systematic search, with trenching or drilling, might find an occurrence. Nickel analyses (Tables 2 and 5) suggest that the potentially best host rocks for nickeliferous sulfide deposits are the dunites, serpentinites, and altered harzburgites, but not the clinopyroxenites. These high-Ni rocks are characterized by high Mg contents and high  $\text{MgO}/(\text{MgO} + \text{FeO})$  ratios, typical of the environments where nickel sulfide deposits are found. For a nickel sulfide deposit to form, sulfur is essential in addition to the nickel. We have found very few sulfide minerals in the ultramafic outcrops or samples. A concentration of sulfide minerals in or adjacent to an ultramafic body would indicate a promising environment

in which to search further for nickel. We have not examined polished sections with a microscope, however, so we are uncertain if fine-grained sulfide minerals are concentrated in any of the ultramafic rocks, but it is unlikely for the ones we have studied.

Because deep weathering has developed extensively in granitic and metamorphic rocks throughout the region, nickeliferous laterite deposits might have formed here during the early Tertiary, as they did in Oregon. Loose fragments of limonitic chalcedony exhibiting leached boxwork textures are also found at some of the ultramafic occurrences. Such iron oxide-enriched chalcedonic rocks commonly develop through near-surface processes during the formation of laterites and associated deposits. Yet, given the small size of the western Idaho ultramafic bodies, we doubt if any would have a nickeliferous laterite of sufficient size preserved with it to be of economic interest.

## PLATINUM-GROUP ELEMENTS

Platinum and palladium are the two principal elements of the platinum-group of elements. Ore deposits containing significant amounts of these elements typically are in magmatic segregations associated with ultramafic rocks. These elements are obtained either as byproducts of nickel smelting operations or as deposits mined primarily for platinum or palladium. Other minable sources with sufficient platinum or palladium to be of economic interest are secondary deposits, such as placers, where heavy durable minerals, like chromite or native metals, have been concentrated by surficial processes.

Platinum, palladium, and the other the platinum-group elements occur in a variety of ways. These include in solution or as minute inclusions in sulfide minerals and chromite and as platinum-group minerals such as arsenides, selenides, tellurides and native alloys. Because of their small size and scarcity, platinum-group-element minerals are notoriously difficult to find by microscope in polished sections. In addition, analytical methods more sensitive than x-ray fluorescence are necessary to detect the quantities of platinum or palladium that might be of significance for an exploration program. Having neither examined polished sections nor analyzed for platinum-group elements, we are unsure if the western Idaho ultramafic belt has a potential for platinum or palladium beyond the presence of favorable host rocks. To further examine this possibility it might be useful to concentrate chromite, and sulfides if they can be found, from the ultramafic rocks or from streams that cut across ultramafic rocks, and to analyze such concentrates for their contents of platinum-group and associated elements by a sensitive technique such as neutron activation.

## GOLD

Gold concentrations are known in ultramafic rocks. Most occur in quartz-rich pods and veins formed during episodes of regional metamorphism, and commonly accompany the injection of dioritic to granitic stocks and batholiths. Many gold deposits in this environment are secondary in nature, having been concentrated to an economic tenor in stream placers or as residual deposits left behind on and near ultramafic bodies as impurities were washed or



leached away. Deposits like these are present both in the Mother Lode of California and in association with the ultramafic masses of southwestern Oregon (Brooks and Ramp, 1968). Clearly, these types of deposits are possible in the western Idaho ultramafic belt. The location and trend of the western Idaho ultramafic belt fall near areas where numerous placer gold deposits have been mined (Gaston and Bonnicksen, 1978). Part of the gold in these deposits was probably derived from some of the nearby ultramafic bodies.

## NONMETALLIC DEPOSITS

Very thin veins of chrysotile asbestos cut several of the ultramafic bodies, particularly in the New Meadows and Riggins areas. No fibrous veins of any significant size have been found, however. The relatively low rank of the metamorphism in the Riggins area probably makes it the best place to search further for chrysotile. Extensive deposits of anthophyllite-bearing altered harzburgites and rocks consisting almost exclusively of anthophyllite occur in the New Meadows region and in that part of the ultramafic belt from Asbestos Peak northward. As noted previously, Anderson (1930, 1931) documented the mining of anthophyllite deposits near Glenwood as a refractory material in the early part of the century. Additional large resources of anthophyllite-rich rock clearly are present in the region. Anderson (1930) has described some of them in considerable detail. However, regardless of the amount and quality of these materials that might be available in west-central Idaho, the revelation in recent years that at least the amphibole types of asbestos are potential health hazards makes it unlikely that either the chrysotile occurrences or the more extensive anthophyllite deposits will be exploited in the near future.

Although talc is very abundant in many ultramafic bodies in intimate mixtures with other minerals, especially anthophyllite, we are unaware of relatively pure talc bodies of minable size. The greatest concentrations of talc-rich rock are in the form of small blocks, a foot or two across, that have tumbled from the Time Zone Bridge ultramafic occurrence near Riggins. These rocks probably came from some sort of talc-rich alteration zone marginal to the serpentinite body. Probably the best region for larger talc-rich bodies would be near the various ultramafic bodies in the Riggins region, because of the lower rank of metamorphism there.

In some regions, dunites have been mined as the raw material for the manufacture of high-temperature magnesian refractories, such as used as lining furnaces. Dunites in the New Meadows area might be of interest for this purpose, since they are quite Mg-rich (Tables 2, 3, and 5). At least parts of these bodies seem to be relatively free of secondary hydrous minerals. Key items to be considered before these bodies can be profitably exploited include having a large deposit with sufficiently few impurities, and nearby markets to reduce transportation costs. Given their fairly remote locations and the lack of information on their purity and extent, it is unlikely that the dunite deposits in Idaho will be mined in the foreseeable future.

The Mg carbonate mineral, magnesite, also is used for the manufacture of refractory materials. Although small amounts of magnesite occur in some of the serpentinites in the Riggins area, we have not found any large bodies of this mineral.

## ADDITIONAL POSSIBLE ECONOMIC DEPOSITS

Other deposits that could be associated with the ultramafic bodies of western Idaho include massive volcanogenic sulfide, barite, and bedded manganese minerals. Manganiferous beds have been found in the New Meadows block near the ultramafic bodies (Bonnichsen, 1987). The peculiar rock (sample W-218; Table 2) that may be a metamorphosed exhalatite and which contains more than 10 percent barium as barite, suggests other Ba concentrations could lurk nearby. In all likelihood, however, the occurrence of the Ba and Mn concentrations are of only passing interest. They are unlikely big enough to attract mining interests. Their existence suggests that the environment in which they formed was one of submarine volcanism accompanied by sea floor hot springs activity. The presence of these deposits, along with the submarine volcanic rocks in which the ultramafic bodies are enclosed, makes it feasible that undiscovered massive sulfide deposits of elements such as Cu, Zn, Ag, Au, and even Co and Ni could be present in western Idaho.

## DISCUSSION

Our systematic inventory and description of the western Idaho ultramafic belt bring a bit of order from the chaos, but the new knowledge also raises additional questions. We propose that the ultramafic bodies in western Idaho initially formed in an oceanic environment. The bodies either accumulated at an oceanic ridge crest as new basaltic material upwelled from the interior of the earth or formed in a major rifting environment between the continent and an island arc. In either case, the ultramafic rocks were subsequently transported by major plate-tectonic motions to their present geologic settings.

Motion during the Mesozoic between the Earth's tectonic plates played a large role in bringing the ultramafic rocks to their present position within North America. The Blue Mountains island arc terrane (Vallier and Brooks, 1987) lies immediately west of the Precambrian-cored continental crust. The ultramafic rocks are in the zone of greatest structural deformation between these terranes, or simply are part of the Blue Mountains terrane. Whether the ultramafic rocks were obducted onto the continental margin at a convergent plate margin or were brought into the continental margin environment by a more complex series of plate motions has yet to be resolved. Our investigation has not sought to definitively answer this question. That task may ultimately prove impossible. However, some of the geologic characteristics of the ultramafic rocks can eventually bear on other questions: Exactly how did ultramafic rocks get to where they are? And what happened to them along the way?

## SUMMARY OF GEOLOGIC HISTORY

Three geologic episodes -- the Early Cretaceous docking of the Blue Mountains island arc terrane, the Late Cretaceous emplacement of the Idaho batholith, and the vertical uplift, faulting, and volcanism during the Tertiary -- have collectively obscured the earlier history of the western Idaho ultramafic belt. The docking process nestled the Blue Mountains island arc terrane against the pre-existing continental crust in Early Cretaceous time. Even though not well understood, this event was accompanied by considerable east-west compression and perhaps by north-south translation, so that flattening and shearing were concentrated where the accreted terrane-continental crust suture zone developed. Then, in the Late Cretaceous, the intrusion of the Idaho batholith adjacent to the suture zone continued the metamorphism and deformation of the ultramafic rocks. The east-west compressive forces probably were still acting on the suture zone when the melting and emplacement of the large plutonic mass of the Idaho batholith higher into the crust contributed to the development of the steeply dipping structures that penetrate the rocks along the suture zone. These steep lineations suggest that the area east of the suture zone was uplifted and perhaps thrust westward over the edge of the accreted terrane. Later, during the Tertiary, other events -- uplift that varied in amount from place to place, extensive displacement on high-angle faults, and volcanism that was copious in places -- added further to the geologic complications of the suture zone and to the evolution of the ultramafic bodies.

## SOME UNANSWERED QUESTIONS AND POSSIBLE ANSWERS

The geologic setting of the ultramafic bodies varies significantly from place to place. Thus, it is not straightforward to interpret how they were emplaced. After the ultramafic bodies had arrived within the Mesozoic continental margin environment, the major geologic events that followed impacted them and obscured their earlier history. All ultramafic bodies near the suture zone were regionally metamorphosed to the greenschist or amphibolite facies, and all were deformed. Some bodies had only their margins disturbed; others had their interiors completely tectonized. The ultramafic bodies are probably fragments that were structurally detached from the original bodies. This suggestion is compatible with their consistent close spatial association with major faults. Some of the key unanswered questions that emerge regarding their origin and evolution include:

*Why are two apparently different kinds of ultramafic rocks present, those belonging to a dominant dunite-harzburgite suite and those belonging to a suite of Ca pyroxene-rich rocks?* Worldwide occurrences indicate that the dunite-harzburgite suite, including the serpentinites, are the expected ultramafic rocks in a continental margin environment. These are the common ultramafic rocks that form in oceanic environments and which eventually may be obducted onto continental margins by plate convergence. Ca pyroxene-rich pyroxenites are not widespread in this environment. For now, we do not know if these Ca pyroxene-rich rocks were a small part of an otherwise normal dunite-harzburgite sequence, or if they were formed independently in some other upper mantle or lower crust environment and were later tectonically emplaced into the same structural zone as the dunites and harzburgites. The high

MgO/(MgO+FeO) ratios and high Cr contents of these Ca pyroxene-rich rocks are consistent with them originating in an environment similar to that of the dunites and harzburgites. We suggest that the Ca pyroxene-rich rocks were not formed in their own special environment, but simply represent minor variants of the dunite-harzburgite suite. This question should remain open for further scrutiny, however.

*Are the ultramafic bodies fragments of ophiolite complexes?* Direct evidence is scant that the western Idaho ultramafic rocks are fragments of ophiolite complexes (deep slices of the sea floor in which ultramafic cumulates are first overlain by gabbros, then by diabase dike complexes, and finally by pillow basalts and submarine sediments). A few observations suggest that this interpretation is reasonable for at least some of the ultramafic bodies. These include the presence of metachert and other sediments including probable exhalatites, and metaroddingite dikes, in association with the ultramafic bodies in the New Meadows region. The metachert lenses (Hoover, 1986) in the Grouse Creek area and the gradational upwards transition from olivine-pyroxene metagabbro to metaperidotite to highly altered pyroxenite in the North Blacktail Butte ultramafic body (Myers, 1982) also suggest this conclusion. Apart from these observations, however, we are forced to conclude that, if the ultramafic bodies were once within ophiolite complexes, then they have been thoroughly changed from those rock-sequence configurations by subsequent structural events. Also, even if some of the ultramafic bodies are from ophiolite sequences, it is not necessary that all are; some may have originated from crystal fractionation in calcalkaline magmas in island-arc or continental-margin environments.

*Why do different host rocks -- the Riggins Group in the south, the Proterozoic(?) Syringa metamorphic sequence in the Lowell-Orofino region, and rocks of the Proterozoic-age Belt Supergroup at the northern extent of the belt -- enclose the ultramafic bodies?* The apparent major variations in the host rocks that enclose the ultramafic bodies associated with the suture zone presents an interesting dilemma for interpreting how and when the ultramafic rocks were formed. If only Mesozoic or late Paleozoic ultramafic rocks exist, then the ultramafic bodies enclosed within the Proterozoic-age Syringa metamorphic sequence (Lewis and others, 1992) and the Belt Supergroup metasediments (Hietanen, 1963) cannot be stratabound fragments enclosed within those formations, because the ultramafic rocks are much younger. This interpretation requires that either the ultramafic bodies were structurally emplaced into the Syringa and Belt host rocks or the map units labeled as the Syringa metamorphic sequence and the Belt Supergroup by Lewis and others (1992) and Hietanen (1963) are actually a northward extension of the Mesozoic terrane and the Riggins group. Of these explanations, we prefer that the ultramafic rocks within the Syringa and Belt map units were structurally emplaced into these units along major faults, but we cannot provide conclusive evidence that this is so. Alternatively, there may be two or more ages of ultramafic rocks. This would permit all the ultramafic bodies to be stratabound. One group would be Mesozoic and enclosed within the Riggins Group. The other would be Proterozoic and stratabound within their enclosing formations. Although we do not favor this explanation particularly, it is a plausible interpretation for the emplacement of northernmost ultramafic bodies, especially the Breakfast Creek occurrence, and should not be dismissed summarily.

Since significant metamorphism of the ultramafic bodies occurred after they were emplaced, the rocks would have become very similar if they had started with comparable compositions.

*When did the chemical alteration take place, relative to the other events?* We have assumed there were two stages in the alteration of the ultramafics and their associated wall rocks. First, we suggest that rodingization, which reduces silica and alkali element abundances and increases the calcium (within carbonate minerals before metamorphism) abundance, occurred early in the mafic and ultramafic rocks, while they were still part of the oceanic lithosphere. Sea floor hot-spring activity and sub-sea floor hydrothermal fluid circulation and rock alteration have been recognized as important processes accompanying the upwelling of basaltic magma and the formation of ultramafic cumulates at midoceanic ridges. The metarodingites in the New Meadows ultramafic bodies probably obtained their chemical characteristics during this early pre-obduction and pre-metamorphism time, rather than later during the regional metamorphism.

Secondly, we have assumed that the extreme silica-depletion, which occurred as the hornblende-garnet blackwall rocks formed from basaltic or andesitic protoliths, occurred after the ultramafic rocks had been emplaced into their present host rocks. In addition, at least part of the apparently excess silica, especially in the high-silica altered harzburgites associated with the hornblende-garnet blackwall rocks in the South Fork of the Clearwater River region, entered the ultramafic rocks during regional metamorphism, rather than earlier. To us, it seems logical to view these two processes, silica loss from the wall rocks and silica gain in the adjacent ultramafic rocks, as coupled complementary processes, although we have not offered compelling evidence.

We have yet to rule out the possibility that the silica-poor hornblende-garnet rocks actually underwent alteration early in their history, perhaps in a sea-floor environment. If so, they would have more in common with the metarodingites than we have acknowledged. Moreover, the high-silica altered harzburgites possibly started as rocks composed almost entirely of orthopyroxene (e.g., bronzitites), rather than as harzburgites consisting of both olivine and orthopyroxene. If so, then little or no silica would have been added to give them their present bulk compositions; only H<sub>2</sub>O would be needed to convert the orthopyroxene to anthophyllite and talc.

## CONCLUDING COMMENTS

We believe that all the ultramafic bodies are of the same general Mesozoic age even though they are enclosed within formations of varying age. Furthermore, we suggest that the northern occurrences (Tamarack Ridge, Teakean, Olson, Ahsahka, Orofino Creek, Lolo Creek, Glenwood, Placer Creek, Lowell, Swiftwater Creek, and Stillman Point) were moved along major faults into much older host rocks. We can ask if part or all of the ultramafic bodies in the Riggins Group were faulted into their host rocks, or if they are stratabound bodies deformed along with their host rocks when the Blue Mountains island arc docked against North America. As noted previously, this was discussed by Hamilton (1963) and by

Onasch (1977, 1987). Both favored the idea that the ultramafic bodies in the Riggins region were faulted into their final resting places. This happened after the ultramafic rocks had been emplaced within the continental margin before or during the docking of the Blue Mountains island arc. Later, some of the faults may have been deformed and partially or completely obliterated as deformation and metamorphism continued within the suture zone. We believe this interpretation to be quite reasonable, and applicable elsewhere along the suture zone, especially in the case of the northern ultramafic bodies.

Given the lack of preserved ophiolite sequences and the persistence of faults near the ultramafic occurrences, especially in the Riggins and South Fork of the Clearwater River regions, and given the variable deformation of ultramafic bodies there, we suggest the ultramafic bodies have become completely dismembered and have moved along faults as the suture zone was deformed after the Blue Mountains island arc terrane had docked. Even so, all of the ultramafic bodies in those areas probably started within ophiolite sequences.

Only the ultramafic bodies in the New Meadows region show sufficient evidence of being associated with rocks possibly considered part of an oceanic, inner-trench-wall assemblage to warrant the possible interpretation that they are stratabound within their host rocks. Major, post-docking faults are not needed to account for their locations. This view is consistent with the generally less altered and less deformed nature of the ultramafic rocks in the New Meadows region, as compared with other parts of the suture zone.

Farther to the southwest in the Cuddy Mountains-Sturgill Peak region, the highly deformed ultramafic rocks occur along a zone resulting from high-angle reverse faulting (Skurla, 1974; Mann, 1989) that marks the boundary between major subterrane within the Blue Mountain island arc. This observation, of course, shows that those ultramafic rocks were deformed by tectonic processes that were independent of, and may have occurred before, during, or after, the development of the accreted terrane-continental crust suture zone.

As indicated by the foregoing discussion, important questions about the origin and evolution of the ultramafic rocks in western Idaho remain unanswered. These general questions apply not only to the ultramafic rocks themselves but also to the evolution of the suture zone and the processes involved in juxtaposing the Blue Mountains island arc against the Mesozoic margin of the North America, and the evolution of the Idaho batholith. In this regard, the western Idaho ultramafic rocks may hold answers to how the western margin of North America has evolved.

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Table 1: Locations and rock types, western Idaho ultramafic belt

NAME OF ULTRAMAFIC BODY AND LOCATION	MAIN ULTRAMAFIC ROCK TYPES, GEOLOGIC ASSOCIATIONS, AND REFERENCES
New Meadows area bodies, secs. 2, 3, 10, and 15, T. 18 N., R. 1 E., New Meadows quadrangle.	Variably metamorphosed dunite, harzburgite, and chromitite associated with metachert, metagreywacke, and exhalatites in the New Meadows tectonic block; Bonnicksen (1987).
Thrush Creek area, sec. 18, T. 18 N., R. 2 E., New Meadows quadrangle.	Talc-chlorite-tremolite schist, in felsic to amphibolitic gneisses; Bonnicksen (1987).
Meadows shear zone blocks, sec. 5, T. 18 N., R. 2 E., Meadows quadrangle.	Clinopyroxenite partially replaced by hornblende, in trondhjemitic pegmatite along major shear zone; Bonnicksen (1987).
Time Zone Bridge body, sec. 34, T. 25 N., R. 1 E., and secs. 2 and 3, T. 24 N., R. 1 E., Riggins quadrangle.	Serpentinite, at the contact between the Squaw Creek and Lightning Creek Schists of the Riggins Group; Hamilton (1963) and Onasch (1977).
Occurrences between Pollock Rest Stop and Whitebird Ridge, secs. 7, 8, 16, 17, and 18, T. 23 N., R. 1 E., Pollock and Heavens Gate quadrangles.	Serpentinite and talc-chlorite-tremolite schist, in lower part of Squaw Creek Schist and in Lightning Creek Schist of Riggins Group; Hamilton (1963), Onasch (1977), and Sarewitz (1982).
Occurrence near Pollock, sec. 20, T. 23 N., R. 1 E., Pollock quadrangle.	Serpentinite, in lower part of Squaw Creek Schist of Riggins Group; Onasch (1977).

Table 1 continued

North Fork Sheep Creek area, secs. 9, 10, and vicinity, T. 23 N., R. 1 E., Pollock quadrangle.	Serpentinite, in lower part of Squaw Creek Schist of Riggins Group; Hamilton (1963) and Onasch (1977).
Occurrences in Cat Creek-Shorts Creek area, sec. 24, T. 24 N., R. 1 E.; secs. 19 and 20, T. 24 N., R. 2 E., Riggins and Riggins Hot Springs quadrangles.	Metaperidotite, in lower part of Squaw Creek Schist of Riggins Group; Onasch (1977).
Occurrences in Alum Gulch-Emery Creek area, secs. 29, 32, 33, T. 24 N., R. 1 E., and secs. 4 and 5, T. 23 N., R. 1 E., Riggins and Pollock quadrangles.	Serpentinite, in lower part of Squaw Creek Schist of Riggins Group, part of ultramafic rocks may be incorporated in large landslide area; Hamilton (1963).
Mullin Spring occurrence, sec. 19, T. 23 N., R. 1 E., Heavens Gate quadrangle.	Talc-serpentine, talc-tremolite, and talc-chlorite schists, in Squaw Creek Member of Riggins Group; Sarewitz (1982).
Asbestos Peak area, sec. 26, T. 28 N., R. 3 E., Dairy Mountain quadrangle.	Metaharzburgite and blackwall rocks, in metamorphosed Riggins Group schists and gneisses.
Misery Ridge area, secs. 1 and 12, T. 28 N., R. 3 E., Goodwin Meadows quadrangle.	Deformed and altered harzburgite and clinopyroxenite, and blackwall rocks, in schists and gneisses equivalent to the Riggins Group.
Grouse Creek area, secs. 31 and 32, T. 29 N., R. 4 E., Goodwin Meadows and Hungry Ridge quadrangles.	Metaharzburgite and metaclinopyroxenite cut by chlorite-rich veins, in schists and gneisses equivalent to the Riggins Group; Hoover (1986).

Table 1 continued

Asbestos Point area, sec. 27, T. 29 N., R. 4 E., Hungry Ridge quadrangle.	Dunite (found only as float) in granodiorite/quartz monzonite orthogneiss unit; Hoover (1986).
Castle Creek area, secs. 10 and 15, T. 29 N., R. 4 E., Hungry Ridge quadrangle.	Clinopyroxenite and metagabbro, in Castle Creek fault zone, between metamorphosed Riggins Group rocks and trondhjemitic pluton; Myers (1982).
North Blacktail Butte area, secs. 15, 16, 21, 27, and 28, T. 30 N., R. 4 E., Harpster quadrangle.	Metaharzburgite, with metagabbro and metapyroxenite, in metamorphosed equivalent of Squaw Creek Schist of the Riggins Group; Myers (1982).
Stillman Point area, sec. 16, T. 31 N., R. 8 E., Stillman Point quadrangle.	Dunite and pyroxenite, enclosed in Syringa metamorphic sequence; Lewis and others (1992).
Swiftwater Creek Bridge, sec. 16, T. 32 N., R. 7 E., Goddard Point quadrangle.	Metadunite or harzburgite, enclosed in Syringa metamorphic sequence; Lewis and others (1992).
Occurrences in Lowell area, secs. 28, 29, 31, and 33, T. 33 N., R. 7 E., Lowell and Syringa quadrangles.	Metadunite, metaharzburgite, and talc schist in Cretaceous foliated tonalite and in Syringa metamorphic sequence; Anderson (1930) and Lewis and others (1992).
Placer Creek area, sec. 18, T. 33 N., R. 7 E., Syringa quadrangle.	Ultramafic body enclosed in the Syringa metamorphic sequence; Lewis and others (1992).
Glenwood area occurrences, secs. 9, 10, and vicinity, T. 33 N., R. 5 E., Glenwood quadrangle.	Metadunite, metaharzburgite, and anthophyllite deposits, enclosed in Riggins Group or Belt Supergroup; Anderson (1930, 1931).

Table 1 continued

Lolo Creek area, probably Brown Creek Ridge or Weippe South quadrangles.	Anthophyllite occurrences; Anderson (1930).
Orofino Creek area, sec. 1, T. 36 N., R. 3 E., Rudo quadrangle.	Metaharzburgite and anthophyllite deposits, in the Belt Supergroup; Anderson (1930) and Johnson (1947).
Ahsahka area, sec. 1 or 2, T. 36 N., R. 1 E., Orofino West quadrangle.	Ultramafic body in Cretaceous diorite and tonalite, or the Belt Supergroup; Anderson (1930) and Johnson (1947).
Teakean asbestos deposit, sec. 16, T. 37 N., R. 1 E., Ahsahka quadrangle.	Metaharzburgite with Tertiary granite dikes, and the Belt Supergroup; Anderson (1930) and Johnson (1947).
Olson asbestos deposit, sec. 15 or 22, T. 37 N., R. 1 E., Ahsahka quadrangle.	Possible ultramafic occurrence with Cretaceous tonalite, or Belt Super- group; Hustedde and others (1981).
Tamarack Ridge body, sec. 29, T. 41 N., R. 4 E., Township Butte quadrangle.	Metadunite and chlorite blackwall rocks in Belt Supergroup; Hietanen (1963).
Cuddy Mountain occurrences, secs. 2, 10, 11, 15, 16, 21 and 30, T. 17 N., R. 4 W., and sec. 25, T. 17 N., R. 5 W., Cuddy Mountain and Brownlee Dam quadrangles.	Serpentinite along Cuddy Mountain high-angle reverse fault zone between the Baker and Izee terraces; Mann (1989).
Sturgill Peak area, sec. 17, T. 15 N., R. 5 W., Neil Gulch quadrangle.	Partially serpentinized harzburgite along reverse fault zone between Izee and Baker terraces; Skurla (1974).

Table 2: Part A. Analyses of ultramafic and associated rocks from the western Idaho ultramafic belt, listed by area.

Area	New Meadows:					
Sample	W-63	W-68	W-107	W-114	W-192	W-193
Rk.Type	ABW	LSAH	ACPX	LSAH	DUN	DUN
wt. %						
SiO <sub>2</sub>	43.72	44.09	51.06	49.65	40.66	41.03
TiO <sub>2</sub>	1.96	0.02	0.52	0.35	0.01	0.00
Al <sub>2</sub> O <sub>3</sub>	10.00	2.24	7.65	7.13	0.17	0.31
Fe <sub>2</sub> O <sub>3</sub>	12.72	9.62	7.75	11.45	8.69	10.07
MnO	0.22	0.12	0.19	0.17	0.16	0.19
MgO	22.29	42.30	14.35	25.12	48.05	47.05
CaO	8.04	0.41	17.26	4.22	0.03	0.22
Na <sub>2</sub> O	0.73	0.30	0.74	2.06	0.89	0.17
K <sub>2</sub> O	0.07	0.01	0.28	0.10	0.03	0.01
P <sub>2</sub> O <sub>5</sub>	0.40	0.00	0.05	0.11	0.02	0.00
Total	100.15	99.11	99.85	100.36	98.71	99.05
ppm						
Nb	8	0	1	1	1	0
Zr	117	1	14	21	0	1
Sr	116	3	104	8	1	4
Zn	204	51	85	103	88	114
Ni	361	2118	151	1024	3104	2403
Cr	320	2970	2146	2393	3026	3116
V	216	47	346	90	15	23
Ce	19	0	11	8	3	0
Ba	9	5	435	177	0	6
La	5	0	5	4	1	2
Y			12	7	0	
U						
Rb			1	0	0	
Th			1	0	0	
Pb			3	2	3	
Ga			10	9	1	



Table 2, Part A, continued:

Area	New Meadows, continued:					
Sample Rk. Type wt. %	W-194 DUN	W-203 MROD	W-205 MROD	W-218 BEXH	W-220 CHR	W-391 CHR
SiO <sub>2</sub>	42.91	41.73	41.88	27.98	18.78	17.65
TiO <sub>2</sub>	0.00	2.13	2.24	3.06	0.14	0.07
Al <sub>2</sub> O <sub>3</sub>	0.30	16.08	14.66	22.07	11.35	7.44
Fe <sub>2</sub> O <sub>3</sub>	9.92	13.17	12.76	17.52	9.67	14.41
MnO	0.19	0.54	0.46	0.19	0.22	0.50
MgO	45.31	6.08	7.84	10.73	24.98	23.45
CaO	0.11	19.13	18.77	0.85	0.02	0.01
Na <sub>2</sub> O	0.17	0.98	0.97	1.97	0.32	0.30
K <sub>2</sub> O	0.01	0.27	0.45	5.42	0.02	0.02
P <sub>2</sub> O <sub>5</sub>	0.01	0.31	0.28	0.43	0.01	0.00
Total	98.93	100.42	100.31	90.22	65.51	63.85
ppm						
Nb	0	7	7	8	0	0
Zr	1	164	184	205	1	3
Sr	3	530	362	714	1	1
Zn	108	355	269	154	175	1225
Ni	2189	118	147	98	2158	1290
Cr	3753	168	209	162	294641	294228
V	14	345	350	762	726	881
Ce	0	24	25	344	5	9
Ba	0	450	281	108901	0	0
La	5	9	7	1	133	149
Y		33		44		
U		2				
Rb		3		141		
Th		1		1		
Pb		9		21		
Ga		20		13		

Table 2, Part A, continued

Area	Time Zone Bridge:				
Sample Rk. Type wt. %	W-6 SERP	TBR-3 SERP	TBR-10 MBS	TBR-11 MBS	SR14-1 SERP
SiO2	47.49	47.79	50.15	52.74	38.90
TiO2	0.04	0.02	1.51	1.28	0.02
Al2O3	1.22	2.37	16.72	15.20	1.70
Fe2O3	8.19	8.26	13.45	11.86	7.80
MnO	0.07	0.11	0.23	0.24	0.08
MgO	41.14	39.65	6.67	6.77	37.20
CaO	0.15	0.06	6.40	6.70	0.08
Na2O	0.76	0.08	4.56	4.64	0.07
K2O	0.03	0.02	0.16	0.16	0.02
P2O5	0.01	0.01	0.11	0.10	0.00
Total	99.10	98.37	99.96	99.69	85.87
ppm					
Nb	0	1	1	1	
Zr	0	1	94	73	
Sr	1	2	118	115	
Zn	58	70	118	344	
Ni	1504	1850	32	27	1500
Cr	2532	2069	4	8	1500
V	31	58	316	276	70
Ce	5	4	11	9	
Ba	0	0	16	27	3
La	3	2	0	0	
Y	1	1	32	26	
U		0	0	0	
Rb	0	0	1	0	
Th	0	0	2	0	
Pb	0	1	3	6	
Ga	2	4	21	16	

Table 2, Part A, continued:

Area	Pollock Rest Stop:			Asbestos Peak:		
Sample Rk. Type wt. %	W-35 SERP	W-36 HSAH	SR37-3 SERP	AP-3 HSAH	AP-4 HGBW	AP-5 HGBW
SiO2	47.70	58.55	42.20	57.91	38.86	33.47
TiO2	0.02	0.02	0.04	0.03	1.91	3.18
Al2O3	1.90	1.91	2.20	1.06	19.77	20.08
Fe2O3	8.60	6.10	8.47	6.61	14.45	22.60
MnO	0.12	0.07	0.10	0.09	0.20	0.24
MgO	39.91	31.91	34.60	29.87	10.49	11.18
CaO	0.11	0.01	0.45	3.29	12.38	7.78
Na2O	0.25	0.06	0.11	0.09	1.77	1.11
K2O	0.01	0.01	0.06	0.03	0.47	0.39
P2O5	0.00	0.00	0.00	0.01	0.13	0.01
Total	98.62	98.64	88.23	98.99	100.43	100.04
ppm						
Nb	0	0		0	1	1
Zr	0	1	15	4	107	32
Sr	4	1		14	78	62
Zn	54	58		62	110	128
Ni	1748	1701	1500	1583	216	108
Cr	4738	2610	1500	1706	411	3
V	55	35	70	37	330	722
Ce	5	4		10	17	3
Ba	0	0	15	3	139	178
La	4	1		3	2	0
Y	1	1		3	33	15
U				0	0	1
Rb	0	0		1	3	2
Th	0	0		1	1	0
Pb	2	0		2	7	6
Ga	3	3		2	21	18

Table 2, Part A, continued:

Area	Asbestos Peak, continued:					
Sample Rk. Type wt. %	AP-6 CBW	AP-9 HSAH	C-75 HGBW	C-89 CBW	C-91 HGBW	C-115 LSAH
SiO <sub>2</sub>	33.06	57.10	34.39	39.36	35.27	48.98
TiO <sub>2</sub>	1.66	0.04	3.28	0.76	1.52	0.02
Al <sub>2</sub> O <sub>3</sub>	20.37	1.66	19.33	15.14	24.21	0.83
Fe <sub>2</sub> O <sub>3</sub>	12.05	8.42	22.23	12.45	14.76	11.25
MnO	0.08	0.11	0.23	0.20	0.23	0.16
MgO	32.51	30.57	10.19	31.99	12.04	37.98
CaO	0.03	0.14	8.70	0.12	10.93	0.14
Na <sub>2</sub> O	0.01	0.58	1.38	0.17	1.11	0.14
K <sub>2</sub> O	0.01	0.07	0.46	0.01	0.28	0.01
P <sub>2</sub> O <sub>5</sub>	0.03	0.01	0.02	0.05	0.06	0.01
Total	99.81	98.70	100.21	100.25	100.41	99.52
ppm						
Nb	6	1	1	3	1	0
Zr	85	1	20	45	39	1
Sr	1	3	73	2	197	1
Zn	90	77	95	70	97	92
Ni	318	2955	86	569	221	1972
Cr	157	2229	24	283	459	2002
V	276	41	782	166	373	21
Ce	6	4	0	6	6	3
Ba	14	14	537	63	125	41
La	1	8	0	0	2	0
Y	1	18	17			
U	0	0	0			
Rb	0	0	2			
Th	0	0	0			
Pb	1	2	6			
Ga	13	4	15			

Table 2, Part A, continued:

Area	Misery Ridge:				
Sample Rk. Type wt. %	C-137 HGBW	MR-3 ACPX	MR-10 ACPX	MR-14 HGBW	MR-f HSAH
SiO <sub>2</sub>	32.14	53.18	59.22	31.24	58.87
TiO <sub>2</sub>	3.25	0.30	0.06	3.45	0.02
Al <sub>2</sub> O <sub>3</sub>	25.40	4.25	0.28	23.90	1.30
Fe <sub>2</sub> O <sub>3</sub>	19.54	8.37	3.15	17.62	6.31
MnO	0.28	0.25	0.07	0.37	0.10
MgO	7.40	23.00	24.25	8.59	30.64
CaO	10.77	9.59	11.68	12.57	1.67
Na <sub>2</sub> O	0.87	0.16	0.08	1.44	0.06
K <sub>2</sub> O	0.36	0.05	0.03	0.25	0.01
P <sub>2</sub> O <sub>5</sub>	0.28	0.19	0.01	0.86	0.00
Total	100.29	99.34	98.83	100.29	98.98
ppm					
Nb	25	1	1	32	0
Zr	221	41	12	255	1
Sr	672	13	23	183	8
Zn	338	77	49	146	94
Ni	295	1151	1199	338	2052
Cr	436	920	550	327	2193
V	277	102	25	363	26
Ce	30	14	12	49	4
Ba	1001	0	10	45	2
La	13	1	5	23	4
Y		17	13		2
U		0	0		0
Rb		0	0		0
Th		0	1		1
Pb		3	2		0
Ga		5	2		2

Table 2, Part A, continued:

Area	Grouse Creek:				
Sample	C-93	C-95	C-98	C-131	C-136
Rk.Type	FCPX	CBWV	CBW	ACPX	FCPX
wt. %					
SiO2	45.80	23.78	39.15	55.27	54.40
TiO2	1.52	4.66	1.60	0.03	0.04
Al2O3	9.36	21.67	15.18	3.28	0.97
Fe2O3	11.21	25.97	11.40	6.21	3.46
MnO	0.23	0.39	0.19	0.12	0.13
MgO	22.30	18.19	31.38	22.59	19.00
CaO	8.50	2.83	0.57	11.79	21.19
Na2O	0.65	0.23	0.21	0.23	0.29
K2O	0.06	0.03	0.01	0.04	0.01
P2O5	0.26	2.18	0.12	0.00	0.00
Total	99.89	99.93	99.81	99.56	99.49
ppm					
Nb	6	35	6	0	0
Zr	83	507	85	2	1
Sr	111	45	4	17	8
Zn	183	332	101	40	16
Ni	348	275	469	1249	211
Cr	354	590	278	1798	3490
V	195	523	130	55	108
Ce	13	97	6	1	4
Ba	13	0	2	6	55
La	7	41	12	1	3
Y	24				
U	1				
Rb	0				
Th	0				
Pb	2				
Ga	14				

Table 2, Part A, continued:

Area	Castle Creek:				North Blacktail:	
Sample	C-151	C-157	C-161	C-169	C-142	C-146
Rk.Type	FCPX	MROD	FCPX	FCPX	LSAH	LSAH
wt. %						
SiO2	51.62	45.40	52.14	51.82	48.62	49.38
TiO2	0.12	0.07	0.10	0.12	0.01	0.02
Al2O3	3.56	14.73	2.20	3.17	0.56	1.60
Fe2O3	4.92	6.05	5.05	4.83	8.20	8.00
MnO	0.12	0.12	0.12	0.12	0.10	0.12
MgO	17.59	14.52	21.07	17.29	41.95	38.91
CaO	21.40	18.99	18.73	21.96	0.04	0.53
Na2O	0.37	0.41	0.22	0.27	0.18	0.17
K2O	0.04	0.08	0.01	0.01	0.01	0.01
P2O5	0.00	0.00	0.00	0.00	0.00	0.01
Total	99.74	100.37	99.64	99.59	99.67	98.75
ppm						
Nb	0	0	0	0	0	0
Zr	2	1	1	2	0	3
Sr	7	25	6	8	1	6
Zn	20	26	24	21	37	75
Ni	261	221	356	324	1396	2092
Cr	2858	519	4163	2858	1140	2848
V	211	113	150	219	14	48
Ce	1	2	4	6	0	2
Ba	9	22	3	3	10	8
La	1	0	4	5	0	0
Y						
U						
Rb						
Th						
Pb						
Ga						

Table 2, Part A, continued:

Area	Other Areas:			
Sample Rk. Type wt. %	C-165 DUN	C-174 HSAH	W-357A SERP	BB-1 FCPX
SiO <sub>2</sub>	41.57	56.04	46.70	54.09
TiO <sub>2</sub>	0.00	0.01	0.02	0.06
Al <sub>2</sub> O <sub>3</sub>	0.28	0.61	1.28	0.81
Fe <sub>2</sub> O <sub>3</sub>	9.50	7.35	9.08	3.57
MnO	0.13	0.09	0.06	0.10
MgO	47.31	35.09	41.71	19.86
CaO	0.51	0.06	0.15	20.59
Na <sub>2</sub> O	0.22	0.09	0.19	0.52
K <sub>2</sub> O	0.01	0.00	0.01	0.02
P <sub>2</sub> O <sub>5</sub>	0.00	0.01	0.00	0.01
Total	99.53	99.35	99.20	99.63
ppm				
Nb	0	0	0	0
Zr	1	0	1	2
Sr	5	1	12	12
Zn	55	62	36	18
Ni	2475	1362	2743	198
Cr	2803	1894	2553	3615
V	26	15	50	98
Ce	3	1	0	5
Ba	2	0	2	2
La	3	3	2	0
Y				1
U				
Rb				0
Th				1
Pb				1
Ga				2



Table 2, Part B: Descriptions of analyzed rocks and rock-type abbreviations.

## DESCRIPTIONS OF ANALYZED ROCKS

### New Meadows area:

W-63: Amphibole-rich blackwall rock. A layered, foliated, and folded tremolite-chlorite schist that consists mainly of prismatic to acicular tremolite and contains irregular zones of chlorite and accompanying grains of opaque oxides; from margin of ultramafic body in SE1/4, sec. 10, T. 18 N., R. 1 E., New Meadows quadrangle.

W-68: Low-silica altered dunite. A coarse-grained metadunite with large strained and fractured olivine crystals accompanied by abundant acicular anthophyllite and chlorite, and minor opaque oxides, serpentine, tremolite, and orthopyroxene; from SE1/4, sec. 10, T. 18 N., R. 1 E., New Meadows quadrangle.

W-107: Altered Ca-rich pyroxenite. A coarse-grained nonfoliated clinopyroxenite that has been partially replaced by hornblende; from an inclusion within the Meadows shear zone in SE1/4, sec. 5, T. 18 N., R. 2 E., Meadows quadrangle.

W-114: Low-silica altered harzburgite. A coarse-grained, foliated talc-chlorite-tremolite schist with scattered subhedral grains of opaque oxides; from a small ultramafic body near Thrush Creek in NE1/4, sec. 18, T. 18 N., R. 2 E., New Meadows quadrangle.

W-192: Relatively fresh dunite. A nondeformed dunite with a well-developed mosaic texture characterized by 120-degree olivine grain contacts, with large subhedral oxide (chromite?) grains, minor amounts of orthopyroxene and anthophyllite, and crosscut by chrysotile veinlets; from near Vick Creek in NE1/4, sec. 15, T. 18 N., R. 1 E., New Meadows quadrangle.

W-193: Relatively fresh dunite. An intensely deformed dunite in which the olivine grains are cut by iddingsite? veinlets and which contains modest amounts of talc, chlorite, and opaque oxides; from near Vick Creek in NE1/4, sec. 15, T. 18 N., R. 1 E., New Meadows quadrangle.

W-194: Relatively fresh dunite. A strongly foliated dunite in which the olivine grains were recrystallized (they show 120-degree grain contacts) but were subsequently flattened and sheared, and which are accompanied by selvages of chlorite, by subparallel anthophyllite needles that mostly were converted to talc, and by opaque oxide grains; from near Vick Creek in NE1/4, sec. 15, T. 18 N., R. 1 E., New Meadows quadrangle.

W-203: Metaroddingite. A nonfoliated hornblende-epidote rock with minor amounts of sphene and which may initially have been a diabase; from near Vick Creek in NE1/4, sec. 15, T. 18 N., R. 1 E., New Meadows quadrangle.

W-205: Metarodinite. A nonfoliated hornblende-epidote rock that may initially have been a diabase, that contains minor amounts of sphene and opaque oxides, and in which the epidote and sphene are granular and some of the hornblende grains contain Ca pyroxene cores; from near Vick Creek in NE1/4, sec. 15, T. 18 N., R. 1 E., New Meadows quadrangle.

W-218: Biotite-rich exhalatite. A strongly foliated biotite schist containing barite and minor amounts of opaque oxides and dark green spinel, in which some biotite and barite grains are intergrown and in which the larger oxide grains form rows that parallel the schistosity; associated with dunite area in NW1/4, sec. 15, T. 18 N., R. 1 E., New Meadows quadrangle.

W-220: Chromitite. A metamorphosed and expanded chromitite in which fractured chromite grains are set in a fine-grained serpentine or chlorite matrix that also contains coarser areas of chlorite; from an area of old prospect pits in NW1/4, sec. 2, T. 18 N., R. 1 E., New Meadows quadrangle.

W-391: Chromitite. A metamorphosed chromitite with large rounded and fractured chromite grains surrounded by interstitial serpentine or chlorite; from an area of old prospect pits in NW1/4, sec. 2, T. 18 N., R. 1 E., New Meadows quadrangle.

Time Zone Bridge area:

W-6: Serpentinite. A metaperidotite consisting mainly of antigorite accompanied by chlorite flakes and equant masses of opaque oxides, and cut by carbonate veinlets, in which the texture shows replacement of original olivine by antigorite and orthopyroxene by chlorite; from highway U.S. 95 roadcut in SW1/4, sec. 2, T. 24 N., R. 1 E., Riggins quadrangle.

TBR-3: Serpentinite. A fine-grained metaperidotite consisting mainly of chlorite, with subordinate serpentine, and minor talc, anthophyllite, and opaque oxides, in which some areas are strongly sheared and crenulated whereas intervening talc-rich areas have a decussate texture; from margin of ultramafic mass in NE1/4, sec. 3, T. 24 N., R. 1 E., Riggins quadrangle.

TBR-10: Metabasalt. A fine-grained, actinolite-rich nonfoliated metamorphic rock containing a little plagioclase and poikiloblastic grains of opaque oxide minerals; from near the west end of the Time Zone Bridge ultramafic body, near center N1/2, sec. 3, T. 24 N., R. 1 E., Riggins quadrangle.

TBR-11: Metabasalt. A medium-grained, actinolite-rich metamorphic rock accompanied by minor amounts of plagioclase, quartz, and opaque oxide minerals; from near the west end of the Time Zone Bridge ultramafic body, near center N1/2, sec. 3, T. 24 N., R. 1 E., Riggins quadrangle.

SR14-1: Serpentinite. A magnesite-talc-antigorite metaperidotite analysis that was reported by Hamilton (1963, p.64); from highway U.S. 95 roadcut in SW1/4, sec. 2, T. 24 N., R. 1 E.,

Riggins quadrangle. Hamilton's analysis includes 1.8 %  $\text{Fe}_2\text{O}_3$ , 5.4 %  $\text{FeO}$ , 10.0 %  $\text{H}_2\text{O}$ , and 4.6 %  $\text{CO}_2$  for a total of 100 percent.

Pollock Rest Stop area:

W-35: Serpentinite. A metamorphosed peridotite containing patches of talc and a carbonate mineral and shears and fans of chlorite, and in which oxidized patches in the rock might have initially been pyrite; from highway U.S. 95 roadcut in SW1/4, sec. 16, T. 23 N., R. 1 E., Pollock quadrangle.

W-36: High-silica altered harzburgite. A fine-grained talc schist with scattered augenlike nodes of serpentine and minor amounts of skeletal opaque oxide minerals, and in which closely spaced shears in the rock have aligned talc flakes; from highway U.S. 95 roadcut in SW1/4, sec. 16, T. 23 N., R. 1 E., Pollock quadrangle.

SR37-3: Serpentinite. A metamorphosed peridotite analysis reported by Hamilton (1963, p. 64) and noted by him to contain 98 percent antigorite with minor talc and opaques and traces of magnesite and phlogopite; from highway U.S. 95 roadcut in SW1/4, sec. 16, T. 23 N., R. 1 E., Pollock quadrangle. Hamilton's analysis includes 1.8 %  $\text{Fe}_2\text{O}_3$ , 6.0 %  $\text{FeO}$ , 12.6 %  $\text{H}_2\text{O}$  and 0.65 %  $\text{CO}_2$ , for a total of 101 percent.

Asbestos Peak area:

AP-3: High-silica altered harzburgite. A coarse-grained talc-anthophyllite schist with elongate anthophyllite needles partially replaced by talc and minor chlorite; from SE1/4, sec. 26, T. 28 N., R. 3 E., Dairy Mountain quadrangle.

AP-4: Hornblende-garnet blackwall rock. A hornblende-garnet-spinel rock consisting mainly of subhedral amphibole crystals and poikiloblastic garnets with amphibole inclusions, in which the spinels are anhedral and have tiny associated grains of cordierite or sapphirine, and in which ilmenite and perhaps other opaque oxides occur as rounded blebs; from marginal zone of ultramafic occurrence in SE1/4, sec. 26, T. 28 N., R. 3 E., Dairy Mountain quadrangle.

AP-5: Hornblende-garnet blackwall rock. A hornblende-garnet-ilmenite-spinel rock consisting mainly of prismatic hornblende and sieve-structured garnet, accompanied by minor green spinel and chlorite; from marginal zone of ultramafic occurrence in SE1/4, sec. 26, T. 28 N., R. 3 E., Dairy Mountain quadrangle.

AP-6: Chlorite-rich blackwall rock. A coarse-grained chlorite rock containing minor opaque oxides and an unidentified reddish brown mineral (perhaps stilpnomelane); from margin of the ultramafic body in SE1/4, sec. 26, T. 28 N., R. 3 E., Dairy Mountain quadrangle.

AP-9: High-silica altered harzburgite. A very coarse-grained metaharzburgite consisting mainly of intergrown talc and chlorite, which replace anthophyllite that has local relict cores of orthopyroxene, and in which possible tiny relict olivine grains are associated with local

areas of flaky antigorite; from SE1/4, sec. 26, T. 28 N., R. 3 E., Dairy Mountain quadrangle.

C-75: Hornblende-garnet blackwall rock. A hornblende-garnet-ilmenite rock containing traces of green spinel and late-stage chlorite flakes, in which local layering due to trains of cataclastic garnet granules and ilmenite is evident, and in which the hornblende is fine grained and nonaligned; from marginal zone of ultramafic occurrence in SE1/4 sec. 26, T. 28 N., R. 3 E., Dairy Mountain quadrangle.

C-89: Chlorite-rich blackwall rock. A chlorite schist with minor amphibole and opaque oxides; from margin of ultramafic body in SE1/4, sec. 26, T. 28 N., R. 3 E., Dairy Mountain quadrangle.

C-91: Hornblende-garnet blackwall rock. A hornblende-garnet-ilmenite-spinel rock in which much of the garnet and spinel has been partially replaced by chlorite and clinozoisite; from marginal zone of ultramafic occurrence in SE1/4, sec. 26, T. 28 N., R. 3 E., Dairy Mountain quadrangle.

C-115: Low-silica altered harzburgite. An metaharzburgite in which all the orthopyroxene has been replaced by anthophyllite, talc, and chlorite, and in which the olivine grains are highly fractured; from SE1/4, sec. 26, T. 28 N., R. 3 E., Dairy Mountain quadrangle.

#### Misery Ridge area:

C-137: Hornblende-garnet blackwall rock. A hornblende-garnet-ilmenite rock with abundant chlorite and minor spinel, in which the garnet is poikiloblastic and the ilmenite is skeletal, and which contains possible cordierite or sappharine; from margin of small ultramafic occurrence that probably is in SE1/4, sec. 1, T. 28 N., R. 3 E., Goodwin Meadows quadrangle.

MR-3: Altered Ca-rich pyroxenite. A fine-grained, strongly lineated and microfolded tremolite-rich schist with some finely divided chlorite, which is cut by a lensoidal shear filled with chlorite; from central part of ultramafic occurrence in NE1/4, sec. 1, T. 28 N., R. 3 E., Goodwin Meadows quadrangle.

MR-10: Altered Ca-rich pyroxenite. A strongly sheared and lineated talc-tremolite schist with minor amounts of chlorite and possible antigorite, but no opaque oxides; from margin of ultramafic occurrence in NE1/4, sec. 1, T. 28 N., R. 3 E., Goodwin Meadows quadrangle.

MR-14: Hornblende-garnet blackwall rock. A hornblende-garnet-spinel-ilmenite rock with a cataclastic fabric and with abundant chlorite replacing the poikiloblastic garnets, in which opaque oxide clumps are rimmed by green spinel; from edge of ultramafic occurrence in NE1/4, sec. 1, T. 28 N., R. 3 E., Goodwin Meadows quadrangle.

MR-f: High-silica altered harzburgite. A fine-grained talc-chlorite schist with possible minor carbonates, in which chlorite has formed at the expense of talc; float from adjacent to ultramafic occurrence in NE1/4, sec. 1, T. 28 N., R. 3 E., Goodwin Meadows quadrangle.

Grouse Creek area:

C-93: Relatively fresh Ca-rich pyroxenite. A very coarse-grained pyroxenite with minor carbonates that has more augite than hypersthene, in which both pyroxenes contain abundant coarse exsolution lamellae, and in which abundant anthophyllite? (or gedrite) replaces hypersthene; from SE1/4, sec. 31, T. 29 N., R. 4 E., Goodwin Meadows quadrangle.

C-95: Chlorite-rich blackwall vein rock. A sheared chlorite schist with abundant clots of ilmenite (some more than a cm across), euhedra of apatite, and sparse sieve-textured garnets, that is cut by a microfolded layer rich in apatite; from vein or dikelike body cutting ultramafic rocks in SE1/4, sec. 31, T. 29 N., R. 4 E., Goodwin Meadows quadrangle.

C-98: Chlorite-rich blackwall rock. A chlorite schist with large ilmenite anhedral and scattered anthophyllite grains; from ultramafic occurrence in SE1/4, sec. 31, T. 29 N., R. 4 E., Goodwin Meadows quadrangle.

C-131: Altered Ca-rich peridotite. A strongly sheared metaperidotite with granulated and strungout olivine enclosed in a matrix of talc, tremolite, anthophyllite, opaque oxides, and abundant, finely divided calcite, but no orthopyroxene; from SE1/4, sec. 31, T. 29 N., R. 4 E., Goodwin Meadows quadrangle.

C-136: Relatively fresh Ca-rich pyroxenite. A clinopyroxenite with accompanying orthopyroxene and abundant secondary tremolite and that shows abundant exsolution lamellae in the pyroxenes; from SE1/4, sec. 31, T. 29 N., R. 4 E., Goodwin Meadows quadrangle.

Castle Creek area:

C-151: Relatively fresh Ca-rich pyroxenite. A clinopyroxenite consisting of coarse-grained augite grains with irregular outlines enclosed by small zoned euhedral hornblende grains that replace their margins; probably from SW1/4, sec. 10, T. 29 N., R. 4 E., Hungry Ridge quadrangle.

C-157: Metaroddingite. A metamorphosed gabbro that consists of ragged augite grains and megacrysts that are partially altered to hornblende, and plagioclase which has been completely replaced by clinozoisite and amphiboles; probably from SW1/4, sec. 10, T. 29 N., R. 4 E., Hungry Ridge quadrangle.

C-161: Relatively fresh Ca-rich pyroxenite. A clinopyroxenite consisting mainly of large augite grains with patches of exsolution lamellae and replacement patches of amphibole, probably tremolite, in which orthopyroxene is largely replaced by chlorite with possible

serpentine and anthophyllite, and that contains minor zoisite and epidote but no feldspar; probably from SW1/4, sec. 10, T. 29 N., R. 4 E., Hungry Ridge quadrangle.

C-169: Relatively fresh Ca-rich pyroxenite. A clinopyroxenite consisting almost completely of coarse-grained augite with abundant exsolution lamellae and replaced by minor quantities of hornblende and chlorite; from NW1/4, sec. 15, T. 29 N., R. 4 E., Hungry Ridge quadrangle.

#### North Blacktail area:

C-142: Low-silica altered harzburgite. A metaharzburgite containing abundant serpentine and talc, some chlorite, opaque oxides, possible anthophyllite, and many remnant grains of olivine and orthopyroxene, and in which the opaque oxide grains occur in curvilinear trains that enclose sheaves of chlorite; from NE1/4, sec. 28, T. 30 N., R. 4 E., Harpster quadrangle.

C-146: Low-silica altered harzburgite. A metaharzburgite with numerous large olivine grains partially replaced by chlorite or antigorite, enclosed in a matrix of talc, chlorite, carbonate (magnesite?), and minor antigorite, and in which sparse opaque oxide grains occur along fractures in the olivines; from NE1/4, sec. 28, T. 30 N., R. 4 E., Harpster quadrangle.

#### Other areas:

C-165: Relatively fresh dunite. A granular, unsheared dunite with minor talc and with olivine grains occurring in an equilibrium fabric characterized by 120 degree grain contacts, in which brownish opaque oxide granules and clumps outline earlier large grains, and in which chrysotile veinlets follow fractures in the olivine grains; from Asbestos Point in SE1/4, sec. 27, T. 29 N., R. 4 E., Hungry Ridge quadrangle.

C-174: High-silica altered harzburgite. A very coarse-grained metaharzburgite consisting mainly of large, undeformed rosettes (up to several cm across) of anthophyllite partially replaced by talc, and which contains minor chlorite and opaque oxides; from the Panhandle Asbestos Mine probably in NE1/4, sec. 9, T. 33 N., R. 5 E., Glenwood quadrangle.

W-357A: Serpentinite. A metaharzburgite consisting mainly of sheared serpentine, accompanied by minor opaque oxides and carbonate, and with unaltered relicts of original olivine and orthopyroxene; from the Sturgill Peak ultramafic body of Skurla (1974) in SE1/4, sec. 17, T. 15 N., R. 5 W, Neil Gulch quadrangle.

BB-1: Relatively fresh Ca-rich pyroxenite. A clinopyroxenite consisting principally of augite; location unknown for certain, but probably from the Grouse Creek ultramafic occurrence in SE1/4, sec. 31, T. 29 N., R. 4 E., Goodwin Meadows quadrangle.

## ROCK-TYPE ABBREVIATIONS

### Ultramafic rock types:

DUN	relatively fresh dunite
SERP	serpentinite
LSAH	low-silica altered harzburgite or dunite
HSAH	high-silica altered harzburgite
FCPX	relatively fresh Ca-rich pyroxenite
ACPX	altered Ca-rich pyroxenite or peridotite
CHR	chromitite

### Associated metamorphic rocks:

MBS	metabasalt
HGBW	hornblende-garnet blackwall rock
CBW	chlorite-rich blackwall rock
ABW	amphibole-rich blackwall rock
CBWV	chlorite-rich blackwall vein rock
BEXH	biotite-rich exhalatite
MROD	metaroddingite

Table 3: Normalized values of major oxides for the various types of ultramafic rocks.

Dunite:				
Sample	W-192	W-193	W-194	C-165
wt. %				
SiO <sub>2</sub>	40.84	41.11	43.01	41.46
TiO <sub>2</sub>	0.01	0.00	0.00	0.00
Al <sub>2</sub> O <sub>3</sub>	0.17	0.31	0.30	0.28
Fe <sub>2</sub> O <sub>3</sub>	8.73	10.09	9.94	9.48
MnO	0.16	0.19	0.19	0.13
MgO	48.27	47.14	45.42	47.19
CaO	0.03	0.22	0.11	0.51
Na <sub>2</sub> O	0.89	0.17	0.17	0.22
K <sub>2</sub> O	0.03	0.01	0.01	0.01
P <sub>2</sub> O <sub>5</sub>	0.02	0.00	0.01	0.00
NiO	0.40	0.31	0.28	0.31
Cr <sub>2</sub> O <sub>3</sub>	0.44	0.46	0.55	0.41
Total	100.00	100.00	100.00	100.00
MgO/ MgO+FeO	0.86	0.84	0.84	0.85

Serpentinite:						
Sample	W-35	W-6	TBR-3	W-357A	SR37-3	SR14-1
wt. %						
SiO <sub>2</sub>	47.92	47.65	48.32	46.74	47.61	45.09
TiO <sub>2</sub>	0.02	0.04	0.02	0.02	0.05	0.02
Al <sub>2</sub> O <sub>3</sub>	1.91	1.22	2.40	1.28	2.48	1.97
Fe <sub>2</sub> O <sub>3</sub>	8.64	8.22	8.35	9.09	9.56	9.04
MnO	0.12	0.07	0.11	0.06	0.11	0.09
MgO	40.10	41.28	40.09	41.74	39.03	43.12
CaO	0.11	0.15	0.06	0.15	0.51	0.09
Na <sub>2</sub> O	0.25	0.76	0.08	0.19	0.12	0.08
K <sub>2</sub> O	0.01	0.03	0.02	0.01	0.07	0.02
P <sub>2</sub> O <sub>5</sub>	0.00	0.01	0.01	0.00	0.00	0.00
NiO	0.22	0.19	0.24	0.35	0.22	0.22
Cr <sub>2</sub> O <sub>3</sub>	0.70	0.37	0.31	0.37	0.25	0.25
Total	100.00	100.00	100.00	100.00	100.00	100.00
MgO/ MgO+FeO	0.84	0.85	0.84	0.84	0.82	0.84



Table 3, continued:

## Low-silica altered harzburgite:

Sample wt. %	W-68	C-115	C-142	C-146	W-114
SiO <sub>2</sub>	44.17	48.95	48.61	49.66	49.24
TiO <sub>2</sub>	0.02	0.02	0.01	0.02	0.35
Al <sub>2</sub> O <sub>3</sub>	2.24	0.83	0.56	1.61	7.07
Fe <sub>2</sub> O <sub>3</sub>	9.64	11.24	8.20	8.05	11.35
MnO	0.12	0.16	0.10	0.12	0.17
MgO	42.38	37.96	41.94	39.13	24.91
CaO	0.41	0.14	0.04	0.53	4.18
Na <sub>2</sub> O	0.30	0.14	0.18	0.17	2.04
K <sub>2</sub> O	0.01	0.01	0.01	0.01	0.10
P <sub>2</sub> O <sub>5</sub>	0.00	0.01	0.00	0.01	0.11
NiO	0.27	0.25	0.18	0.27	0.13
Cr <sub>2</sub> O <sub>3</sub>	0.43	0.29	0.17	0.42	0.35
Total	100.00	100.00	100.00	100.00	100.00
MgO/ MgO+FeO	0.83	0.79	0.85	0.84	0.71

## High-silica altered harzburgite:

Sample wt. %	W-36	AP-9	MR-f	C-174	AP-3
SiO <sub>2</sub>	59.00	57.44	59.13	56.15	58.24
TiO <sub>2</sub>	0.02	0.04	0.02	0.01	0.03
Al <sub>2</sub> O <sub>3</sub>	1.92	1.67	1.31	0.61	1.07
Fe <sub>2</sub> O <sub>3</sub>	6.15	8.47	6.34	7.36	6.65
MnO	0.07	0.11	0.10	0.09	0.09
MgO	32.16	30.75	30.77	35.16	30.04
CaO	0.01	0.14	1.68	0.06	3.31
Na <sub>2</sub> O	0.06	0.58	0.06	0.09	0.09
K <sub>2</sub> O	0.01	0.07	0.01	0.00	0.03
P <sub>2</sub> O <sub>5</sub>	0.00	0.01	0.00	0.01	0.01
NiO	0.22	0.38	0.26	0.17	0.20
Cr <sub>2</sub> O <sub>3</sub>	0.38	0.33	0.32	0.28	0.25
Total	100.00	100.00	100.00	100.00	100.00
MgO/ MgO+FeO	0.85	0.80	0.84	0.84	0.83

Table 3, continued:

## Ca-rich pyroxenite:

Sample wt. %	C-93	BB-1	C-136	C-151	C-161	C-169
SiO <sub>2</sub>	45.81	53.99	54.39	51.52	51.99	51.79
TiO <sub>2</sub>	1.52	0.06	0.04	0.12	0.10	0.12
Al <sub>2</sub> O <sub>3</sub>	9.36	0.81	0.97	3.55	2.19	3.17
Fe <sub>2</sub> O <sub>3</sub>	11.21	3.56	3.46	4.91	5.04	4.83
MnO	0.23	0.10	0.13	0.12	0.12	0.12
MgO	22.30	19.82	18.99	17.56	21.01	17.28
CaO	8.50	20.55	21.18	21.36	18.68	21.95
Na <sub>2</sub> O	0.65	0.52	0.29	0.37	0.22	0.27
K <sub>2</sub> O	0.06	0.02	0.01	0.04	0.01	0.01
P <sub>2</sub> O <sub>5</sub>	0.26	0.01	0.00	0.00	0.00	0.00
NiO	0.04	0.03	0.03	0.03	0.05	0.04
Cr <sub>2</sub> O <sub>3</sub>	0.05	0.53	0.51	0.42	0.61	0.42
Total	100.00	100.00	100.00	100.00	100.00	100.00
MgO/ MgO+FeO	0.69	0.86	0.86	0.80	0.82	0.80

## Altered Ca-rich pyroxenite:

## Chromitite:

Sample wt. %	W-107	MR-3	MR-10	C-131	W-220	W-391
SiO <sub>2</sub>	50.97	53.38	59.78	55.28	17.25	16.49
TiO <sub>2</sub>	0.52	0.30	0.06	0.03	0.13	0.07
Al <sub>2</sub> O <sub>3</sub>	7.64	4.27	0.28	3.28	10.43	6.95
Fe <sub>2</sub> O <sub>3</sub>	7.74	8.40	3.18	6.21	8.88	13.47
MnO	0.19	0.25	0.07	0.12	0.20	0.47
MgO	14.32	23.09	24.48	22.59	22.95	21.91
CaO	17.23	9.63	11.79	11.79	0.02	0.01
Na <sub>2</sub> O	0.74	0.16	0.08	0.23	0.29	0.28
K <sub>2</sub> O	0.28	0.05	0.03	0.04	0.02	0.02
P <sub>2</sub> O <sub>5</sub>	0.05	0.19	0.01	0.00	0.01	0.00
NiO	0.02	0.15	0.15	0.16	0.25	0.15
Cr <sub>2</sub> O <sub>3</sub>	0.31	0.13	0.08	0.26	39.56	40.18
Total	100.00	100.00	100.00	100.00	100.00	100.00
MgO/ MgO+FeO	0.67	0.75	0.90	0.80	0.74	0.64

Table 4: Normalized values of major oxides for the various types of analyzed rocks associated with the ultramafic bodies.

Hornblende-garnet blackwall rocks:

Sample wt. %	AP-4	AP-5	C-75	C-91	C-137	MR-14
SiO <sub>2</sub>	38.69	33.46	34.32	35.13	32.05	31.15
TiO <sub>2</sub>	1.90	3.18	3.27	1.51	3.24	3.44
Al <sub>2</sub> O <sub>3</sub>	19.69	20.07	19.29	24.11	25.33	23.83
Fe <sub>2</sub> O <sub>3</sub>	14.39	22.59	22.18	14.70	19.48	17.57
MnO	0.20	0.24	0.23	0.23	0.28	0.37
MgO	10.45	11.18	10.17	11.99	7.38	8.57
CaO	12.33	7.78	8.68	10.89	10.74	12.53
Na <sub>2</sub> O	1.76	1.11	1.38	1.11	0.87	1.44
K <sub>2</sub> O	0.47	0.39	0.46	0.28	0.36	0.25
P <sub>2</sub> O <sub>5</sub>	0.13	0.01	0.02	0.06	0.28	0.86
Total	100.00	100.00	100.00	100.00	100.00	100.00
MgO/ MgO+FeO	0.45	0.35	0.34	0.48	0.30	0.35

Chlorite-rich blackwall rocks:

Sample wt. %	AP-6	C-89	C-98
SiO <sub>2</sub>	33.12	39.26	39.22
TiO <sub>2</sub>	1.66	0.76	1.60
Al <sub>2</sub> O <sub>3</sub>	20.41	15.10	15.21
Fe <sub>2</sub> O <sub>3</sub>	12.07	12.42	11.42
MnO	0.08	0.20	0.19
MgO	32.57	31.91	31.44
CaO	0.03	0.12	0.57
Na <sub>2</sub> O	0.01	0.17	0.21
K <sub>2</sub> O	0.01	0.01	0.01
P <sub>2</sub> O <sub>5</sub>	0.03	0.05	0.12
Total	100.00	100.00	100.00
MgO/ MgO+FeO	0.75	0.74	0.75

Table 4, continued:

Sample wt. %	Metabasalt:		Metarodrigite:		
	TBR-10	TBR-11	W-203	W-205	C-157
SiO <sub>2</sub>	50.17	52.90	41.56	41.75	45.23
TiO <sub>2</sub>	1.51	1.28	2.12	2.23	0.07
Al <sub>2</sub> O <sub>3</sub>	16.73	15.25	16.01	14.61	14.68
Fe <sub>2</sub> O <sub>3</sub>	13.46	11.90	13.11	12.72	6.03
MnO	0.23	0.24	0.54	0.46	0.12
MgO	6.67	6.79	6.05	7.82	14.47
CaO	6.40	6.72	19.05	18.71	18.92
Na <sub>2</sub> O	4.56	4.65	0.98	0.97	0.41
K <sub>2</sub> O	0.16	0.16	0.27	0.45	0.08
P <sub>2</sub> O <sub>5</sub>	0.11	0.10	0.31	0.28	0.00
Total	100.00	100.00	100.00	100.00	100.00
MgO/ MgO+FeO	0.36	0.39	0.34	0.41	0.73

Miscellaneous rocks:			
Sample wt. %	C-95	W-63	W-218
SiO <sub>2</sub>	23.80	43.65	31.01
TiO <sub>2</sub>	4.66	1.96	3.39
Al <sub>2</sub> O <sub>3</sub>	21.69	9.99	24.46
Fe <sub>2</sub> O <sub>3</sub>	25.99	12.70	19.42
MnO	0.39	0.22	0.21
MgO	18.20	22.26	11.89
CaO	2.83	8.03	0.94
Na <sub>2</sub> O	0.23	0.73	2.18
K <sub>2</sub> O	0.03	0.07	6.01
P <sub>2</sub> O <sub>5</sub>	2.18	0.40	0.48
Total	100.00	100.00	100.00
MgO/ MgO+FeO	0.44	0.66	0.40

Table 5: Average normalized compositions for the major types of ultramafic and associated rocks (see Table 2, part B, for rock-type abbreviations).

Rock Type	Ultramafic Rocks:					
	DUN	SERP	LSAH	HSAH	FCPX	ACPX
wt. %						
SiO <sub>2</sub>	41.61	47.22	47.85	57.99	52.74	54.85
TiO <sub>2</sub>	0.00	0.03	0.02	0.02	0.09	0.23
Al <sub>2</sub> O <sub>3</sub>	0.27	1.88	1.31	1.32	2.14	3.87
Fe <sub>2</sub> O <sub>3</sub>	9.56	8.82	9.28	6.99	4.36	6.38
MnO	0.17	0.09	0.13	0.09	0.12	0.16
MgO	47.00	40.89	40.35	31.78	18.93	21.12
CaO	0.22	0.18	0.28	1.04	20.74	12.61
Na <sub>2</sub> O	0.36	0.25	0.20	0.18	0.33	0.30
K <sub>2</sub> O	0.02	0.03	0.01	0.02	0.02	0.10
P <sub>2</sub> O <sub>5</sub>	0.01	0.00	0.01	0.01	0.00	0.06
NiO	0.32	0.24	0.24	0.25	0.03	0.12
Cr <sub>2</sub> O <sub>3</sub>	0.46	0.37	0.33	0.31	0.50	0.20
Total	100.00	100.00	100.00	100.00	100.00	100.00
MgO/						
MgO+FeO	0.85	0.84	0.83	0.83	0.83	0.78
ppm						
Nb	0	0	0	0	0	1
Zr	1	1	1	1	2	17
Sr	3	4	3	5	8	40
Zn	91	54	64	71	20	63
Ni	2543	1808	1895	1931	270	938
Cr	3175	2482	2240	2126	3397	1354
V	20	48	32	31	157	132
Ce	2	4	1	5	4	10
Ba	2	0	16	4	14	113
La	3	3	0	4	2	3
Samples in the average	W-192 W-193 W-194 C-165	W-35 W-6 TBR-3 W-357A SR37-3* SR14-1*	W-68 C-115 C-142 C-146	W-36 AP-9 MR-f C-174 AP-3	C-136 C-151 C-161 C-169 BB-1	W-107 MR-3 MR-10 C-131

\* excluded from minor element averages

Table 5, continued:

Rock Type wt. %	Associated Rocks:				
	CHR	MBS	HGBW	CBW	MROD
SiO <sub>2</sub>	16.87	51.54	34.13	37.20	41.65
TiO <sub>2</sub>	0.10	1.40	2.76	1.34	2.18
Al <sub>2</sub> O <sub>3</sub>	8.69	15.99	22.05	16.91	15.31
Fe <sub>2</sub> O <sub>3</sub>	11.17	12.68	18.49	11.97	12.92
MnO	0.33	0.24	0.26	0.16	0.50
MgO	22.43	6.73	9.95	31.97	6.94
CaO	0.01	6.56	10.49	0.24	18.88
Na <sub>2</sub> O	0.29	4.61	1.28	0.13	0.97
K <sub>2</sub> O	0.02	0.16	0.37	0.01	0.36
P <sub>2</sub> O <sub>5</sub>	0.00	0.11	0.23	0.07	0.29
NiO	0.20				
Cr <sub>2</sub> O <sub>3</sub>	39.87				
Total	100.00	100.00	100.00	100.00	100.00
MgO/ MgO+FeO	0.69	0.37	0.38	0.75	0.37
ppm					
Nb	0	1	10	5	7
Zr	2	84	112	72	174
Sr	1	117	211	3	446
Zn	700	231	152	87	312
Ni	1724	29	211	452	132
Cr	294435	6	277	239	188
V	804	296	475	190	348
Ce	7	10	18	6	24
Ba	0	22	337	26	365
La	141	0	7	4	8
Samples in the average	W-220 W-391	TBR-10 TBR-11	AP-4 AP-5 C-75 C-91 C-137 MR-14	AP-6 C-89 C-98	W-203 W-205

Table 6: Comparison of the adjusted analyses of the hornblende-garnet blackwall rocks with other metavolcanic rocks.

Adjusted hornblende-garnet blackwall rock compositions:

Sample wt. %	AP-4	AP-5	C-75	C-91	C-137	MR-14
SiO <sub>2</sub>	50.18	50.27	48.93	54.26	54.40	50.88
TiO <sub>2</sub>	1.55	2.38	2.55	1.07	2.17	2.45
Al <sub>2</sub> O <sub>3</sub>	16.00	15.00	15.00	17.00	17.00	17.00
Fe <sub>2</sub> O <sub>3</sub>	11.69	16.88	17.25	10.36	13.08	12.53
MnO	0.16	0.18	0.18	0.16	0.19	0.26
MgO	8.49	8.35	7.91	8.45	4.95	6.11
CaO	10.02	5.81	6.75	7.68	7.21	8.94
Na <sub>2</sub> O	1.43	0.83	1.07	0.78	0.58	1.02
K <sub>2</sub> O	0.38	0.29	0.36	0.20	0.24	0.18
P <sub>2</sub> O <sub>5</sub>	0.11	0.01	0.02	0.04	0.19	0.61
Total	100.01	100.00	100.02	100.00	100.01	99.98
MgO/ MgO+FeO	0.45	0.35	0.34	0.48	0.30	0.35
Orig*						
SiO <sub>2</sub>	38.69	33.46	34.38	35.13	32.05	31.15
Add**						
SiO <sub>2</sub>	23.06	33.80	28.60	41.82	49.00	40.18
Sum***						
SiO <sub>2</sub>	61.75	67.26	62.98	76.95	81.05	71.33

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\* Original SiO<sub>2</sub> is the value listed in Table 4.

\*\* Added SiO<sub>2</sub> is the amount added to the analysis.

\*\*\* Sum of SiO<sub>2</sub> is the pre-normalization value.

Once an oxide analysis was renormalized to a total of 100% by including the new sum of SiO<sub>2</sub> value, its adjusted analysis given above was generated.

Table 6, continued:

## Normalized volcanic rocks from Hamilton (1963):

Sample wt. %	SR-114	SR-127C	SR-34	SR-539	SR-51
SiO <sub>2</sub>	49.72	49.70	53.61	53.22	56.52
TiO <sub>2</sub>	1.57	1.55	1.17	0.91	1.38
Al <sub>2</sub> O <sub>3</sub>	17.10	15.47	15.80	17.57	16.44
Fe <sub>2</sub> O <sub>3</sub>	13.73	11.46	12.20	10.23	12.58
MnO	0.20	0.21	0.23	0.14	0.21
MgO	8.81	7.32	4.70	5.45	5.73
CaO	4.09	10.72	8.33	8.18	3.39
Na <sub>2</sub> O	4.30	3.20	3.74	3.84	2.76
K <sub>2</sub> O	0.25	0.23	0.11	0.22	0.78
P <sub>2</sub> O <sub>5</sub>	0.23	0.14	0.11	0.23	0.21
Total	100.00	100.00	100.00	99.99	100.00
MgO/ MgO+FeO	0.42	0.42	0.30	0.37	0.34

## Averages of analyses:

Sample wt. %	HGBW(1)	MBS(2)	HAM(3)
SiO <sub>2</sub>	52.20	51.54	52.55
TiO <sub>2</sub>	2.00	1.40	1.32
Al <sub>2</sub> O <sub>3</sub>	16.00	15.99	16.48
Fe <sub>2</sub> O <sub>3</sub>	13.41	12.68	12.04
MnO	0.19	0.24	0.20
MgO	7.22	6.73	6.40
CaO	7.61	6.56	6.94
Na <sub>2</sub> O	0.93	4.61	3.57
K <sub>2</sub> O	0.27	0.16	0.32
P <sub>2</sub> O <sub>5</sub>	0.16	0.11	0.18
Total	99.99	100.02	100.00
MgO/ MgO+FeO	0.38	0.37	0.37

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(1) HGWB - Average for the 6 adjusted hb-gnt blackwall rocks.

(2) MBS -- Average for the 2 metabasalts given in Table 4.

(3) HAM -- Average for Hamilton's (1963) 5 metavolcanic rocks.



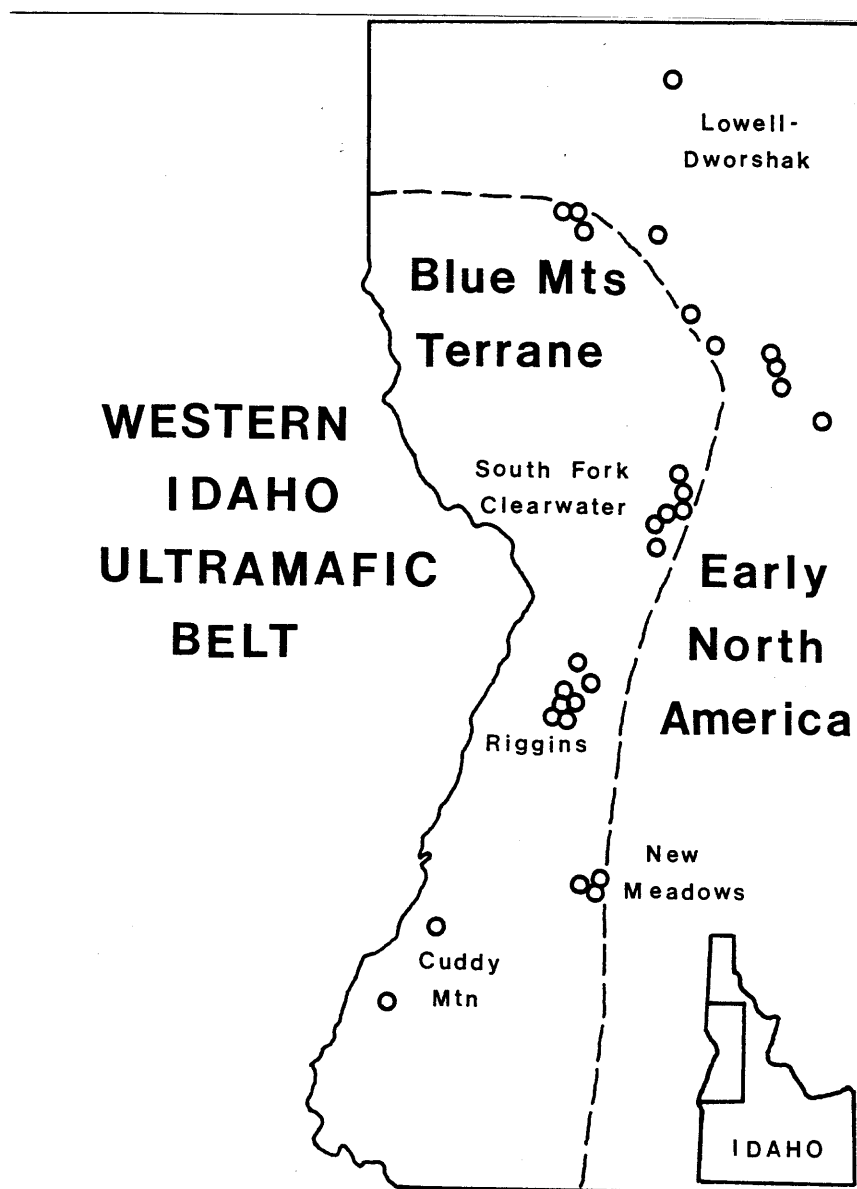


Figure 1. Map of west-central Idaho showing the locations of the ultramafic occurrences in the western Idaho ultramafic belt. The dashed line indicates the location of the continental crust-accreted terrane suture zone.

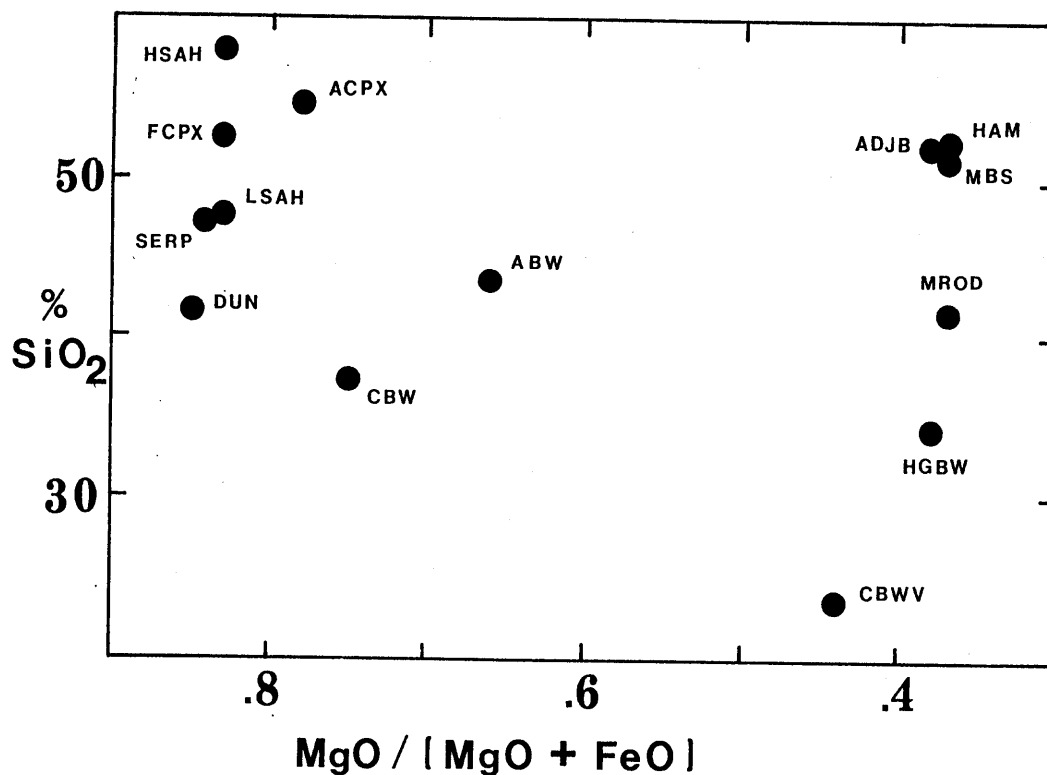


Figure 2. Plot of percent silica vs.  $\text{MgO}/(\text{MgO} + \text{FeO})$  ratios for the average normalized compositions of the major types of ultramafic and associated rocks (see Tables 5 and 6 for data). Abbreviations for rock types are:

#### ULTRAMAFIC ROCKS

DUN	relatively fresh dunite
SERP	serpentinite
LSAH	low-silica altered harzburgite or dunite
HSAH	high-silica altered harzburgite
FCPX	relatively fresh Ca-rich pyroxenite
ACPX	altered Ca-rich pyroxenite or peridotite

#### OTHER ROCKS

MBS	mestabasalt
HGBW	hornblende-garnet blackwall rock
CBW	chlorite-rich blackwall rock
CBWV	chlorite-rich blackwall vein rock
ABW	amphibole-rich blackwall rock
MROD	metaroddingite
ADJB	adjusted hb-gnt blackwall rock composition
HAM	Hamilton's (1963) average Riggins Group metabasalt

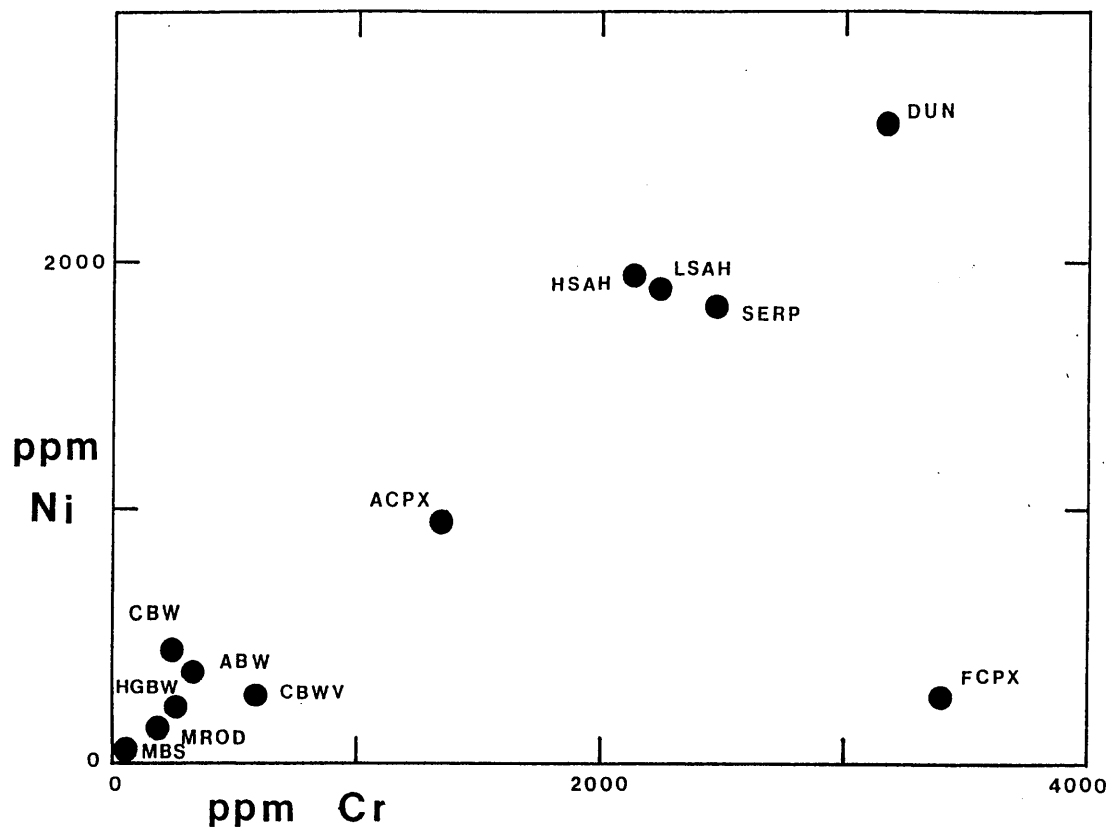


Figure 3. Plot of Ni concentration vs. Cr concentration for the average normalized compositions for the major types of ultramafic and associated rocks (see Table 5 for data). Abbreviations for rock types are:

#### ULTRAMAFIC ROCKS

DUN	relatively fresh dunite
SERP	serpentinite
LSAH	low-silica altered harzburgite or dunite
HSAH	high-silica altered harzburgite
FCPX	relatively fresh Ca-rich pyroxenite
ACPX	altered Ca-rich pyroxenite or peridotite

#### OTHER ROCKS

MBS	mestabasalt
HGBW	hornblende-garnet blackwall rock
CBW	chlorite-rich blackwall rock
CBWV	chlorite-rich blackwall vein rock
ABW	amphibole-rich blackwall rock
MROD	metarodingite