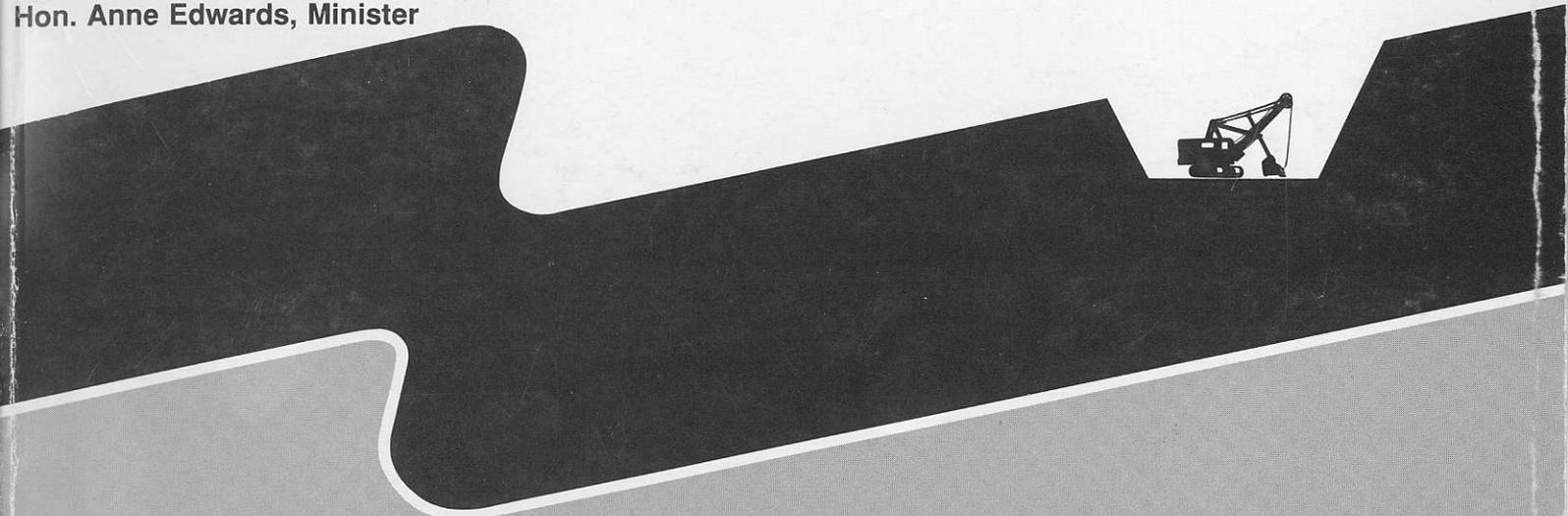




Province of British Columbia
Ministry of Energy, Mines
and Petroleum Resources
Hon. Anne Edwards, Minister

MINERAL RESOURCES DIVISION
Geological Survey Branch



DISTRIBUTION AND BEHAVIOUR OF
PLATINUM IN SOILS OF THE TULAMEEN
ULTRAMAFIC COMPLEX, SOUTHERN
BRITISH COLUMBIA

By S.J. Cook and W.K. Fletcher

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EXECUTIVE SUMMARY

Geochemical exploration for chromitite-associated platinum deposits is hampered by a poor understanding of the distribution and behaviour of platinum in the surficial environment. This study investigates platinum content, residence sites and mineralogy of soils developed on till and colluvium above the Tulameen Ultramafic Complex in southern British Columbia.

Seventy-six soil profiles, as well as sediments, bogs and waters were sampled above the dunite core of the Tulameen Complex, within which platinum occurrences consist of massive-to-discontinuous segregations of platinitic chromitite. Platinum content of the -70-mesh (-212 micron) fraction of soils and sediments was determined by fire assay-inductively coupled plasma spectrometry. Samples from fourteen selected profiles were then examined in detail to determine platinum mineralogy and its distribution between different size, density and magnetic fractions.

Platinum concentrations in the -70-mesh fraction of C-horizon soils range from 2 to 885 ppb and are closely related to soil dunite content, as estimated from magnesium content and verified by XRD mineralogy. Dunite colluvium (mean: 24.2% MgO), locally-derived dunitic till (mean: 16.5% MgO) and exotic non-dunitic till (mean: 5.7% MgO) have median platinum concentrations of 88 ppb, 36 ppb and 8 ppb, respectively. This trend is evident in all size and density fractions. Platinum content of heavy mineral (SG > 3.3) fractions is 10 to 20 times greater than in light mineral fractions.

Platinum is most abundant in the heavy magnetic fraction from non-dunitic tills and dunitic tills remote from known mineralization, but the proportion of platinum in the heavy nonmagnetic fraction increases with increasing proximity to mineralization.

Scanning electron microscope and microprobe studies of heavy mineral fractions from C-horizons identified platinum-iron-copper alloys as free grains, and as inclusions in magnesium silicates and chromites. Chromite occurs as magnesium-chromium-rich anhedral fragments and as iron-rich euhedral to subhedral crystals. The latter, relatively more important in the magnetic fraction, are interpreted as platinum-poor grains disseminated throughout the dunite. Fragments are relatively more important in the nonmagnetic fraction and are interpreted as remnants of platinum-bearing massive chromitite segregations. The abundance of chromite fragments in soils near chromitite segregations accounts for the high platinum content of the nonmagnetic heavy fraction of these soils.

The -270-mesh fraction or the magnetic heavy mineral fraction of C-horizon soils would be the most suitable sample media for reconnaissance geochemical sampling. However, the greater contrast, more limited dispersion and magnesium-chromium-rich chromite association of the nonmagnetic heavy mineral fraction make it a more suitable media for detailed geochemical sampling.

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INTRODUCTION

CHAPTER 1

In British Columbia significant production of platinum has been limited to placer deposits associated with the Tulameen Ultramafic Complex. No lode production has been recorded. Nevertheless, there is a periodic renewal of interest in exploration for primary platinum deposits. Alaskan-type complexes in the Canadian Cordillera, many of which occur in the accreted Quesnel and Stikine terranes, offer good geologic targets for chromite-associated platinum-group element deposits (Ruble, 1986; Evenchick *et al.*, 1987; Hancock, 1991; Nixon, 1990). Platinum-group elements are also associated with chromite in alpine-type or ophiolitic ultramafic bodies within oceanic terranes, particularly the Cache Creek Terrane (Whittaker and Watkinson, 1985; Ruble, 1986).

Use of geochemical methods in the search for platinum deposits in the Canadian Cordillera is hampered by the presence of complex glacial drift and the very limited information on distribution and dispersion of the metal in tills and soils as a result of glacial, postglacial and pedogenic processes. Similarly, very little is known about the behaviour of platinum in stream sediments and natural waters. A further problem is the particle sparsity effect, arising from the very low abundance and erratic distribution of the platinum-group minerals (PGM), which makes it difficult to collect and analyze representative samples.

Objectives of this study were twofold:

- (i) To determine the distribution and behaviour of platinum in the surficial environment near a known platinum occurrence. Specifically to:
 - establish background and anomalous platinum contents of ultramafic dispersion trains in tills and other surficial deposits;
 - determine the vertical distribution and residence sites of platinum in soil profiles, and the mineralogy and morphology of platinum-group minerals in soils;
 - evaluate the relative importance of physical and chemical dispersion of platinum in the surficial environment in response to glacial, postglacial and pedogenic processes.
- (ii) Based on the foregoing, to make recommendations for the design and interpretation of exploration geochemical surveys for platinum in British Columbia, specifically with respect to:

- the background and anomalous platinum contents of a variety of surficial deposits;
- the choice of optimum soil horizon, and size, density or magnetic fraction to be used;
- the choice of suitable pathfinder elements.

Following preliminary evaluation of the dispersion of platinum around several ultramafic bodies (Fletcher, 1989), behaviour of platinum in the surficial environment of the Tulameen Ultramafic Complex in southwestern British Columbia was selected for detailed study by Cook (1991). The recommendations made in this study should not be applied to other areas without further orientation studies to confirm their applicability.

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Newmont Exploration of Canada made its geological information on Grasshopper Mountain available and provided base maps. The study formed the basis of a M.Sc. thesis by the senior author at The University of British Columbia. It was made possible by funding from the Science Council of British Columbia (Grant: STDF-AGAR #27(SA-2)); the British Columbia Ministry of Energy, Mines and Petroleum Resources; the Geological Survey of Canada; and Placer Dome Inc.

DESCRIPTION OF THE STUDY AREA

The field area (NTS 92 H/10) is on Grasshopper Mountain on the north side of the Tulameen River (Plate 1), approximately 25 kilometres west of Princeton in southwestern British Columbia. The main study area is located on the southern slope of the mountain with a second, smaller area (the A-zone) near the summit (Figure 1). Road access is from Princeton and Tulameen or, via forestry roads, from the Coquihalla Highway to the northwest.



Plate 1. View from the summit of Grasshopper Mountain, looking southwest up the Tulameen River valley into the Hozameen Range of the Cascade Mountains.

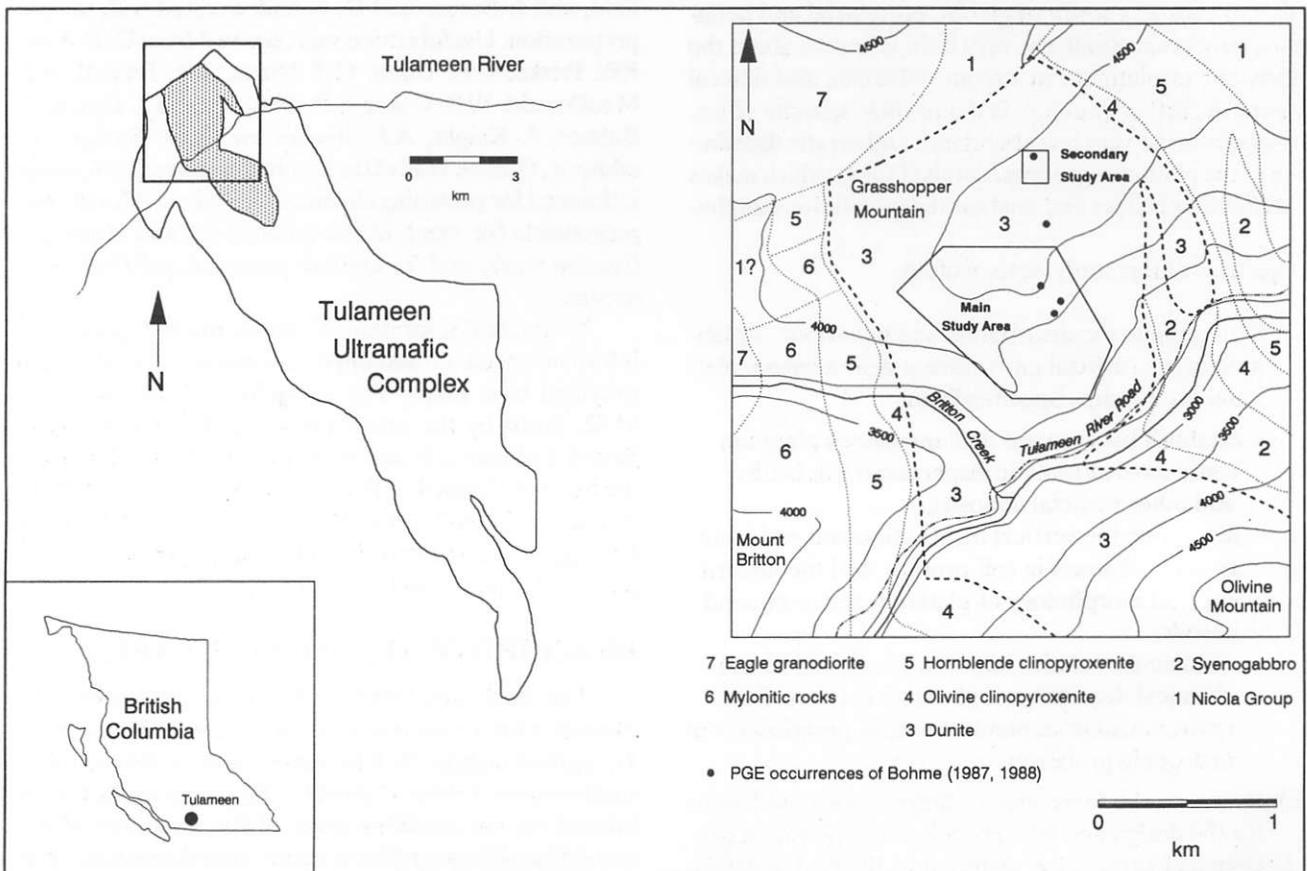


Figure 1. Location and generalized geology of the study areas within the dunite core of the Tulameen ultramafic complex in southwestern British Columbia (modified after Nixon and Rublee, 1988; elevation contours in feet).

The Tulameen district was a prominent producer of placer gold and platinum near the end of the 19th century. Placer gold was first discovered near the mouth of the Tulameen River in 1860, but the area was bypassed by prospectors travelling to placer gold camps in the Cariboo district. Platinum, recovered with the gold, was initially discarded by the miners during the first few years (Kemp, 1902), but by 1891 the district had become the largest platinum producer in North America (Camsell, 1913). The Tulameen River and its tributaries ultimately yielded approximately 600 000 grams of platinum between 1887 and 1936 (Rice, 1947; Mertie, 1969). Production had declined by the turn of the century (Rice, 1947), but has continued intermittently on a small scale up to the present day.

BEDROCK GEOLOGY AND REGIONAL SETTING

Grasshopper Mountain is at the northern end of the Tulameen Ultramafic Complex, an Alaskan-type-ultramafic-gabbroic intrusion emplaced within metasedimentary and metavolcanic rocks of the Upper Triassic Nicola Group. The southeast-trending complex is 20 kilometres-long and covers an area of 60 square kilometres near the western edge of the Quesnel Terrane. It is the largest and most southerly of several Alaskan-type complexes within the Intermontane Belt (Nixon and Rublee, 1988; Nixon, 1990). Recent U-Pb zircon dating (204-212 Ma) suggests a Late Triassic to Early Jurassic age of emplacement (Rublee and Parrish, 1990).

The geology of the complex was first described by Camsell (1913) and Rice (1947), and more recently by Findlay (1963, 1969), Nixon (1988) and Nixon and Rublee (1988). It comprises a dunite core surrounded by crudely concentric shells of olivine clinopyroxenite, hornblende clinopyroxenite and gabbroic rocks (Figure 1). Metasedimentary and intermediate to felsic metavolcanic country rocks of the Nicola Group near Tulameen have been regionally metamorphosed to greenschist grade and comprise primarily argillite, tuffaceous siltstone, lapilli tuff, pyroxene andesite and hornblende dacite flows. Subordinate lithologies include rhyolite, chert, chert breccia and limestone. The Eagle Plutonic Complex, comprising granodiorite and granite, occurs to the west of the Tulameen Complex. The complex is unconformably overlain by terrigenous sedimentary and volcanic rocks of the Eocene Princeton Group.

The Tulameen Complex is one of three alkaline plutons which intrude the Nicola Group and which have been interpreted as being comagmatic with the Nicola volcanics (Findlay, 1969; Mortimer, 1987). Findlay suggested that the gabbroic and ultramafic rocks of the complex represent separate but genetically related intrusions. The intrusion of alkaline gabbroic rocks, and their subsequent intrusion by later partially consolidated ultramafic rocks, was contemporaneous with regional deformation of the

Nicola rocks. The ultramafic rocks were formed by fractional crystallization of an ultramafic magma, forming a sill-like stratiform body, in the sequence dunite, olivine clinopyroxenite and hornblende clinopyroxenite. He considered diapiric emplacement of dunite as a crystal mush intruding pyroxenite. The present crudely concentric distribution of rock units may in part reflect later deformation during accretionary events, and in part original magmatic zonation.

The dunite core occupies about 6 square kilometres on Olivine and Grasshopper mountains at the northern end of the Tulameen Complex. The dunite is typically fine grained, green to black, and weathers buff brown. The primary mineralogy comprises forsteritic olivine (Fo₈₈-Fo₉₁) with accessory chromite and rare clinopyroxene. Secondary alteration minerals include serpentine, carbonate, magnetite, talc, chlorite and antigorite (Nixon and Rublee, 1988; Bohme, 1988). Serpentine is the most common alteration mineral. Serpentinization of primary olivine is widespread and variable, but decreases from east to west and is locally structurally controlled by contacts and faults (Findlay, 1969). Large zones of serpentinization were mapped by Bohme (1987, 1988) as inferred fault or shear zones. These areas of almost total serpentinization are fine grained, light green to white, and contain fine magnetite (Bohme, 1988). They weather to a distinctive rusty orange colour.

Chromite occurs as randomly distributed, massive to discontinuous pods, segregations, schlieren and disseminated grains. Schlieren are typically from 5 to 25 centimetres long and 1 to 4 centimetres wide, with maximum lengths of about 4 metres. They are distributed through the dunite and may exhibit fracturing, boudinage and isoclinal folding (Nixon and Rublee, 1988). Nixon *et al.* (1990) stated that chromitite segregations are bordered by 1 to 2-millimetre chromite crystals which grade sharply into much smaller disseminated grains (<20 microns) within the surrounding dunite. Olivine grains in chromitites are more forsteritic (Fo₉₂ to Fo₉₅) than those in dunite (Nixon *et al.*, 1990). The segregations are thought to represent remnants of former cumulate layers which were deposited, disrupted by slumping and redeposited in a crystal mush prior to magmatic consolidation (Rice, 1947; Nixon and Rublee, 1988; Nixon *et al.*, 1990).

Chromite segregations are usually associated with pale green alteration halos that consist primarily of serpentine, with subordinate carbonate and chlorite (Bohme, 1988). The halos weather to a paler colour than the surrounding dunite and are particularly well developed around discontinuous chromite segregations. Tulameen chromite has an unusually high Fe³⁺ content, containing 15 to 25 per cent Fe₂O₃, and is moderately to strongly magnetic (Findlay, 1969).



Plate 2. The Cliff zone platinum occurrence in dunite on the southeast face of Grasshopper Mountain.

PLATINUM-GROUP ELEMENT OCCURRENCES

Platinum is preferentially associated with the massive chromitite segregations in the dunite rather than with the disseminated chromite grains (Findlay, 1965; St. Louis *et al.*, 1986). The mean platinum content of unmineralized dunite and serpentinized dunite is in the range 60 to 85 ppb (Findlay, 1965; St. Louis, 1984). Massive chromitite segregations, however, have platinum contents of up to 16 000 ppb (Findlay, 1965; Bohme, 1987; Nixon *et al.*, 1990).

Chromitite segregations are most common on southern Grasshopper Mountain in the central region of the dunite core; platinum is somewhat erratically distributed within them. Five zones of chromitite-associated platinum mineralization were identified in this area by Bohme (1987, 1988) within a well-exposed 1000 by 300 metre area (Figure 1). The near-vertical Cliff zone (Plate 2) measures about 250 by 150 metres and contains two zones, each about 6 metres square, containing 2000 to 3000 ppb platinum (Bohme, 1987, 1988). The A-Zone, near the summit of Grasshopper Mountain, contains more wispy and disseminated chromite than the Cliff zone, with a more uniform platinum content of 0.85 gram per tonne (Bohme, 1987, 1988).

PLATINUM-GROUP MINERALOGY

Platinum-group element mineralogy of Grasshopper Mountain chromitite has been studied by St. Louis *et al.* (1986) and Nixon *et al.* (1989, 1990). The latter observed ten platinum-group minerals (PGM), the most common of which are the three platinum-iron alloys (tetraferroplatinum (Pt_2Fe_2), isoferroplatinum (Pt_3Fe) and tulameenite (Pt_2FeCu)). Geversite ($PtSb_2$), hollingworthite-irarsite [$Rh-Ir(AsS)$], sperrylite ($PtAs_2$), platinian copper (Cu, Pt), platinum oxide, erlichmanite (OsS_2) and laurite (RuS_2), in decreasing order of abundance, were also observed. St. Louis *et al.* also reported stumpflite ($PtSb$) and genkinite [$(Pt, Pd)_4Sb_3$] but considered platinum-iron alloys, sperrylite and irarsite to be the most abundant platinum-group minerals.

The PGM occur as both discrete minerals and as complex polymineralic grains (Nixon *et al.*, 1990). Discrete PGM usually range in size from less than 2 microns to about 30 microns, although a platinum oxide grain of 150 microns was reported by Nixon *et al.* (1990). Large free grains of up to 115 microns were also observed during this study.

St. Louis *et al.* (1986) recognized two types of PGM Type 1 occur as discrete euhedral to subhedral inclusions within chromite grains, while Type 2 are anhedral grains interstitial to chromite grains. Type 1 grains are dominantly platinum-iron alloys, geversite, stumpflite and ir-

arsite, and have been interpreted as being of primary magmatic origin. Sperrylite, the most common Type 2 grain, replaces the rims of platinum-iron alloys in fractured chromite grains (St. Louis *et al.*, 1986; Nixon *et al.*, 1990). St. Louis *et al.* (1986) interpreted Type 2 grains as having been hydrothermally remobilized from platinum originally present in sulphides. Nixon *et al.* (1990) considered the alloys (except tulameenite), cooperite, erlichmanite and laurite, to be of magmatic origin and the remaining PGM to be of hydrothermal origin.

Base metal sulphides, native metals and oxides, and base metal arsenides and antimonides are a minor interstitial and fracture-filling constituent of chromite segregations (St. Louis *et al.*, 1986; Nixon *et al.*, 1990). Sulphide minerals in chromitite are very rare, but disseminated pyrite (Nixon *et al.*, 1990) and pentlandite (St. Louis *et al.*, 1986) have been observed. Other nickel and nickel-cobalt-iron sulphides include violarite and bravoite (St. Louis *et al.*, 1986) and millerite/heazlewoodite (Nixon *et al.*, 1989, 1990). Other fracture-filling minerals include serpentine, chlorite, magnetite, carbonate, nickel antimonides, nickel arsenides, native copper, native silver and copper and nickel oxides (Nixon *et al.*, 1989, 1990).

QUATERNARY AND SURFICIAL GEOLOGY

The Late Wisconsin Fraser glaciation was the last of the Cordilleran ice sheets (Blaise *et al.*, 1990) to occupy southern British Columbia. All of the southern Cordillera, including the Tulameen area, was completely ice covered. Cold conditions leading to ice-sheet development began about 25 000 years ago and glaciation commenced about 19 000 years ago (Fulton, 1975). The Tulameen valley was probably a local channel for the eastward advance of alpine glaciers originating in the Cascade Mountains to the west.

Coalescence of valley glaciers resulted in the southern interior being covered by a continental ice sheet. Striae reported by Rice (1947) indicate that the continental ice sheet moved in a southerly direction but began to move more to the southwest in the area north of Grasshopper Mountain. Striae mapped by Camsell (1913) on nearby Rabbit, Britton and Olivine mountains range from 205° to 240°, whereas those reported by Findlay (1963) from Lodestone Mountain average 220° to 230°. Rare striae near the summit of Grasshopper Mountain also indicate a south-southwesterly direction of ice movement.

The Fraser ice sheet retreated through the southern interior of British Columbia about 10 500 years ago and most of the area was probably ice free by 9510 BP (Fulton, 1975, 1984; Blaise *et al.*, 1990). Fulton (1984) suggests that the climate was warmer and drier than at present. Ice damming during deglaciation created glacial lakes in the upper Similkameen and in the headwaters of the Tulameen River (Mathews, 1944; Hills, 1962).

The surficial deposits of Grasshopper Mountain and the surrounding area are mainly products of the Fraser glaciation. The mountain is mantled by a yellow-brown to brown basal till (Kamloops Lake drift) that consists of subrounded to subangular lithic fragments in an oxidized silt-clay matrix. Clasts do not usually exceed cobble size. Till cover on the plateau region of the mountain is thin and discontinuous, and near the summit till and disintegrating bedrock locally form a rubbly residual-like soil in which the contribution of till to the soil parent material is minimal. Glaciofluvial sediments dominate at lower elevations in the valleys of the Tulameen River, its tributaries, and former drainage channels north of Grasshopper Mountain. A restricted area of clay-rich soil parent material at the southern end of the main study area may be glaciolacustrine.

A postglacial apron of active colluvium blankets the till beneath steep cliffs on the southeast face of the mountain. Boulder accumulations, locally stabilized by vegetation, form the lower margin of the colluvium in some parts of the western forested area, but are absent from the eastern part. A prominent talus cone, stabilized at lower levels, occurs on the margin of the boulder field and extends from the colluvium into the forest. Multiple parent materials are common and generally take the form of till overridden by stabilized dunitic colluvium (Plate 3). This situation is particularly widespread in the western part of the main study area.

Active alluvial deposits are restricted to a small intermittent stream, Grasshopper Creek. It rises on the plateau in a series of interconnected bogs in bedrock depressions. The creek then disappears during its plunge down a steep slope, but reappears to flow through the lower levels of the study area before entering the Tulameen River from a hanging valley.

TOPOGRAPHY AND PHYSIOGRAPHY

Grasshopper Mountain lies on the western margin of the Thompson Plateau in a transitional zone with the Hozomeen Range of the Cascade Mountains (Holland, 1976). This region of the Interior Plateau is characterized by a rolling upland topography of broadly rounded summits and low relief lying between 1220 and 1525 metres elevation (4000' and 5000').

The summit region of the mountain has a rolling plateau-like topography with a maximum elevation of 1507 metres (4940'). Slopes steepen below about 1400 metres (4600') and prominent cliffs and scree slopes are exposed on the steep southeast face of the mountain (Plate 4). Relatively flat lying ledge and bench areas at about 1220 metres (4000') and 1070 metres (3500') provide isolated topographic breaks to steep slopes that plunge to the Tulameen River and Britton Creek on the southeast and southwest faces of the mountain. The Tulameen River occupies a deep valley between Grass-

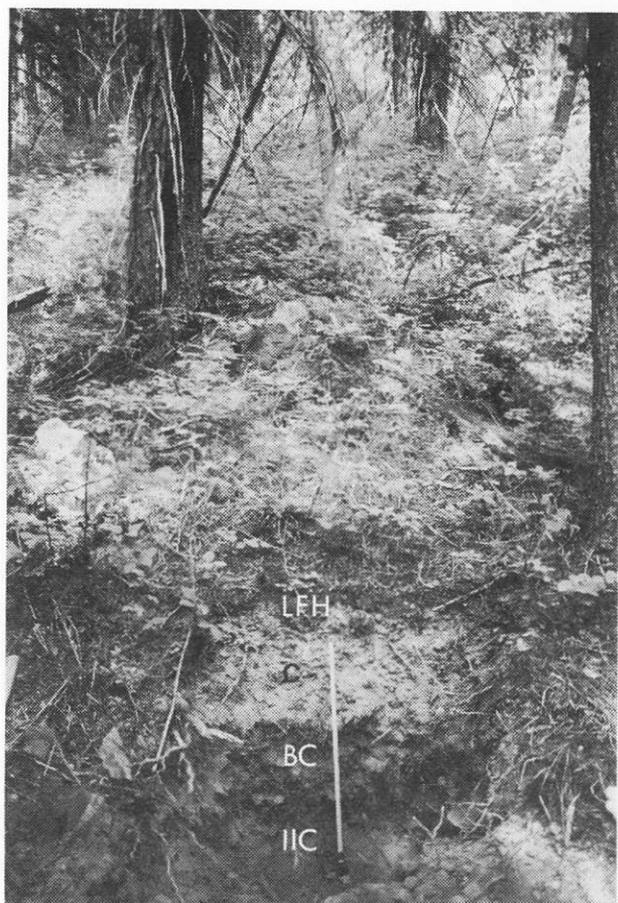


Plate 3. Composite soil profile of stabilized colluvium (C) above non-dunitic till (BC, IIC) at site 31 on a gentle slope.

hopper and Olivine mountains at an elevation of 885 to 900 metres (2900' to 2950').

There are four major physiographic zones within the study area, each having characteristic relief, forest cover and soil development. They are: steep dunite cliffs and extensive accumulations of talus and colluvium (Plate 4); the rolling plateau and western forested slopes with discontinuous outcrop and a cover of thin till (Plate 5); the southern forested slopes with stabilized colluvium in the west but not in the east; and the flat-lying bench, with bogs and seepage zones in a area of low relief.

CLIMATE

The climate is transitional between that of the dry southern interior and the much moister Cascade and Coast mountains to the west. Summers are hot and dry, and winters are cold with heavy snowfall at high elevations. Temperatures at Princeton airport (elevation 696 m; 2283') ranged from a summer high of 41.7°C to a winter low of -42.8°C during the years 1941 to 1970 (Atmospheric Environment Service, 1974). Temperatures at Allison Pass (elevation 1342 m; 4400') in the Cascades southwest of Grasshopper Mountain ranged from 31.7°C to -42.8°C during the same period. Total annual precipitation over this period averaged 1452 millimetres at Allison Pass (snowfall: 9652 millimetres), but only 359 mm at Princeton (snowfall: 1570 mm). Patches of snow may remain on the plateau of Grasshopper Mountain until late May. The mountain is well drained, however, and dries rapidly during the summer.



Plate 4. Active colluvium beneath steep cliffs on the southeast face of Grasshopper Mountain. The Cliff zone platinum occurrence is at the far right.



Plate 5. Rolling plateau area adjacent to site 73.



Plate 6. Orthic regosol profile (site 37) in active colluvium near base of slope.



Plate 7. Orthic regosol profile (site 16) in active colluvium immediately beneath one of the Cliff zone platinum occurrences, showing absence of horizon development. Free PGM grains (Plate 12) were observed in heavy mineral concentrates from this site.

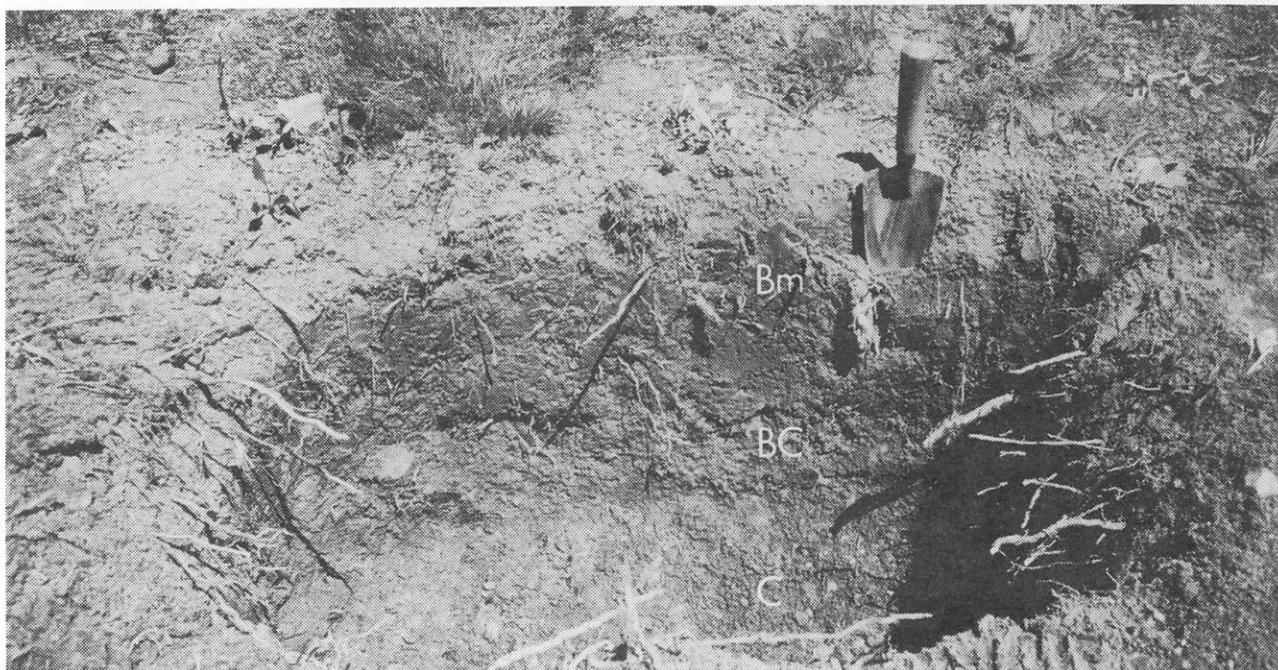


Plate 8. Eutric brunisol profile (site 65) developed on dunitic till, showing Bm, BC and C mineral horizons. The profile, located on a flat, sparsely vegetated ridgetop, is atypical due to the absence of an LFH horizon.



Plate 9. Orthic regosol soil profile (site 56) developed on dunitic rubble above trenched A zone platinum occurrence, secondary study area.

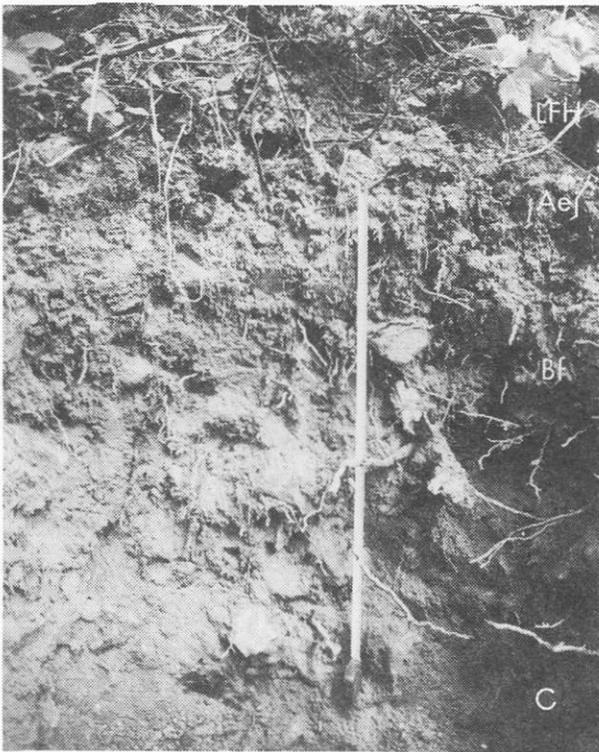


Plate 10. Humo-ferric podzol profile (LFH, Aej, Bf, C) developed on non-dunitic till (site 19) on steep, forested southeast slope of Grasshopper Mountain.

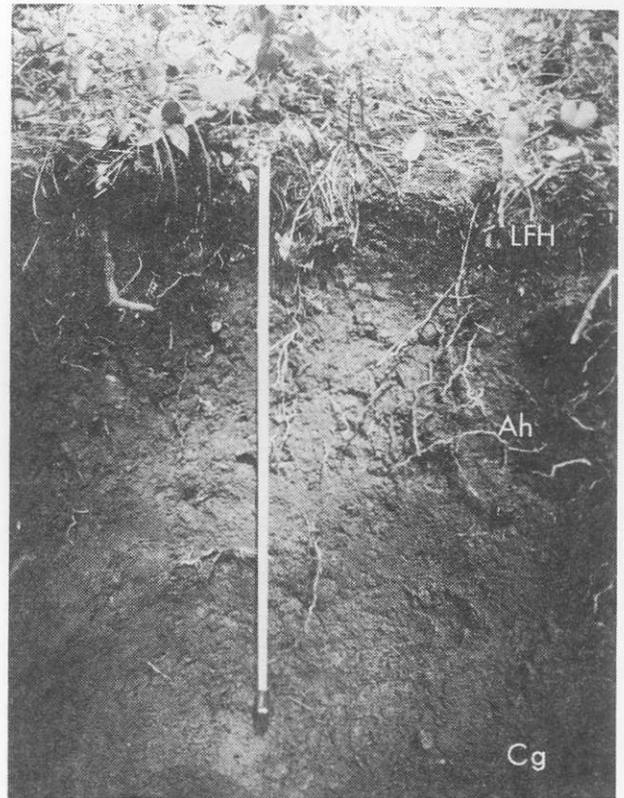


Plate 11. Gleyed melanic brunisol profile (LFH, Ah, Cg) developed on non-dunitic till (site 2) in flat seepage area.

SOILS

Soil development, limited by high relief and active colluvial processes, is generally juvenile. The thickness of surficial LFH horizons seldom exceeds a few centimetres and they are particularly thin on steep slopes. The four physiographic zones of Grasshopper Mountain correspond roughly to different types and stages of soil development which are more diverse than shown on regional maps (Lord and Green, 1974).

Active colluvium is characterized by orthic regosols (Plates 6 and 7). Genetic horizons are absent, although sites on the western part of the colluvial slope have a distinctive orange-brown surface and an increasing fines content with depth. These appear to relate to upslope outcrops of serpentinite. LFH horizons are generally absent on active colluvium: those that do occur usually contain abundant rock fragments derived from upslope material.

Eutric brunisols (Plate 8) are the dominant soil on the rolling plateau area of Grasshopper Mountain, and on ridges and the gentle western slope where colluvial activity is absent or minimal. Surficial Bm-horizons are well developed and may be gradational to underlying C-horizons. The soils are semiresidual in plateau areas of thin discontinuous till on dunite bedrock, as seen directly above the trench at the A zone platinum occurrence (Plate 9).

The steep, forested southern slopes of Grasshopper Mountain exhibit the most diverse range of soil types.

The steep, forested southern slopes of Grasshopper Mountain exhibit the most diverse range of soil types. Humo-ferric podzols (plate 10) and minor orthic regosols characterize the eastern portion, whereas the western portion has eutric brunisols, in places buried and modified by later colluvium.

Soil development on the flat-lying bench area is dominated by seepage zones, a relatively high degree of organic production and the local occurrence of a clay parent material. The area is characterized by relatively thick LFH horizons, organic-rich mull Ah-horizons, and gleyed Cg-till and clay parent materials (Plate 11) at lower elevations. These grade upslope to drier and more juvenile regosols at the base of the steep, forested slope.

VEGETATION

Slopes are moderately to well wooded, with more sparsely forested areas on the plateau and open vegetation on active colluvium. The plateau and western flank of the mountain carry mature stands of Douglas fir whereas the secondary study area near the summit has a more mixed assemblage of subalpine fir, with minor Douglas fir, lodgepole pine and whitebark pine. The southern slope of the mountain is thickly forested with much younger Douglas fir. The forested bench area is populated primarily by mature Douglas fir, with subordinate cedar, subalpine fir, Englemann spruce and lodgepole pine. Dry, well-drained colluvial slopes and cliffs are open with scattered Douglas fir, ponderosa pine and juniper.

FIELD AND LABORATORY PROCEDURES

CHAPTER 2

SAMPLE COLLECTION

Soils, stream sediments and associated stream bank, bog and water samples were collected (Figure 2; Appendix 1). Procedures for sample collection, preparation and analysis are described in greater detail by Cook (1991).

Soils were profiled and sampled in 76 pits in two study areas to give a total of 180 mineral soils and 47 surficial LFH samples. Soil pits were generally dug to a depth of slightly less than 1 metre. Genetic horizons were identified and the profile classified according to the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey, 1987). Duplicate, 10 to 15-kilogram samples were then taken from each mineral horizon by sampling from the bottom up. Organic LFH horizons were collected, prior to digging the pit, by turning the turf over and carefully separating the organic material from the underlying mineral matter.

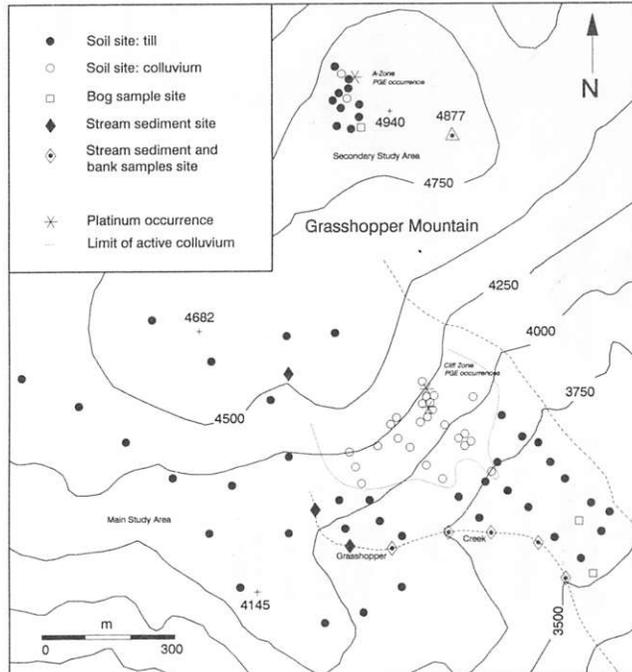


Figure 2. Sample location map showing soil, sediment, bank and bog sample sites within the dunite core of the Tulameen Ultramafic Complex, Grasshopper Mountain, B.C. Site numbers are shown in Appendix 1 (base map adapted from Bohme, 1987; elevation contours in feet).

Stream sediment samples were collected at seven sites from small gravel-filled pools in the active stream channels along Grasshopper Creek. Moss mat samples were also collected where possible. Bank samples were taken at five of the sediment sites.

Bog-centre and margins were sampled for three bogs within the study areas. Two of the bogs are on unconsolidated material in the seepage zone area and the third is a perched bog on bedrock near the A zone occurrence. Samples comprised the uppermost 20 to 35 centimetres of organic material.

Water samples were obtained, during the period May 17 to 20, 1989 after the spring snowmelt, from Grasshopper Creek, from bogs and soil pits in the seepage zone and from perched bogs and ponds on the plateau. Samples were collected several centimetres beneath the water surface to avoid surface scum and then pressure-filtered on site through 0.45-micron Millipore filters. One-litre samples were acidified with 20 millilitres of sub-boiling distilled 6 normal hydrochloric acid within a few hours of collection and stored in acid-washed polypropylene bottles.

SAMPLE PREPARATION

OVERVIEW SAMPLES

Preparation of overview samples is summarized in Figure 3. Representative subsamples, obtained by coning and quartering field samples of C-horizon soils, stream sediments and bank samples, were wet-sieved using a recirculating water system to obtain the -70-mesh fraction. After dewatering, drying and disaggregating, a 200 to 300-gram riffle split was pulverized in a tungsten carbide ring mill to approximately -200-mesh. A 10-gram subsample of the ground material was then taken in a riffle splitter for analysis.

Preliminary preparation of stream and moss mat samples for wet sieving was slightly different. Samples were weighed, oven-dried, and disaggregated in their plastic bags by gently pounding with a rubber mallet (Gravel and Matysek, 1989). They were then reweighed and homogenized before removing a split for sieving.

LFH horizon samples were air-dried, mixed, weighed and a one-half split ground in a Wiley mill. This was then transferred to a Coors crucible, weighed, and ignited in a muffle furnace at 700°C until a white ash was

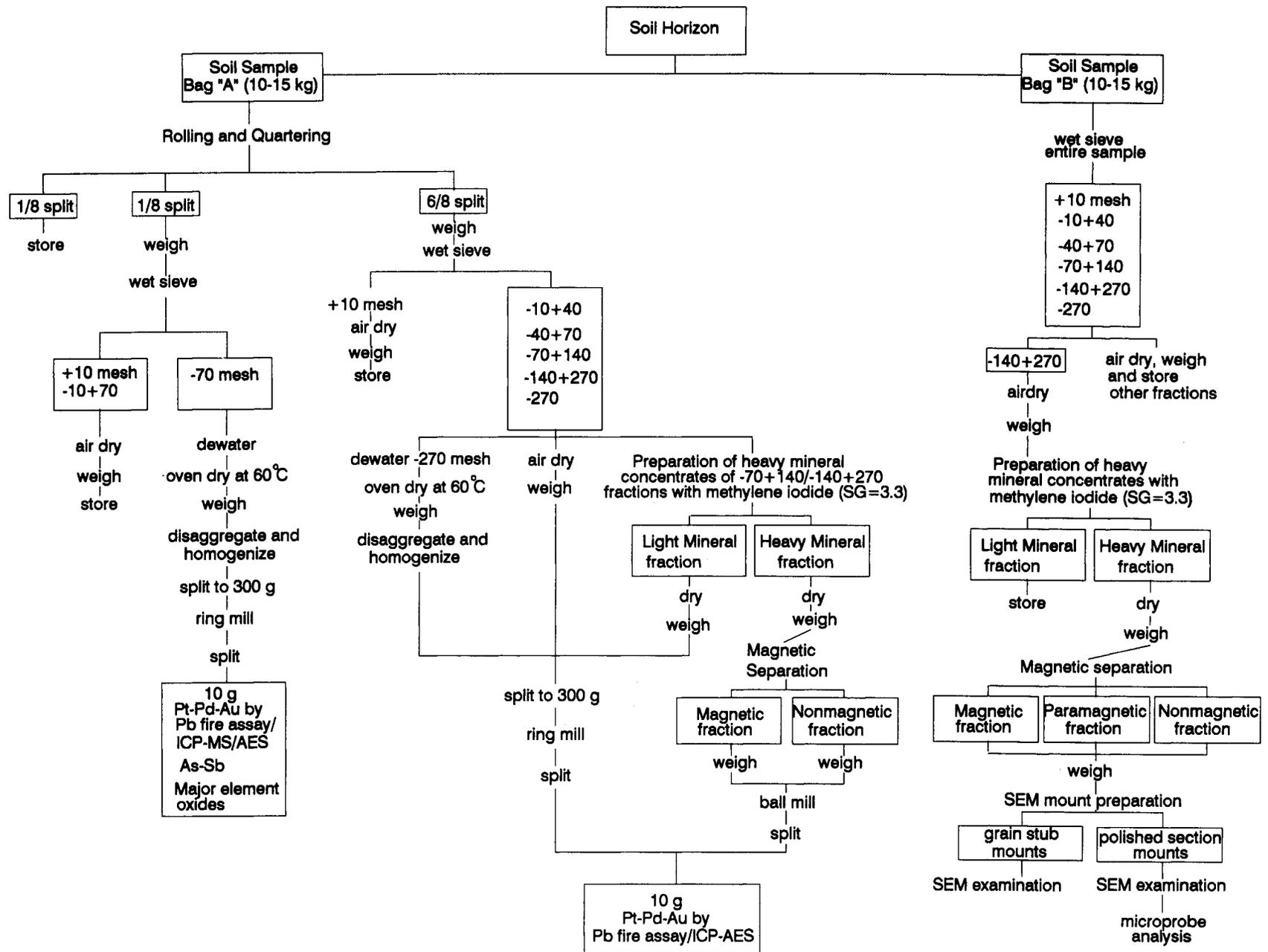


Figure 3. Flowchart for soil preparation and analysis.

obtained. The high ashing temperature is needed to achieve complete recovery of palladium (Dunn *et al.*, 1989).

Bog samples were dried, weighed and disaggregated by pounding with a rubber mallet in a porcelain pestle. The sample was then split into duplicate 150 to 250-gram portions with a Jones riffle splitter. One split was pulverized in a tungsten carbide ring mill for 1 to 2 minutes. The second was hand-ground with a porcelain mortar and pestle and then ashed in a muffle furnace at 700°C.

DETAILED SAMPLES

On the basis of data from the overview study, fourteen soil profiles and one stream sediment were selected for detailed study (Figure 4). These were wet-sieved into six size fractions (+10, -10+40, -40+70, -70+140, -140+270, and -270-mesh), dried and weighed. Splits of the -10+40 and -40+70-mesh fractions, weighing 200 to 300 grams, were then pulverized to -200-mesh in a tungsten carbide ring mill. Dried aggregates of the -270-mesh fraction were disaggregated in the ring mill.

The dried -70+140 and -140+270-mesh fractions were further processed using methylene iodide (S.G. = 3.3) to separate light and heavy mineral fractions. Magnetic and nonmagnetic components of the -140+270-mesh heavies were then separated by repeatedly passing a hand magnet over the sample. The corresponding light

mineral fractions were split and 200 to 300-gram portions pulverized in a tungsten carbide ring mill. To avoid nugget effects, the entire magnetic and nonmagnetic heavy mineral fractions were pulverized in a Spex ceramic ball mill.

All pulverized samples were further split in a Jones riffle splitter to obtain 10-gram analytical subsamples. In a few cases, where less than 10 grams of sample were available, the entire sample was pulverized and analyzed.

ANALYSIS

SOILS, SEDIMENT AND BOG SAMPLES

Soil, stream sediment, moss mat, bank soil and bog samples were analyzed for three groups of elements and major element oxides at Acme Analytical Laboratories, Vancouver.

Platinum, palladium, gold and rhodium were determined using lead fire assay. Except for rhodium, an inductively coupled plasma - mass spectrometry (ICP-MS) finish was used in 1988 and an inductively coupled plasma - atomic emission spectrometry (ICP-AES) finish in 1989. Rhodium was determined by graphite furnace atomic absorption spectrophotometry. Stated detection limits are 1 ppb for platinum and gold, and 2 ppb for palladium and rhodium. Ashed LFH and bog samples were also analyzed by these procedures.

Nugget effects caused by occasional grains of PGM might be reduced by analysis of as large a sample as possible. Preliminary studies (Cook and Fletcher, 1992a) indicated, however, that with chromiferous samples analysis of 30-gram portions gave lower platinum values than 10-gram subsamples (Figure 5). As reported by Borthwick and Naldrett (1984), this probably results from incomplete dissolution of the chromite during fusion. Ten-gram analytical subsamples were therefore used throughout this study for determination of the platinum-group elements.

To assess reliability of platinum analyses, duplicate samples (n=69) were included in analytical batches throughout the study. Precision was assessed from X_1-X_2 scatterplots and Thompson and Howarth (1978) control charts. Except for platinum concentrations less than about 10 ppb, precision (at the 95% confidence level) is ± 20 per cent for overview and ± 40 per cent for detailed samples (Figure 6). A precision of ± 60 per cent was obtained for platinum content of ashed LFH horizons.

Two drift monitors and a reference standard (PTA-1) were inserted in each analytical batch. The latter gave an average value of 2981 ppb (range: 1626 to 4941 ppb) versus a certified value of 3050 ± 140 ppb from Steger (1986). Quality control results are described in more detail by Cook (1991).

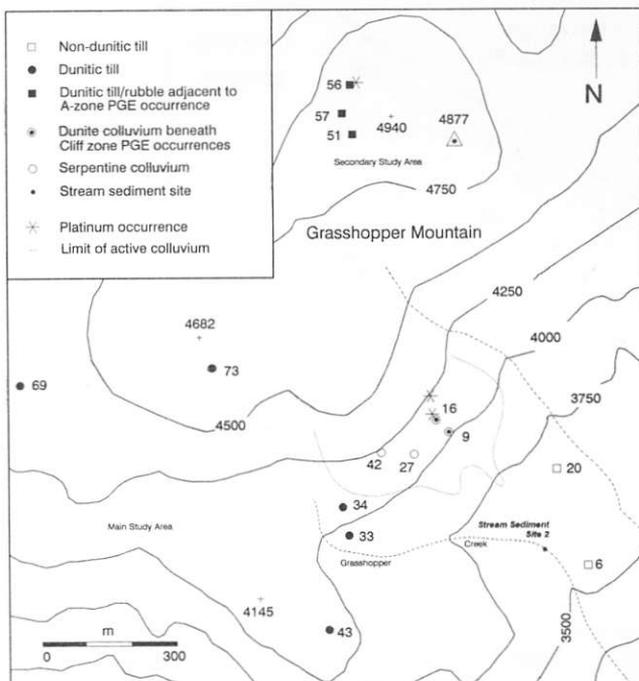


Figure 4. Location map of detailed soil profiles (n=14) and stream sediment site (n=1), showing parent material type and soil site number, Grasshopper Mountain (elevation contours in feet).

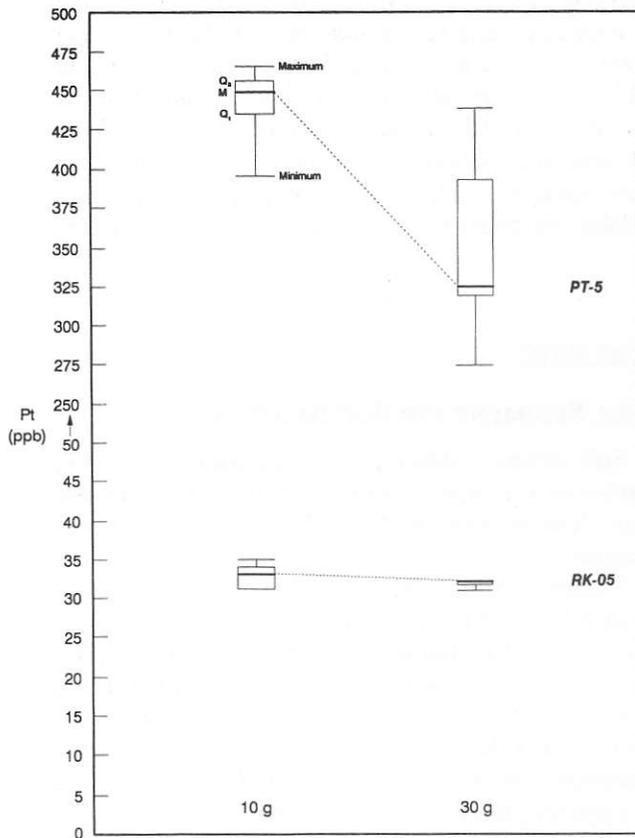


Figure 5. Boxplots showing variations in platinum concentrations (ppb) of control standards RK-05 and PT-5 with 10 and 30-gram analytical subsamples. N = 7 for each group. Boxplots show median (M), and minimum and maximum concentrations for each grouping; 50 per cent of the data for each group lie within the box between the first quartile (Q₁) and the third quartile (Q₃).

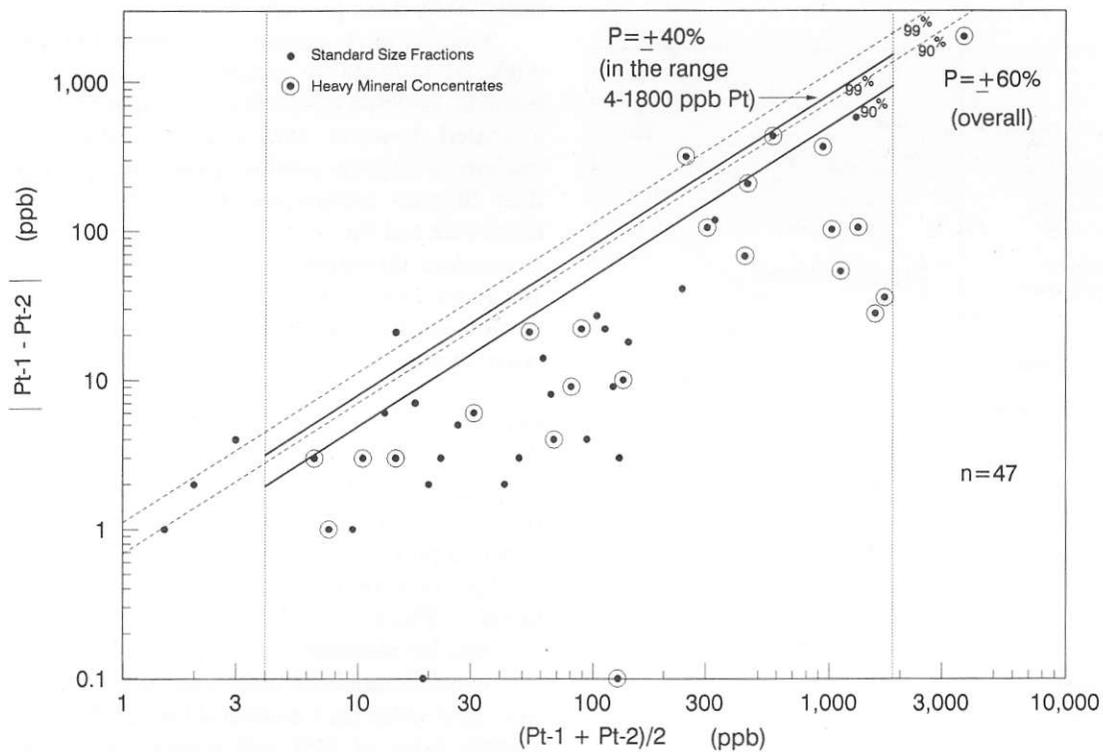


Figure 6. Precision control graph of platinum analyses for duplicate samples from detailed soil profiles. Dashed lines indicate overall precision of $P = \pm 60\%$ at the 95% confidence level; solid lines indicate precision of $P = \pm 40\%$ at the 95% confidence level for soil size fractions and heavy mineral concentrates with platinum concentrations in the range 4-1800 ppb.

In addition to determination of platinum-group elements the overview, but not detailed, samples were analysed for:

- Arsenic, antimony, bismuth, germanium, selenium and tellurium by hydride generation. A 0.5-gram subsample was digested with 3 millilitres of 3:1:2 hydrochloric acid: nitric acid:water at 95°C for one hour and diluted to 10 millilitres with water. The elements are then introduced as hydrides into the ICP-AES. Stated detection limits for arsenic, antimony and bismuth are 0.1 ppm. Detection limits for germanium, selenium and tellurium were 0.2, 0.2 and 0.3 ppm in 1988, and 0.1 ppm for all three in 1989.
- Major elements. A 0.2-gram subsample was fused with LiBO₂, the fused mass dissolved in 100 millilitres of nitric acid, and analyzed for silicon, aluminum, iron, magnesium, calcium, sodium, potassium, manganese, titanium, phosphorus, chromium and barium by ICP-AES. Loss on ignition was also determined.

After ashing, the iron content of LFH horizons was determined at the University of British Columbia by flame atomic absorption spectrophotometry after digestion with nitric:perchloric:hydrofluoric acids. Insoluble residues remaining after digestion were dried, weighed and visually examined.

WATERS

Platinum content of water samples was determined by G. Hall at the Geological Survey of Canada, Ottawa. Dissolved platinum in filtered water samples is absorbed onto 300 milligrams of activated charcoal (Hall, 1988; Hall and Bonham-Carter, 1988). The charcoal is filtered off, ashed at 650°C, and platinum dissolved in 1.5 millilitres of aqua regia. The volume is increased to 5 millilitres prior to determination of platinum by ICP-MS.

SCANNING ELECTRON MICROSCOPY

Backscatter electron imaging on a SEMCO Nanolab 7 scanning electron microscope was used to search for platinum-group minerals in -140 + 270-mesh magnetic, paramagnetic and nonmagnetic fractions of eight duplicate C-horizon soils. Grain mount stubs and polished grain mounts, prepared in methacrylate to minimize plucking of fine PGM grains (Y. Douma, personal communication), were first manually scanned at low power (50x) and then almost grain by grain (500 to 1000x) to locate small PGM grains.

ELECTRON MICROPROBE ANALYSIS

One hundred and twenty chromite grains were analyzed for silicon, aluminum, titanium, chromium, iron, manganese and magnesium on a Cameca SX-50 electron microprobe. The procedure consisted of analyzing both the cores and edges of up to fifteen chromite crystals and fragments randomly selected from magnetic and non-magnetic fractions. Oxide weight per cents were converted to mineral formula units on the basis of a spinel unit cell of 24 cations and 32 oxygens. Iron was distributed as Fe²⁺ and Fe³⁺ using the FORMULA program of Ercit (1987).

X-RAY DIFFRACTION

Mineralogy of 48 samples from the detailed soil profiles was determined with a fully automated Siemens D-5000 X-ray diffractometer. Pulverized -10 + 40 and -270-mesh samples were applied to a glass slide as a water suspension and allowed to dry. Operating conditions were 40 kilovolts and 30 milliamps using CuK α radiation. The angle of scan was 5° to 60° at the rate of 100 seconds per degree. Peak identification was made with DIF-FRAC/AT software.

RESULTS

CHAPTER 3

Results are presented in three sections: (1) overview results - platinum content of -70-mesh C-horizon soils throughout the study area, together with associated LFH samples, banks, stream sediments, moss mat sediments and waters; (2) detailed results - distribution of platinum in selected soil profiles and between size, density and magnetic fractions from those profiles; and (3) mineralogy and composition of the platinum-group minerals and their host mineral grains.

OVERVIEW RESULTS

MAJOR ELEMENT GEOCHEMISTRY AND MINERALOGY OF SOIL PARENT MATERIALS

Soil texture and major element composition of soil parent materials are summarized in Tables 1 and 2, respectively. High magnesium contents distinguish colluvium (average 24.16% MgO) and a magnesium-rich till (16.51 % MgO) in the western half of the area from magnesium poor-till (5.66% MgO) to the east (Figures 7 and 8). Distribution of chromium is generally similar to that of magnesium (Figure 9). Thus, colluvium has the greatest mean chromium content (0.33% Cr₂O₃ ; 2257 ppm Cr), whereas soils on magnesium-rich and magnesium-poor tills within the main study area have mean Cr₂O₃ contents of 0.20 per cent (1368 ppm Cr) and 0.07 per cent (479 ppm Cr), respectively. Locally derived dunitic till in the secondary study area has a mean Cr₂O₃ content of 0.28 per cent (1915 ppb Cr). Conversely, the

magnesium-poor tills are characterized by higher concentrations of silica, aluminum, calcium, sodium, potassium than the other soil parent materials (Appendix 2).

Mineralogically, colluvium below dunite cliffs is characterized by serpentine-group minerals and talc, and the absence of quartz, plagioclase and amphiboles (Figure 10; Appendix 3). Olivine is surprisingly rare. Talc and chrysotile are most abundant, particularly in the finer fractions, in areas of serpentinization. In areas less affected by serpentinization lizardite is the dominant mineral.

Serpentine-group minerals, particularly chrysotile, are also ubiquitous in soils on magnesium-rich till. Talc and vermiculite are locally important and quartz and plagioclase are found at most sites. In comparison, soils from two profiles on magnesium-poor till consist principally of quartz, plagioclase, ferrohornblende and clinocllore. Serpentine-group minerals are absent from one of the profiles but chrysotile occurs in the other. Chromite was detected in three dunitic till and one colluvial profile.

Based on major element composition and the abundance of serpentine-group minerals, it is apparent that the magnesium-rich till consists mainly of material derived from the dunite. Conversely, magnesium-poor till is mainly of non-ultramafic origin, although there has probably been some minor intermixing with dunitic material. Henceforth these two till types are referred to as dunitic and non-dunitic, respectively.

TABLE 1
MEAN $\pm 1\sigma$ (X), MEDIAN (M) AND RANGE (R) OF GRAIN SIZE DISTRIBUTION IN TILL AND COLLUVIUM AS WEIGHT PER CENT OF THE TOTAL DRY WEIGHT

Fraction	Till (n=49)	Colluvium (n=27)	Clay (n=2)
+ 10 mesh	X: 45.85 \pm 11.24 M: 46.03 R: (25.07-70.68)	71.65 \pm 9.82 73.51 (53.39-93.94)	17.66 \pm 22.43 17.66 (1.80-33.52)
-10 + 70 mesh	19.98 \pm 5.06 19.78 (9.37-33.03)	13.71 \pm 5.34 12.79 (3.84-31.66)	14.12 \pm 4.85 14.12 (10.69-17.55)
-70 mesh	34.17 \pm 9.51 34.22 (16.21-54.72)	14.63 \pm 6.12 12.90 (2.22-31.05)	68.22 \pm 17.58 68.22 (55.79-80.65)

TABLE 2
MEAN, MEDIAN AND RANGE OF MAJOR ELEMENTS, SUBDIVIDED BY PARENT MATERIAL, IN
THE -70-MESH FRACTION OF C-HORIZON SOILS

		MgO (%)	Cr2O3 (%)	Fe2O3 (%)	SiO2 (%)	Al2O3 (%)	CaO (%)	Na2O (%)	K2O (%)	TiO2 (%)	P2O5 (%)	MnO (%)	Ba (ppm)	LOI (%)
CLAY	x	5.01	0.04	9.50	53.14	16.00	4.02	2.54	1.39	1.00	0.2	0.19	587	6.9
Main Study Area	M	5.01	0.04	9.50	53.14	16.00	4.02	2.54	1.39	1.00	0.2	0.19	587	6.9
n=2	Min	4.22	0.04	9.11	51.87	15.41	3.75	2.52	1.33	0.98	0.16	0.12	555	6.5
	Max	5.80	0.04	9.89	54.41	16.58	4.29	2.56	1.45	1.02	0.24	0.26	619	7.3
NON-DUNITIC TILL	x	5.66	0.07	9.86	54.00	14.62	4.73	2.65	1.34	0.95	0.13	0.16	474	5.7
Main Study Area	M	5.44	0.06	9.87	53.74	14.53	4.79	2.60	1.34	0.95	0.13	0.15	473	5.6
n=19	Min	3.86	0.03	8.38	51.4	12.84	3.13	2.34	1.09	0.87	0.06	0.12	376	4.1
	Max	8.23	0.16	11.75	56.95	15.83	5.51	3.2	1.64	1.05	0.21	0.22	554	8
DUNITIC TILL	x	16.51	0.20	10.87	46.67	9.07	3.71	1.27	0.83	0.63	0.12	0.18	248	9.9
Main Study Area	M	16.25	0.19	10.82	46.52	8.89	3.61	1.13	0.83	0.60	0.11	0.18	242	9.9
n=17	Min	10.45	0.12	8.82	44.23	6.90	1.88	0.85	0.57	0.41	0.08	0.13	195	3.3
	Max	28.73	0.29	13.12	50.64	12.44	5.58	2.08	1.07	0.90	0.19	0.22	352	16.4
DUNITIC TILL	x	13.84	0.28	11.78	48.15	10.15	3.28	1.72	0.66	0.64	0.08	0.18	270	9.3
Secondary Study Area	M	13.21	0.26	11.09	50.00	10.27	3.46	1.83	0.73	0.69	0.08	0.15	264.5	8.5
n=8	Min	10.64	0.12	9.53	42.96	7.86	1.24	1.06	0.35	0.37	0.06	0.12	182	7.2
	Max	19.06	0.51	14.96	51.01	12.08	4.48	2.29	0.79	0.79	0.15	0.29	334	14.4
COLLUVIUM	x	24.16	0.33	11.89	40.67	5.51	1.73	0.83	0.3	0.35	0.12	0.27	125	13.8
Main Study Area	M	23.29	0.32	12.10	40.65	5.57	1.90	0.85	0.22	0.37	0.11	0.25	112	12.7
n=25	Min	14.29	0.20	9.37	34.6	1.21	0.35	0.08	0.05	0.08	0.07	0.15	38	9.4
	Max	32.78	0.50	13.72	46.38	9.73	3.29	1.44	0.82	0.62	0.22	0.57	226	22.8

x=mean Min=minimum value
M=median Max=maximum value

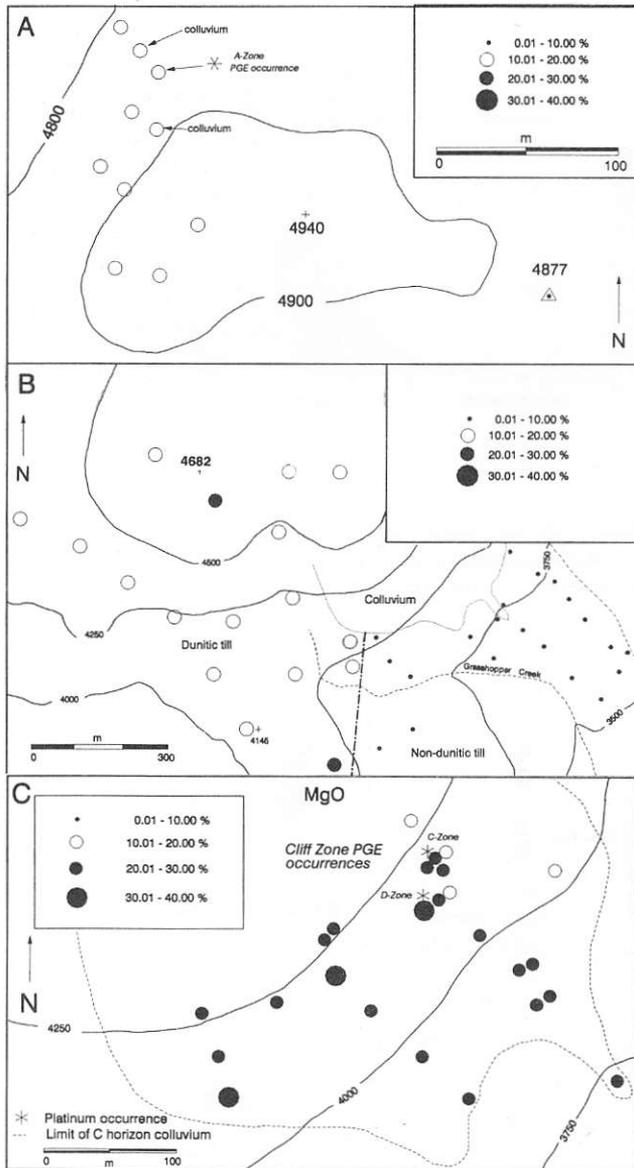


Figure 7. MgO (%) content in overview -70-mesh C-horizon soils in: (A) dunitic till, rubble and colluvium adjacent to PGE mineralization in the secondary study area; (B) dunitic and non-dunitic till in the main study area; and (C) colluvium in the main study area. Dashed line at lower centre represents the boundary between dunitic and non-dunitic tills (base map adapted from Bohme, 1987; elevation contours in feet).

C-HORIZON SOILS

Distribution of platinum in C-horizon soils on Grasshopper Mountain is summarized in Figure 11 and Table 3: original analytical data are given in Appendix 2. A preliminary report on these data has been given by Cook and Fletcher (1990).

The platinum content of colluvium is considerably greater than that of till (Figure 12). However, further

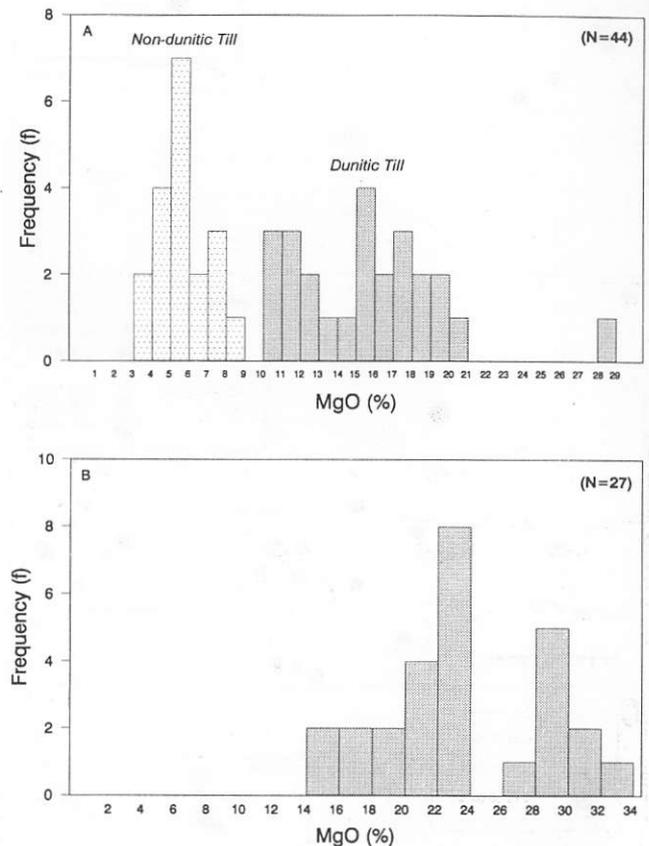


Figure 8. Arithmetic frequency distributions of MgO content (%) in overview C-horizon soils in (A) till and (B) colluvium.

subdivision of till on the basis of origin provides a more meaningful comparison (Figure 13). Thus, the mean platinum content of colluvium from the main study area (120.0 ppb) is double that of dunitic till (52.8 ppb) whereas the non-dunitic till has a much lower platinum content (mean 9.5 ppb). The corresponding medians of 88 ppb, 36 ppb and 8 ppb are less biased by extreme values and provide a better estimate of background concentrations of platinum. Palladium content of the soils is very low compared to platinum: median values are 3 ppb in non-dunitic till, 7 ppb in dunitic till and 2 ppb in dunitic colluvium.

Till samples taken to the west of the dunitic core, at sites 403 and 404, have similar platinum and chromium contents to non-dunitic tills and magnesium contents intermediate between the two till types (Figure 14). Till samples farther south but still west of the dunite (sites 405 and 406) have platinum, magnesium and chromium contents that are more similar to those in the dunitic till.

The gold content of colluvium in the main study area (mean: 21 ppb) is three to four times greater than in till,

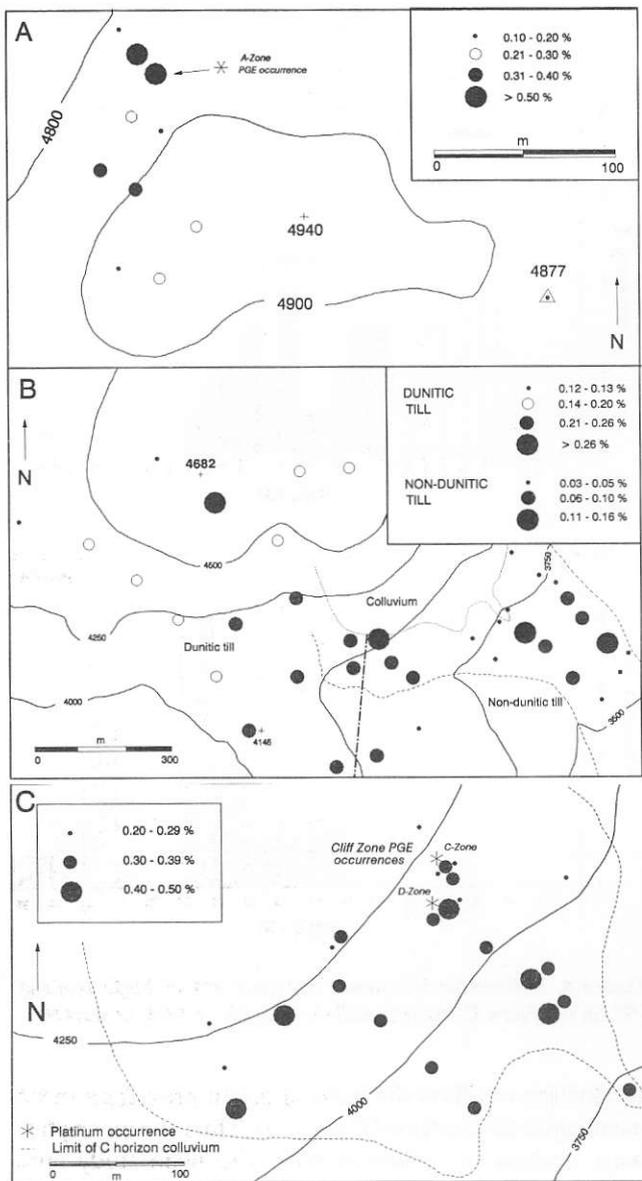


Figure 9. Cr₂O₃ content (%) of overview -70-mesh C-horizon soils in (A) dunitic till, rubble and colluvium adjacent to PGE mineralization in the secondary study area; (B) dunitic and non-dunitic till in the main study area; and (C) colluvium in the main study area. Dashed line at lower centre represents the boundary between dunitic and non-dunitic tills (base map adapted from Bohme, 1987; elevation contours in feet).

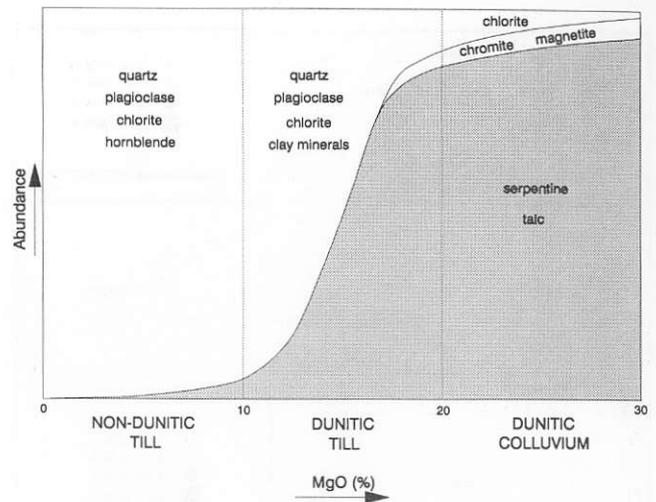


Figure 10. Schematic diagram illustrating the general relation of MgO content to soil mineralogy in surficial materials on Grasshopper Mountain (11 profiles).

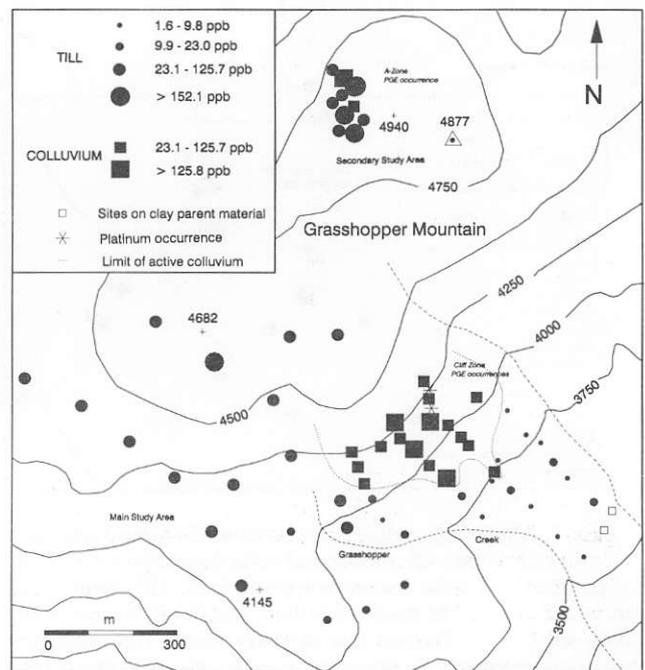


Figure 11. Platinum content (ppb) of overview -70-mesh C-horizon soils in till and colluvium on the dunitic core of the Tulameen Ultramafic Complex, Grasshopper Mountain, (base map adapted from Bohme, 1987; elevation contours in feet). Some samples omitted for clarity.

TABLE 3
MEAN, MEDIAN AND RANGE OF PGE AND OTHER SELECTED CONSTITUENTS OF THE
-70-MESH FRACTION OF C-HORIZON SOILS ON VARIOUS PARENT MATERIALS

PARENT MATERIAL		Pt (ppb)	Pd (ppb)	Rh (ppb)	Au (ppb)	As (ppm)	Sb (ppm)
CLAY	X	5.5	2.5	2	5	11.9	0.9
Main Study Area	M	5.5	2.5	2	5	11.9	0.9
(n=2)	Min	4	2	2	5	9.4	0.5
	Max	7	3	2	5	14.3	1.2
NON-DUNITIC TILL	X	9.5	4.1	2	8.2	15.5	1.0
Main Study Area	M	8	3	2	7	14.7	0.9
(n=19)	Min	2	2	2	2	8.1	0.5
	Max	20	15	2	34	23.2	1.8
DUNITIC TILL	X	52.8	8.9	2.1	8.4	15.8	0.3
Main Study Area	M	36	6.5	2	8	13.1	0.2
(n=17)	Min	16	2	2	2	5.3	0.1
	Max	311	48	3	21	52.5	0.8
DUNITIC TILL	X	158.1	7.0	2.5	5.1	18.5	0.4
Secondary Study	M	89	2.5	2	4	15.6	0.4
Area (n=8)	Min	42	2	2	1	7.4	0.1
	Max	455	36	6	10	30.5	0.8
COLLUVIUM	X	120.0	2.6	2	21.0	21.3	0.6
Main Study Area	M	88	2	2	18.5	15.8	0.5
(n=25)	Min	24	2	2	2	7.5	0.2
	Max	885	5	3	56	56.3	1.2

X = mean

M = median

Min = minimum value

Max = maximum value

whereas dunitic and non-dunitic tills have mean gold contents of 8.4 ppb and 8.2 ppb, respectively. Values for arsenic, ranging from 5.3 to 52.5 ppm in till and from 7.5 to 56.3 ppm in colluvium, occur throughout the study area, with 90 per cent of the soils containing more than 10 ppm arsenic. These rather high values were independently confirmed by analysis of selected samples by the Geological Survey Branch of the British Columbia Ministry of Energy, Mines and Petroleum Resources.

As would be expected from the major element geochemistry, the platinum content of tills has strong positive correlations with their magnesium ($r=0.75$) and chromium (0.84) content and strong negative correlations with silicon, aluminium, sodium, potassium and titanium. In colluvium, platinum correlates with chromium (0.58) but not with magnesium (0.23). Scatterplots of platinum with magnesium and chromium are shown in Figure 15.

LFH HORIZONS

Analytical results for LFH horizon soils are summarized in Table 4; original data are given in Appendix 4.

The platinum content of LFH horizons generally increases from southeast to northwest across the study area (Figures 16 and 17). Median platinum concentrations on non-dunitic till and dunitic till in the main study area are 7 ppb and 12.5 ppb, respectively. Platinum content increases dramatically in LFH horizons above colluvium (median 65 ppb) and on dunitic till, rubble and stabilized colluvium in the secondary study area (median 122 ppb). Appreciably higher values for weight per cent ash (range 5 to 24 %), iron content (range 0.38 to 4.83%) and insoluble residue in ash (range 0.0 to 36.0 %) are also associated with LFH horizons on colluvium.

The above relationships result in platinum content of LFH horizons being positively correlated with iron and

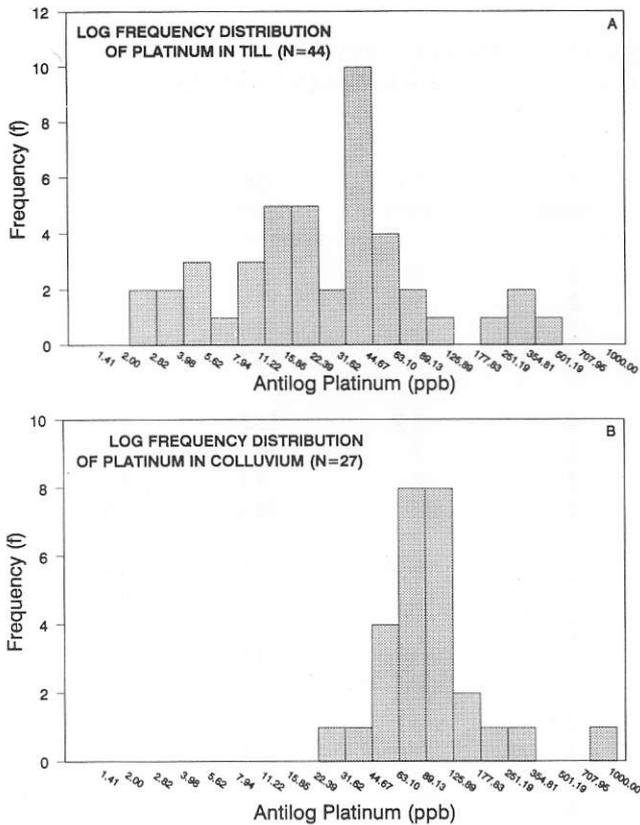


Figure 12. Log frequency distributions of platinum content (ppb) of overview C-horizon soils in (A) till; and (B) colluvium.

insoluble residue content of the ash, and the platinum content of the associated C-horizon (Table 5). There is a particularly good correlation between platinum and iron in LFH horizons on dunitic till, A zone till-rubble and colluvium (Figure 18). A scatterplot of platinum content of the LFH horizons and the underlying C-horizon is shown in Figure 19. Platinum content of the LFH horizon is generally less than that of the C-horizon except at A zone sites and on non-dunitic till. The latter are clustered in the seepage zone and southern forested slope area (Figure 20).

STREAM SEDIMENTS, MOSS MATS AND BANKS

The distribution of platinum, palladium and gold in stream sediments and moss mats is shown in Figure 21 with the original data in Appendix 5. Concentrations are usually slightly higher (8 to 91 ppb in sediments; 8 to 47 ppb in moss mats) than those in associated bank soils (7 to 33 ppb). Data are limited, but higher platinum concentrations in sediments seem to occur at breaks of slope. Chromium content of sediments ranges from 0.10 to 0.35 per cent Cr₂O₃ and magnesium content from 6.25 to 13.04 per cent MgO.

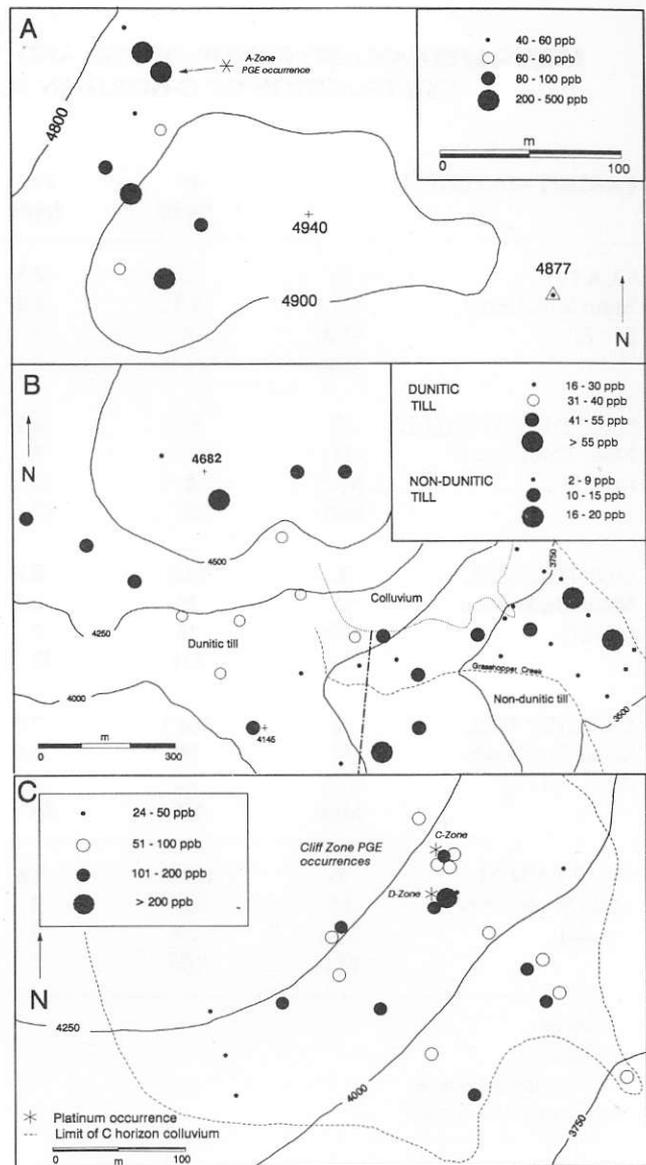


Figure 13. Platinum content (ppb) of overview -70-mesh C-horizon soils in : (A) dunitic till, rubble and colluvium adjacent to PGE mineralization in the secondary study area; (B) dunitic and non-dunitic till in the main study area; and (C) colluvium in the main study area. Dashed line at lower centre represents the boundary between dunitic and non-dunitic tills (base map adapted from Bohme, 1987; elevation contours in feet).

BOGS

Analytical results for bog samples are summarized in Figure 22. Platinum contents range from 1 to 21 ppb in unashed material and from 8 to 67 ppb in ashed samples (Appendix 6). The higher platinum concentrations in ashed samples reflect concentration during the ashing process. Recalculated dry weight platinum concentrations for ashed samples are invariably within 1 to 2.5 ppb

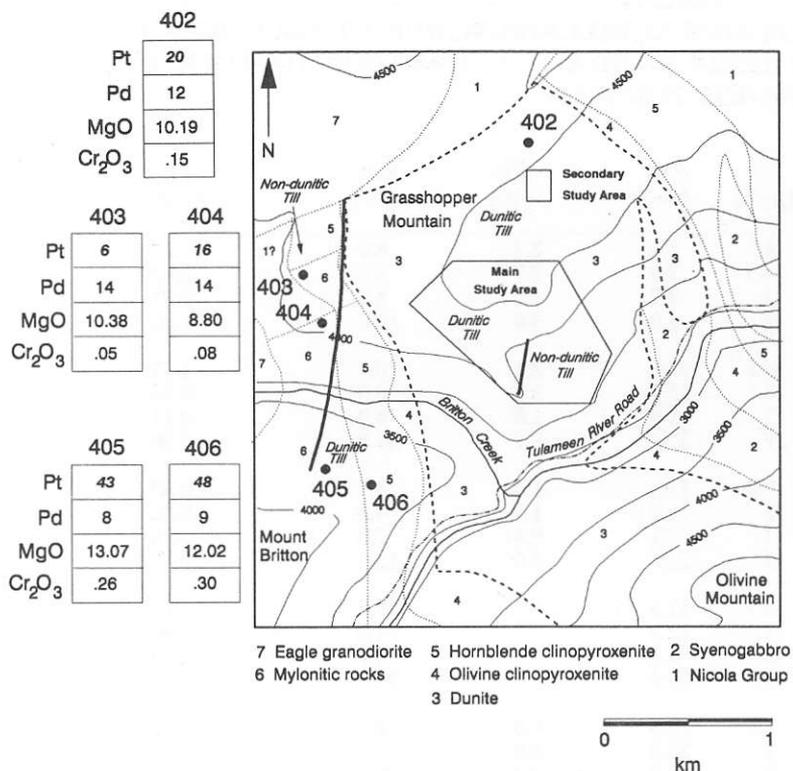


Figure 14. Concentrations of selected elements in background C-horizon till samples north and west of the dunitic core of the Tulameen Ultramafic Complex. Platinum and palladium concentrations in ppb; MgO and Cr₂O₃ concentrations in per cent. (Geology modified after Nixon and Rublee, 1988; elevation contours in feet).

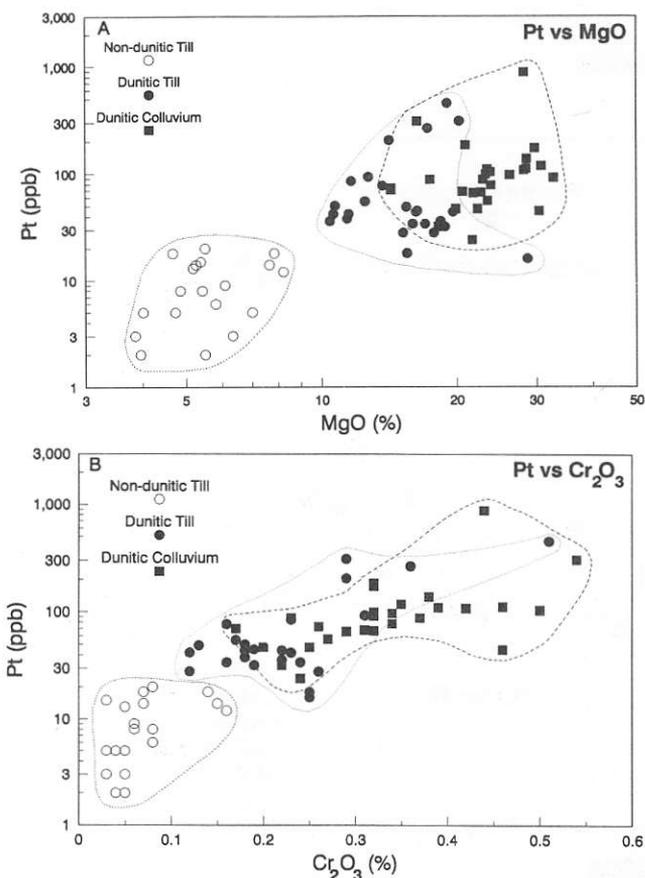


Figure 15. Scatterplots of platinum (ppb) in -70-mesh C-horizon soils versus: (A) MgO (%) and (B) Cr₂O₃ (%).

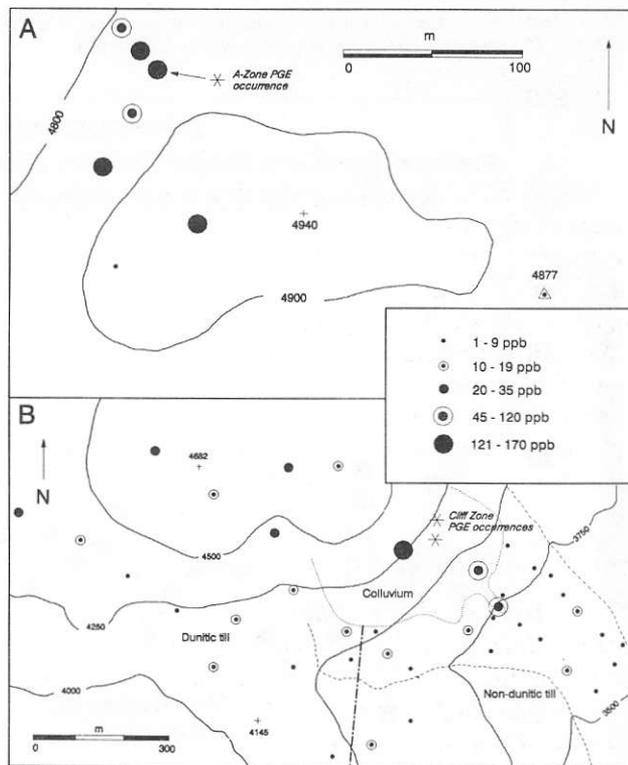


Figure 16. Platinum distribution (ppb) in LFH horizons of the (A) secondary study area, and (B) main study area on Grasshopper Mountain (elevation contours in feet).

TABLE 4
MEAN, MEDIAN AND RANGE OF PLATINUM, PALLADIUM, WEIGHT PER CENT ASH,
IRON, AND PER CENT INSOLUBLE RESIDUE AND LFH/C-HORIZON PLATINUM RATIO,
IN LFH HORIZON SAMPLES

Parent material	n		Pt (ppb)	Pd (ppb)	Ash (%)	Fe (%)	Res. (%)	Pt ratio
Clay	2	X	4.0	4.5	7.9	2.7	8.0	0.63
		M	4	4.5	7.9	2.7	8.0	0.63
		min	1	2	7.7	1.6	6.0	0.25
		max	7	7	8.2	3.8	10.0	1.00
Non-dunitic till	13	X	7.6	4.5	14.4	2.1	10.1	1.17
		M	7	3	13.9	1.8	8.0	0.80
		min	2	2	5.8	1.0	0.0	0.11
		max	18	19	37.7	3.7	32.0	3.50
Dunitic till	16	X	14.0	2.0	13.5	1.5	4.7	0.37
		M	12.5	2	11.5	1.5	4.0	0.36
		min	6	2	7.1	0.4	0.0	0.06
		max	32	2	21.6	3.0	12.0	0.71
Dunitic till-rubble colluvium (A zone)	7	X	104.7	2.7	12.3	3.6	15.8	1.14
		M	122	2	11.3	3.6	14.0	1.36
		min	9	2	5.5	2.8	7.0	0.12
		max	167	5	23.4	4.1	36.0	2.29
Dunite colluvium	3	X	85.0	2.3	22.6	4.6	18.0	0.72
		M	65	2	22.0	4.6	18.0	0.76
		min	49	2	8.9	4.3	18.0	0.56
		max	141	3	37.0	4.8	18.0	0.83

X = Mean; M = median; min = minimum value; max = maximum value; ratio = Pt content LFH horizon / Pt content C horizon.

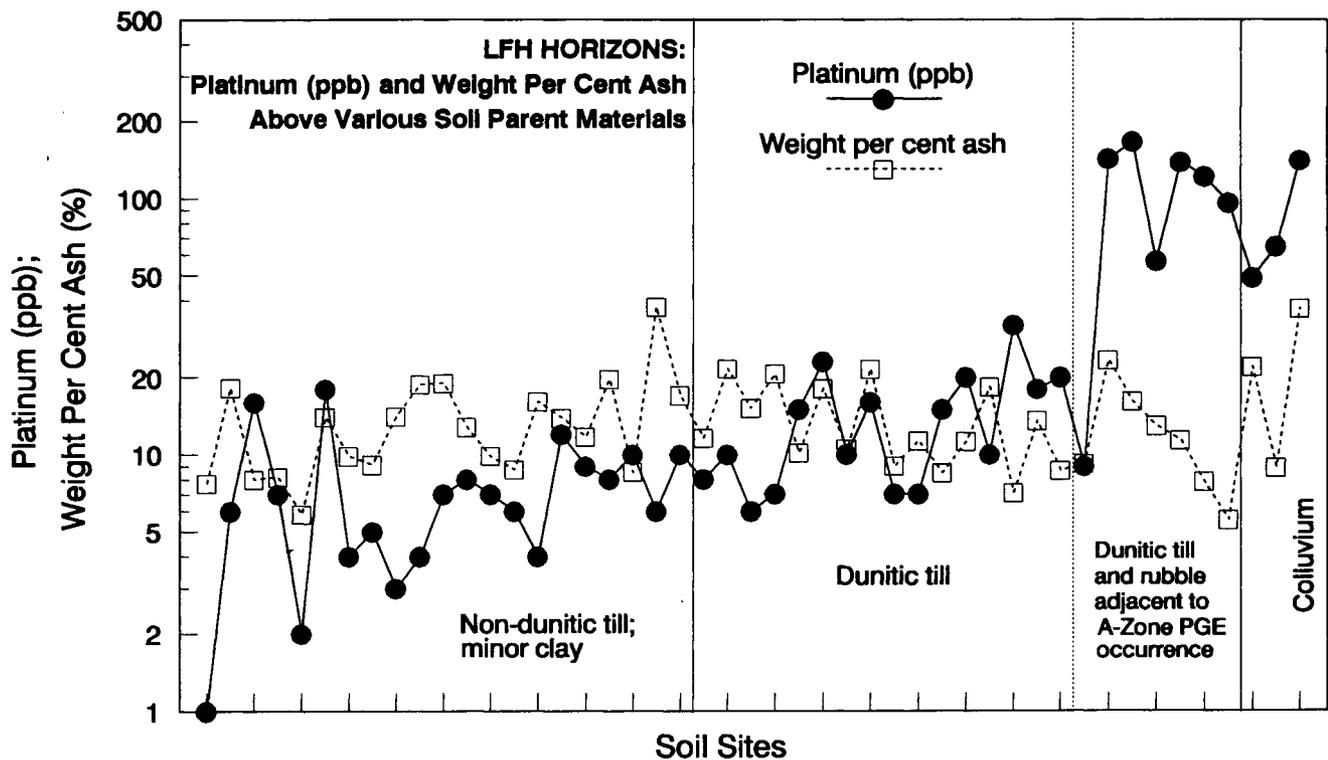


Figure 17. Relation of platinum (ppb) content to weight per cent ash in LFH horizons (n=38) above various parent materials on Grasshopper Mountain.

TABLE 5
CORRELATION MATRIX FOR CONSTITUENTS
OF LFH HORIZONS (N=38)

	Pt	Pd	Au	Pt-C	Ash	Fe	IR
Pt	1.00						
Pd	-0.04	1.00					
Au	0.07	<u>0.78</u>	1.00				
Pt-C	<u>0.58</u>	-0.05	-0.05	1.00			
Ash	0.24	-0.10	-0.12	0.09	1.00		
Fe	<u>0.64</u>	0.13	0.11	<u>0.40</u>	0.27	1.00	
IR	<u>0.45</u>	-0.15	-0.10	0.12	<u>0.33</u>	<u>0.64</u>	1.00

Pt-C = Pt content of C-horizon

IR = Insoluble residue

Values of significant at P0.05 underlined

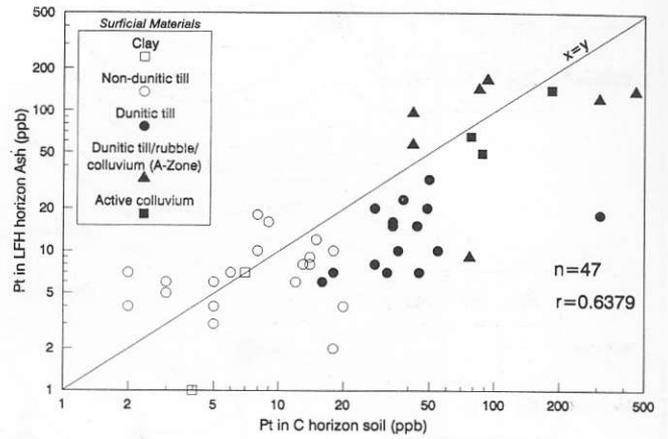


Figure 19. Scatterplot of platinum content (ppb) of ashed LFH versus C-horizon soils.

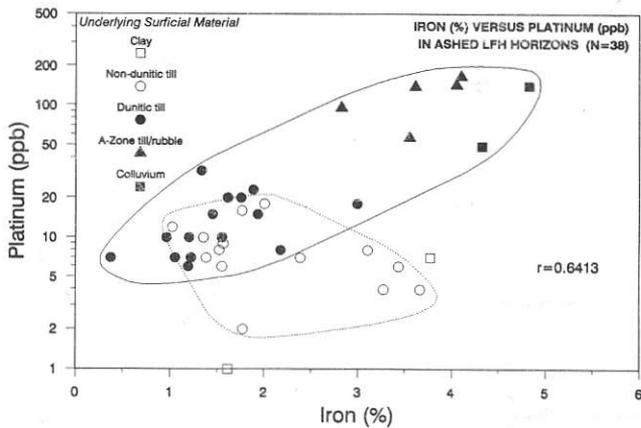


Figure 18. Scatterplot of platinum (ppb) versus iron (%) in ashed LFH horizons (n=38) above various parent materials on Grasshopper Mountain.

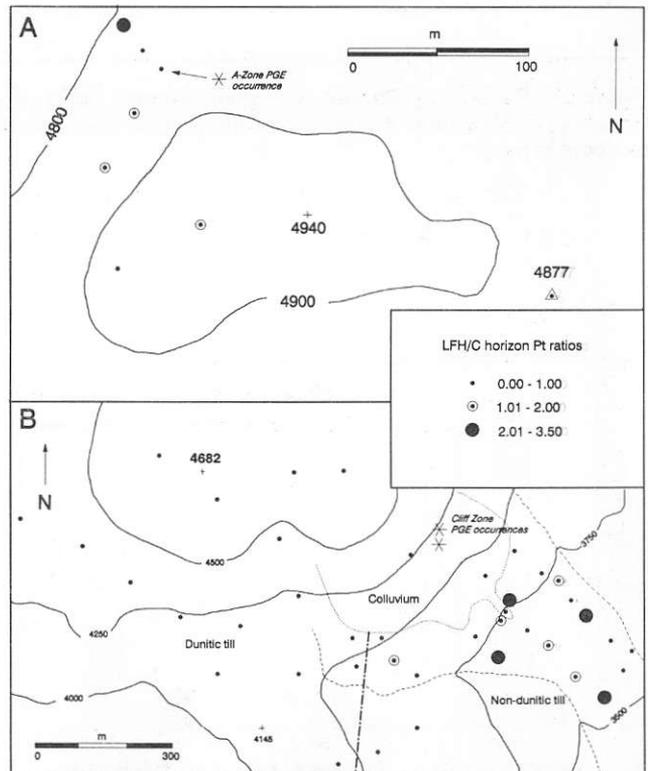


Figure 20. Distribution of LFH: C-horizon platinum ratios on Grasshopper Mountain. Dashed line at lower centre represents the boundary between dunitic and non-dunitic tills. The majority of the high-ratio soil sites are located in or near the seepage zone area in non-dunitic till (elevation in contours in feet).

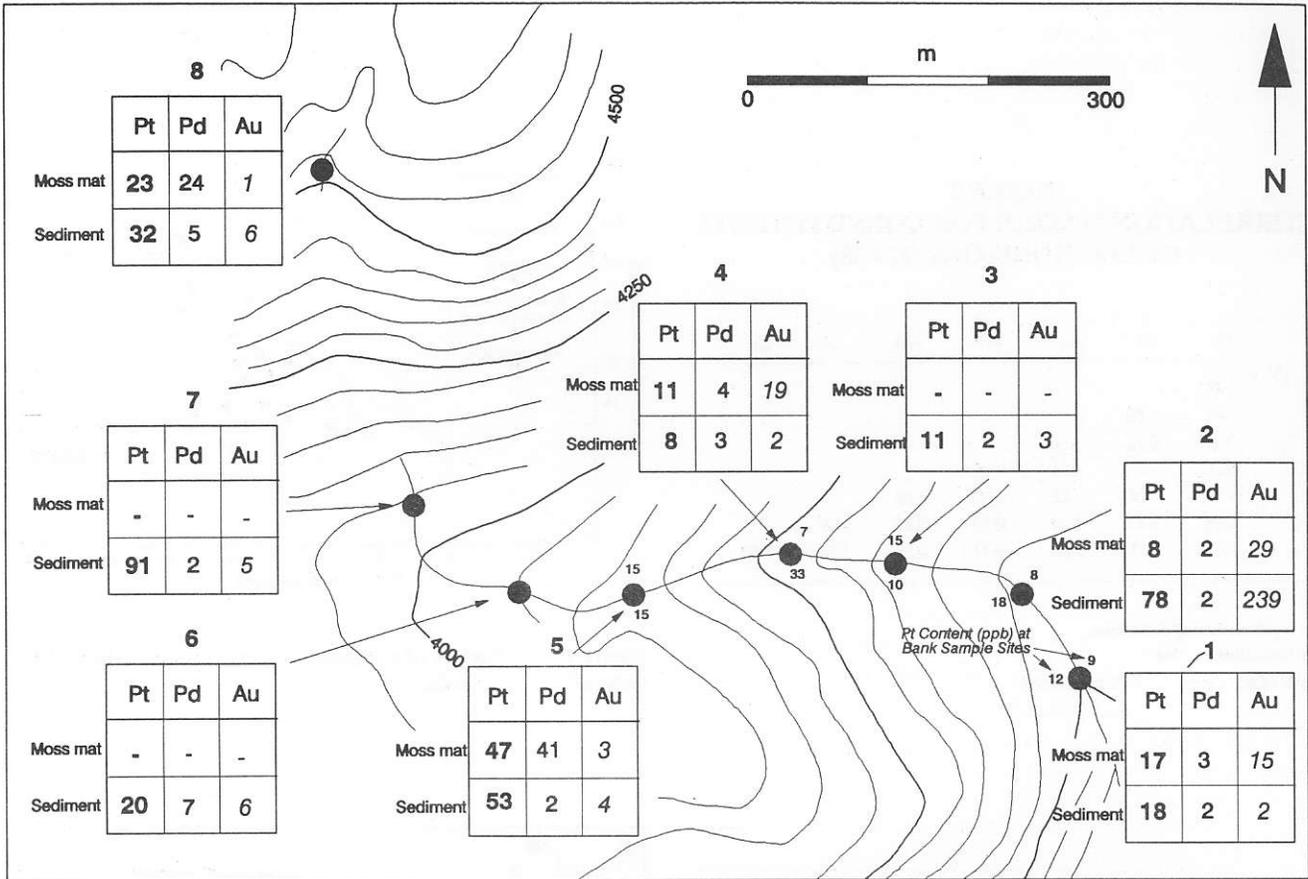


Figure 21. Platinum, palladium and gold contents (ppb) of stream sediments and moss mats from Grasshopper Creek on Grasshopper Mountain. Platinum content (ppb) of bank samples at sites 1 to 4 are shown adjacent to the site marker (elevation contours in feet).

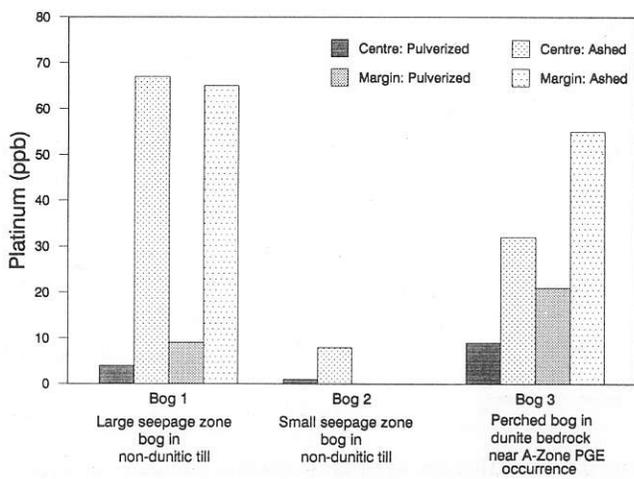


Figure 22. Platinum content (ppb) of pulverized and ashed splits of organic bog soils from three Grasshopper Mountain bogs.

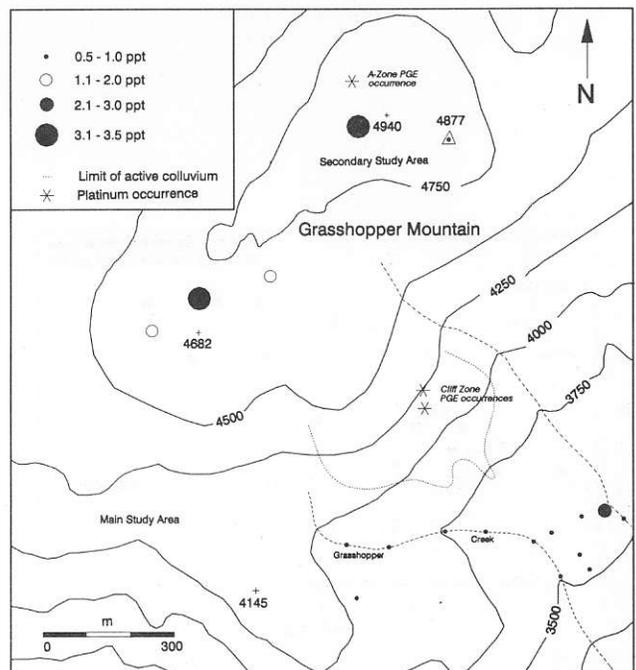


Figure 23. Platinum content (ppt) of filtered (<0.45 micron) stream, bog and seepage waters, Grasshopper Mountain (elevation contours in feet).

of those for unashed material and indicate that platinum is not lost during ashing. Particularly in the case of the perched bog (Site 3) a sample near the bog margin gave higher platinum results than a bog-centre sample.

Pulverized bog samples also contain up to 4.1 ppm antimony, with the highest values occurring in the seepage zone at Site 1. These are more than six times higher than the median antimony content of soils developed on till and colluvium, and are more than twice the highest antimony concentration in seepage zone soils.

WATERS

The platinum content of water samples is very low (Table 6; Figure 23; Appendix 7). Stream waters almost always contain less than 1 ppt platinum. They have a mean platinum content of 0.81 ppt versus 1.05 ppt for waters from seepage zones in bogs and soil pits in the lower part of the main study area. Bog and pond waters from the plateau region of the mountain contain 1.3 to 3.5 ppt platinum (mean 2.45 ppt). The trend to higher platinum values is associated with increasing intensity of water colour, from colourless to light brown or brown, although not all brown or light brown samples have high platinum contents.

TABLE 6
MEAN, $\pm 1\alpha$ AND RANGE OF PLATINUM
CONTENT (PPT) AND pH OF FILTERED
(< 0.45 MICRONS) AND ACIDIFIED SURFACE
WATERS (N = 17)

Sample Type	n	Pt (ppt)	pH
Stream waters	7	0.81 \pm 0.15 (0.5 - 0.9)	7.79 \pm 0.40 (7.11 - 8.16)
Seepage-zone bogs and soil pits on non-dunitic till and clay	6	1.05 \pm 0.58 (0.6 - 2.2)	7.04 \pm 0.57 (6.30 - 7.99)
Plateau bogs and ponds on dunitic till	4	2.45 \pm 1.07 (1.3 - 3.5)	7.38 \pm 0.16 (7.24 - 7.59)

Platinum analyses courtesy of G.E.M. Hall, Geological Survey of Canada, Ottawa, Ontario.

DISTRIBUTION OF PLATINUM IN DETAILED SOIL PROFILES

PLATINUM RESIDENCY SITES

Platinum residency sites are considered with respect to its distribution between size fractions (-10 +40, -40 + 70, -70 + 140, -140 + 270, -270-mesh) and, for the -70 + 140 and -140 + 270-mesh fractions, platinum distribution between light mineral and both magnetic and nonmagnetic heavy mineral fractions. As in the -70-mesh

overview samples, platinum concentrations in all fractions generally increase according to parent material in the order non-dunitic till, to dunitic till, to colluvium and A zone till and rubble (Tables 7, 8 and 9). Original analytical data are given in Appendix 8.

TABLE 7
MEDIAN AND RANGE OF PLATINUM
CONCENTRATIONS (PPB) AMONG SIZE
FRACTIONS OF SOILS DEVELOPED ON
DIFFERENT PARENT MATERIALS

Parent material and/or horizon	Size Fraction (ASTM)				
	-10 +40	-40 +70	-70 +140	-140 +270	-270
A) Non-dunitic Till: Near-surface Horizons (n=3)					
	7 (3-13)	5 (3-11)	4 (4-8)	2 (2-9)	7 (7-10)
Non-dunitic Till: C Horizon (n=2)					
	43 (9-77)	15 (8-21)	15 (6-23)	14 (5-23)	12 (9-14)
B) Dunitic Till: Near-surface Horizons (n=5)					
	49 (6-81)	19 (1-113)	20 (3-104)	35 (6-172)	36 (16-104)
Dunitic Till: C Horizon (n=6)					
	34 (1-101)	26 (1-76)	24 (2-167)	29 (7-50)	23 (2-41)
C) Dunitic Till/Rubble (A-zone): Near-surface Horizons (n=5)					
	92 (74-355)	128 (103-402)	83 (74-149)	53 (38-90)	76 (53-131)
Dunitic Till/Rubble (A-zone): C Horizon (n=3)					
	119 (96-722)	588 (152-632)	157 (155-278)	164 (141-257)	150 (89-260)
D) Colluvium: (n=9)					
	106 (16-248)	128 (53-388)	74 (42-277)	90 (41-167)	89 (53-147)

PLATINUM DISTRIBUTION BETWEEN SIZE FRACTIONS

The platinum content of five size fractions from each horizon of 14 profiles is summarized in Table 7 and Figure 24. These diagrams are arranged to show, from left to right, increasing proximity to A-zone platinum mineralization. Colluvium, including dunitic colluvium below the Cliff zone platinum occurrences, is shown on the far right.

Although the platinum content of a single soil horizon may vary up to five times among the size fractions systematic trends are generally absent (Figure 25). The relatively uniform distribution between size fractions is particularly notable in profiles 51 and 57 on dunitic till, 27 and 42 on serpentine colluvium, and profile 16 on dunitic colluvium. In contrast to the general absence of systematic trends, platinum values seem to increase in the

TABLE 8
MEDIAN AND RANGE OF PLATINUM
CONCENTRATIONS (PPB) BETWEEN LIGHT
(S.G. < 3.3) AND HEAVY (S.G. > 3.3) MINERAL
FRACTIONS OF SOILS ON DIFFERENT
PARENT MATERIALS

Parent material and/or horizon	Size Fraction (ASTM)			
	Light		Heavy	
	-70 +140	-140 +270	-70 +140	-140 +270
A) Non-dunitic Till: Near-surface Horizons (n=3)	3 (2-6)	1 (1-6)	22 (18-61)	30 (22-46)
Non-dunitic Till: C Horizon (n=2)	8 (5-10)	9 (3-14)	105 (67-142)	154 (66-242)
B) Dunitic Till: Near-surface Horizons (n=5)	9 (1-36)	4 (3-50)	142 (18-767)	338 (78-1429)
Dunitic Till: C Horizon (n=6)	13 (1-31)	12 (1-20)	90 (11-669)	219 (98-329)
C) Dunitic Till/Rubble (A-zone): Near-surface Horizons (n=5)	30 (21-50)	24 (18-57)	744 (526-1292)	340 (193-607)
Dunitic Till/Rubble (A-zone): C Horizon (n=3)	70 (69-160)	110 (74-137)	787 (754-1590)	817 (756-2027)
D) Colluvium: (n=9)	40 (4-69)	70 (2-128)	388 (261-2538)	503 (154-1000)

coarser fractions of dunitic rubble at site 56, in the uppermost colluvium sample from site 9 below the Cliff zone platinum occurrences, and in the C-horizon of non-dunitic till at site 20.

DISTRIBUTION OF PLATINUM IN LIGHT AND HEAVY MINERAL FRACTIONS

The abundance of heavy minerals in the -70 + 140 and -140 + 270-mesh fractions ranges from 2.40 to 22.32 per cent of the original fraction, with most samples in the range 5 to 15 per cent (Table 10). Heavy minerals are slightly more abundant in the -70 + 140-mesh fraction than in the -140 + 270-mesh fraction, probably at least partly as a function of less efficient heavy liquid separation of the smaller particles. Soils on non-dunitic till (and the stream sediments) have roughly equal proportions of magnetic and nonmagnetic heavy minerals whereas the magnetic component typically accounts for more than 70 per cent of the heavy mineral content of all other soils.

Concentrations of platinum in the heavy mineral fractions are 10 to 20 times greater than in the corresponding light fractions (Table 8, Figure 26). For example,

TABLE 9
MEDIAN AND RANGE OF PLATINUM
CONCENTRATIONS (PPB) IN MAGNETIC AND
NONMAGNETIC HEAVY MINERAL FRACTIONS
OF SOILS ON DIFFERENT PARENT MATERIALS

Parent material and/or horizon	Magnetic		Nonmagnetic	
	-70 +140	-140 +270	-70 +140	-140 +270
A) Non-dunitic Till: Near-surface Horizons (n=3)	95 (34-96)	47 (30-97)	5 (4-8)	9 (4-23)
Non-dunitic Till: C Horizon (n=2)	356 (148-563)	330 (143-517)	12 (9-15)	28 (22-33)
B) Dunitic Till: Near-surface Horizons (n=5)	179 (51-1142)	338 (95-1549)	30 (10-112)	95 (51-1195)
Dunitic Till: C Horizon (n=6)	87 (58-1732)	261 (59-525)	10 (5-183)	105 (5-539)
C) Dunitic Till (A-zone): Near-surface Horizons (n=5)	759 (653-962)	358 (185-413)	57 (8-3225)	261 (193-1053)
Dunitic Till (A-zone): C Horizon (n=3)	1075 (695-1671)	987 (359-1857)	466 (28-870)	1371 (278-3172)
D) Dunitic Colluvium: (n=4)	1561 (331-2782)	234 (168-855)	361 (43-1601)	673 (86-1128)
Serpentine Colluvium: (n=5)	317 (253-393)	284 (85-738)	530 (257-587)	2730 (1655-4950)

in the C-horizon -70 + 140-mesh fraction average platinum values range from 8 ppb in non-dunitic tills to 70 ppb in dunitic till-rubble from the A zone. The corresponding values in the heavy mineral fraction are 105 and 787 ppb, respectively. Platinum concentrations exceed 1000 ppb in several heavy mineral concentrates of colluvium and dunitic till-rubble from the A zone.

In the heavy mineral fractions of soils on non-dunitic till and dunitic till away from known platinum mineralization, platinum is usually most abundant in the magnetic component (Table 9). Concentrations are typically 10 to 20 times greater than in the corresponding nonmagnetic fraction, with the difference being greatest in the -70 + 140-mesh fraction. This relationship changes at dunitic till-rubble and colluvium sites close to platinum occurrences, where platinum content of the nonmagnetic component is similar to or exceeds concentrations in the magnetic fractions (Figure 27). Similar platinum contents were also found in the -140 + 270-mesh fraction of the only stream-sediment sample studied in detail (Figure 28).

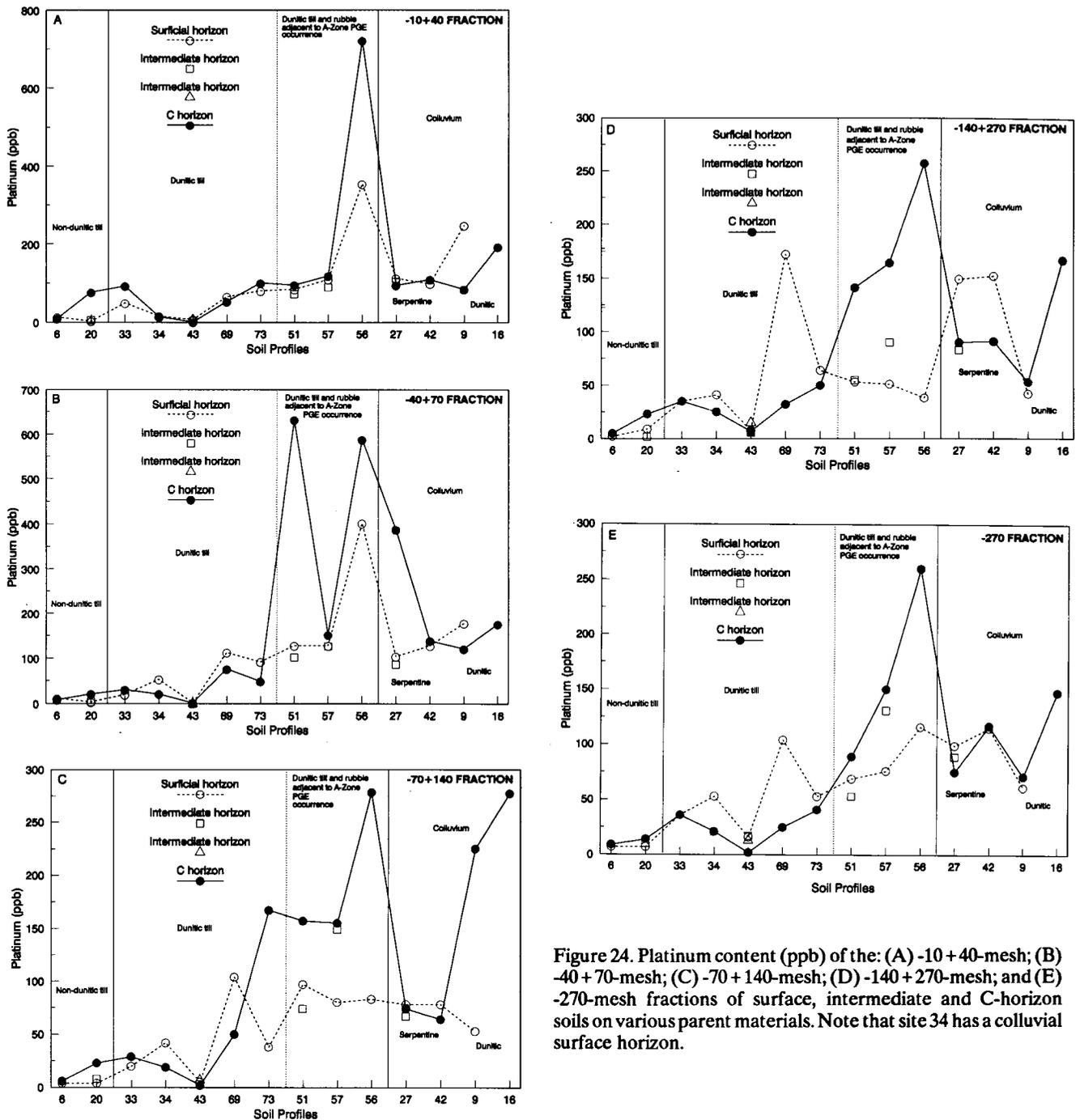


Figure 24. Platinum content (ppb) of the: (A) -10+40-mesh; (B) -40+70-mesh; (C) -70+140-mesh; (D) -140+270-mesh; and (E) -270-mesh fractions of surface, intermediate and C-horizon soils on various parent materials. Note that site 34 has a colluvial surface horizon.

DISTRIBUTION OF PLATINUM BETWEEN HORIZONS

Down-profile variations in platinum content between the various fractions analyzed are shown for four profiles in Figures 29 to 32, and for an additional ten profiles in Appendix 9. Variations in platinum content with depth are also shown for specific fractions in Figures 24 to 27.

Soils in the study area are complex and too few profiles were examined to fully characterize down-profile distribution of platinum in all soil types developed on the various parent materials. Nevertheless several reasonably

consistent trends are apparent. For example, on non-dunitic till, platinum content of all fractions (*i.e.*, light mineral, and magnetic and nonmagnetic heavy mineral fractions) usually increases down the profile (Figure 29). This is also generally the case in profiles on till-rubble at the A zone (Figures 30 and 31). On dunitic tills outside the A zone, platinum content of the light mineral fractions also increases with depth. However, in the associated magnetic and nonmagnetic heavies this general trend may

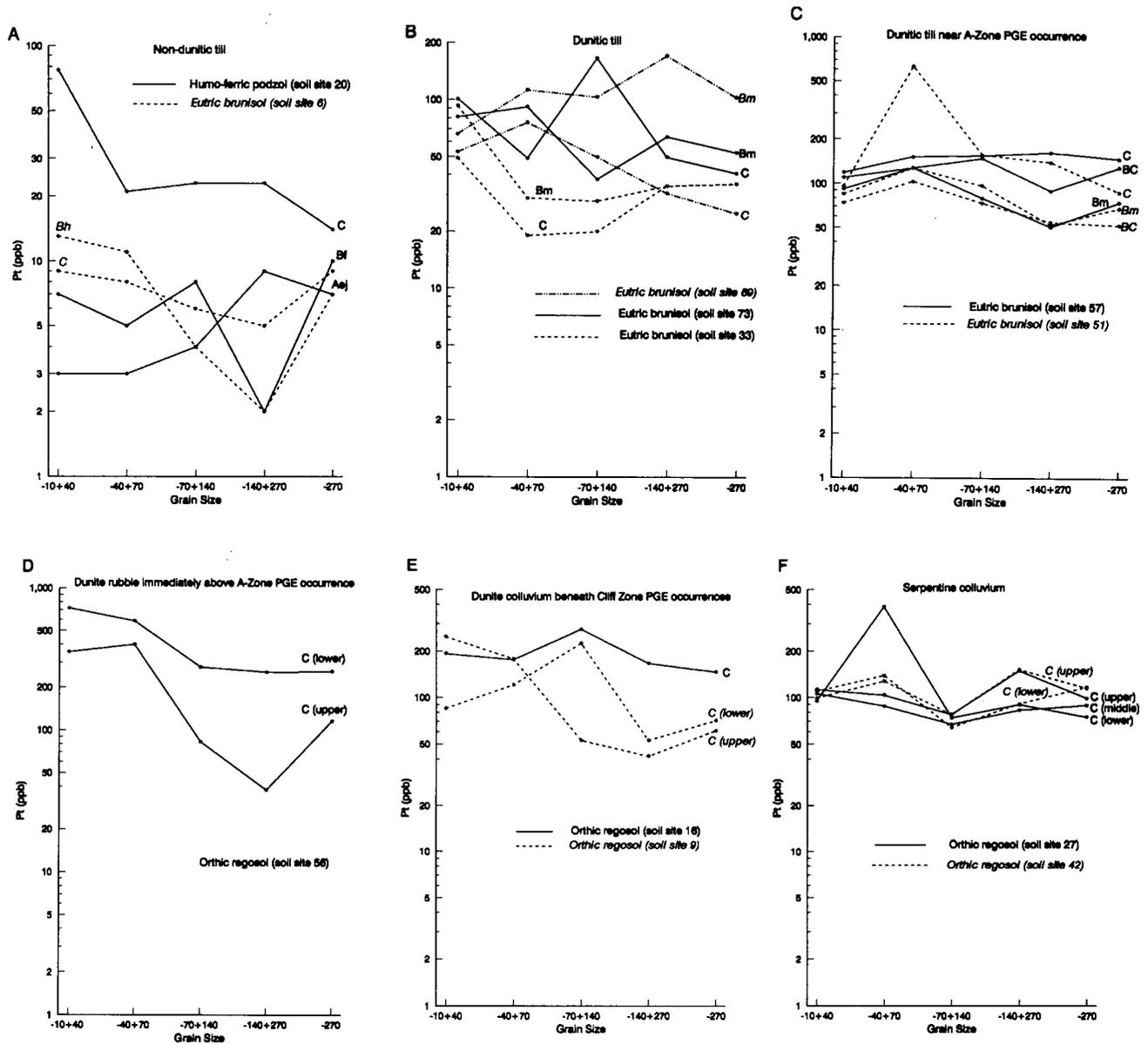


Figure 25. Platinum distribution (ppb) among size fractions of individual horizons of some Grasshopper Mountain soils from: (A) non-dunitic till; (B) dunitic till; (C) dunitic till adjacent to the A zone PGE occurrence; (D) dunitic rubble immediately above the A zone PGE occurrence (Plate 9); (E) dunitic colluvium beneath the Cliff zone PGE occurrences; and (F) serpentine colluvium.

TABLE 10
WEIGHT PER CENT HEAVY MINERALS (S.G. > 3.3) AND PROPORTIONS OF
MAGNETIC AND NONMAGNETIC FRACTIONS IN THE -70 + 140 AND -140 + 270-MESH
FRACTIONS OF DETAILED SOIL PROFILES

	Soil Site	Sample Number	Horizon	Wt.% Heavy Minerals	Wt.% Heavy Minerals	Wt.% Mag Heavies	Wt.% Nonmag Heavies	Wt.% Mag Heavies	Wt.% Nonmag Heavies
				(-70+140)	(-140+270)	(-70+140)	(-70+140)	(-140+270)	(-140+270)
Non-dunitic till	8	18	Ah	3.57	4.72	58.90	41.10	64.23	35.77
	8	19	Cg	2.29	3.62	39.26	60.74	30.39	69.61
	20	38	Aej	12.16	6.83	15.88	84.12	31.62	68.38
	20	39	Bf	2.83	3.55	58.89	40.11	60.88	39.12
	20	40	C	10.00	3.84	23.95	76.05	44.43	55.57
Dunitic till	33	78	Bm	8.85	9.25	70.61	29.39	64.43	35.56
	33	79	C	13.17	9.88	62.30	37.70	62.19	37.81
	34	81	IC	8.87	10.71	80.06	19.95	81.80	18.20
	34	82	IIC	15.37	16.50	58.65	41.35	53.89	46.11
	43	110	Bm	5.40	4.85	32.33	67.67	45.34	54.66
	43	111	Bm	13.97	3.45	11.56	88.44	47.40	52.60
	43	112	BC/C	17.95	6.86	9.59	90.41	28.59	71.41
	43	113	C	5.75	3.77	26.27	73.73	50.19	49.81
	69	199	Bm	9.37	8.87	63.60	36.40	66.11	33.88
	69	200	C	10.91	5.56	40.07	59.93	61.96	38.04
	73	215	Bm	18.73	12.79	19.51	80.49	31.79	68.20
	73	216	C	22.32	11.20	35.48	64.52	56.80	43.20
	Dunitic till/rubble (A-Zone)	51	133	Bm	10.93	11.03	89.06	10.94	83.40	16.60
51		134	BC	10.43	9.28	80.22	19.78	77.32	22.68
51		135	C	12.25	4.79	72.51	27.49	67.42	32.58
57		154	Bm/IC	6.00	8.73	90.15	9.85	71.20	28.80
57		155	BC	7.99	5.92	79.44	20.55	69.65	30.34
57		158	IIC	12.49	12.06	66.49	33.51	54.73	45.26
56		152	C (upper)	6.91	8.34	87.01	12.99	77.29	22.71
56		153	C (lower)	8.28	6.34	93.27	6.73	87.07	12.93
Colluvium	27	59	C (upper)	9.73	2.40	76.08	23.92	87.97	12.03
	27	60	C (middle)	8.66	4.20	83.11	16.89	87.36	12.64
	27	61	C (lower)	8.41	2.75	81.53	18.47	89.74	10.26
	42	104	C (upper)	8.67	3.99	83.72	16.28	76.65	23.35
	42	105	C (lower)	7.46	6.49	80.85	19.15	80.36	19.64
	9	24	C (upper)	7.48	5.67	82.53	17.48	82.85	17.35
	9	23	C (lower)	15.67	4.92	45.44	54.56	80.24	19.76
	16	31	C	8.41	6.37	83.67	16.33	83.22	16.77
	2	503	Sediment	9.65	7.98	53.05	46.95	52.82	47.18

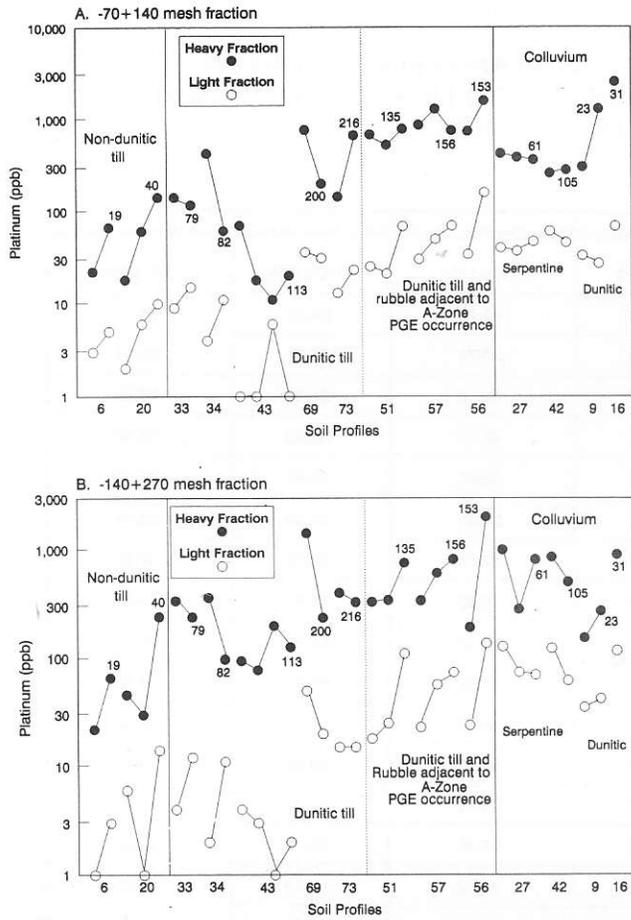


Figure 26. Platinum distribution (ppb) in heavy and light mineral fractions of : (A) -70+140-mesh and (B) -140+270-mesh size fractions from soil horizons on various parent materials. Solid lines connect horizons within individual soil profiles and indicate changes in concentration with increasing depth (left to right; numbers are C-horizon sample numbers) in the profile.

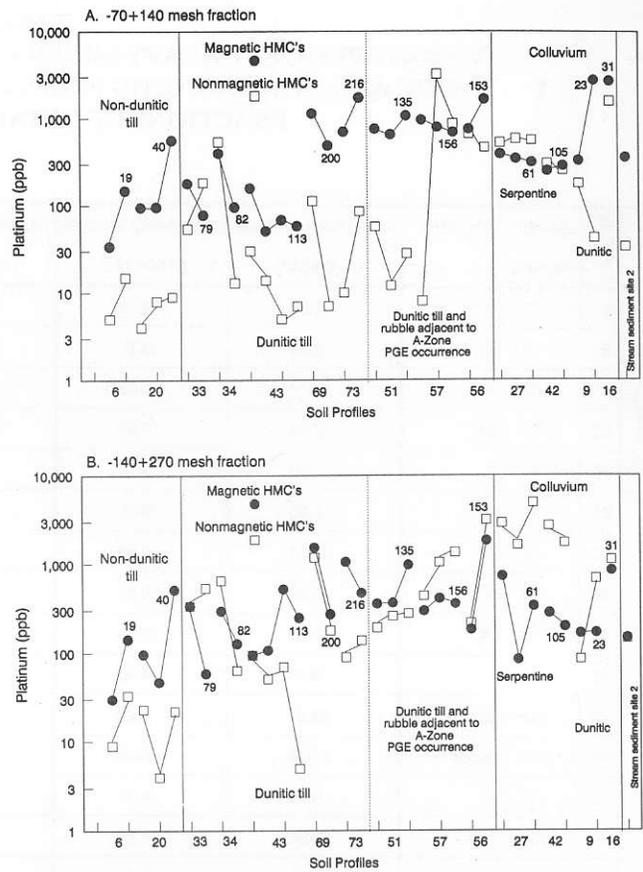


Figure 27. Platinum distribution (ppb) in magnetic and non-magnetic heavy mineral fractions of: (A) -70+140-mesh and (B) -140+270-mesh size fractions from soil horizons on various parent materials and a stream sediment. Solid lines connect horizons within individual soil profiles and indicate changes in concentration with increasing depth (left to right; numbers are C-horizon sample numbers) in the profile.

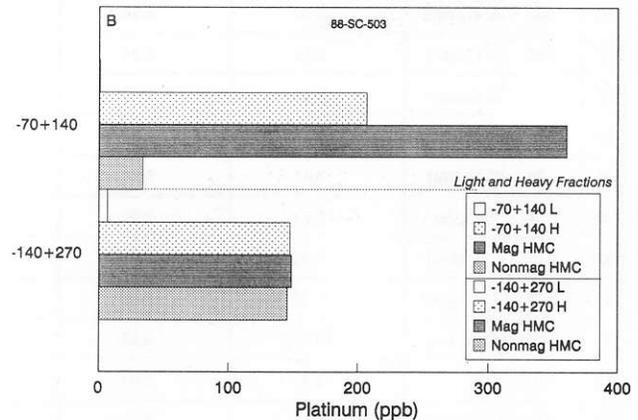
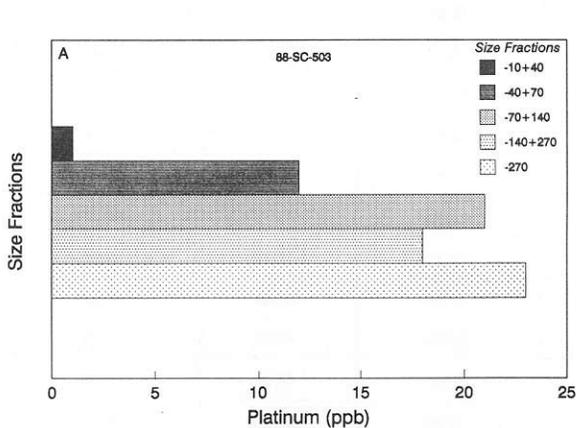


Figure 28. Platinum distribution (ppb) in (A) five size fractions and (B) light, heavy, heavy magnetic and heavy nonmagnetic mineral fractions of the -70+140-mesh and -140+270-mesh size fractions, stream sediment site 2, Grasshopper Creek.

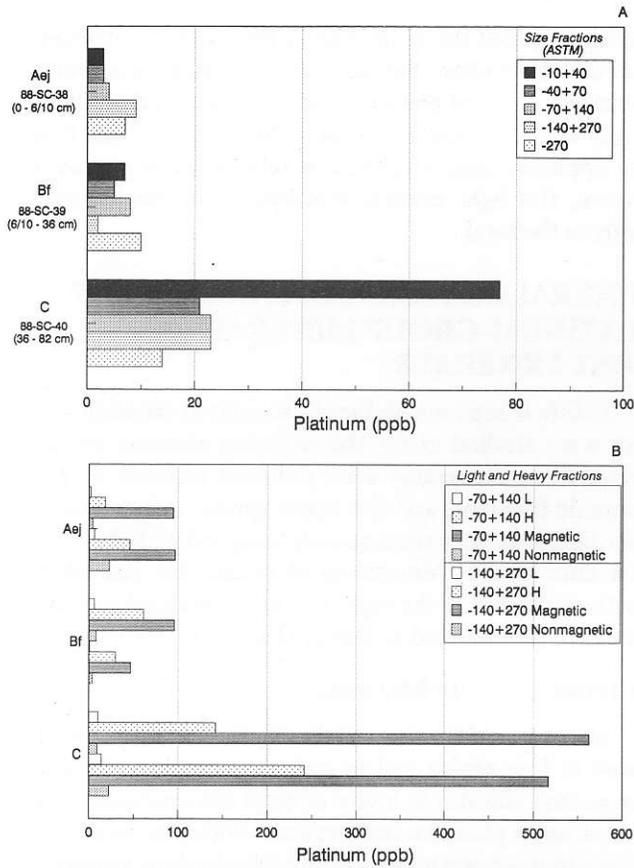


Figure 29. Platinum distribution (ppb) in humo-ferric podzol (soil site 20) on non-dunitic till, showing (A) platinum content of five size fractions and (B) platinum content of light, heavy, heavy magnetic and heavy nonmagnetic mineral fractions of the -70 + 140-mesh and -140 + 270-mesh size fractions.

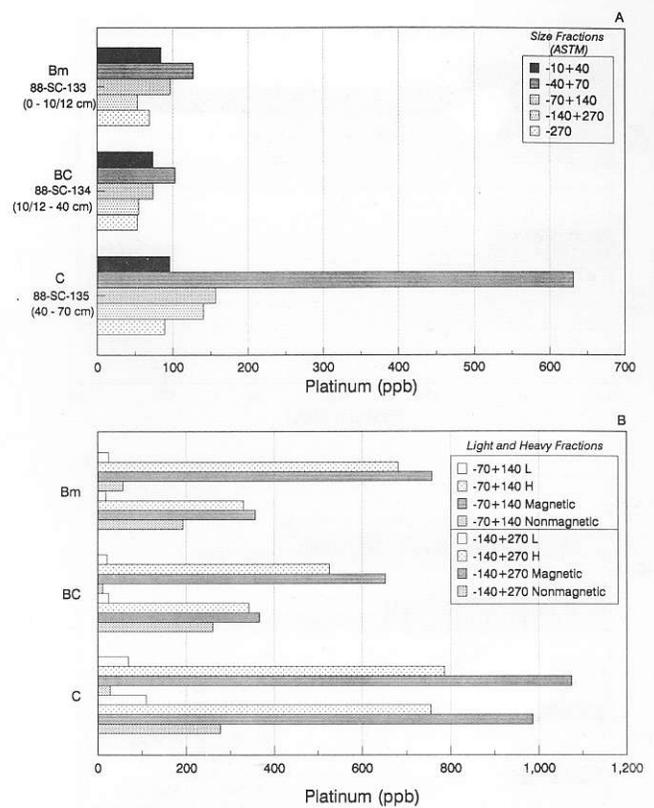


Figure 30. Platinum distribution (ppb) in eutric brunisol (soil site 51) on dunitic till adjacent to the A zone PGE occurrence, secondary study area, showing (A) platinum content of five size fractions and (B) platinum content of light, heavy, heavy magnetic and heavy nonmagnetic mineral fractions of the -70 + 140-mesh and -140 + 270-mesh size fractions.

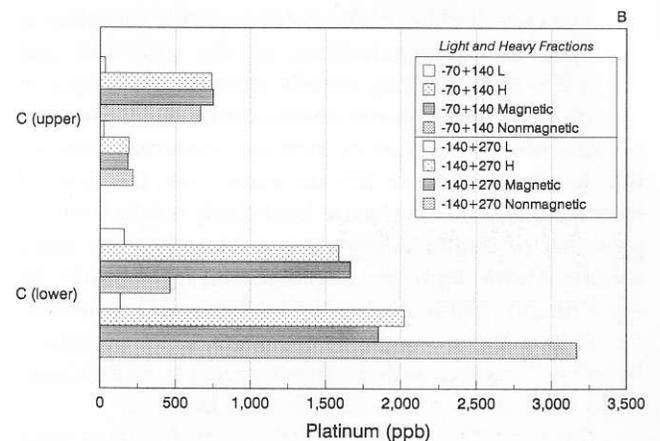
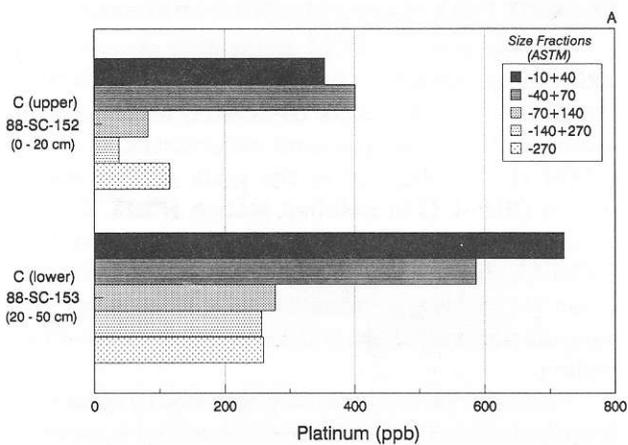


Figure 31. Platinum distribution (ppb) in orthic regosol (soil site 56) on dunitic rubble immediately above the A zone PGE occurrence, secondary study area, showing (A) platinum content of five size fractions and (B) platinum content of light, heavy, heavy magnetic and heavy nonmagnetic mineral fractions of the -70 + 140-mesh and -140 + 270-mesh size fractions.

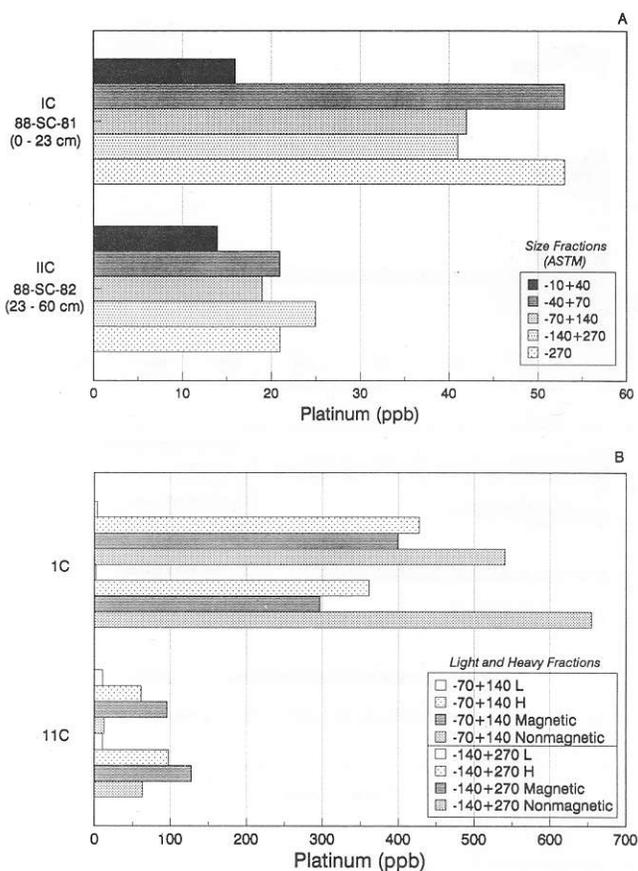


Figure 32. Platinum distribution (ppb) in composite soil profile (soil site 34) of dunitic colluvium (IC) overlying dunitic till (IIC), showing (A) platinum content of five size fractions and (B) platinum content of light, heavy, heavy magnetic and heavy nonmagnetic mineral fractions of the -70+140-mesh and -140+270-mesh size fractions.

be reversed and platinum content locally increases upwards (Figure 26). Platinum content is relatively constant with depth in colluvium.

The overall effect of these down-profile variations is that platinum concentrations in the -70+140 and -140+270-mesh fraction usually increase with depth in soils on non-dunitic till and on till-rubble near the A zone, but may remain constant or increase upwards on dunitic till. At site 34 (Figure 32) on dunitic till, the upward increase of platinum values at least partly results from the presence of dunite colluvium overlying till. The same variations with depth are also observed for the -10+40, -40+70 and -270-mesh fractions (Figure 24). However, on dunitic till the difference between platinum content of horizons decreases with decreasing grain size and is generally negligible for the -10+40-mesh fraction.

Based on the content of the various fractions, total platinum contents and contribution of each fraction to the total content has been calculated for several profiles (Figure 33). In soils on till the -270-mesh fraction contains the greatest proportion of platinum and contributes ap-

proximately half the total. This is reversed in colluvium and till-rubble where the -10+40-mesh fraction contains about half the total platinum content compared to about 20 per cent contributed by the -270-mesh fraction. It is also apparent that, despite their relatively low platinum content, the light mineral fractions contribute significantly to the total.

MINERALOGY AND COMPOSITION OF PLATINUM-GROUP MINERALS AND HOST MINERALS

Polished sections and grain mounts from eight soil sites were studied under the scanning electron microscope. Chromite grains from polished sections of five magnetic fractions, and five nonmagnetic and paramagnetic fractions were subsequently analyzed with the electron microprobe. Mineralogical results for individual fractions of each of the eight soil heavy mineral concentrates are summarized in Tables 11 and 12.

PLATINUM-GROUP MINERALS

Seven PGM grains, all Pt-Fe-Cu-Ni alloys, were found as free grains and as inclusions in chromite and magnesium silicates in heavy mineral concentrates from soils close to platinum occurrences. With one exception the platinum-group minerals were found in heavy mineral fractions with a platinum content of at least 1000 ppb. None were found in background-level dunitic or non-dunitic tills. No platinum arsenides, antimonides or other non-platinum-iron alloy PGM phases previously identified in Tulameen chromitites or placer nuggets (Aubut, 1978; St. Louis *et al.*, 1986; Nixon *et al.*, 1990) were found in the soils.

All identifications of platinum-group minerals are based on EDS signatures and are tentative.

DISCRETE FREE PLATINUM-GROUP MINERALS

Two discrete free PGM grains were observed, both within the paramagnetic heavy fraction of C-horizon colluvium (soil site 16; sample 88-SC-031) immediately beneath the Cliff zone platinum occurrences. One grain (31PM-1) was observed in the grain stub mount, the second (31PM-2) in polished section (Plate 12). Both were by far the largest PGM grains encountered. Grain 31PM-1 is about 115 by 103 microns, with an equant habit. Grain 31PM-2 is approximately 85 by 53 microns with an elongate prismatic shape and weakly crystalline outline in section.

Grain 31PM-1 was partially obscured by other grains in the stub mount but is tentatively identified as tulameenite (Pt_2FeCu). The section of grain 31PM-2 has a platinum-iron-copper (tulameenite) surface rim composition, but contains a relict internal platinum-iron core tentatively identified as isoferroplatinum on the basis of rela-

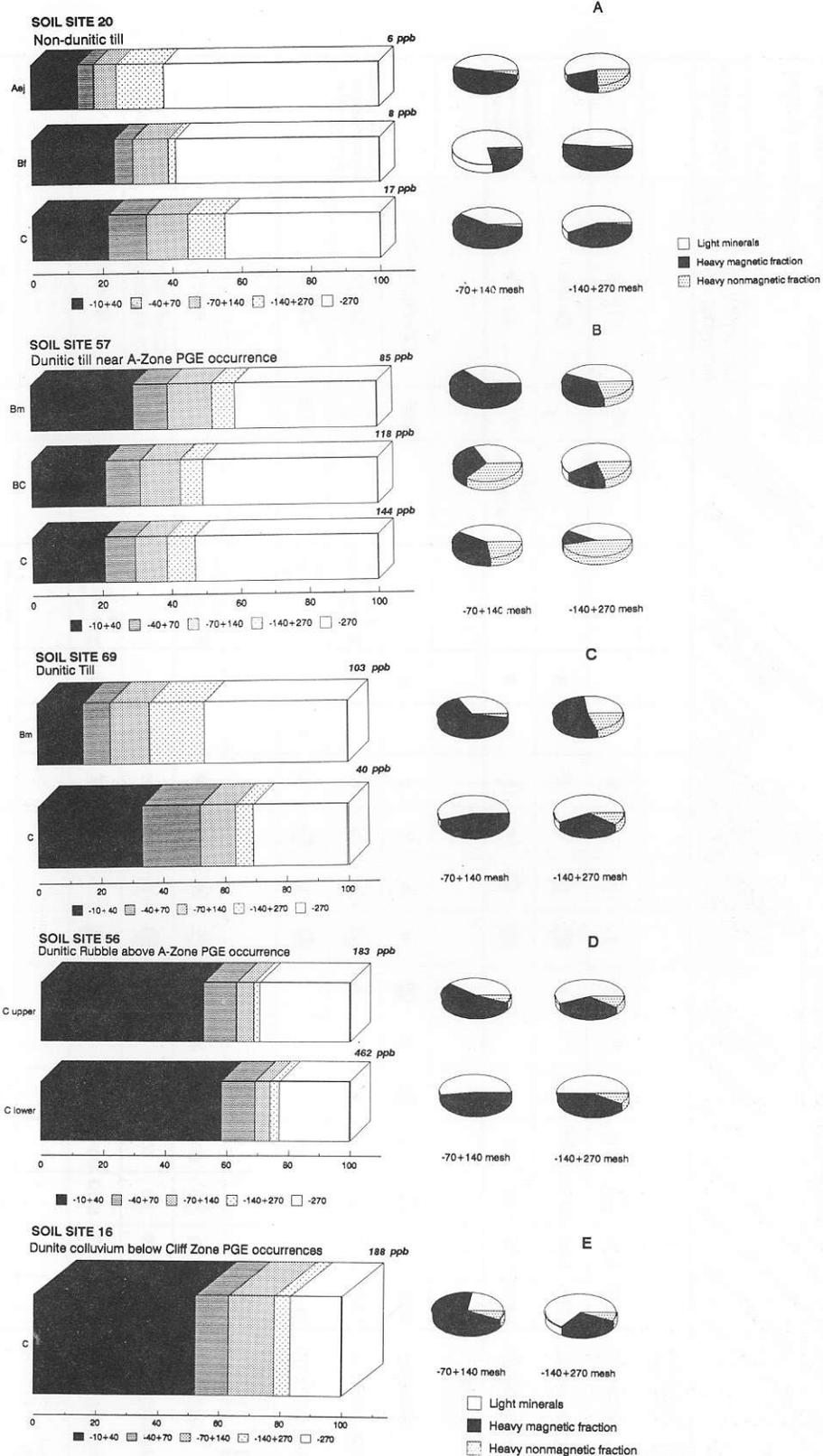


Figure 33. Contribution of individual size fractions to total platinum content (ppb; shown on right-hand side of each bar) of individual soil horizons developed in: (A) non-dunitic till; (B) dunitic till adjacent to the A zone PGE occurrence; (C) dunitic till; (D) dunitic rubble immediately above the A zone PGE occurrence; and (E) dunite colluvium beneath the Cliff zone PGE occurrences. Contributions of light, heavy magnetic and heavy nonmagnetic mineral fractions to the -70+140-mesh and -140+270-mesh fractions are shown in pie graphs to the right of corresponding horizon bars.

TABLE 11
 MINERALOGY OF HEAVY MINERAL CONCENTRATES FROM COLLUVIUM AND DUNITIC
 TILL-RUBBLE. HIGH ATOMIC NUMBER GRAINS DEFINED AS THOSE 22 OR GREATER

Site	Sample	Serpentine Colluvium		Vol. % of the Total Size Fraction		Vol. % of High Atomic No. Grains		Vol. % of Low Atomic No. Grains		Magnetite		Chromite		Fe oxides/sulphides		Zircon		Platinum-group Minerals		Pt content (ppb)		Chromite EDS Analysis Summary		Comments
		wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	
SITE 42	105	MAGNETIC	68.64	5.28	95-100	0-5	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	199	Cr > Fe	
		PARAMAGNETIC	12.03	0.93	85-90	10-15	X	●	●	●	●	●	●	●	●	●	●	●	●	●	●		Cr > Fe	
		NONMAGNETIC	19.33	1.49	30	70		●	●	●	●	●	●	●	●	●	●	●	●	●	●	1749	Cr > Fe	chromite crystals more abundant than fragments
SITE 16	31	MAGNETIC	66.67	1.71	95-100	0-5	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	855	Cr > Fe; Cr > Fe	
		PARAMAGNETIC	13.84	0.35	50	50	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		Cr > Fe	chromite crystals more abundant than fragments
		NONMAGNETIC	19.49	0.50	15	85		●	●	●	●	●	●	●	●	●	●	●	●	●	●	1128	Cr > Fe	
SITE 56	153	MAGNETIC	52.16	0.93	95-100	0-5	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	1857	Fe = Cr	
		PARAMAGNETIC	10.49	0.19	90	10		●	●	●	●	●	●	●	●	●	●	●	●	●	●		Cr > Fe (crystals) Cr > Fe (fragments)	primarily chromite
		NONMAGNETIC	37.35	0.67	5-10	90-95		●	●	●	●	●	●	●	●	●	●	●	●	●	●	3172	Cr > Fe	
SITE 57	156	MAGNETIC	67.15	5.59	95-100	0-5	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	359	Fe > Cr	
		PARAMAGNETIC	3.50	0.29	50	50	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		Cr > Fe	
		NONMAGNETIC	29.35	2.44	10	90		●	●	●	●	●	●	●	●	●	●	●	●	●	●	1371	Cr > Fe	only 4 chromites

TABLE 12
MINERALOGY OF HEAVY MINERAL CONCENTRATES FROM DUNITIC AND NON-DUNITIC TILLS
HIGH ATOMIC NUMBER RAINS DEFINED AS THOSE 22 OR GREATER

Site	Sample	Dunitic Till	Vol. % of the Total HMC	Vol. % High Atomic No. Grains	Vol. % Low Atomic No. Grains	Magnetite		Chromite		Fe oxides/sulphides		Zircon		Platinum-group Minerals		Pt content (ppb)	Chromite EDS Analysis Summary		Comments					
						Total	Irregular Crystals	Total	Fragments	Ilmenite	Other	Other	Other	Other	Other									
SITE 88	200	MAGNETIC	58.87	3.25	95-100	0-5	●	●	●							273	Fe > Cr	chromites are primarily crystals						
							●	●	●	●	●											chromite fragments more abundant than crystals		
							●	●	●	●	●													
SITE 73	216	MAGNETIC	56.80	6.35	80	20	●	●	●							474	Fe ≥ Cr	concentrations split from original; no duplicate						
							●	●	●	●	●													
							●	●	●	●	●													
SITE 20	40	MAGNETIC	41.58	2.24	95-100	0-5	●	●	●							517	Fe = Cr	concentrations split from original; no duplicate						
							●	●	●	●	●													
							●	●	●	●	●													
SITE 6	19	MAGNETIC	56.03	3.02	20	80	●	●	●							22	Cr > Fe	1 chromite only						
							●	●	●	●	●													
							●	●	●	●	●													
SITE 6	19	PARAMAGNETIC	21.03	0.88	95-100	0-5	●	●	●							143	Cr ≥ Fe							
							●	●	●	●	●													
							●	●	●	●	●													
SITE 6	19	NONMAGNETIC	74.17	3.10	10	90	●	●	●							33	Cr > Fe	10 chromites only						
							●	●	●	●	●													
							●	●	●	●	●													

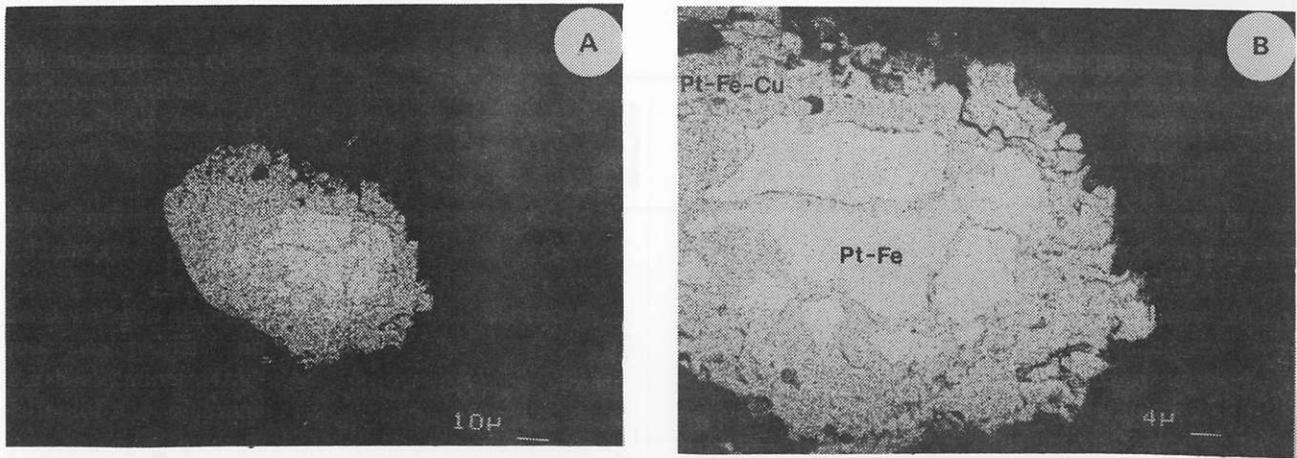


Plate 12. Discrete free platinum-group minerals. (A) Backscatter SEM image of free PGM grain (31PM-2) from paramagnetic heavy fraction of C-horizon colluvium beneath Cliff zone PGE occurrence. (B) Backscatter SEM image showing close-up of 31PM-2. A Pt-Fe-Cu alloy rim surrounds relict core of Pt-Fe alloy.

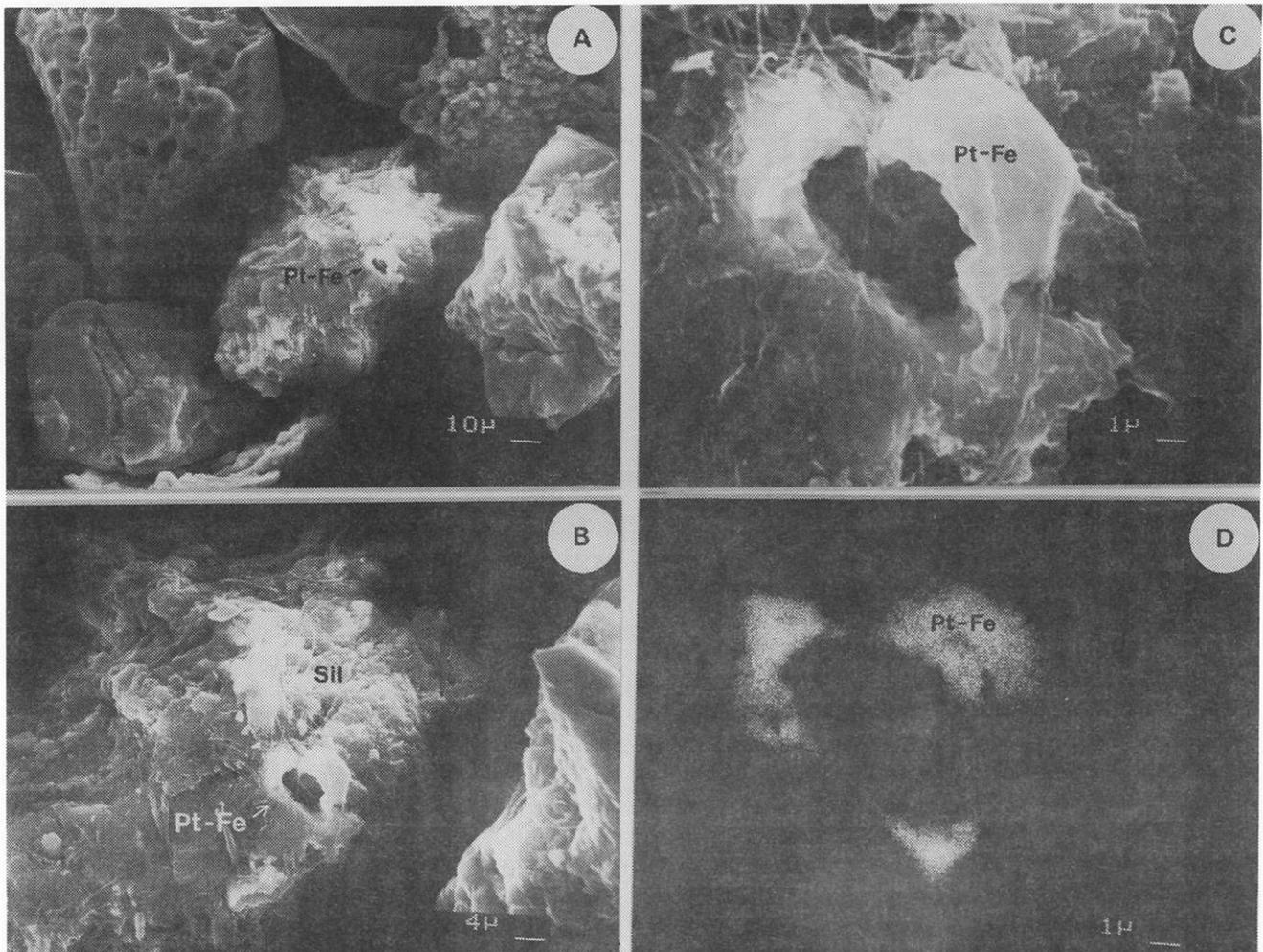


Plate 13. Platinum-group mineral inclusions in magnesium silicates.
 (A) SEM image of Pt-Fe alloy inclusion (156M-1) in magnesium silicate (talc?) grain with minor magnetite from magnetic heavy fraction of C-horizon till (site 57) near the A zone PGE occurrence.
 (B) SEM image showing close-up of Pt-Fe alloy inclusion 156M-1 in magnesium silicate (sil).
 (C) SEM image of Pt-Fe alloy inclusion 156M-1.
 (D) Backscatter SEM image of Pt-Fe alloy inclusion 156M-1. Brighter areas indicate locations of higher platinum content in the grain.

tive peak heights. The core, comprising about a third of the grain, is distinguished from the surrounding tulameenite in backscatter electron imaging as a slightly brighter area. Copper is virtually absent in the core compared to the surrounding tulameenite whereas the proportion of iron, as estimated from peak heights, is approximately the same in both the rim and core. The generally corroded appearance of the core suggests replacement of platinum-iron alloy by tulameenite and supports a low-temperature origin for this alloy as proposed by Nixon *et al.* (1990). The corroded outer rim of the grain suggests surface weathering.

PLATINUM-GROUP MINERAL INCLUSIONS IN MAGNESIUM SILICATES

A single PGM inclusion (156M-1) was found in a magnesium silicate grain from the magnetic fraction of the C-horizon of a dunitic till profile (site 57) about 70 metres south southwest of the A zone. The magnesium silicate is probably talc, based on magnesium and silicon peak heights from EDS analyses and from the X-ray diffraction determination of talc as the dominant magnesium-silicate constituent of the -270-mesh fraction. The talc grain (Plate 13) is approximately 100 by 65 microns and contains disseminated magnetite and possibly chromite.

The PGM inclusion is triangular and approximately 9 by 9 microns (Plate 13C). Part of the upper two-thirds exhibits the remnant of a partially shattered hexagonal crystal. Backscatter electron imaging (Plate 13D) and EDS analyses show it to be a platinum-iron alloy with very little copper or nickel, but considerable differences in the relative proportions of platinum and iron as estimated by peak heights. Three darker areas exhibit a relatively high iron composition relative to platinum, suggestive of a tetraferroplatinum (Pt_2Fe_2) composition. The lower portion of the crystal has a much darker backscatter image than the upper portion, and contains a much higher proportion of iron to platinum. It may be a more platinum-poor platinum-iron alloy. Conversely, the top left corner of the grain has a much higher proportion of platinum to iron, similar to that observed in the free platinum-group minerals grain 31PM-2. This portion is tentatively identified as isoferroplatinum (Pt_3Fe).

PLATINUM-GROUP MINERAL INCLUSIONS IN CHROMITE

Four PGM inclusions (Plates 14 and 15) were found in three soil chromite grains, all from near platinum-group element showings. Three PGM, including two within the same host grain, were found in chromite grains from both the magnetic and nonmagnetic heavy fractions of C-horizon dunitic rubble (site 56) directly above the A zone platinum occurrence. The fourth was found in chromite of the nonmagnetic heavy fraction from C-horizon colluvium (site 16) beneath the Cliff zone.

The two PGM in the magnetic fraction occur within a single chromite crystal (Plate 14), while the two in nonmagnetic fractions are inclusions within chromite fragments (Plate 15). EDS analyses of the PGM-bearing fragments indicate a $Cr > Fe$ composition similar to those of other fragments from these sites. EDS analyses of the PGM-bearing chromite crystal indicate a subequal $Cr > Fe$ composition similar to other chromite crystals at that site. Each of the PGM is located near the edge of its host chromite grain.

The four PGM inclusions have similar euhedral to subhedral habits. The largest is prismatic and measures approximately 3 by 1 microns (Plate 14C). The remaining three are much smaller, less than 2 microns in diameter, and more equigranular. The inclusions are platinum-iron-nickel-copper alloys tentatively identified as isoferroplatinum (Pt_3Fe). Nickel is present in small amounts and is a more important constituent than copper. Backscatter imaging of the largest inclusion (153M-1; Plate 14C) shows it to be compositionally uniform.

MAGNETITE

Magnetic heavy mineral concentrates usually contain 70 to 90 per cent magnetite (Tables 11 and 12). It commonly occurs as irregular, rough-surfaced anhedral aggregate grains of magnetite and silicate, and as smoother, more angular fragments. Silicates in other heavy fractions may contain a small proportion of magnetite inclusions. Magnetite crystals are less common: they do not occur at all sites but are most abundant in magnetic concentrates from non-dunitic till. The crystals are generally octahedral but are rarely well formed. Those in non-dunitic till are typically subhedral to anhedral. Euhedral magnetite crystals are most common in serpentinite colluvium (88-SC-105), where they exhibit prismatic cast marks more commonly seen on ilmenite grains in the heavy mineral concentrates.

In polished section magnetite is usually easily distinguishable from chromite by both its association with silicates and by the much more cracked and furrowed appearance of the surface. Fine magnetite, sometimes altered to hematite or limonite, frequently occurs together with magnesium-silicate as a thin coating on chromite crystals (Plate 16). Magnetite crystals are sometimes titaniferous, but their composition and distribution were not further investigated. No magnetite grains were found directly associated with PGM grains.

CHROMITE

Chromite is either the dominant constituent or a major constituent of the paramagnetic and nonmagnetic heavy mineral fractions. It is also a common to subordinate constituent of the magnetic fractions (Tables 11 and 12).

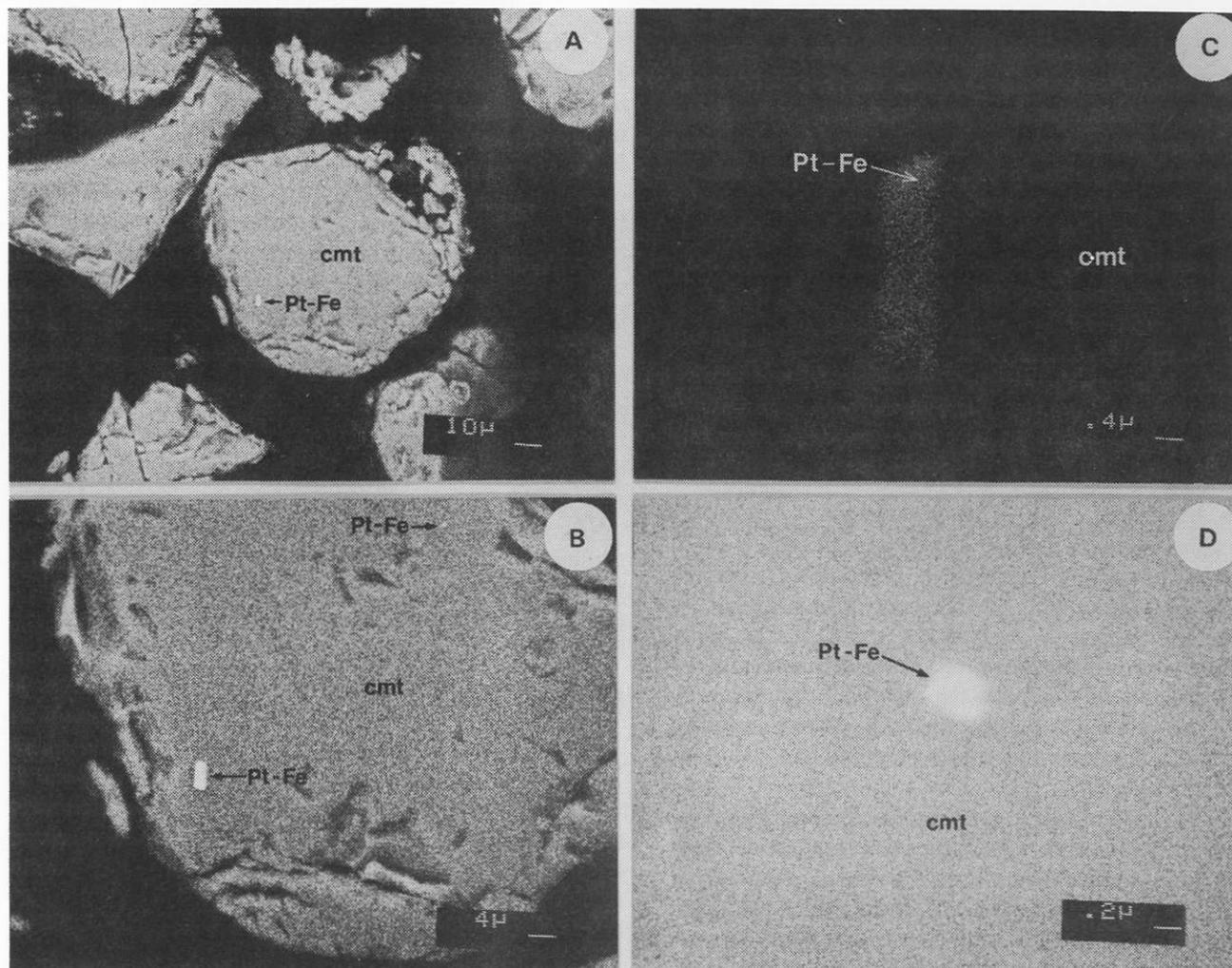


Plate 14. Platinum-group mineral inclusions in a chromite crystal.

(A) Backscatter SEM image of PGM-hosting detrital chromite crystal (cmt) from magnetic heavy fraction of C-horizon rubble (site 56) immediately above the A zone PGE occurrence.

(B) Backscatter SEM image showing location of two Pt-Fe alloy inclusions (153M-1, lower; and 153M-2, upper) in the same chromite crystal (cmt) as in (A) above.

(C) Backscatter SEM image showing close-up of Pt-Fe alloy inclusion 153M-1 in detrital chromite crystal (cmt). Note absence of compositional zoning.

(D) Backscatter SEM image showing close-up of Pt-Fe alloy inclusion 153M-2 in detrital chromite crystal (cmt).

Magnetic fractions from sites adjacent to the A zone platinum occurrence contain the greatest proportion of chromite (30 to 40%), while those from background dunitic and non-dunitic till sites have least (5 to 10%). Because the magnetic heavy mineral fraction typically accounts for more than 70 per cent of the heavy mineral content of many soils, absolute abundance of chromite in the magnetic fraction, where it is subordinate to magnetite, may exceed its abundance in the nonmagnetic fraction where it is the dominant mineral.

Chromite occurs as both discrete euhedral to subhedral crystals and anhedral fragments. Crystals (Plate 16) are typically octahedral to subrounded, frequently have a partial coating of fine magnetite and magnesium silicate, and may exhibit minor weathering or erosional features such as scaling or pockmarked faces and chipped corners. Fragments (Plate 17) are elongate to blocky, often wedge

or sliver-shaped grains with sharp corners and an apparent conchoidal fracture. The fragments usually have extremely smooth and unaltered surfaces compared to those of crystals.

Crystals are much more abundant than fragments in magnetic fractions whereas fragments are relatively more abundant in most nonmagnetic fractions (Tables 11 and 12). The relative proportion of fragments in the nonmagnetic fraction is very variable. They are dominant constituents (65 to 90%) of the heavy metallic component at sites adjacent to both A zone and Cliff zone platinum occurrences, but are common to trace constituents of most other nonmagnetic fractions. They are absent from nonmagnetic fractions at two sites in non-dunitic till and background dunitic till. It is stressed that while fragments are **relatively** more important than crystals in nonmagnetic fractions, fragments are more **numerically** abun-

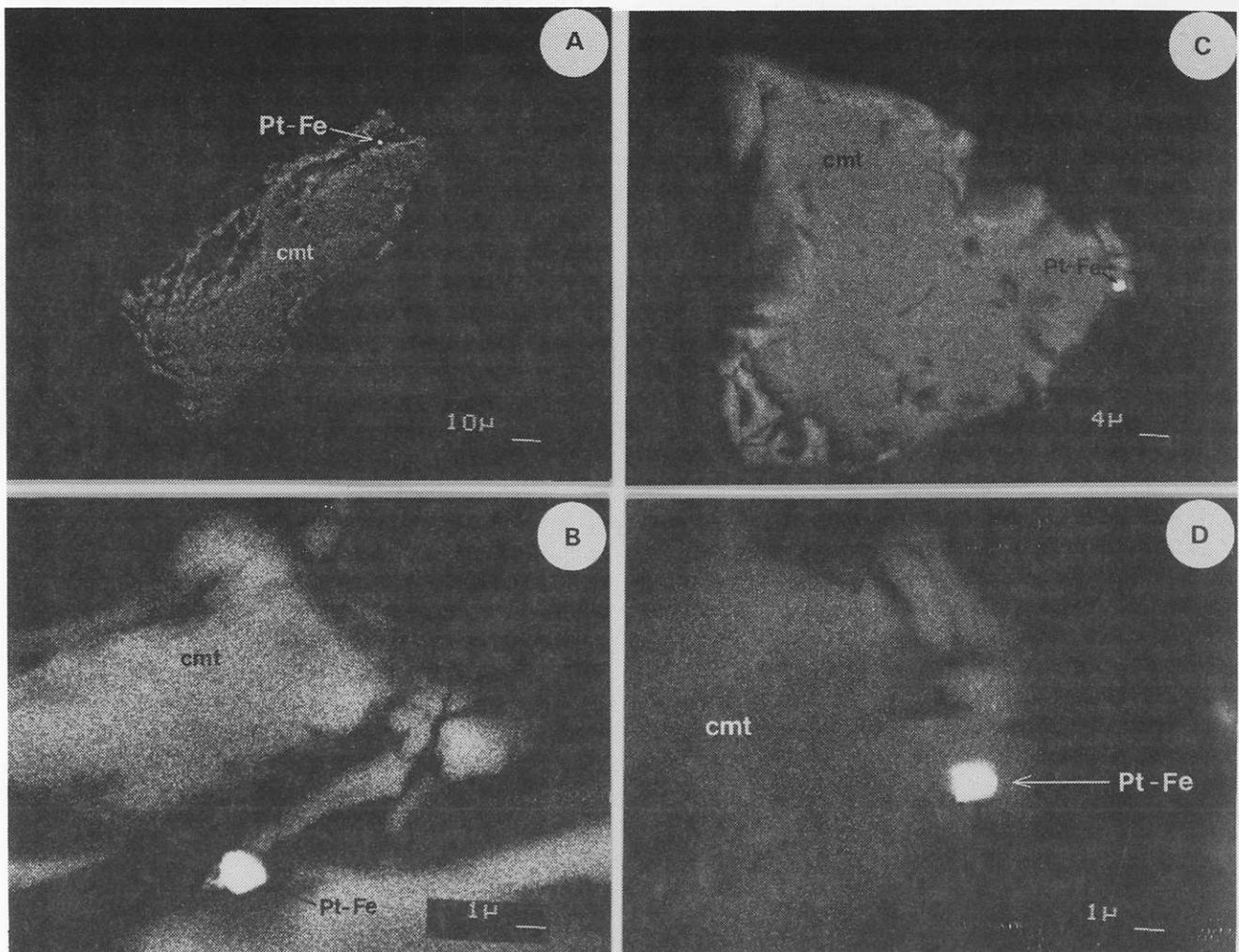


Plate 15. Platinum-group mineral inclusions in chromite fragments.

(A) Backscatter SEM image of PGM-hosting detrital chromite fragment (cmt) from nonmagnetic heavy fraction of C-horizon rubble (site 56) immediately above the A zone PGE occurrence.

(B) Backscatter SEM image showing close-up of Pt-Fe alloy inclusion from A. (153NM-1) in detrital chromite fragment (cmt).

(C) Backscatter SEM image of PGM-hosting detrital chromite fragment (cmt) from nonmagnetic heavy fraction of C-horizon colluvium (site 16) beneath Cliff zone PGE occurrence.

(D) Backscatter SEM image showing close-up of Pt-Fe alloy inclusion from C. (31NM-1) in detrital chromite fragment (cmt).

dant in the magnetic fractions than in the nonmagnetic fractions.

Preliminary EDS analysis indicated that chromite fragments are systematically more chromium-rich than crystals. Because of the close association of PGM with the chromites, composition of chromite crystals and fragments from five soil C-horizons was determined quantitatively by electron microprobe (EMP) analysis. Results are plotted on faces of the spinel prism (Stevens, 1944) in Figures 34 and 35.

Analyses of grain cores (Table 13) and edges (Table 14) are almost identical. There are, however, considerable compositional differences between crystals and fragments. Mean Cr_2O_3 content of crystals ranges from 35.23 to 39.54 weight per cent compared to a range of 41.07 to 45.83 weight per cent for fragments. Ferric ion concentra-

tions, recalculated from total Fe_2O_3 on the basis of the spinel structural formula, show the opposite trend with mean Fe^{3+} (as Fe_2O_3) content ranging from 21.63 to 26.25 weight per cent in crystals to 17.54 to 20.48 weight per cent in fragments. Mean Fe^{2+} content ranges from 23.80 to 26.26 weight per cent FeO in crystals and from 21.65 to 24.11 weight per cent FeO in chromite fragments from paramagnetic fractions at sites 6, 57 and 69. However, the FeO content of fragments in the nonmagnetic fractions of sites 16 and 56 is considerably less (range of means: 17.17 to 18.75 wt% FeO). $\text{Cr}/\text{Fe}_{\text{tot}}$ ratios range from 0.94 to 1.32 in fragments to 0.68 to 0.87 in iron-rich crystals.

Manganese concentrations follow iron in being greater in crystals than in fragments. Conversely, magnesium content of crystals is less (range of means: 4.15 to

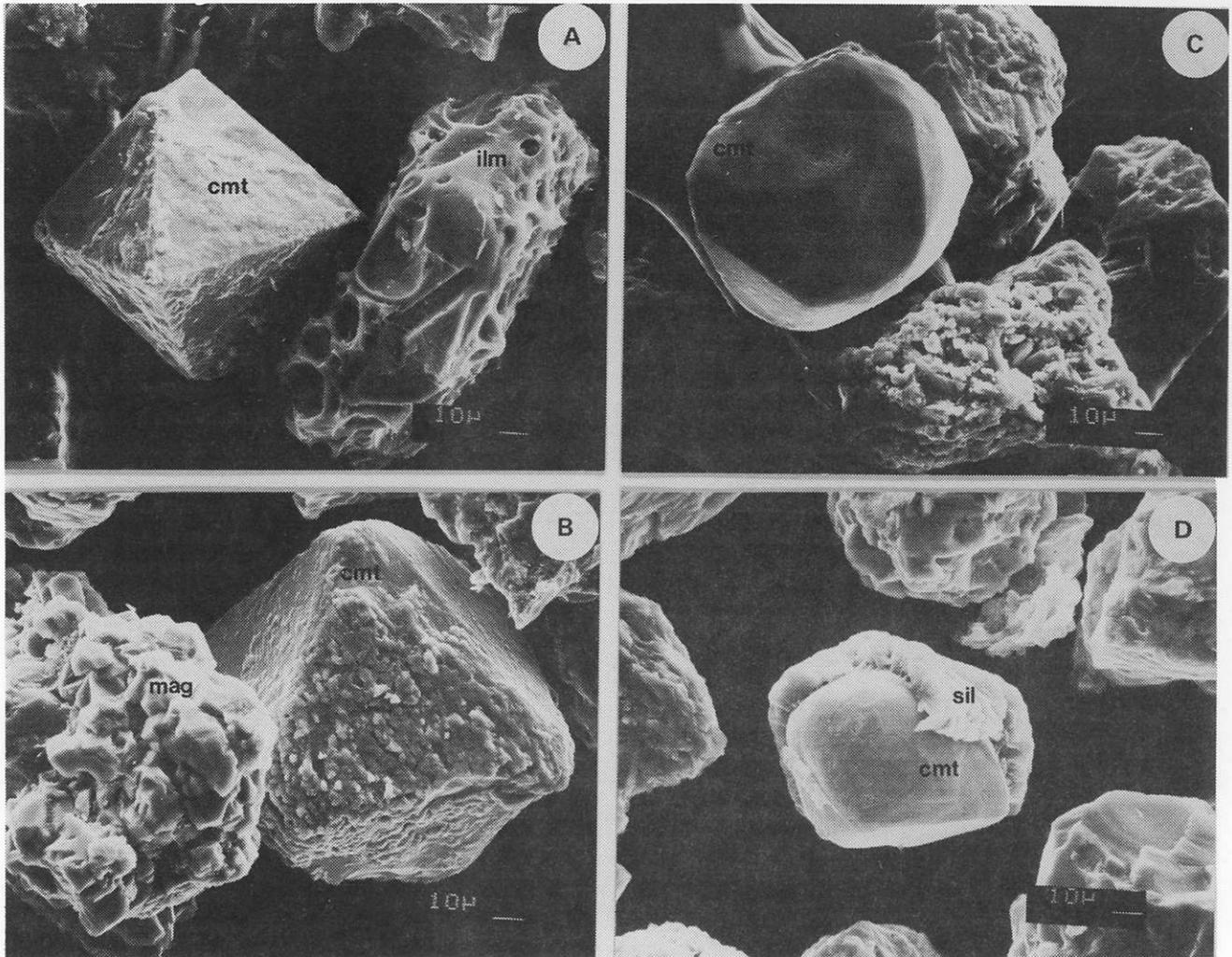


Plate 16. Morphology of chromite crystals.

(A) SEM image of euhedral chromite crystal (cmt), with adhering magnesium silicate, beside an ilmenite (ilm) grain. Dunitic colluvium (site 16), 88-SC-31, paramagnetic fraction.

(B) SEM image of euhedral chromite crystal (cmt), with adhering magnetite-silicate, beside a magnetite-silicate (mag) aggregate grain. Non-dunitic till (site 20), 88-SC-40, paramagnetic fraction.

(C) SEM image of subhedral chromite crystal (cmt). Non-dunitic till (site 20), 88-SC-40, magnetic fraction.

(D) SEM image of subhedral chromite crystal (cmt) enveloped in magnesium-silicate (sil). Non-dunitic till (site 6), 88-SC-19, paramagnetic fraction.

5.78 wt% MgO) than in associated fragments with the difference being greater if the fragments are from non-magnetic fractions (range of means: 9.07 to 10.19 wt% MgO) rather than from paramagnetic suites (range of means: 5.59 to 7.12 wt% MgO). Concentrations of aluminum and titanium in crystals and fragments are similar.

Based on t-tests, the compositional differences between chromite crystals and fragments are statistically significant ($P_{0.05}$) for chromium content at all sites and for magnesium at four out of five.

ILMENITE

Ilmenite, identified on the basis of iron and titanium EDS peaks, occurs as subhedral crystals and as poorly formed subhedral to anhedral grains and is a common to subordinate constituent of paramagnetic and, in some cases, nonmagnetic heavy concentrates (Tables 11 and 12). It is most common in paramagnetic fractions from colluvium, where it comprises 45 per cent of the metallic heavy grains in serpentine colluvium (site 42) and 35 per cent of that fraction in colluvium beneath the Cliff zone platinum occurrences (site 16). However, it is relatively uncommon adjacent to the A zone and has no apparent association with PGM.

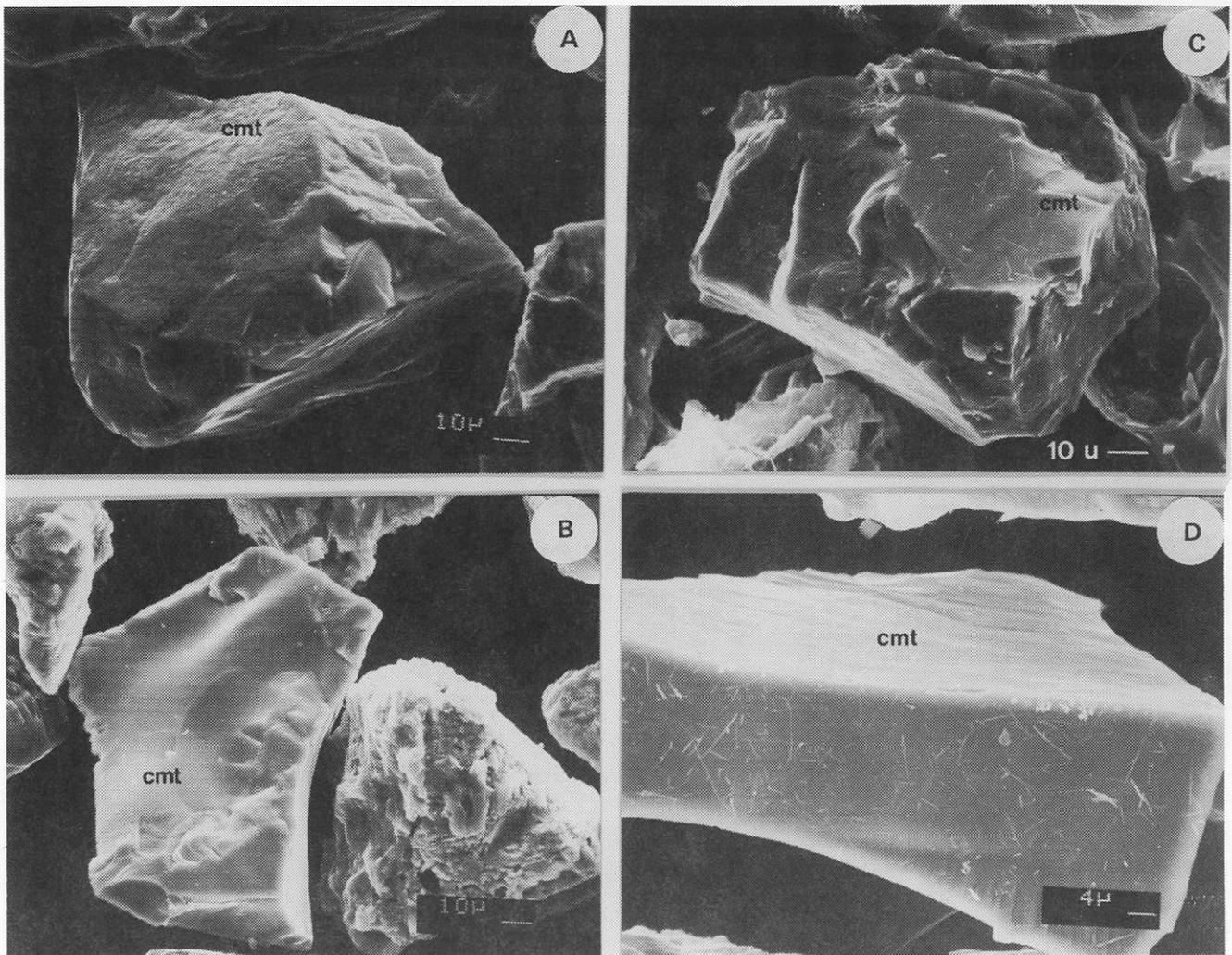


Plate 17. Morphology of chromite fragments.

- (A) SEM image of anhedral chromite fragment (cmt). Dunitic till (site 69), 89-SC-200, paramagnetic fraction.
 (B) SEM image of anhedral chromite fragment (cmt). Non-dunitic till (site 6), 88-SC-19, paramagnetic fraction.
 (C) SEM image of anhedral chromite fragment (cmt) from immediately above the A zone PGE occurrence. Dunitic rubble (site 56), 88-SC-153, nonmagnetic fraction.
 (D) SEM image of anhedral chromite fragment (cmt) from immediately above the A zone PGE occurrence. Dunitic rubble (site 56), 88-SC-153, paramagnetic fraction.

OTHER MINERALS

Other minerals observed during scanning electron microscopy examination of heavy mineral concentrates include iron oxides and oxidized sulphides, zircon, rare-earth element minerals and a uranium-niobium-yttrium-potassium mineral. A variety of metallic contaminants are also present.

Iron oxides and oxidized sulphides are most abundant in nonmagnetic concentrates. They are the dominant constituents of this fraction at non-dunitic and some dunitic till sites, but are only subordinate constituents of colluvium and dunitic till-rubble near known platinum-group element showings (Tables 11 and 12). They occur as anhedral grains and masses of iron oxide and as oxidized anhedral to euhedral pyrite pseudomorphs. These

often contain irregular-shaped cores of relict pyrite, visible in polished section, and are particularly common in background dunitic till (sites 69 and 73) and in non-dunitic till at site 20. Pyrite pseudomorphs may show surface striations or etch pits. A single irregular grain of iron-nickel sulphide, possibly pentlandite, was observed in the polished section of a nonmagnetic concentrate from serpentine colluvium (88-SC-105).

Zircons occur as trace to subordinate constituents of nonmagnetic concentrates. They are most abundant in a non-dunitic till (site 6). Most are euhedral but a single well-rounded grain was observed in A zone dunitic till (site 57) from the summit of Grasshopper Mountain.

A variety of rare minerals were found in polished sections of concentrates from non-dunitic till. An 8 by 4-

TABLE 13
COMPOSITION OF CORES OF DETRITAL CHROMITE CRYSTALS (MAGNETIC HEAVY FRACTION) AND FRAGMENTS (PARAMAGNETIC AND NONMAGNETIC HEAVY FRACTIONS) FROM C-HORIZON SOILS

	19 (n=9)	200 (n=9)	156 (n=15)	153 (n=15)	31 (n=15)
CRYSTALS					
SiO ₂	0.00	0.00	0.07	0.01	0.01
Al ₂ O ₃	6.70	5.99	5.88	6.14	6.96
TiO ₂	0.71	1.02	0.73	0.65	0.67
Cr ₂ O ₃	36.60	35.23	36.17	36.59	39.54
Fe ₂ O ₃	24.65	26.25	25.44	25.04	21.63
FeO	24.86	25.82	26.26	24.73	23.80
MnO	0.65	0.71	0.49	0.44	0.45
MgO	4.53	4.47	4.15	5.00	5.78
Total	98.70	99.49	99.19	98.60	98.84
Cr/Fe	0.74	0.68	0.70	0.74	0.87
FRAGMENTS					
SiO ₂	0.00	0.00	0.01	0.01	0.01
Al ₂ O ₃	7.10	7.20	5.98	6.57	6.93
TiO ₂	0.66	0.57	0.60	0.64	0.61
Cr ₂ O ₃	41.07	43.81	42.10	42.86	45.83
Fe ₂ O ₃	19.92	17.92	20.48	20.20	17.54
FeO	23.49	21.65	24.11	18.75	17.17
MnO	0.52	0.51	0.36	0.24	0.23
MgO	5.92	7.12	5.59	9.07	10.19
Total	98.68	98.78	99.23	98.34	98.51
Cr/Fe	0.95	1.11	0.94	1.10	1.32

TABLE 14
COMPOSITION OF EDGES OF DETRITAL CHROMITE CRYSTALS (MAGNETIC HEAVY FRACTION) AND FRAGMENTS (PARAMAGNETIC AND NONMAGNETIC HEAVY FRACTIONS) FROM C-HORIZON SOILS

	19 (n=9)	200 (n=9)	156 (n=15)	153 (n=15)	31 (n=14)
CRYSTALS					
SiO ₂	0.00	0.00	0.07	0.00	0.01
Al ₂ O ₃	6.49	5.77	5.83	6.02	6.72
TiO ₂	0.70	0.92	0.70	0.67	0.67
Cr ₂ O ₃	36.15	34.45	35.74	35.80	39.12
Fe ₂ O ₃	24.29	27.19	25.74	25.63	22.18
FeO	25.55	25.54	26.86	25.05	24.00
MnO	0.83	0.77	0.59	0.60	0.57
MgO	4.18	4.44	3.67	4.63	5.54
Total	98.19	99.08	99.20	98.40	98.81
Cr/Fe	0.73	0.65	0.68	0.71	0.85
FRAGMENTS					
SiO ₂	0.00	0.00	0.01	0.01	0.00
Al ₂ O ₃	6.94	7.25	5.97	6.63	6.93
TiO ₂	0.71	0.58	0.60	0.61	0.61
Cr ₂ O ₃	40.24	43.66	41.05	42.83	45.54
Fe ₂ O ₃	20.35	18.16	20.72	19.87	17.51
FeO	23.78	21.57	25.81	18.64	17.21
MnO	0.58	0.51	0.36	0.26	0.23
MgO	5.59	7.22	4.42	9.02	10.07
Total	98.19	98.95	98.94	97.87	98.10
Cr/Fe	0.91	1.10	0.88	1.11	1.31

Note: Sample 19, non-dunitic till; 200, dunitic till; 156, dunitic till near A-zone PGE mineralization; 153, dunitic till-rubble above A zone; 31, colluvium beneath Cliff zone PGE mineralization.

Note: Sample 19, non-dunitic till; 200, dunitic till; 156, dunitic till near A-zone PGE mineralization; 153, dunitic till-rubble above A zone; 31, colluvium beneath Cliff zone PGE mineralization.

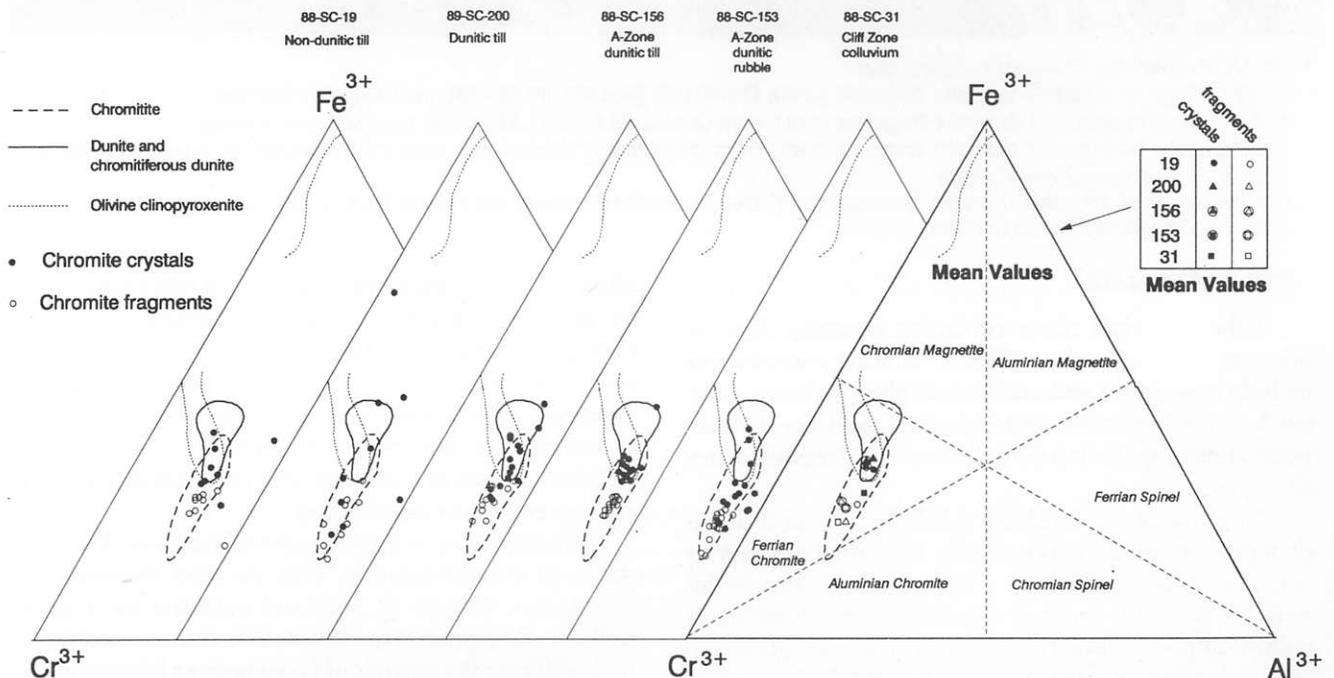


Figure 34. Fe-Cr-Al spinel composition plot of detrital chromite crystals (n=63) and fragments (n=57) from various C-horizon soils and from some major rock types of the Tulameen Ultramafic Complex (adapted from Nixon *et al.*, 1990; Stevens, 1944).

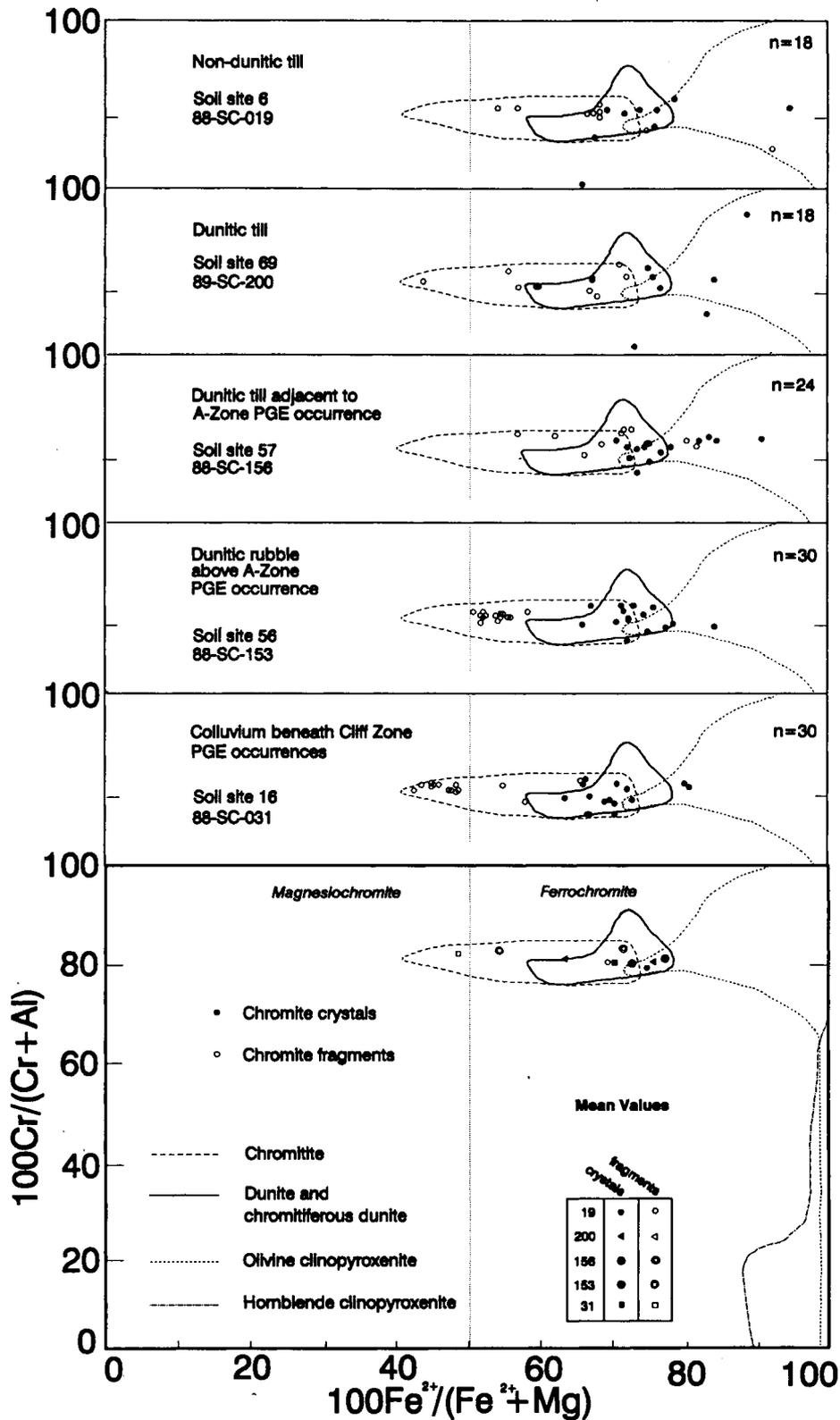


Figure 35. Plot of $\text{Fe}^{2+}/(\text{Fe}^{2+} + \text{Mg}^{2+})$ versus $\text{Cr}/(\text{Cr} + \text{Al})$ for detrital chromite crystals (n=63) and fragments (n=57) from various C-horizon soils and from some major rock types of the Tulameen Ultramafic Complex (adapted from Nixon *et al.*, 1990).

micron inclusion of an unidentified uranium-niobium-yttrium-potassium mineral was found in an ilmenite grain from a paramagnetic concentrate (site 6). Two discrete cerium-bearing rare-earth element minerals were found within the nonmagnetic fraction of the same sample. One is a cerium-thorium-lanthanum-phosphorus mineral; the

other an iron-calcium-cerium-lanthanum silicate. A third rare-earth element mineral was found in the nonmagnetic concentrate of the other non-dunitic till sample (site 20). It occurred as several small inclusions of an unidentified cerium-lanthanum mineral within an apatite grain.

DISCUSSION

CHAPTER 4

In this section the mineralogical association of platinum, and its distribution and dispersion from the platinum-group element occurrences on Grasshopper Mountain are discussed. Recommendations for design and interpretation of geochemical exploration surveys are then presented. It is stressed that these recommendations are directly applicable only to exploration for similar, chromiferous platinum deposits in glaciated terrains having comparable geomorphic and pedological conditions to those on Grasshopper Mountain. Elsewhere, further testing would be required to assess the validity of both the dispersion model and related recommendations for exploration.

DISTRIBUTION OF PLATINUM IN SOILS

OVERVIEW

Platinum content of Grasshopper Mountain soils is strongly dependent on the amount of contained dunite as estimated by their magnesium content (Tables 2 and 3, Figure 15). The mean concentration of 88 ppb platinum in active colluvium is close to the mean contents of 48 to 180 ppb reported by St. Louis *et al.* (1986) for dunite and serpentized dunite.

Lower platinum contents of dunitic till (36 ppb) and non-dunitic till (8 ppb) compared to colluvium are a result of their lower content of dunite. The high magnesium content of tills from the western part of the main study area (16.51%) and A zone (13.84%) suggests their local derivation. Conversely, the lower magnesium content (5.66% MgO) of till in the eastern part of the main study area indicates less mixing with dunitic material. Based on the south-southwesterly direction of ice movement, the non-dunitic till is probably largely material derived from rock units to the north or northeast that has been transported over the eastern boundary of the dunite (Figure 1). Similarly, on the western side of the dunite, dunitic till has been transported west beyond the boundary of the dunite core (Figure 14).

The terms "dunitic till" and "non-dunitic till" are not absolute and the range of major element compositions suggests a degree of till mixing. Thus high calcium and sodium contents in dunitic till compared to those of colluvium suggest that dunitic till contains some non-dunitic, exotic component. Similarly, the mean chromium content of non-dunitic till (0.07%) indicates at least a minor dunite component as the chromium content of non-dunitic soils is usually less than 100 ppm (Brooks, 1987). The

abundance of serpentine, talc, vermiculite and chromite in dunitic tills compared to the predominance of quartz, plagioclase, hornblende and chlorite in non-dunitic tills confirms the interpretation of till origin based on major element geochemistry.

Chromium has a similar distribution to platinum and magnesium because of the association of disseminated chromite and massive chromitite segregations with the dunite (Findlay, 1963; St. Louis *et al.*, 1986; Nixon *et al.*, 1990). The mean chromium content of Grasshopper Mountain colluvium (2257 ppm) and dunitic till (1368 ppm) is within the range of 1000 to 5000 ppm chromium found in soils developed on ultramafic rocks (Kabata-Pendias and Pendias, 1984; Brooks, 1987). St. Louis *et al.* (1986) report the mean chromium content of Grasshopper Mountain dunite and serpentized dunite to be 2902 ppm.

The relationship between platinum and unusually high concentrations of arsenic and gold is less clear. Arsenic values (median 15.8 ppm) in colluvium may be partly attributed to the mechanical dispersion of sperrylite (PtAs₂), but equally high arsenic concentrations are found in soils on all parent materials. Nicola Group rocks generally contain less than 4 ppm arsenic, but dunite and chromitite have very erratic arsenic contents ranging from 1 to 26 ppm (G. Nixon, personal communication, 1989). Gold concentrations of 9 to 37 ppb in serpentinite colluvium and beneath platinum-chromitite occurrences are only slightly higher than lithochemical results of 4.1 ppb and 8.2 ppb reported by St. Louis *et al.* (1986) for serpentinite and chromitite, respectively.

Data on the platinum content of soils associated with platinum mineralization elsewhere are very limited. Fletcher (1989) reported 8 to 67 ppb in soils on pyroxenites in the Franklin Camp north of Grand Forks and 2 to 10 ppb on serpentized peridotites at Scottie Creek near Cache Creek. In other occurrences, 10 to 30 ppb platinum was found in soils and 30 to 180 ppb in pan concentrates from soils associated with the Unst ophiolite (Gunn, 1989); Fuchs and Rose (1974) reported up to 150 ppb in soils near a chromitite showing in the Stillwater Complex; and Wood and Vlassopoulos (1990) reported up to 1600 ppb, but typically less than 50 ppb, near platinum-copper-nickel prospects in Quebec.

VARIATIONS OF PLATINUM DISTRIBUTION WITH DEPTH IN MINERAL SOIL

EFFECTS OF GLACIAL DISPERSION

The total platinum content and concentrations in different size and density fractions of dunitic till-rubble adjacent to known mineralization at the A zone usually increases with depth (Figure 24). Conversely, at sites on dunitic tills farther from known platinum occurrences, platinum content of soils and of the magnetic and non-magnetic heavy mineral fractions may increase up the profile.

At some sites increased platinum concentrations in the upper part of soil profiles clearly result from platinum-rich colluvium overlying dunitic till in a composite soil profile. This is the case at site 34 (Figure 32, Plate 3). More generally, however, the increase in platinum concentrations down profiles close to platinum occurrences and up profiles at more distal sites is consistent with the general models of clastic glacial dispersion plumes proposed by Drake (1983) and Miller (1984). Here, the plumes can be envisaged as three-dimensional geochemical features in which dunitic and/or chromititic material, entrained at the base of the glacier as lodgement till, becomes mixed and diluted with exotic material as it rises from the bedrock toward the till surface. Thus, there is a

gap between the subcrop location of a geochemically distinct unit and the appearance of the related geochemical anomaly at the surface (Figure 36).

Platinum concentrations increase with depth in the non-dunitic till profiles at site 6 and 20 on the eastern side of the main study area. This is particularly pronounced at site 20 with soil platinum concentrations of 3 to 10 ppb in the Ae_j and Bf-horizons versus 14 to 77 ppb in the C-horizon. These increases probably result from the basal part (now the C-horizon) of a non-dunitic till, derived from the rock units east of the dunite core, becoming increasingly mixed with dunitic material as it moves over the dunite; the abrupt downprofile increases in platinum concentration mark the subsurface top of the dunite dispersion plume.

On a more detailed scale within the dunitic till, platinum concentrations will depend on: local source-rock lithology, in particular, whether the till is derived from comminution of dunite containing only ubiquitous disseminated chromites, or contains an additional component from erosion of platinum-rich chromitites; and the extent of intermixing and dilution with exotic material. Because the chromitite segregations in the dunite are small (the largest in the Cliff zone is only 1 metre long) it is likely that fragments of platinum-rich chromitite will be

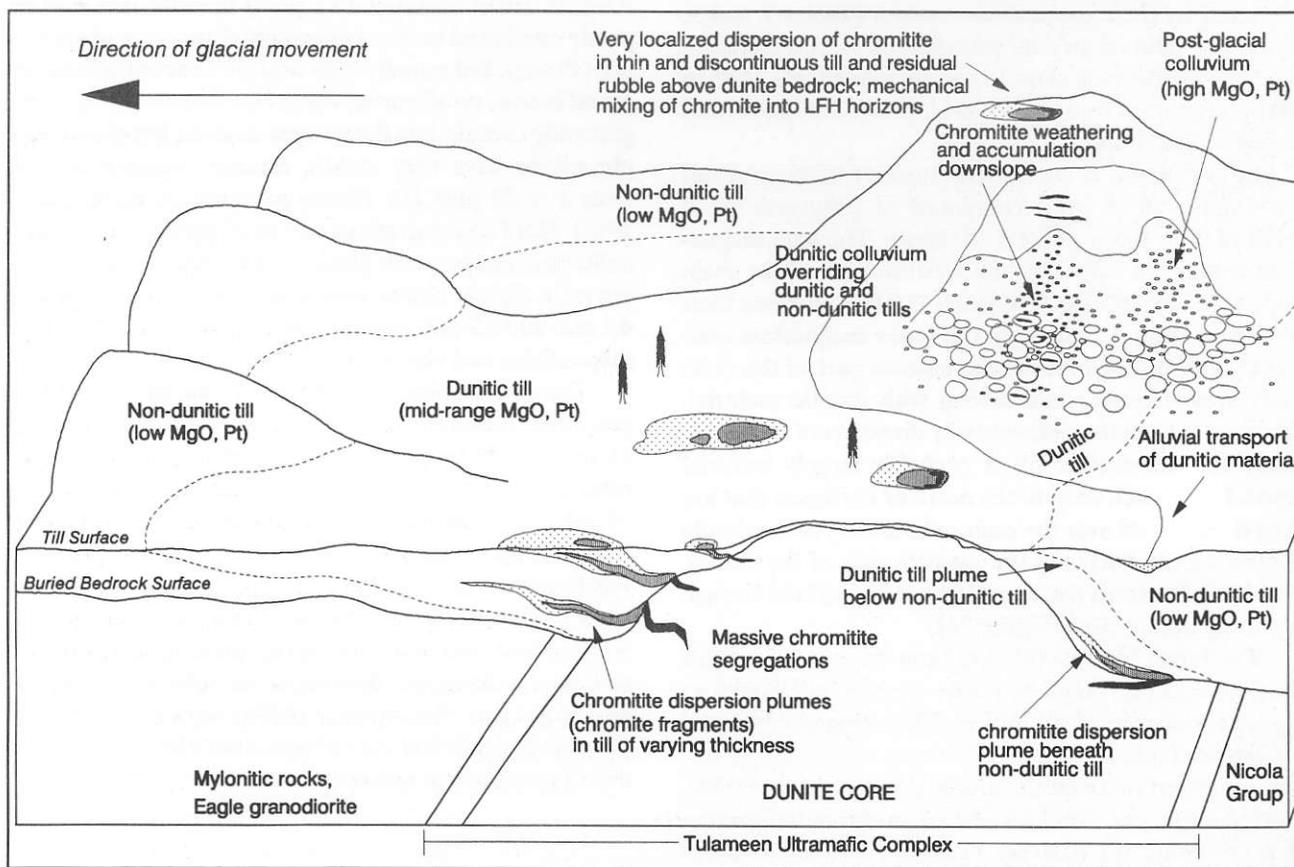


Figure 36. Idealized model for mechanical dispersion of platinum on Grasshopper Mountain.

diluted rapidly by more effective glacial abrasion of the softer dunite. Dispersion trains of chromitite fragments are therefore unlikely to be found far from their bedrock source. It follows that strongly anomalous platinum concentrations may only reach the till surface in areas of thin overburden (Figure 36). This may account for the thin dunitic till-rubble at the A zone having greater platinum and chromium concentrations than the dunitic tills of the main study area.

POSTGLACIAL PROCESSES

The platinum content of active dunite and serpentine colluvium below the Cliff zone is most constant with depth (Figure 25). This is consistent with the absence of genetic horizons and constantly evolving nature of active colluvium. However, at some sites (e.g., site 34; Figure 32) burial of till by platinum-rich colluvium prior to vegetation of the area has resulted in near-surface platinum concentrations that are two to six times that of the underlying till. This is not observed at A zone soil site 57 because high platinum concentrations in the colluvial surface horizon are similar to those in the underlying till.

Pedogenic processes may also influence distribution of platinum in soil profiles. However, there is little evidence that this has occurred to any significant extent in soils on Grasshopper Mountain. This can be attributed to rather weak profile development as a consequence of: the immaturity of the soils and the rather dry climate, and the resistate character of both the PGM minerals and their host chromite grains. Although pedogenic processes do not appear to have redistributed platinum between horizons, the proportion contributed by the fine fractions tends to increase upwards in some till and rubble profiles (Figure 33). This is probably a result of disintegration of mineral grains during weathering, releasing PGM and PGM-bearing silicate and chromite grains to finer size fractions.

PLATINUM RESIDENCE SITES IN MINERAL SOILS

Despite being somewhat erratic, platinum concentrations in all five size fractions of soils on tills and colluvium are rather similar and there is no evidence (except perhaps in the coarser fractions of dunitic rubble close to the bedrock at site 56) that platinum is strongly partitioned into any particular size fraction (Figure 25). However, because of the considerably greater amounts of silt and clay in till compared to colluvium (Table 1), about half the total platinum content of till is contributed by the -270-mesh fraction versus only about 20 per cent for colluvium and rubble.

DiLabio (1988) reported extremely erratic platinum distribution between size fractions of gossanous material from the Ferguson Lake nickel-copper sulphide occurrence in the Northwest Territories. Variations from less than 10 ppb to 100-1000 ppb platinum in adjacent frac-

tions were attributed to the presence of erratic micronuggets hosted in coarser grains and also present as fine free grains. Based on our scanning electron microscopy studies, the more uniform distribution of platinum in Grasshopper Mountain soils probably reflects the importance of the very fine (~1 micron) platinum-iron alloys that occur as both free grains and as inclusions within chromite grains that are themselves included in larger serpentine and talc particles. The presence of very fine PGM in fine chromite inclusions in silicates also accounts for the presence of significant concentrations of platinum in the light mineral fractions.

Within the heavy minerals, partitioning of platinum into the magnetic and nonmagnetic fractions is related to distance from the source and source-rock mineralogy. This is depicted schematically in Figure 37. Sites on both dunitic and non-dunitic till distal to known mineralization contain 10 to 20 times more platinum in the magnetic than the nonmagnetic fraction whereas till, rubble and colluvium sites close to known platinum occurrences have high platinum contents and a much greater proportion in the nonmagnetic fraction. This clearly reflects the rather limited dispersion of material from platinum-rich chromitite segregations versus the platinum content of the dunite as a whole. Partitioning of platinum between the magnetic and nonmagnetic fraction is closely related to the composition and morphology of the associated chromite grains. This is considered in the next section.

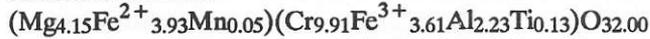
COMPOSITION OF SOIL CHROMITES

As described above, the distribution of platinum in soils is closely related to abundance, morphology and composition of detrital chromite grains. This has important implications for both the choice of analytical fractions for determination of platinum and for interpretation of the resulting geochemical patterns. The character of the detrital chromite grains is therefore considered in some detail.

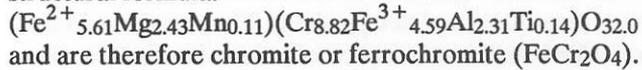
Based on the data of Nixon *et al.* (1990), chromites from major rock units of the Tulameen Complex plot in the ferric chromite field on the Fe^{3+} -Cr-Al ternary diagram of the spinel prism (Figure 34). With few exceptions, detrital soil chromites analyzed in this study also plot in the ferric chromite field. Within this field chromite fragments almost always fall in the relatively chromium-rich chromitite-related field of Nixon *et al.* (1990). Composition of chromite crystals shows greater scatter but is generally within the field of more iron-rich chromites associated with dunite and, to a lesser extent, olivine clinopyroxenite.

Plotted on the Cr-Al versus Fe^{+2} -Mg face of the spinel prism (Figure 35) chromite fragments again plot in the chromitite-related field of Nixon *et al.* (1990). They are more magnesium-rich than the associated crystals with the most magnesium-rich, from the nonmagnetic

fraction of colluvium beneath the Cliff zone, having the structural formula:



This places these fragments in the magnesium-rich chromite series end-member magnesiochromite ($MgCr_2O_4$), also known as picrochromite. Associated detrital crystals from the magnetic fraction have the structural formula:



and are therefore chromite or ferrochromite ($FeCr_2O_4$). The separation of crystal and fragment compositions is shown in Figure 35, where a $Fe^{2+}/(Fe^{2+} + Mg^{2+})$ cation ratio of 0.5 in the A site has been used to separate the magnesiochromite and chromite end members of Deer *et al.* (1962).

Fragments from the nonmagnetic fraction of dunitic rubble above the A zone form a tight compositional group close to, but not in, the magnesiochromite field (Figure 35). In this respect, it may be significant that the magne-

sium-rich Cliff zone chromitite horizons contain massive to semimassive segregations, whereas the A zone is the most widespread occurrence of wispy chromite lenses and coarsely disseminated grains (Bohme, 1987, 1988). Detrital fragments from sites unrelated to known mineralization have similar chromium contents (Table 13) but are even less magnesium rich. Detrital crystals from the magnetic fractions have greater compositional scatter than associated fragments and are invariably ferrochromites.

The compositional similarity of the detrital chromite fragments to the analyses of massive chromitite reported by Irvine (1967) and Nixon *et al.* (1990) strongly suggest that the fragments are derived from these chromitites (Table 15, Figures 34 and 35). This is supported morphologically, by the absence of crystal habit, and spatially, by the increased abundance of chromite fragments close to the occurrences of massive chromitite (Table 11). Conversely, the subhedral to euhedral crystal habit and com-

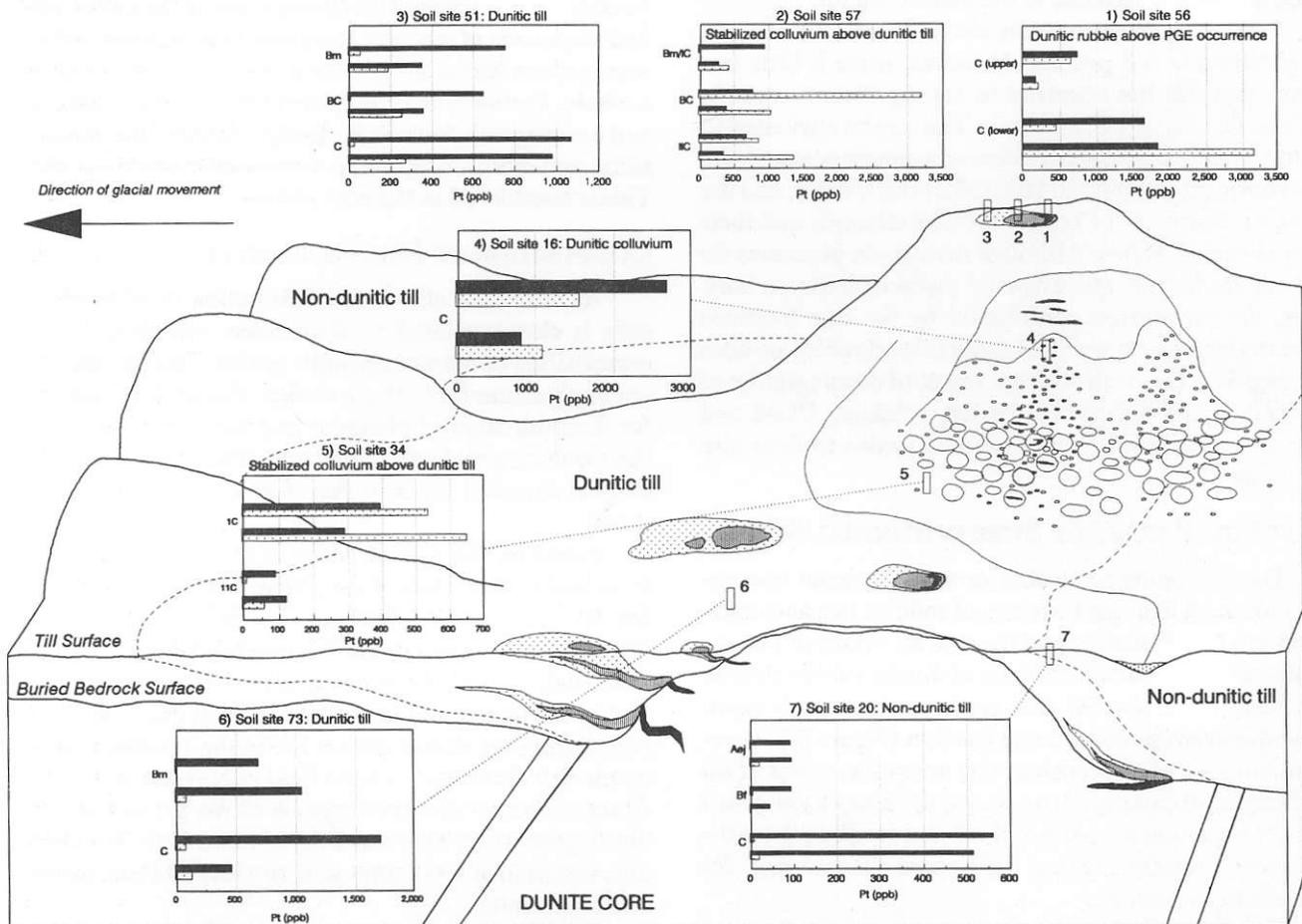


Figure 37. Platinum distribution (ppb) in magnetic (black bars) and nonmagnetic (stippled bars) heavy fractions of selected soil profiles, and their relation to idealized platinum occurrences and landscape elements of Grasshopper Mountain. Symbols and surficial materials as in Figure 36. Platinum distributions as in Appendix 8; for each horizon, upper two bars represent the -70 + 140-mesh fraction and lower two bars represent the -140 + 270-mesh fraction.

positional similarity of soil chromite crystals to the disseminated chromite grains of the dunite (and possibly clinopyroxenite) suggest that the crystals are derived from these units.

Although their compositions differ, both the chromite fragments and crystals from a variety of soil and parent material types have rather narrow compositional ranges (Table 13, Figures 34 and 35). This is particularly true for sites adjacent to platinum-group element occur-

TABLE 15
COMPOSITION OF DETRITAL SOIL CHROMITE
FRAGMENTS COMPARED TO THAT OF
CHROMITITE SEGREGATIONS

	Soil chromite fragments		Chromitite segregations				
	88-SC-133 (n=15)	88-SC-031 (n=15)	147 ¹ (n=10)	148 ¹ (n=12)	50 ¹ (n=8)	FJT80-55A ²	FJT80-540 ²
SiO ₂	0.01	0.01	0.27	0.19	0.19	0.61	0.02
Al ₂ O ₃	6.57	6.93	6.31	7.28	7.45	6.90	8.10
TiO ₂	0.64	0.61	0.78	0.42	0.51	0.58	0.86
Cr ₂ O ₃	42.86	45.83	37.03	43.65	49.01	43.90	37.70
Fe ₂ O ₃	20.20	17.54	26.70	20.88	15.36	20.80	25.10
FeO	18.75	17.17	20.71	18.40	17.20	18.50	19.50
MnO	0.24	0.23	0.47	0.45	0.35	0.40	0.39
MgO	9.07	10.19	7.96	9.57	10.49	8.80	8.50
CaO	.	.	.	.	.	<0.05	<0.05
V ₂ O ₃	.	.	.	.	.	0.06	0.12
NiO	.	.	.	.	.	0.06	0.08
Total	98.34	98.51	100.23	100.84	100.56	100.10	100.40

Note: Soil chromite fragments are from nonmagnetic fractions of two soil sites adjacent to PGE-chromite occurrences.

rences and presumably reflects the relatively restricted source areas of soils developed on dunitic colluvium and rubble at these sites. The greater compositional variation in crystals and fragments from till sites is presumably indicative of their derivation from a larger and more varied source area.

Magnetic properties of chromite depend on its composition (Stevens, 1944; Hawkes, 1951; Svoboda, 1987). Usually it is nonmagnetic or only weakly magnetic. However, increased iron content has been associated with increased magnetic susceptibility of chromites from India (Rao, 1978; Radhakrishna Murthy and Gopalakrishna, 1982), the Stillwater Complex (Peoples and Eaton, 1952), and elsewhere (Stevens, 1944; Owada and Harada, 1985). Fracture-filling magnetite veinlets (Jenness, 1959), the formation of magnetite or ferrichromite rims by either hydrothermal alteration (Beeson and Jackson, 1969; Kimball, 1990) or lateritic weathering (Michailidis, 1990),

and the presence of fine coatings of magnetite or other iron oxides can also increase magnetic susceptibility.

According to Irvine (1967), chromites from Alaskan-type ultramafic complexes are typically iron-rich and magnetic.

The Tulameen-chromite described by Findlay (1963, 1969) and ferrochromites described here are in this category. However, the iron-poor, magnesium-rich fragmental chromites most closely associated with the platinum occurrences have a lower magnetic susceptibility and therefore appear in the nonmagnetic heavy mineral fraction. This accounts for the association of high platinum values, that equal or exceed platinum values in the magnetic fractions, with abundant fragmental chromites in the nonmagnetic fraction of soils from dunite rubble and colluvium in the vicinity of platinum occurrences (Figure 27).

Preferential association of magnesian chromite with massive segregations relative to disseminated grains has been documented in other ultramafic intrusions. For example, similar magnesium-iron compositional variations have been reported from the Turnagain Alaskan-type complex in northwestern British Columbia (Clark, 1978). Also, the cation fraction of Mg²⁺ relative to Fe²⁺ + Mg²⁺ increases with increasing modal chromite content in chromitite zones of both the Stillwater Complex (Jackson, 1969) and the Bushveld Complex (Van der Walt, 1941; Cameron and Desborough, 1969; Cameron, 1977; Eales, 1987).

The magnesium and chromium composition of the Tulameen chromitites is consistent with the chromitites and associated PGM being early products of high-temperature coprecipitation from a primitive magma (Nixon *et al.*, 1990). Nixon *et al.*, have also shown that chromite inclusions in some Tulameen placer PGM nuggets are among the most magnesium and chromium-rich chromites of all.

PLATINUM IN LFH HORIZONS

There are several reports of uptake of platinum by plants. These include black spruce (*Picea mariana*), jack-pine (*Pinus banksiana*) (Dunn, 1986; Dunn *et al.*, 1989), Douglas fir (*Pseudotsuga menziesii*) (Riese and Arp, 1986) and glandular birch (*Betula glandulosa*) (Coker *et al.*, 1989), as well as understory shrubs such as Labrador tea (*Ledum groenlandicum*) (Dunn, 1986). Dunn *et al.*, (1989) also found that platinum content of plants reflected the presence of nearby sperrylite mineralization.

Based on the above, it is reasonable to suppose that LFH horizons might also carry anomalous concentrations of platinum. However, biogeochemical studies on the A zone at Grasshopper Mountain show that platinum content of ashed twigs and bark of Douglas fir, lodgepole pine and whitebark pine rarely exceeds 10 ppb even at sites where LFH horizon ash contains 100 to 150 ppb platinum

(Dunn 1990, and personal communication). It is therefore unlikely that the platinum content of Grasshopper Mountain LFH horizons, which is ten times greater near known mineralization than in background areas, can be attributed to biogeochemical cycling. This poor biogeochemical response is attributed to the stability of PGM encapsulated in chromite, preventing dissolution of platinum and its uptake by plants.

Several factors suggest that the platinum content of LFH horizons is caused by dunite or chromite fragments within the LFH material. Foremost is the almost universal presence of a small proportion of insoluble residue after acid digestion of the ash. Most silicate minerals are decomposed in the nitric-perchloric-hydrofluoric acid solution used (Langmyhr and Sveen, 1965). However, spinels are not (Riley, 1958) and probably comprise the bulk of the residue. The amount of residue is generally greatest at the A zone and at colluvial sites where the LFH horizon is continually inundated with downslope-moving rock fragments. Contamination of the LFH horizon by lithic material is corroborated by iron contents of up to 3 to 5 per cent compared to the few thousand ppm (Rose *et al.*, 1979) found in plant ash uncontaminated by mineral matter.

Assuming that platinum content of LFH horizons is largely a result of their contamination by mineral matter both the correlation between platinum content of the LFH horizon and the underlying mineral soils, and the high concentrations of platinum in LFH horizons at the A zone and on colluvium, are easily understood (Figures 19 and 20). It is less clear why the platinum content of ashed LFH material on non-dunitic tills at some sites exceeds the content of the underlying C-horizon. There is a weak positive correlation between platinum concentrations and iron and insoluble residue at these sites so that their platinum content may also be caused by lithic contamination. However, the sites cluster on relatively thick non-dunitic till in the seepage zone and adjacent slope, suggesting the possibility of at least some biogenic accumulation of platinum as a result of its hydromorphic dispersion.

PLATINUM IN OTHER MEDIA

STREAM SEDIMENTS AND MOSS MATS

The platinum content in stream and moss-mat sediments, from the stream draining the main study area, ranges from 8 to 91 and 8 to 47 ppb, respectively, concentrations comparable to those in associated soils. In comparison, Fletcher (1989) reported only 2 ppb platinum in sediments of streams draining pyroxenite and serpentinized peridotite in southern British Columbia.

Platinum residence sites were only studied in one sediment sample. Platinum is strongly partitioned into the heavy mineral fraction, as also observed by Fletcher

(1989) in sediments from Britton Creek, draining the western side of Grasshopper Mountain, and Olivine Creek draining the dunite core on the southern side of the Tulameen River (Table 16). Magnetic and nonmagnetic fractions of the -70 + 140-mesh fraction contain 361 and 34 ppb platinum, respectively. However, in the -140 + 270-mesh fraction platinum, at approximately 150 ppb, is equally distributed between the magnetic and nonmagnetic components. This is very similar to the partitioning in soils on dunitic till and colluvium close to platinum occurrences.

BOGS

There do not appear to be any published data for platinum content of bogs. However, based on platinum concentrations being similar to or greater than those in either C or ashed LFH horizons of nearby soils, it is reasonable to assume that their platinum content is anomalous and therefore related to the presence of mineraliza-

TABLE 16
PLATINUM AND PALLADIUM
CONCENTRATIONS (PPB) IN LIGHT (S.G. <3.3)
AND HEAVY MINERAL (S.G. >3.3) FRACTIONS
OF STREAM SEDIMENTS FROM BRITTON AND
OLIVINE CREEKS ADJACENT TO THE
TULAMEEN ULTRAMAFIC COMPLEX

Size fraction (ASTM)	Lights		Heavies	
	Pt	Pd	Pt	Pd
Britton Creek				
-70+100	2	3	336	8
-100+140	2	2	41	6
-140+200	2	2	46	3
-200+270*	2	2	522	4
-270*			7	2
Olivine Creek				
-70+100	2	3	25	12
-100+140	3	4	25	1
-140+200	3	5	204	17
-200+270*	6	3	329	19
-270*			29	8

* Lights + heavies. All values in ppb. From Fletcher (1989)

Note: From Fletcher, 1989

tion upslope in the Cliff zone. These relationships are most notable in Bog 1, in the large base-of-slope seepage zone, for which ashed bog samples contain 65 ppb platinum, versus concentrations of 2 to 16 ppb in LFH and 6 to 18 ppb in C-horizons of the three closest soil sites.

The ability of bogs to scavenge base metals is well known (e.g., Bradshaw, 1975; Lett and Fletcher, 1979). There is also evidence that, like gold, dissolved platinum species can be reduced and fixed by organic matter (Kucha, 1982; Dissanayake *et al.*, 1984). Although the data are very limited, the high concentrations of platinum in the seepage zone bogs compared to surrounding soils

suggest that there may be some hydromorphic mobilization and subsequent accumulation in bogs on Grasshopper Mountain.

WATERS

Lower concentrations of platinum (mean: 0.81 ppt) in clear stream waters on Grasshopper Mountain than in organic-coloured waters from plateau bogs (mean: 2.45 ppt) are probably largely a function of greater dilution of the stream waters. However, the difference may also partly reflect the ability of the more organic-rich bog waters to transport platinum as either soluble organic complexes or organic-acid stabilized colloidal suspensions (Wood, 1990).

The few published data for platinum content of natural waters are from sulphide rather than chromite-associated platinum-group element occurrences. Pogrebnyak *et al.* (1984) reported maximum platinum concentrations of 40 ppt (mean: 15 ppt) in stream waters draining a copper sulphide platinum-group element occurrence in Transbaikal. However, Wood and Vlassopoulos (1990) found that the dissolved platinum in lake waters associated with platinum-group element - copper-nickel prospects in Quebec, was below their 25 ppt detection limit in almost all samples.

CLASTIC VERSUS HYDROMORPHIC DISPERSION OF PLATINUM

Clastic glacial dispersion and postglacial mass wasting are clearly the dominant processes influencing platinum distribution on Grasshopper Mountain. This reflects the resistate character of both free platinum-bearing PGM alloys and of chromite grains in which PGM are encapsulated. Nevertheless, as discussed above, the relatively high platinum contents of LFH horizons (versus C-horizons) and of bogs (versus surrounding soils) in the main seepage zone area suggests the possibility of some minor hydromorphic dispersion of anomalous concentrations into the seepage zone. This is supported by the relatively high platinum contents found in organic-coloured bog waters (Cook and Fletcher, 1992b).

Theoretical studies on the transport of platinum in natural aqueous solutions have been provided by Fuchs and Rose (1974), Mountain and Wood (1988a, 1988b), Plimer and Williams (1988) and Wood *et al.* (1989). Based on these studies metallic platinum is the stable species. It can only be mobilized as chloride complexes (PtCl_4^{2-}), under very strongly oxidizing acidic conditions. Bisulphide, thiosulphate, hydroxide and ammonia might form complexes with platinum under the neutral to weakly alkaline conditions found in the natural waters on Grasshopper Mountain. Organic complexes and organic acid stabilized colloids may also be involved (Wood, 1990).

Although platinum is usually considered immobile (and all the more so if the PGM are encapsulated in

chromite) there is growing evidence of its hydromorphic mobility in the surficial environment (Stumpfl and Tarkian, 1976; Cousins and Kinloch, 1976; Burgath, 1988). Much of this evidence comes from geochemical environments that are more extreme than that of Grasshopper Mountain. For example, from gossans (Travis *et al.*, 1976; McGoldrick and Keays, 1981) and lateritic soils (Taufen and Marchetto, 1989; Ottemann and Augustithis, 1967; Bowles, 1986, 1988). However, the study by Fuchs and Rose (1974) of platinum in the weathering cycle of soil on the Stillwater Complex is reasonably similar to the geochemical environment on Grasshopper Mountain. Appreciable quantities of platinum were found in the exchangeable, organic and iron-oxide fractions of a soil developed on till. They concluded that, provided platinum is not immobilized in chromite, it might be moved short distances in natural solutions during weathering.

The evidence from Grasshopper Mountain supports the conclusion of Fuchs and Rose (1974) and suggests that a time span of only 10 000 years, since deglaciation, may have been sufficient to produce weak hydromorphic modification of clastic platinum dispersion patterns despite much of the PGM being encapsulated in chromite, and the rather dry and neutral to weakly alkaline geochemical conditions of the study area. In this context, it is interesting that Van der Flier-Keller (1991) has suggested that platinum enrichments associated with fault zones in Eocene coals in the Tulameen coal basin, several kilometres east of the Tulameen Ultramafic Complex, might have resulted from precipitation of platinum from circulating groundwaters. Hydromorphic mobility of platinum is of considerable theoretical and practical interest and warrants further study. It must, however, be emphasized that clastic dispersion processes are by far the most important control on platinum dispersion in soils and stream sediments on Grasshopper Mountain.

RECOMMENDATIONS FOR GEOCHEMICAL EXPLORATION FOR CHROMITITE-ASSOCIATED PLATINUM DEPOSITS

Platinum occurrences on Grasshopper Mountain are closely associated with chromitite segregations in a dunite that contains lower, but nevertheless elevated, concentrations of platinum. Geochemical dispersion in the surficial environment takes place at two scales: local dispersion from the platinum-rich chromitites and mixing with predominantly dunitic material, and on a larger scale, dispersion and dilution of dunitic material, including any contained chromitite, with exotic material. Depending on the stage of exploration, effective application of geochemical methods must take advantage of the properties of the PGM and associated minerals to detect these dispersion patterns.

Here we attempt to give guidelines for the choice of sampling media, and sampling and laboratory techniques during regional, reconnaissance and detailed exploration defined as follows: *regional exploration*, the search for buried or unmapped platinum-bearing ultramafic bodies; *reconnaissance exploration*, property-scale exploration on a favourable geological target such as the dunite core of the Tulameen Complex; and, *detailed exploration*, the follow-up of reconnaissance geochemical anomalies. The guidelines are summarized in Table 17.

SOILS

Recommendations are given for the choice of soil horizon, size fraction and sampling density to be employed in platinum geochemical exploration. Two other points are also critical. One is correct field identification and recognition of the origin of the parent material. The second is the grouping of samples into similar categories (Sinclair, 1986), in this study according to parent material and magnesium content, prior to ranking and interpretation of platinum concentrations within each category. This is essential if low-level anomalies, which would otherwise be masked by higher platinum content of samples in other groups, are to be detected.

CHOICE OF SOIL HORIZON

Near-surface B-horizon soils are often used in geochemical surveys because they are relatively inexpensive to collect and are commonly enriched in metals. However, on Grasshopper Mountain soil profiles on tills are juvenile and relatively thin. Furthermore, while the A and B-horizons often bear little resemblance to those of nearby profiles, the character of the C-horizon (*i.e.*, oxidized till) is relatively constant. In particular, use of the C-horizon avoids the problem of interpreting data from composite or mixed profiles in which a thin platinum-rich colluvium has buried till. Except for regional exploration, we cannot recommend sampling B-horizons where soil type and parent materials show as much local variation as on Grasshopper Mountain. If the B-horizon is used, great care should be taken to identify the parent material, both in the field and subsequently, on the basis of major element composition.

Sampling of active colluvium requires a different approach. Colluvium has a relatively uniform platinum distribution with depth, and strict sampling of a particular depth is less important. The main consideration is to obtain the greatest proportion of fine particles, perhaps by field screening to -2 millimetres.

Platinum content of LFH horizons reflects that of the underlying mineral soil and this material is relatively

TABLE 17
RECOMMENDATIONS FOR GEOCHEMICAL EXPLORATION FOR CHROMITITE-ASSOCIATED
PLATINUM DEPOSITS IN ALASKAN-TYPE ULTRAMAFIC COMPLEXES

Level of Exploration	Preferred Soil Horizon	Preferred Size/density/magnetic Soil Fraction	Additional Elements	Sampling Density	Other Sample Media
REGIONAL	C	-70 mesh fraction for delineating distribution of dunitic till	Major elements (MgO, C ₂ O ₃)	1 km ²	1) gravel stream sediments
RECONNAISSANCE	C	TILL: -270 mesh fraction or -70+140/-140+270 mesh magnetic heavy mineral fractions COLLUVIUM: -70+140 mesh magnetic heavy mineral fraction	Major elements (MgO, C ₂ O ₃)	100 m	1) gravel stream sediments 2) bog waters
DETAILED	C or deep till; till profiling	Nonmagnetic heavy mineral fractions: TILL: -140+270 mesh COLLUVIUM: -70+140 mesh	-	10 m	electron microprobe analysis of chromite fragments

simple and inexpensive to collect. However, insofar as platinum content of LFH horizons results from contamination by mineral matter, which is likely to be quite variable depending on till thickness, slope and parent material, their use cannot be recommended. The possibility of detecting hydromorphic dispersion of platinum in base-of-slope LFH horizons requires further research.

CHOICE OF SOIL FRACTION

There is some evidence that platinum anomalies at the A zone are most consistent in the two finest fractions. However, comparable levels of platinum in all five size fractions (Table 7) suggest that they would all be reasonably effective in detecting the presence of anomalous concentrations associated with both the dunite and the chromitite occurrences. Use of traditional, -80-mesh soil samples would presumably give very similar geochemical patterns to those obtained in the overview survey using the -70-mesh fraction. However, sample representativity and the effects of anomaly dilution both limit the use of conventional soil samples.

Based on the scanning electron microscopy studies the platinum-group minerals occur as very fine (~ 1 micron) grains, often encapsulated in larger chromite grains, to grains as large as 100 microns. Unless samples are ground and thoroughly mixed, the larger PGM grains have the potential to cause a serious nugget effect whatever size fraction is used. Grinding is also necessary to ensure complete fusion of chromite-rich samples during fire assay (Figure 5).

Anomaly dilution is a more serious problem. As platinum-rich material associated with chromitite segregations is mixed with dunitic material at a local scale, or dunitic material mixes with exotic material on a regional scale, soil anomalies will be diluted to background levels. Using normal soil samples it may therefore be difficult to detect the small platinum-rich chromitites without very detailed sampling. This is likely to be a particularly severe problem in areas of non-dunitic or thick till. Similarly, with low-density regional sampling the platinum-magnesium-chromium signature of the dunite might become indistinguishable from the regional background for these elements. In either case, preparation of a heavy mineral concentrate will improve sample representativity and, by removing unwanted dilutants, increase anomaly contrast and allow the signature to be recognized at a greater distance from source. For example, at site 20 in non-dunitic till the -270-mesh fraction contains relatively low levels of platinum because of dilution by exotic material. However, platinum concentrations greater than 500 ppb in the magnetic heavy fractions exceed those at some nearby dunitic till sites and suggest that the site is anomalous.

The difficulty of fusing chromite-rich samples larger than 10 grams makes it desirable to concentrate the PGM

as much as practical. This can be achieved by preparation of magnetic or nonmagnetic heavy mineral concentrates, the choice depending on the object of the survey. Because platinum is most abundant in the magnetic fraction of non-dunitic till and in dunitic till distant from mineralization, this fraction is to be preferred for regional or reconnaissance sampling. Because of the high cost of preparing heavy mineral concentrates, the possibility of direct separation of the magnetic fraction warrants investigation.

The highest platinum concentrations are found, together with abundant nonmagnetic magnesium and chromium-rich chromitite fragments, at sites close to platinum-rich chromitite segregations (Figure 37). Analysis and mineralogical examination of the nonmagnetic heavy fractions of tills and colluvium are therefore useful for pinpointing targets during detailed follow-up. Use of the -140 + 270-mesh nonmagnetic heavies is recommended on the basis of their relatively high platinum content and abundance of chromitite fragments.

SAMPLING DENSITY

No comparative evaluation of differing sample densities was attempted. Nevertheless, some generalized recommendations can be made for the various stages of exploration.

On the basis of platinum-magnesium-chromium dispersion patterns in till on and around the dunite core (Figure 14), sampling densities of about 1 per square kilometre seem reasonable for regional sampling based on analysis of till. Presence of chromite and high platinum values in magnetic heavy mineral concentrates of tills might detect the presence of platiniferous ultramafics using lower sample densities, as used, for example, in regional geochemical mapping surveys of Scandinavia (Brundin and Bergstrom, 1977). With either soils or heavy mineral concentrates the anomaly offset and down-ice dispersion due to glacial transport should be taken into account in interpreting the results.

Because of the relatively small size of the platinum-group element occurrences and individual chromitite segregations, a minimum sampling density of 100 by 100 metres is suggested for preliminary property-scale sampling of soils on tills. Subsequently, a much closer sampling interval would probably be required to trace anomalies back to a chromitite source. The presence of composite soil profiles and variable dilution by exotic material requires both careful field identification of the overburden type and classification based on their magnesium and chromium content.

Hoffman (1977) used base-of-slope talus sampling to complement stream sediments in the Cordillera. Talus is of a more limited distribution than till on Grasshopper Mountain. Nevertheless, where talus is present, base-of-slope sampling of talus colluvium and examination of talus float at intervals of about 100 metres would probably

indicate the presence of platinum-rich chromitites up-slope. This would be most useful for property-scale investigations.

OTHER MEDIA

SEDIMENTS

Based on the data from the small stream draining the main study area, together with data of Fletcher (1989) from Britton and Olivine creeks, there is no difficulty in recognizing the presence of anomalous concentrations of platinum in streams draining the dunite core of the Tulameen Complex. Among size fractions, the highest platinum content is found in the -270-mesh fraction, but differences in concentration between the three finest fractions are quite small (Figure 28). As in soils, anomaly contrast could be improved by use of a heavy mineral concentrate.

Because of the strong partitioning of platinum into the heavy mineral fractions, its distribution in stream sediments is likely to be controlled by the same factors as other heavy minerals in streams. Thus, based on detailed studies of gold and magnetite (Day and Fletcher, 1989, 1991; Fletcher, 1990; and Fletcher and Wolcott, 1991) and depending on local circumstances, there are likely to be large variations in platinum content between different energy environments on the stream bed. Platinum anomalies might also show seasonal variability and increase, depending on stream gradient and bed roughness, away from the source. The rather erratic distribution along Grasshopper Creek may partly result from stream energy-gradient interactions. However, these effects are more likely to be important in larger drainages.

WATERS AND BOGS

The use of hydrogeochemistry in platinum exploration is severely constrained by the lack of data on platinum concentrations in natural waters, the extremely low concentrations of platinum that would need to be determined and the practical difficulties that arise from the corresponding need to process large volumes of water, and absence of commercial laboratories providing determination of platinum content of water samples for routine exploration purposes. This situation is unlikely to change in the near future. However, the increasing evidence of (slight) hydromorphic mobility for platinum and its subsequent accumulation in bogs and seepage-zone soils warrants further investigation of possible uses of these media for exploration.

SAMPLE PREPARATION

No specific field-sample size recommendations are provided, but it is stressed that dry sieving will produce a considerably smaller subsample of, for example, -270-mesh material, than the wet sieving method used in this study. Using wet sieving there is no problem with either colluvium or till in obtaining sufficient sample (10 g for determination of platinum) for analysis from a standard

size (~ 500 g) soil sample. As previously discussed, samples should be ground to minimize nugget effects and to facilitate fire assay fusion. Hardened steel grinding equipment causes chromium contamination and should not be used.

Ideally the starting sample for preparation of heavy mineral concentrates should be of sufficient size (typically 1 to 5 kg of -2 mm material) to provide at least 10 grams of either a magnetic or nonmagnetic concentrate. This can then be sized and the heavies separated using heavy liquids. However, because of the large sample size required this is time consuming and costly. More rapid and cost-effective methods should be developed for routine exploration purposes. These might include direct separation of a magnetic fraction (Sabelin *et al.*, 1986; Foley *et al.*, 1987) or combined gravity-magnetic methods. The topic is further reviewed by Cook (1991).

Mineralogical examination of the heavy mineral concentrates is essential. The entire heavy mineral concentrate should then be pulverized to minimize nugget effects and facilitate fusion of chromite-rich samples. A less desirable alternative is to reserve a small subsample, taken with a microsplitter to maintain sample representativity, for mineralogical study.

ANALYSIS

With careful attention to sample preparation, a standard lead fire assay fusion, combined with an ICP finish, appears to be quite capable of giving acceptable precision for exploration purposes. However, use of analytical subsamples larger than 10 grams should be avoided, particularly if the material is chromite-rich, unless it can be demonstrated that complete fusion and recovery of platinum can be obtained.

Magnesium and chromium content of soils and sediments can be determined by any suitable whole-rock total fusion procedure followed by AAS or ICP determination. Alternatively X-ray fluorescence could be used. Decompositions using hydrofluoric acid should not be used because of the insolubility of chromite (Fletcher, 1986).

MINERALOGICAL AND SCANNING ELECTRON MICROSCOPY-MICROPROBE TECHNIQUES

Nixon *et al.* (1989) decried the limited use of the electron microprobe in exploration geochemistry. In this study morphology and composition of chromite grains played a critical role in understanding dispersion of platinum. We therefore recommend that all heavy mineral concentrates, prepared for determination of platinum, be examined with respect to abundance, morphology and composition of chromite grains. Microprobe analysis of these grains provides a powerful interpretative technique. The presence of chromitite fragments having a characteristic magnesium and chromium-rich composition is of particular interest, as they may pinpoint the dispersed remnants of platinum-hosting massive chromitite segregations.

CONCLUSIONS

CHAPTER 5

DISTRIBUTION AND BEHAVIOUR OF PLATINUM

- (1) Glacial dispersion and mass wasting are the dominant processes influencing the surficial distribution of platinum on Grasshopper Mountain.
- (2) Platinum content of the -212 micron soil fraction ranges from 2 to 885 ppb and is dependent on the amount of contained dunite, as expressed by magnesium content, in the parent material. Median platinum concentrations of dunite colluvium, dunitic till and non-dunitic till are 88 ppb, 36 ppb and 8 ppb, respectively.
- (3) Platinum content generally increases or is relatively constant with depth in soils on till, and is constant with depth in soils on colluvium.
- (4) Platinum is preferentially associated with heavy mineral fractions in soil. Partitioning between magnetic and nonmagnetic heavy mineral fractions is dependent on both distance from source and parent material mineralogy; sites adjacent to known occurrences contain a higher proportion of platinum in the nonmagnetic fractions.
- (5) Detrital soil PGM, comprising platinum-iron-copper alloys, occur as free grains, as inclusions in magnesium silicates and, most commonly, as inclusions within chromites.
- (6) Soil chromites occur as iron-rich euhedral to subhedral crystals and as chromium-magnesium-rich anhedral fragments. Crystals are relatively more abundant in magnetic heavy fractions and are interpreted to be disseminated chromite crystals from the dunite. Fragments are relatively more abundant in nonmagnetic heavy mineral fractions and are interpreted to represent dispersed remnants of massive chromite segregations. Their abundance in soils near known platinum-group element occurrences accounts for the relatively high platinum content of the corresponding nonmagnetic heavy fractions.
- (7) Platinum content of LFH horizons, which is up to ten times greater near known mineralization than elsewhere, is attributed to mixing of inorganic particles into the organic matrix.
- (8) Platinum content of bog waters in a dunite-dominated environment is three times that of stream water flowing through dunitic and non-dunitic till. Enhanced platinum content of bog waters and seepage-zone bogs suggests a minor hydromorphic modification of the dominantly clastic platinum dispersion patterns.

RECOMMENDATIONS FOR GEOCHEMICAL EXPLORATION

- (1) Because of the complexity of surficial deposits and presence of composite soil profiles, C-horizon soils are the preferred sampling medium for reconnaissance and detailed exploration. C-horizon soils and stream sediments are both suitable for low-density regional surveys.
- (2) Heavy mineral and -270-mesh fractions offer the greatest contrast for geochemical exploration: their use provides the greatest likelihood of detecting platinum mineralization hidden beneath till. Magnetic heavy minerals would be most useful for detection of anomalous platinum concentrations during reconnaissance sampling, but the more limited dispersion, greater contrast and chromite fragment association of platinum in the -140 + 270 nonmagnetic heavy fraction may be more useful for detailed follow-up surveys.
- (3) Samples should be classified for data interpretation and anomaly recognition on the basis of careful field identification of the parent material, and grouping according to MgO content as an indicator of the contribution of dunite-derived material.
- (4) Scanning electron microscopy and microprobe techniques should be used to determine abundance, morphology and composition of chromite grains in heavy mineral concentrates.

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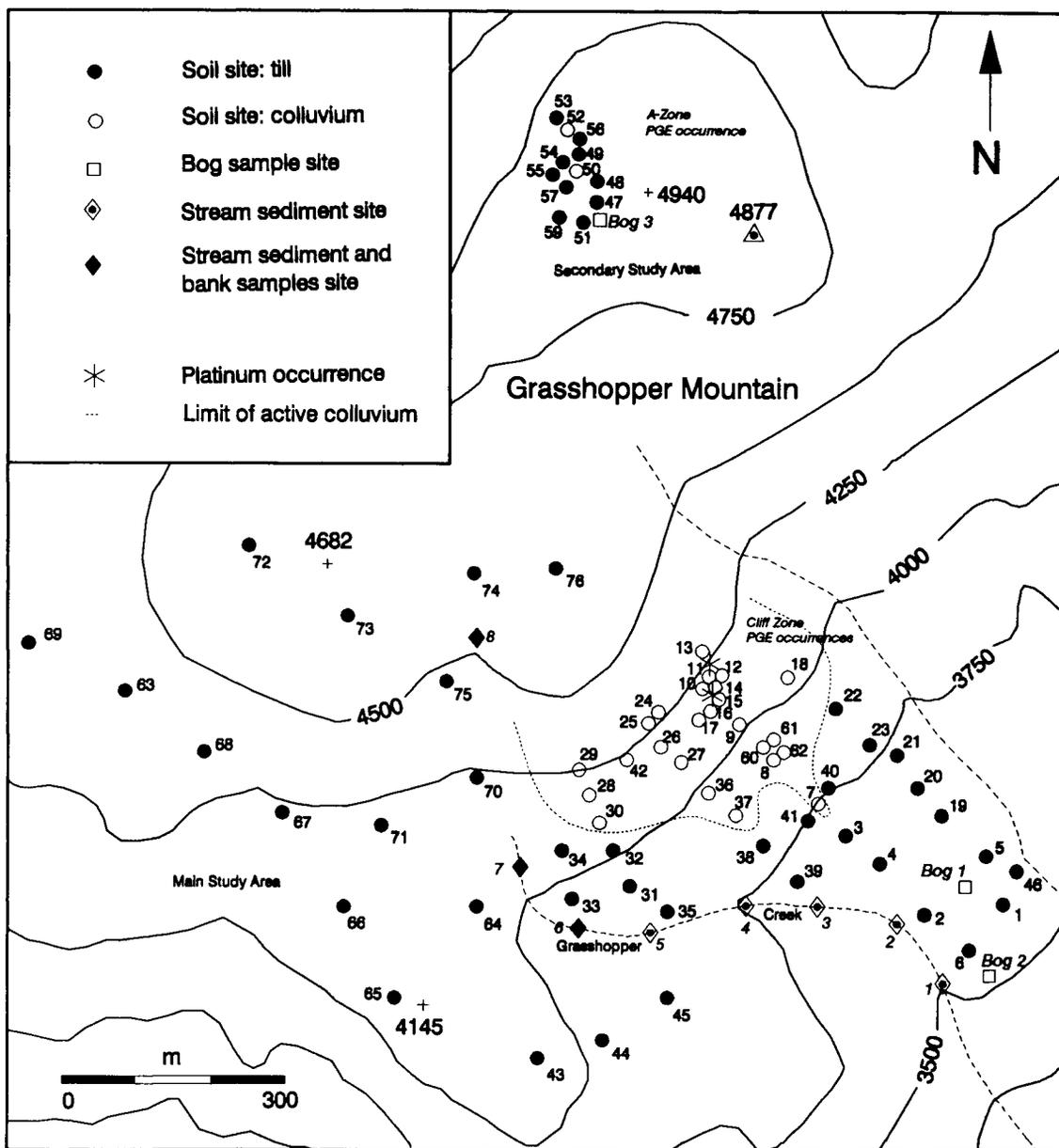
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APPENDICES



Appendix 1. Sample location map of soil, sediment and bog sites within the dunite core of the Tulameen complex (base map adapted from Bohme, 1987, elevation contours in feet).

APPENDIX 2.1
OVERVIEW ANALYTICAL RESULTS:TILL
NONDUNITIC TILL AND CLAY

	Site	Sample	Parent Material	Pt (ppb)	Pd (ppb)	Rh (ppb)	Au (ppb)	As (ppm)	Sb (ppm)	Bi (ppm)	Ge (ppm)	Se (ppm)	Te (ppm)
1	Soil Site 2	88-SC-006	Nondunitic Till	9	5	2	8	14.7	1.8	0.4	0.2	0.2	0.3
2	Soil Site 3	88-SC-009	Nondunitic Till	14	3	2	6	12.6	1.7	0.1	0.2	0.2	0.3
3	Soil Site 4	88-SC-012	Nondunitic Till	6	2	2	2	18.3	1.5	0.2	0.2	0.2	0.3
4	Soil Site 5	88-SC-016	Nondunitic Till	18	4	2	5	21.9	0.9	0.6	0.2	0.3	0.3
5	Soil Site 6	88-SC-019	Nondunitic Till	3	4	2	34	10.9	1.6	0.2	0.3	0.2	0.3
6	Soil Site 19	88-SC-036	Nondunitic Till	8	3	2	16	17.8	0.9	0.3	0.2	0.2	0.3
7	Soil Site 20	88-SC-040	Nondunitic Till	20	3	2	9	20.2	1.0	0.2	0.2	0.2	0.3
8	Soil Site 21	88-SC-044	Nondunitic Till	3	2	2	7	12.9	0.7	0.2	0.2	0.2	0.3
9	Soil Site 22	89-SC-048	Nondunitic Till	5	6	2	7	16.4	1.0	0.2	0.4	0.4	0.5
10	Soil Site 23	88-SC-051	Nondunitic Till	5	2	2	13	20.1	1.8	0.3	0.2	0.4	0.3
11	Soil Site 31	88-SC-072	Nondunitic Till	8	2	2	2	10.4	1.0	0.2	0.2	0.2	0.3
12	Soil Site 32	88-SC-076	Nondunitic Till	12	5	2	3	8.1	0.6	0.2	0.2	0.2	0.3
13	Soil Site 35	88-SC-088	Nondunitic Till	14	5	2	5	14.7	0.6	0.3	0.3	0.2	0.3
14	Soil Site 38	88-SC-163	Nondunitic Till	15	5	2	6	23.2	1.0	0.3	0.2	0.2	0.3
15	Soil Site 39	88-SC-098	Nondunitic Till	2	2	2	4	14.3	0.6	0.2	0.2	0.2	0.3
16	Soil Site 40	88-SC-102	Nondunitic Till	2	2	2	2	12.9	0.7	0.4	0.2	0.2	0.3
17	Soil Site 41	88-SC-108	Nondunitic Till	5	6	2	11	23.0	0.7	0.4	0.2	0.3	0.3
18	Soil Site 44	88-SC-117	Nondunitic Till	18	2	2	7	10.5	0.6	0.3	0.2	0.2	0.3
19	Soil Site 45	88-SC-120	Nondunitic Till	13	15	2	9	12.1	0.5	0.3	0.2	0.2	0.3
20	Soil Site 1	88-SC-003	Clay	4	2	2	5	9.4	0.5	0.5	0.2	0.2	0.3
21	Soil Site 46	88-SC-124	Clay	7	3	2	5	14.3	1.2	0.3	0.2	0.2	0.3

Site	Sample	Parent Material	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)	MgO (%)	CaO (%)	Na ₂ O (%)	K ₂ O (%)	TiO ₂ (%)	P ₂ O ₅ (%)	MnO (%)	Cr ₂ O ₃ (%)	Ba (ppm)	LOI (%)	Total	
1	Soil Site 2	88-SC-006	Nondunitic Till	53.70	14.27	9.53	6.10	4.87	2.44	1.32	0.96	0.10	0.20	0.06	468	6.3	99.93
2	Soil Site 3	88-SC-009	Nondunitic Till	52.12	13.04	11.62	7.66	5.51	2.34	1.09	0.90	0.10	0.20	0.15	376	5.2	99.99
3	Soil Site 4	88-SC-012	Nondunitic Till	52.95	14.86	9.65	5.82	4.74	2.60	1.37	0.91	0.11	0.15	0.08	501	6.5	99.83
4	Soil Site 5	88-SC-016	Nondunitic Till	51.40	13.20	11.75	7.85	4.74	2.36	1.23	0.88	0.13	0.18	0.14	400	6.1	100.03
5	Soil Site 6	88-SC-019	Nondunitic Till	53.74	14.39	8.38	6.35	4.81	2.52	1.15	0.87	0.15	0.15	0.05	473	7.4	100.04
6	Soil Site 19	88-SC-036	Nondunitic Till	54.19	14.79	9.87	5.44	4.92	2.46	1.32	0.93	0.13	0.15	0.06	508	5.5	99.85
7	Soil Site 20	88-SC-040	Nondunitic Till	54.87	14.46	9.93	5.52	4.79	2.58	1.24	0.97	0.14	0.17	0.08	449	4.9	99.73
8	Soil Site 21	88-SC-044	Nondunitic Till	56.54	15.64	9.20	3.86	4.68	2.87	1.29	1.05	0.12	0.13	0.03	522	4.5	100.00
9	Soil Site 22	89-SC-048	Nondunitic Till	52.31	13.97	8.76	7.02	4.53	2.57	1.50	0.89	0.21	0.18	0.05	428	8.0	100.08
10	Soil Site 23	88-SC-051	Nondunitic Till	52.76	15.53	10.36	4.02	4.21	2.60	1.37	0.92	0.13	0.17	0.04	554	7.8	100.00
11	Soil Site 31	88-SC-072	Nondunitic Till	56.36	14.24	9.67	4.86	4.96	3.06	1.38	0.96	0.07	0.14	0.08	486	4.1	99.96
12	Soil Site 32	88-SC-076	Nondunitic Till	52.90	12.84	11.00	8.23	4.87	2.50	1.13	0.94	0.06	0.13	0.16	455	5.1	99.94
13	Soil Site 35	88-SC-088	Nondunitic Till	55.18	14.34	10.00	5.27	5.26	2.76	1.23	0.95	0.13	0.15	0.07	442	4.5	99.92
14	Soil Site 38	88-SC-163	Nondunitic Till	52.76	15.50	10.15	5.40	4.60	2.65	1.40	1.04	0.15	0.16	0.03	492	6.2	100.12
15	Soil Site 39	88-SC-098	Nondunitic Till	55.12	14.53	9.88	5.52	5.28	2.51	1.34	0.98	0.16	0.15	0.05	456	4.4	100.00
16	Soil Site 40	88-SC-102	Nondunitic Till	55.03	15.28	9.78	3.97	5.01	3.20	1.64	1.04	0.11	0.14	0.04	461	4.6	99.92
17	Soil Site 41	88-SC-108	Nondunitic Till	52.89	15.83	10.24	4.74	4.76	2.75	1.44	1.04	0.21	0.22	0.03	483	5.8	100.03
18	Soil Site 44	88-SC-117	Nondunitic Till	56.95	15.65	8.47	4.68	3.13	2.66	1.58	0.91	0.11	0.12	0.07	539	5.6	100.02
19	Soil Site 45	88-SC-120	Nondunitic Till	54.29	15.22	9.14	5.19	4.15	2.84	1.43	0.95	0.13	0.14	0.05	508	6.4	100.02
20	Soil Site 1	88-SC-003	Clay	54.41	16.58	9.11	4.22	3.75	2.52	1.33	1.02	0.16	0.12	0.04	619	6.5	99.87
21	Soil Site 46	88-SC-124	Clay	51.87	15.41	9.89	5.80	4.29	2.56	1.45	0.98	0.24	0.26	0.04	555	7.3	100.18

APPENDIX 2.1
OVERVIEW ANALYTICAL RESULTS: TILL
DUNITIC TILL

Site	Sample	Parent Material	Pt (ppb)	Pd (ppb)	Rh (ppb)	Au (ppb)	As (ppm)	Sb (ppm)	Bi (ppm)	Ge (ppm)	Se (ppm)	Te (ppm)	
22	Soil Site 33	88-SC-079	Dunitic Till	28	2	2	6	19.2	0.5	0.3	0.2	0.2	0.5
23	Soil Site 34	88-SC-082	Dunitic Till	36	6	2	11	11.2	0.4	0.2	0.2	0.2	0.3
24	Soil Site 43	88-SC-112	Dunitic Till	16	2	2	4	5.3	0.2	0.4	0.2	0.2	0.3
25	Soil Site 63	89-SC-178	Dunitic Till	44	7	2	10	19.3	0.6	0.5	0.1	0.1	0.1
26	Soil Site 64	89-SC-182	Dunitic Till	18	5	2	2	14.8	0.6	0.2	0.3	0.1	0.4
27	Soil Site 65	89-SC-184	Dunitic Till	44	5	2	4	10.1	0.1	0.2	0.1	0.1	0.1
28	Soil Site 66	89-SC-189	Dunitic Till	34	11	2	9	13.2	0.2	0.2	0.1	0.1	0.1
29	Soil Site 67	89-SC-193	Dunitic Till	32	10	2	12	20.8	0.6	0.2	0.3	0.4	0.5
30	Soil Site 68	89-SC-197	Dunitic Till	45	11	2	8	12.4	0.2	0.4	0.2	0.1	0.4
31	Soil Site 69	89-SC-200	Dunitic Till	49	8	2	9	15.4	0.3	0.6	0.1	0.1	0.2
32	Soil Site 70	89-SC-203	Dunitic Till	34	2	2	7	52.5	0.2	0.1	0.1	0.2	0.4
33	Soil Site 71	89-SC-209	Dunitic Till	36	11	2	8	11.1	0.7	0.2	0.2	0.2	0.4
34	Soil Site 72	89-SC-213	Dunitic Till	28	7	2	14	12.1	0.1	0.2	0.1	0.1	0.1
35	Soil Site 73	89-SC-216	Dunitic Till	311	7	3	21	13.0	0.1	0.3	0.1	0.1	0.2
36	Soil Site 74	89-SC-219	Dunitic Till	50	4	2	7	16.0	0.8	0.1	0.2	0.3	0.3
37	Soil Site 75	89-SC-223	Dunitic Till	38	48	2	8	16.3	0.1	0.1	0.1	0.1	0.3
38	Soil Site 76	89-SC-226	Dunitic Till	55	5	2	3	6.5	0.1	0.1	0.3	0.1	0.4
39	Soil Site 47	88-SC-127	Dunitic Till (A-Zone)	85	2	2	8	7.6	0.5	0.2	0.2	0.2	0.3
40	Soil Site 51	88-SC-135	Dunitic Till (A-Zone)	205	36	2	10	14.4	0.2	0.1	0.2	0.2	0.3
41	Soil Site 53	88-SC-142	Dunitic Till (A-Zone)	42	4	2	4	15.0	0.5	0.2	0.2	0.2	0.3
42	Soil Site 54	88-SC-145	Dunitic Till (A-Zone)	42	2	2	1	30.3	0.1	0.4	0.4	0.2	0.3
43	Soil Site 55	88-SC-148	Dunitic Till (A-Zone)	93	2	2	4	16.1	0.1	0.3	0.2	0.2	0.3
44	Soil Site 56	88-SC-153	Dunitic Rubble(A-Zone)	455	2	2	1	7.4	0.5	0.2	0.2	0.2	0.3
45	Soil Site 57	88-SC-156	Dunitic Till (A-Zone)	266	3	2	3	30.5	0.2	0.1	0.2	0.2	0.3
46	Soil Site 59	88-SC-161	Dunitic Till (A-Zone)	77	5	6	10	26.4	0.8	0.1	0.2	0.2	0.3

Site	Sample	Parent Material	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)	MgO (%)	CaO (%)	Na ₂ O (%)	K ₂ O (%)	TiO ₂ (%)	P ₂ O ₅ (%)	MnO (%)	Cr ₂ O ₃ (%)	Ba (ppm)	LOI (%)	Total	
22	Soil Site 33	88-SC-079	Dunitic Till	47.62	7.20	12.68	17.81	3.36	0.85	0.57	0.60	0.08	0.13	0.26	198	8.8	99.99
23	Soil Site 34	88-SC-082	Dunitic Till	50.64	10.62	13.12	10.45	5.24	2.08	0.78	0.83	0.08	0.13	0.22	320	5.7	99.94
24	Soil Site 43	88-SC-112	Dunitic Till	46.27	6.90	9.95	28.73	2.10	1.12	0.68	0.41	0.10	0.17	0.25	242	3.3	100.02
25	Soil Site 63	89-SC-178	Dunitic Till	44.42	7.66	11.20	19.65	1.88	1.11	0.76	0.49	0.11	0.22	0.18	204	12.2	99.93
26	Soil Site 64	89-SC-182	Dunitic Till	48.23	9.29	9.94	15.52	3.60	1.39	0.94	0.63	0.10	0.14	0.25	278	9.9	100.00
27	Soil Site 65	89-SC-184	Dunitic Till	46.52	10.03	10.22	16.25	2.63	1.46	0.95	0.64	0.14	0.22	0.22	280	10.7	100.05
28	Soil Site 66	89-SC-189	Dunitic Till	47.28	8.25	10.82	17.03	3.95	1.02	0.79	0.60	0.15	0.16	0.16	200	9.7	99.96
29	Soil Site 67	89-SC-193	Dunitic Till	44.95	8.18	10.49	18.86	4.20	0.96	0.78	0.59	0.19	0.22	0.19	211	10.3	99.96
30	Soil Site 68	89-SC-197	Dunitic Till	45.25	9.92	11.00	16.35	2.80	1.14	1.07	0.59	0.10	0.19	0.19	282	11.2	99.87
31	Soil Site 69	89-SC-200	Dunitic Till	48.37	8.89	9.48	15.47	5.05	1.28	0.90	0.59	0.09	0.18	0.13	215	9.6	100.08
32	Soil Site 70	89-SC-203	Dunitic Till	44.23	8.71	11.27	15.99	3.17	1.10	0.69	0.56	0.11	0.18	0.24	228	13.7	100.01
33	Soil Site 71	89-SC-209	Dunitic Till	45.71	7.64	10.70	18.44	4.33	1.00	0.86	0.63	0.16	0.21	0.22	202	10.0	99.95
34	Soil Site 72	89-SC-213	Dunitic Till	47.34	9.95	9.67	15.22	3.68	1.24	1.04	0.63	0.14	0.18	0.12	252	10.7	99.97
35	Soil Site 73	89-SC-216	Dunitic Till	45.81	7.19	11.43	20.29	3.62	0.94	0.58	0.53	0.11	0.19	0.29	195	9.0	100.03
36	Soil Site 74	89-SC-219	Dunitic Till	44.95	12.44	8.82	10.73	2.89	1.65	0.96	0.62	0.15	0.15	0.18	352	16.4	100.02
37	Soil Site 75	89-SC-223	Dunitic Till	47.81	10.86	11.78	11.41	4.96	1.64	0.91	0.80	0.12	0.19	0.18	286	9.3	100.03
38	Soil Site 76	89-SC-226	Dunitic Till	48.05	10.38	12.27	12.51	5.58	1.63	0.87	0.90	0.09	0.18	0.17	272	7.5	100.19
39	Soil Site 47	88-SC-127	Dunitic Till (A-Zone)	49.81	11.26	11.96	11.66	3.65	2.09	0.79	0.74	0.09	0.15	0.23	332	7.6	100.09
40	Soil Site 51	88-SC-135	Dunitic Till (A-Zone)	46.12	9.57	14.96	14.17	3.27	1.50	0.72	0.68	0.06	0.22	0.29	263	8.6	100.20
41	Soil Site 53	88-SC-142	Dunitic Till (A-Zone)	50.27	11.68	10.86	10.64	4.48	1.88	0.73	0.79	0.08	0.15	0.12	273	8.4	100.13
42	Soil Site 54	88-SC-145	Dunitic Till (A-Zone)	51.01	12.08	9.53	11.50	2.75	2.29	0.73	0.61	0.08	0.13	0.23	334	9.1	100.10
43	Soil Site 55	88-SC-148	Dunitic Till (A-Zone)	50.19	10.23	11.20	12.72	4.01	1.77	0.65	0.70	0.06	0.12	0.31	253	8.1	100.10
44	Soil Site 56	88-SC-153	Dunitic Rubble(A-Zone)	42.96	8.20	10.97	19.06	1.24	1.26	0.56	0.37	0.15	0.29	0.51	260	14.4	100.01
45	Soil Site 57	88-SC-156	Dunitic Till (A-Zone)	44.63	7.86	14.05	17.25	2.80	1.06	0.35	0.53	0.07	0.23	0.36	182	10.8	100.02
46	Soil Site 59	88-SC-161	Dunitic Till (A-Zone)	50.21	10.30	10.69	13.69	4.07	1.92	0.73	0.71	0.07	0.15	0.16	266	7.2	99.95

APPENDIX 2.2
OVERVIEW ANALYTICAL RESULTS: COLLUVIUM

	Site	Sample	Parent Material	Pt (ppb)	Pd (ppb)	Rh (ppb)	Au (ppb)	As (ppm)	Sb (ppm)	Bi (ppm)	Ge (ppm)	Se (ppm)	Te (ppm)
1	Soil Site 7	88-SC-021	Colluvium	88	3	2	8	14.2	0.4	0.2	0.2	0.2	0.3
2	Soil Site 8	88-SC-022	Colluvium	108	3	2	17	28.5	0.6	0.3	0.2	0.2	0.3
3	Soil Site 9	88-SC-023	Colluvium	67	3	2	6	14.5	0.4	0.3	0.2	0.2	0.3
4	Soil Site 10	88-SC-025	Colluvium	66	2	2	12	22.2	0.2	0.2	0.2	0.2	0.3
5	Soil Site 11	88-SC-026	Colluvium	110	2	2	34	43.5	0.8	0.5	0.2	0.2	0.3
6	Soil Site 12	88-SC-027	Colluvium	88	2	2	25	28.1	0.9	0.4	0.2	0.2	0.3
7	Soil Site 13	88-SC-028	Colluvium	73	5	2	7	14.1	0.7	0.5	0.2	0.2	0.3
8	Soil Site 14	88-SC-029	Colluvium	68	5	2	20	24.1	0.8	0.4	0.2	0.2	0.3
9	Soil Site 15	88-SC-030	Colluvium	47	2	2	8	15.5	0.7	0.3	0.2	0.2	0.3
10	Soil Site 16	88-SC-031	Colluvium	885	2	3	2	38.1	0.5	0.3	0.2	0.2	0.3
11	Soil Site 17	88-SC-032	Colluvium	118	3	2	56	38.0	1.2	0.4	0.2	0.2	0.3
12	Soil Site 18	88-SC-033	Colluvium	32	2	2	9	10.9	0.5	0.3	0.2	0.2	0.3
13	Soil Site 24	88-SC-054	Colluvium	185	3	2	49	17.2	0.4	0.5	0.2	0.2	0.5
14	Soil Site 25	88-SC-056	Colluvium	56	2	2	33	22.6	1.0	0.3	0.2	0.2	0.3
15	Soil Site 26	88-SC-058	Colluvium	92	2	2	21	56.3	0.7	0.3	0.2	0.2	0.3
16	Soil Site 27	88-SC-061	Colluvium	173	2	2	39	17.9	0.5	0.3	0.3	0.2	0.3
17	Soil Site 28	88-SC-063	Colluvium	24	2	2	21	12.5	0.2	0.1	0.2	0.2	0.3
18	Soil Site 29	88-SC-066	Colluvium	47	3	2	54	21.5	0.7	0.1	0.2	0.2	0.3
19	Soil Site 30	88-SC-069	Colluvium	45	3	2	2	7.5	0.4	0.3	0.4	0.2	0.3
20	Soil Site 36	88-SC-090	Colluvium	97	3	2	27	15.0	0.5	0.3	0.3	0.2	0.3
21	Soil Site 37	88-SC-091	Colluvium	138	2	2	31	16.0	0.6	0.1	0.2	0.2	0.3
22	Soil Site 42	88-SC-105	Colluvium	112	2	2	28	14.2	0.3	0.2	0.2	0.2	0.3
23	Soil Site 60	88-SC-171	Colluvium	104	2	2	6	12.9	0.5	0.1	0.2	0.2	0.3
24	Soil Site 61	88-SC-173	Colluvium	99	2	2	8	13.9	0.2	0.2	0.2	0.2	0.3
25	Soil Site 62	88-SC-174	Colluvium	78	3	2	3	14.0	0.6	0.2	0.3	0.2	0.3
26	Soil Site 50	88-SC-132	Colluvium (A-Zone)	70	2	2	1	23.3	0.8	0.2	0.2	0.2	0.3
27	Soil Site 52	88-SC-139	Colluvium (A-Zone)	308	4	2	1	11.3	0.6	0.1	0.2	0.2	0.3

Site	Sample	Parent Material	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)	MgO (%)	CaO (%)	Na ₂ O (%)	K ₂ O (%)	TiO ₂ (%)	P ₂ O ₅ (%)	MnO (%)	Cr ₂ O ₃ (%)	Ba (ppm)	LOI (%)	Total	
1	Soil Site 7	88-SC-021	Colluvium	39.50	5.23	12.57	22.91	1.87	0.95	0.51	0.34	0.10	0.26	0.37	143	15.6	100.23
2	Soil Site 8	88-SC-022	Colluvium	37.38	3.54	12.21	28.22	1.15	0.58	0.35	0.21	0.11	0.31	0.42	94	15.7	100.20
3	Soil Site 9	88-SC-023	Colluvium	42.17	6.34	12.10	22.67	2.02	1.03	0.57	0.38	0.08	0.22	0.32	186	11.9	99.83
4	Soil Site 10	88-SC-025	Colluvium	39.18	5.91	12.31	21.82	1.93	0.84	0.80	0.37	0.17	0.43	0.29	159	15.9	99.98
5	Soil Site 11	88-SC-026	Colluvium	34.60	4.09	11.13	23.38	1.49	0.57	0.46	0.26	0.22	0.57	0.39	141	22.8	99.98
6	Soil Site 12	88-SC-027	Colluvium	42.97	8.24	12.74	17.46	2.73	1.24	0.58	0.52	0.13	0.32	0.23	216	12.5	99.70
7	Soil Site 13	88-SC-028	Colluvium	43.56	9.73	13.72	14.29	3.29	1.30	0.65	0.62	0.12	0.27	0.26	206	12.0	99.85
8	Soil Site 14	88-SC-029	Colluvium	41.70	7.68	11.66	20.62	2.42	1.07	0.22	0.43	0.16	0.30	0.31	101	13.3	99.89
9	Soil Site 15	88-SC-030	Colluvium	44.15	8.27	11.64	19.95	2.24	1.30	0.29	0.46	0.11	0.23	0.25	136	11.1	100.01
10	Soil Site 16	88-SC-031	Colluvium	38.24	3.86	12.50	28.20	1.16	0.60	0.06	0.24	0.12	0.30	0.44	97	14.3	100.04
11	Soil Site 17	88-SC-032	Colluvium	35.25	2.14	11.97	30.83	0.76	0.22	0.06	0.14	0.15	0.42	0.35	96	17.8	100.11
12	Soil Site 18	88-SC-033	Colluvium	44.41	9.51	10.57	18.22	0.59	1.44	0.48	0.50	0.10	0.23	0.22	211	11.8	100.10
13	Soil Site 24	88-SC-054	Colluvium	36.93	5.57	12.43	20.94	2.51	0.75	0.13	0.40	0.17	0.29	0.32	112	19.7	100.16
14	Soil Site 25	88-SC-056	Colluvium	41.24	6.74	13.58	23.42	2.46	1.09	0.17	0.51	0.10	0.21	0.27	95	10.3	100.11
15	Soil Site 26	88-SC-058	Colluvium	40.64	1.21	11.51	32.78	0.35	0.08	0.06	0.08	0.08	0.25	0.32	39	12.7	100.07
16	Soil Site 27	88-SC-061	Colluvium	41.59	3.93	11.36	29.78	1.16	0.59	0.10	0.23	0.08	0.20	0.32	38	10.8	100.15
17	Soil Site 28	88-SC-063	Colluvium	43.31	8.44	10.20	21.68	2.27	1.41	0.19	0.47	0.08	0.15	0.24	133	11.6	100.06
18	Soil Site 29	88-SC-066	Colluvium	46.38	7.13	9.37	22.28	2.33	1.20	0.82	0.45	0.09	0.15	0.20	226	9.4	99.84
19	Soil Site 30	88-SC-069	Colluvium	35.26	1.87	9.65	30.49	0.65	0.26	0.05	0.12	0.13	0.23	0.46	78	20.8	99.98
20	Soil Site 36	88-SC-090	Colluvium	42.61	5.42	11.56	26.25	1.63	0.85	0.20	0.33	0.07	0.18	0.34	100	10.5	99.95
21	Soil Site 37	88-SC-091	Colluvium	40.65	3.48	12.29	28.61	1.27	0.53	0.21	0.25	0.09	0.24	0.38	95	12.1	100.12
22	Soil Site 42	88-SC-105	Colluvium	45.63	2.71	10.99	28.52	0.81	0.37	0.05	0.19	0.09	0.19	0.46	38	10.1	100.12
23	Soil Site 60	88-SC-171	Colluvium	40.05	5.69	13.58	23.75	2.07	0.87	0.09	0.38	0.10	0.32	0.50	95	12.7	100.12
24	Soil Site 61	88-SC-173	Colluvium	40.19	5.72	12.91	23.20	2.13	0.87	0.22	0.39	0.12	0.32	0.32	154	13.7	100.12
25	Soil Site 62	88-SC-174	Colluvium	39.25	5.33	12.74	23.84	2.06	0.81	0.26	0.36	0.14	0.24	0.34	132	14.8	100.19
26	Soil Site 50	88-SC-132	Colluvium (A-Zone)	45.04	9.51	13.28	14.29	2.79	1.52	0.82	0.60	0.10	0.27	0.17	312	11.8	100.24
27	Soil Site 52	88-SC-139	Colluvium (A-Zone)	43.67	8.45	11.84	16.33	1.99	1.55	0.68	0.45	0.09	0.21	0.54	270	14.3	100.15

APPENDIX 3

XRD MINERALOGY OF -10 + 40-MESH (BLACK CIRCLES) AND -270-MESH (OPEN CIRCLES) FRACTIONS OF SOIL HORIZONS IN (A) NON-DUNITIC TILL; (B) DUNITIC TILL; (C) DUNITIC TILL; (D) DUNITIC TILL AND RUBBLE ADJACENT TO THE A-ZONE PGE OCCURRENCE; AND (E) ACTIVE COLLUVIUM

A

Soil Site and Horizon	Platinum content (ppb)	Serpentine Group	Chlorite Group	Mica Group	Clay Mineral Group	Amphibole Group	Feldspar Group																
		Forsterite	Chrysotile	Lizardite	Clinochlore	Nimite	Gonyerite	Muscovite	Ephesite	Vermiculite	Ferro Saponite	Ferro Hornblende	Ferro Pargasite	Ferro Richterite	Augite	Chromite	Magnetite	Akaganeite	Graphite	Cooperite	Plagioclase Quartz	Orthoclase	
6 18 Bh	13			●	●																	●	●
	7			○	○																	○	○
	9			●	●																	●	●
	9			○	○																	○	○
20 38 Ae _j	3				●																	●	●
	7				○		○															○	○
39 Bf	7				●																	●	●
	10				○																	○	○
40 C	77				●		●															●	●
	14				○		○															○	○

B

Soil Site and Horizon	Platinum content (ppb)	Serpentine Group	Chlorite Group	Mica Group	Clay Mineral Group	Amphibole Group	Feldspar Group																
		Forsterite	Chrysotile	Lizardite	Clinochlore	Nimite	Gonyerite	Muscovite	Ephesite	Vermiculite	Ferro Saponite	Ferro Hornblende	Ferro Pargasite	Ferro Richterite	Augite	Chromite	Magnetite	Akaganeite	Graphite	Cooperite	Plagioclase Quartz	Orthoclase	
33 78 Bm	49		●	●	●																	●	●
	36		○	○	○																	○	○
	93		●	●	●																	●	●
	36		○	○	○															○			
43 110 Bm ₁	7	●		●																		●	●
	16	○		○			○															○	○
111 Bm ₂	6	●		●																		●	●
	17	○		○			○															○	○
112 BC/C	9						●				●											●	●
	13						○				○											○	○
113 C	1						●				●											●	●
	2						○				○											○	○

C

Soil Site and Horizon	Platinum content (ppb)	Serpentine Group	Chlorite Group	Mica Group	Clay Mineral Group	Amphibole Group		Feldspar Group															
		Forsterite	Chrysotile	Clinocllore	Lizardite	Ninrite	Gonyerite	Muscovite	Ephestie	Vermiculite	Ferro Hornblende	Ferro Saponite	Ferro Paragesite	Ferro Richterite	Augite	Chromite	Magnetite	Akaganeite	Graphite	Cooperite	Plagioclase	Orthoclase	
69 199 Bm 200 C	86			●																		●	●
	104			○																		○	○
	53			●																		●	●
	25			○		○				○	○											○	○
73 215 Bm 216 C	81	●	●	●			●				●										●	●	
	53	○	○	○			○				○											○	○
	101	●	●	●			●				●											●	●
	41		○	○	○		○				○											○	○

D

Soil Site and Horizon	Platinum content (ppb)	Serpentine Group	Chlorite Group	Mica Group	Clay Mineral Group	Amphibole Group		Feldspar Group															
		Forsterite	Chrysotile	Clinocllore	Lizardite	Ninrite	Gonyerite	Muscovite	Ephestie	Vermiculite	Ferro Hornblende	Ferro Saponite	Ferro Paragesite	Ferro Richterite	Augite	Chromite	Magnetite	Akaganeite	Graphite	Cooperite	Plagioclase	Orthoclase	
56 152 C	355			●			●											●	●				
	116			○			○												○	○		○	○
	722			●		●														●			
153 C	260			○			○													○			○
154 Bm/IC	110	●		●												●	●						●
	76			○			○										○					○	○
57 155 BC	92			●		●																●	●
	131		○	○		○						○										○	○
156 IIC	119			●		●																●	●
	150			○		○																○	○

E

Soil Site and Horizon	Platinum content (ppb)	Serpentine Group		Chlorite Group		Mica Group		Clay Mineral Group		Amphibole Group		Feldspar Group		Orthoclase									
		Forsterite	Talc	Chrysotile	Lizardite	Clinochlore	Ninrite	Goniyerite	Muscovite	Ephesite	Vermiculite	Saponite	Ferro Hornblende	Ferro Pargasite	Augite	Chromite	Magnetite	Alagansite	Graphite	Cooperite	Plegbockite	Quartz	
16 31 C	193					●	●										●						
	147					○	○										○						
59 C	113	●		●	●												●						
	99	○		○	○												○						
27 60 C	108	●		●	●												●						
	89	○		○	○												○						
61 C	95			●	●											●	●						
	75	○		○	○											○	○						
104 C	99	●	●			●																	
	115	○	○																				
42 105 C	110	●	●			●															●		
	117	○	○																		○		

APPENDIX 4.1
LFH-HORIZON SAMPLES:
ANALYTICAL AND WEIGHT
DATA FOR ENTIRE SUITE (n=47)

Underlying Surficial Material	Site	Sample	Pt (ppb)	Pd (ppb)	Rh (ppb)	Au (ppb)	LFH/C Horizons Pt Ratio	Pre-ash Split Wt (g)	Ash Weight (g)	Weight Percent Ash (%)
Clay	1	88-SC-01	1	2	2	10	0.25	139.10	10.72	7.71
Clay	46	88-SC-121	7	7	2	10	1.00	144.71	11.81	8.16
Non-dunitic till	2	88-SC-04	16	19	2	46	1.78	123.30	9.88	8.01
Non-dunitic till	3	88-SC-07	8	7	2	4	0.57	101.65	13.03	12.82
Non-dunitic till	4	88-SC-10	7	6	2	4	1.17	99.72	18.95	19.00
Non-dunitic till	5	88-SC-13	2	3	2	12	0.11	205.33	12.00	5.84
Non-dunitic till	6	88-SC-17	6	8	2	5	2.00	138.31	25.21	18.23
Non-dunitic till	19	88-SC-34	18	2	2	8	2.25	92.30	12.92	14.00
Non-dunitic till	20	88-SC-37	4	5	2	5	0.20	103.09	10.16	9.86
Non-dunitic till	21	88-SC-42	5	3	2	8	1.67	99.31	9.06	9.12
Non-dunitic till	22	88-SC-45	4	2	2	6	0.80	116.13	21.86	18.82
Non-dunitic till	23	88-SC-49	3	7	2	13	0.60	56.95	8.03	14.10
Non-dunitic till	31	88-SC-70	10	2	3	7	1.25	97.64	8.34	8.54
Non-dunitic till	32	88-SC-74	6	4	2	4	0.50	130.75	49.25	37.67
Non-dunitic till	35	88-SC-83	9	2	2	8	0.64	98.92	11.58	11.71
Non-dunitic till	38	88-SC-92	12	4	2	7	0.80	88.29	12.27	13.90
Non-dunitic till	39	88-SC-95	4	2	2	7	2.00	107.54	17.36	16.14
Non-dunitic till	40	88-SC-100	7	2	2	9	3.50	112.92	11.15	9.87
Non-dunitic till	41	88-SC-103	6	3	2	6	1.20	97.34	8.50	8.73
Non-dunitic till	44	88-SC-114	10	2	2	3	0.56	108.28	18.41	17.00
Non-dunitic till	45	88-SC-118	8	3	2	5	0.62	100.94	19.90	19.71
Dunitic till	33	88-SC-77	8	2	2	9	0.29	93.76	10.87	11.59
Dunitic till	34	88-SC-80	10	2	2	4	0.28	120.80	26.08	21.59
Dunitic till	43	88-SC-109	6	2	2	4	0.38	75.62	11.45	15.14
Dunitic till	63	89-SC-176	15	2	2	4	0.34	177.26	15.03	8.48
Dunitic till	64	89-SC-179	7	2	2	1	0.39	164.71	33.92	20.59
Dunitic till	66	89-SC-186	16	2	2	1	0.47	179.11	38.51	21.50
Dunitic till	67	89-SC-190	7	2	2	2	0.22	132.16	11.90	9.00
Dunitic till	68	89-SC-194	7	2	2	1	0.16	168.37	19.05	11.31
Dunitic till	69	89-SC-198	20	2	2	4	0.41	193.61	21.72	11.22
Dunitic till	70	89-SC-201	15	2	2	4	0.44	138.28	13.99	10.12
Dunitic till	71	89-SC-204	10	2	2	2	0.28	122.53	12.85	10.49
Dunitic till	72	89-SC-210	20	2	4	1	0.71	99.23	8.56	8.63
Dunitic till	73	89-SC-214	18	2	2	1	0.06	96.99	13.15	13.56
Dunitic till	74	89-SC-217	32	2	2	7	0.64	152.51	10.79	7.07
Dunitic till	75	89-SC-220	23	2	2	1	0.61	135.85	24.49	18.03
Dunitic till	76	89-SC-227	10	2	2	3	0.18	137.53	25.18	18.31
Dunitic till (A-Zone)	47	88-SC-125	143	2	2	3	1.68	224.46	52.41	23.35
Colluvium (A-Zone)	52	88-SC-136	122	2	2	5	0.40	115.57	9.04	7.82
Dunitic till (A-Zone)	53	88-SC-137	96	2	2	6	2.29	277.08	15.34	5.54
Dunitic till (A-Zone)	54	88-SC-143	57	2	3	7	1.36	89.09	11.54	12.95
Dunitic till (A-Zone)	55	88-SC-146	167	4	3	6	1.80	91.88	14.82	16.13
Dunitic rubble (A-Zone)	56	88-SC-151	139	5	3	7	0.31	91.59	16.39	11.34
Dunitic till (A-Zone)	59	88-SC-159	9	2	2	9	0.12	101.67	9.35	9.20
Colluvium	7	88-SC-20	49	3	2	4	0.56	95.40	28.95	21.96
Colluvium	24	88-SC-53	141	2	3	17	0.76	134.87	49.95	37.03
Colluvium	62	88-SC-175	65	2	2	13	0.83	168.82	14.98	8.87

APPENDIX 4.2
LFH-HORIZON SAMPLES:
IRON AND INSOLUBLE RESIDUE CONTENTS OF SELECTED SAMPLES (n = 38)

Underlying Surficial Material	Site	Sample	Fe (%)	Ash Subsample Weight (g)	Insoluble Residue Weight (g)	Wt. Percent Insoluble Residue (%)
Clay	1	88-SC-01	1.62	0.50	0.05	10.0
Clay	46	88-SC-121	3.78	0.50	0.03	6.0
Non-dunitic till	2	88-SC-04	1.77	0.37	0.00	0.0
Non-dunitic till	3	88-SC-07	3.11	0.50	0.06	12.0
Non-dunitic till	4	88-SC-10	2.39	0.50	0.04	8.0
Non-dunitic till	5	88-SC-13	1.78	0.50	0.04	8.0
Non-dunitic till	6	88-SC-17	3.44	0.50	0.07	14.0
Non-dunitic till	19	88-SC-34	2.01	0.50	0.04	8.0
Non-dunitic till	22	88-SC-45	3.67	0.50	0.06	12.0
Non-dunitic till	32	88-SC-74	1.56	0.50	0.03	6.0
Non-dunitic till	35	88-SC-83	1.57	0.50	0.08	16.0
Non-dunitic till	38	88-SC-92	1.03	0.50	0.03	6.0
Non-dunitic till	39	88-SC-95	3.28	0.50	0.16	32.0
Non-dunitic till	40	88-SC-100	1.39	0.50	0.04	8.0
Non-dunitic till	44	88-SC-114	1.36	0.50	0.03	6.0
Non-dunitic till	45	88-SC-118	1.53	0.50	0.03	6.0
Dunitic till	33	88-SC-77	2.18	0.50	0.00	0.0
Dunitic till	34	88-SC-80	1.21	0.50	0.02	4.0
Dunitic till	43	88-SC-109	1.20	0.50	0.02	4.0
Dunitic till	63	89-SC-176	1.94	0.50	0.03	6.0
Dunitic till	64	89-SC-179	0.38	0.50	0.01	2.0
Dunitic till	67	89-SC-198	1.23	0.50	0.00	0.0
Dunitic till	68	89-SC-194	1.06	0.50	0.01	2.0
Dunitic till	69	89-SC-198	1.76	0.50	0.02	4.0
Dunitic till	70	89-SC-201	1.46	0.50	0.01	2.0
Dunitic till	71	89-SC-204	1.56	0.50	0.04	8.0
Dunitic till	72	89-SC-210	1.62	0.50	0.03	6.0
Dunitic till	73	89-SC-214	3.80	0.50	0.06	12.0
Dunitic till	74	89-SC-217	1.34	0.50	0.01	2.0
Dunitic till	75	89-SC-220	1.89	0.50	0.06	12.0
Dunitic till	76	89-SC-227	0.97	0.50	0.03	6.0
Dunitic till (A-Zone)	47	88-SC-125	4.86	0.50	0.18	36.0
Dunitic till (A-Zone)	53	88-SC-137	2.83	0.50	0.07	14.0
Dunitic till (A-Zone)	54	88-SC-143	3.56	0.50	0.04	8.0
Dunitic till (A-Zone)	55	88-SC-146	4.11	0.50	0.07	14.0
Dunitic rubble (A-Zone)	56	88-SC-151	3.82	0.43	0.03	7.0
Colluvium	7	88-SC-20	4.33	0.50	0.09	18.0
Colluvium	24	88-SC-53	4.83	0.50	0.09	18.0

APPENDIX 5
Pt, Pd, Rh and Au ANALYTICAL DATA FOR
STREAM SEDIMENT and MOSS MAT SITES, GRASSHOPPER CREEK

Site	Sample	Stream Media	Pt (ppb)	Pd (ppb)	Rh (ppb)	Au (ppb)
1	88-SC-501	Sediment	18	2	4	2
1	88-SC-502	Moss mat	17	3	2	15
2	88-SC-503	Sediment	78	2	2	239
2	88-SC-504	Moss mat	8	2	2	29
3	88-SC-505	Sediment	11	2	2	3
4	88-SC-507A	Sediment	8	3	3	2
4	88-SC-507B	Moss mat	11	4	2	19
5	88-SC-509	Sediment	53	2	2	4
5	88-SC-510	Moss mat	47	41	2	3
6	88-SC-511	Sediment	20	7	4	6
7	88-SC-513	Sediment	91	2	2	5
8	89-SC-515	Sediment	32	5	2	6
8	89-SC-516	Moss mat	23	24	2	1

APPENDIX 6.1
ORGANIC BOG SOILS:
Pt, Pd, Rh and Au ANALYTICAL DATA FOR
PULVERIZED VERSUS ASHED SUBSAMPLES

Sample	Site	Pt	Pt	Pd	Pd	Rh	Rh	Au	Au
		Pulv. (ppb)	Ashed (ppb)	Pulv. (ppb)	Ashed (ppb)	Pulv. (ppb)	Ashed (ppb)	Pulv. (ppb)	Ashed (ppb)
88-SC-701	Bog 1 (Centre)	4	67	3	13	5	2	1	14
88-SC-702	Bog 1 (Margin)	9	65	7	19	2	2	2	7
88-SC-703	Bog 2 (Centre)	1	8	9	2	2	2	4	1
88-SC-707	Bog 3 (Centre)	9	32	7	6	2	2	3	5
88-SC-708	Bog 3 (Margin)	21	55	7	3	2	2	3	4

APPENDIX 6.2
ORGANIC BOG SOILS:
SELECTED ANALYTICAL DATA FOR
PULVERIZED SUBSAMPLES

Sample	Site	As	Sb	MgO	MnO	Cr2O3	Fe2O3	LOI
		(ppm)	(ppm)	(%)	(%)	(%)	(%)	(%)
88-SC-701	Bog 1 (Centre)	2.3	3.9	2.94	0.03	0.01	0.51	93.1
88-SC-702	Bog 1 (Margin)	4.0	4.1	3.21	0.12	0.02	1.25	85.1
88-SC-703	Bog 2 (Centre)	3.2	0.8	2.02	0.02	0.01	2.52	66.0
88-SC-707	Bog 3 (Centre)	2.1	1.1	1.86	0.02	0.02	1.13	67.4
88-SC-708	Bog 3 (Margin)	1.0	1.5	2.92	0.02	0.06	1.49	66.2

APPENDIX 6.3
ORGANIC BOG SOILS:
SAMPLE WEIGHT AND COMPARATIVE LOSS ON IGNITION DATA FOR
PULVERIZED VERSUS ASHED SUBSAMPLES

Sample	Site	Original	Weight of	Weight of	Weight of Ash (g)	LOI	LOI
		Dry Wt. (g)	Split for Pulverizing (g)	Split for Ashing (g)		Ashed (%)	Pulv. (%)
88-SC-701	Bog 1 (Centre)	600.91	142.81	139.04	10.36	92.5	93.1
88-SC-702	Bog 1 (Margin)	903.24	237.37	240.35	38.10	84.1	85.1
88-SC-703	Bog 2 (Centre)	1545.25	225.06	227.14	80.96	64.4	66.0
88-SC-707	Bog 3 (Centre)	2902.39	163.97	168.85	56.66	66.4	67.4
88-SC-708	Bog 3 (Margin)	1518.22	191.95	209.07	71.32	65.9	66.2

APPENDIX 7
 PLATINUM CONTENT and pH OF GRASSHOPPER MOUNTAIN
 SURFACE WATERS (n = 17)

Sample	Water Type	Location		Topography	Pt-1 (ppt)	Pt-2 (ppt)	pH	Colour
		Relative to Other Media						
TU-01	Stream	Stream Site 1		Base of Slope	0.9	-	8.16	Clear
TU-02	Stream	Stream Site 2		Base of Slope	0.8	-	7.92	Clear
TU-03	Stream	Stream Site 3		Slope	0.8	1.3	8.06	Clear/Clear
TU-04	Stream	Stream Site 4		Slope	0.9	-	7.97	Clear
TU-05	Stream	Stream Site 5		Slope	0.9	-	7.99	Clear
TU-06	Stream	Stream Site 6		Slope	0.5	-	7.11	Clear
TU-07	Bog	-		Slope	1.0	-	6.30	Lt brown
TU-09	Bog	-		Plateau	1.3 ^a	-	7.24	Clear
TU-10	Soil pit	Soil Site 6		Base of Slope	0.6	-	7.29	Lt brown
TU-11	Bog	Bog 2		Base of Slope	0.9	-	6.89	Lt brown
TU-12	Soil pit	Soil Site 2		Base of Slope	0.9	-	7.01	Clear
TU-13	Bog	Bog 1		Base of Slope	0.7	-	7.99	Lt brown
TU-14	Soil pit	Soil Site 46		Base of Slope	2.2	1.7	6.73	Lt brown/Lt brown
TU-15	Stream	-		Base of Slope	0.9	-	7.34	Lt brown
TU-16	Bog	Bog 3		Plateau/summit	3.2	-	7.42	Brown
TU-17	Pond	-		Plateau	1.8	-	7.59	Clear
TU-19	Bog	-		Plateau	3.5	1.8 ^b	7.26	Lt brown/brown

^a routine sample is unfiltered and unacidified

^b duplicate sample is unfiltered and unacidified

APPENDIX 8.1
 PLATINUM CONCENTRATIONS IN FIVE STANDARD SIZE FRACTIONS
 OF SELECTED SOIL PROFILES

Site	Sample	Horizon	Surficial Material	-10+40 mesh (ppb)	-40+70 mesh (ppb)	-70+140 mesh (ppb)	-140+270 mesh (ppb)	-270 mesh (ppb)
6	18	Bh	Nondunitic Till	13	11	4	2	7
6	19	Cg	Nondunitic Till	9	8	6	5	9
20	38	Aej	Nondunitic Till	3	3	4	9	7
20	39	Bf	Nondunitic Till	7	5	8	2	10
20	40	C	Nondunitic Till	77	21	23	23	14
33	78	Bm	Dunitic Till	49	19	20	35	36
33	79	C	Dunitic Till	93	30	29	35	36
34	81	IC	Colluvium	16	53	42	41	53
34	82	IIC	Dunitic Till	14	21	19	25	21
43	110	Bm	Dunitic Till	7	1	5	8	16
43	111	Bm	Dunitic Till	6	1	3	6	17
43	112	BC/C	Dunitic Till	9	1	7	15	13
43	113	C	Dunitic Till	1	1	2	7	2
69	199	Bm	Dunitic Till	66	113	104	172	104
69	200	C	Dunitic Till	53	76	50	32	25
73	215	Bm	Dunitic Till	81	92	38	64	53
73	216	C	Dunitic Till	101	49	167	50	41
51	133	Bm	Dunitic Till	85	128	97	53	69
51	134	BC	Dunitic Till	74	103	74	55	53
51	135	C	Dunitic Till	96	632	157	141	89
57	154	Bm/IC	Colluvium	110	128	80	51	76
57	155	BC	Dunitic Till	92	128	149	90	131
57	156	IIC	Dunitic Till	119	152	155	164	150
56	152	C (upper)	Dunitic Till	355	402	83	38	116
56	153	C (lower)	Dunitic Till	722	588	278	257	260
27	59	C (upper)	Colluvium	113	104	78	149	99
27	60	C (middle)	Colluvium	106	88	67	83	89
27	61	C (lower)	Colluvium	95	388	74	90	75
42	104	C (upper)	Colluvium	99	128	78	152	115
42	105	C (lower)	Colluvium	110	139	64	91	117
9	24	C (upper)	Colluvium	248	178	53	42	61
9	23	C (lower)	Colluvium	85	121	225	53	71
16	31	C	Colluvium	193	176	277	167	147
2	503		Stream Sediment	1	12	21	18	23

APPENDIX 8.2
 PLATINUM CONCENTRATIONS IN LIGHT (S.G. <3.3) AND
 HEAVY (S.G. >3.3) MINERAL FRACTIONS
 IN SELECTED SOIL PROFILES

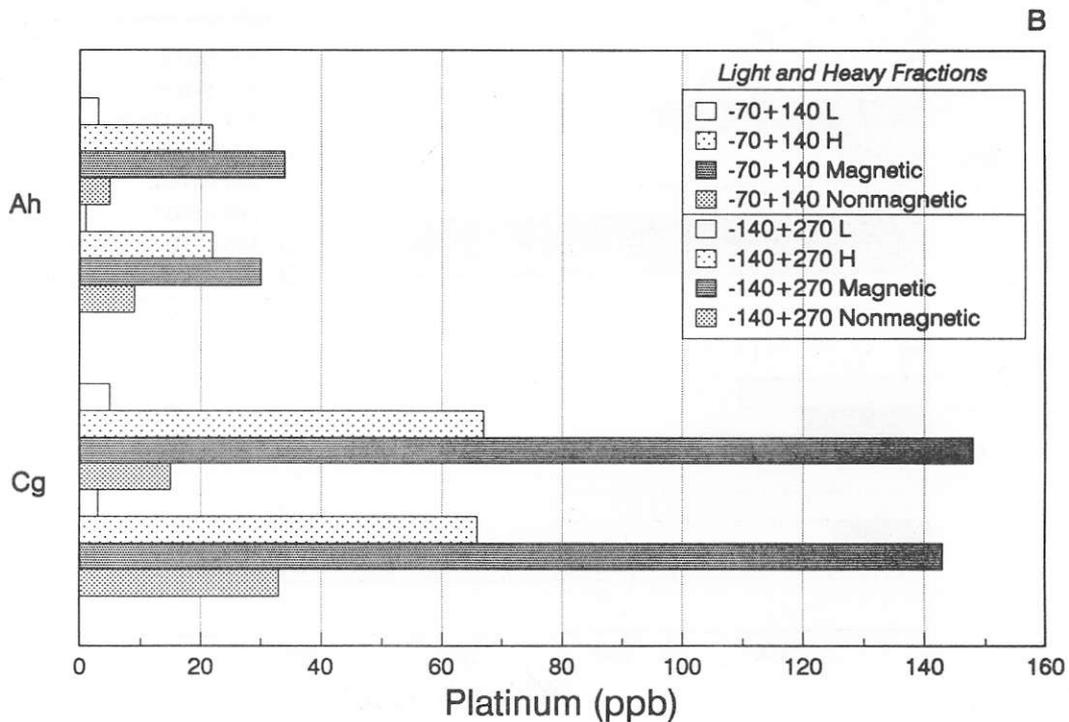
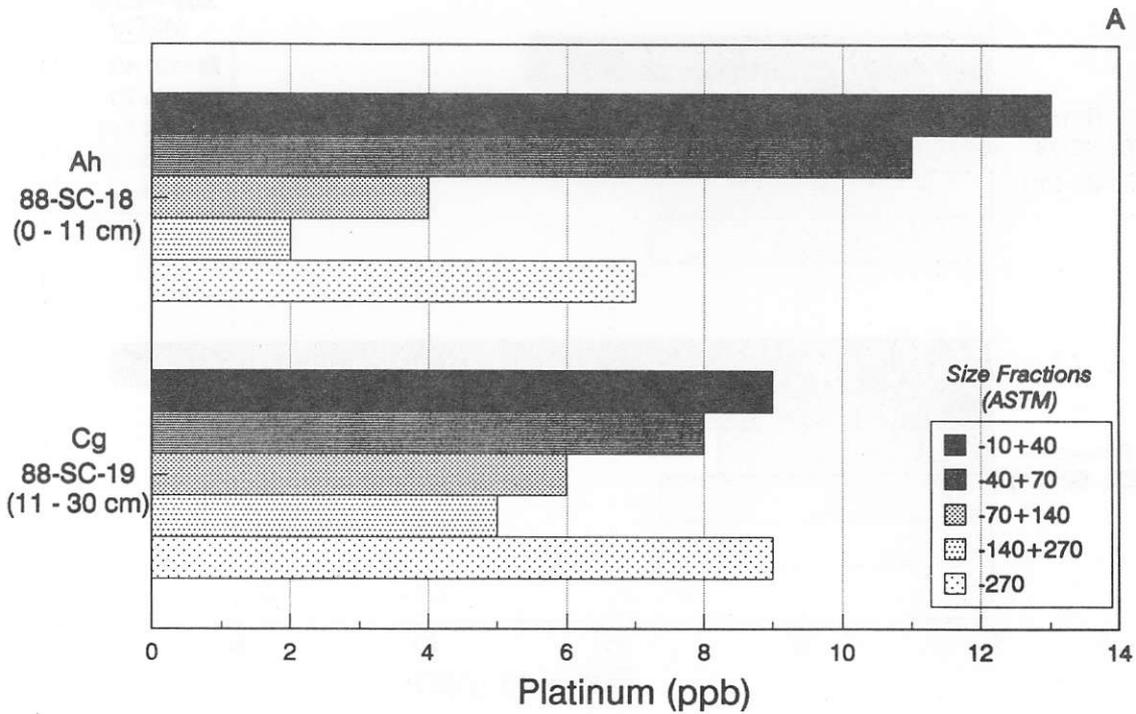
Site	Sample	Horizon	-70+140	-70+140	-140+270	-140+270
			Lights (ppb)	Heavies (ppb)	Lights (ppb)	Heavies (ppb)
6	18	Bh	3	22	1	22
6	19	Cg	5	67	3	66
20	38	Aej	2	18	6	46
20	39	Bf	6	61	1	30
20	40	C	10	142	14	242
33	78	Bm	9	142	4	338
33	79	C	15	118	12	240
34	81	IC	4	428	2	362
34	82	IIC	11	62	11	98
43	110	Bm	1	71	4	95
43	111	Bm	1	18	3	78
43	112	BC/C	6	11	1	200
43	113	C	1	20	2	127
69	199	Bm	36	767	50	1429
69	200	C	31	201	20	237
73	215	Bm	13	145	15	400
73	216	C	23	669	15	329
51	133	Bm	25	682	18	331
51	134	BC	21	526	25	343
51	135	C	69	787	110	756
57	154	Bm/IC	30	868	23	340
57	155	BC	50	1292	57	607
57	156	IIC	70	754	74	817
56	152	C (upper)	34	744	24	193
56	153	C (lower)	160	1590	137	2027
27	59	C (upper)	40	426	128	1000
27	60	C (middle)	37	388	74	283
27	61	C (lower)	47	364	70	812
42	104	C (upper)	61	261	123	855
42	105	C (lower)	46	282	62	503
9	24	C (upper)	33	305	35	154
9	23	C (lower)	27	1288	42	273
16	31	C	69	2538	117	901
2	503	Sediment	1	207	7	148

APPENDIX 8.3
 PLATINUM CONCENTRATIONS IN MAGNETIC AND NONMAGNETIC
 HEAVY FRACTIONS IN SELECTED SOIL PROFILES

Site	Sample	Horizon	-70+140	-70+140	-140+270	-140+270
			Heavy Mags (ppb)	Heavy NonMags (ppb)	Heavy Mags (ppb)	Heavy NonMags (ppb)
6	18	Bh	34	5	30	9
6	19	Cg	148	15	143	33
20	38	Aej	95	4	97	23
20	39	Bf	96	8	47	4
20	40	C	563	9	517	22
33	78	Bm	179	54	338	338
33	79	C	78	183	59	539
34	81	IC	400	541	297	655
34	82	IIC	96	13	128	64
43	110	Bm	158	30	95	95
43	111	Bm	51	14	108	51
43	112	BC/C	68	5	525	70
43	113	C	58	7	249	5
69	199	Bm	1142	112	1549	1195
69	200	C	490	7	273	179
73	215	Bm	704	10	1066	90
73	216	C	1732	85	474	139
51	133	Bm	759	57	358	193
51	134	BC	653	12	367	261
51	135	C	1075	28	987	278
57	154	Bm/IC	962	8	299	442
57	155	BC	792	3225	413	1053
57	156	IIC	695	870	359	1371
56	152	C (upper)	755	669	185	219
56	153	C (lower)	1671	466	1857	3172
27	59	C (upper)	393	530	738	2916
27	60	C (middle)	348	587	85	1655
27	61	C (lower)	317	569	339	4950
42	104	C (upper)	253	305	284	2730
42	105	C (lower)	288	257	199	1749
9	24	C (upper)	331	180	168	86
9	23	C (lower)	2782	43	170	691
16	31	C	2721	1601	855	1128
2	503	Sediment	361	34	149	146

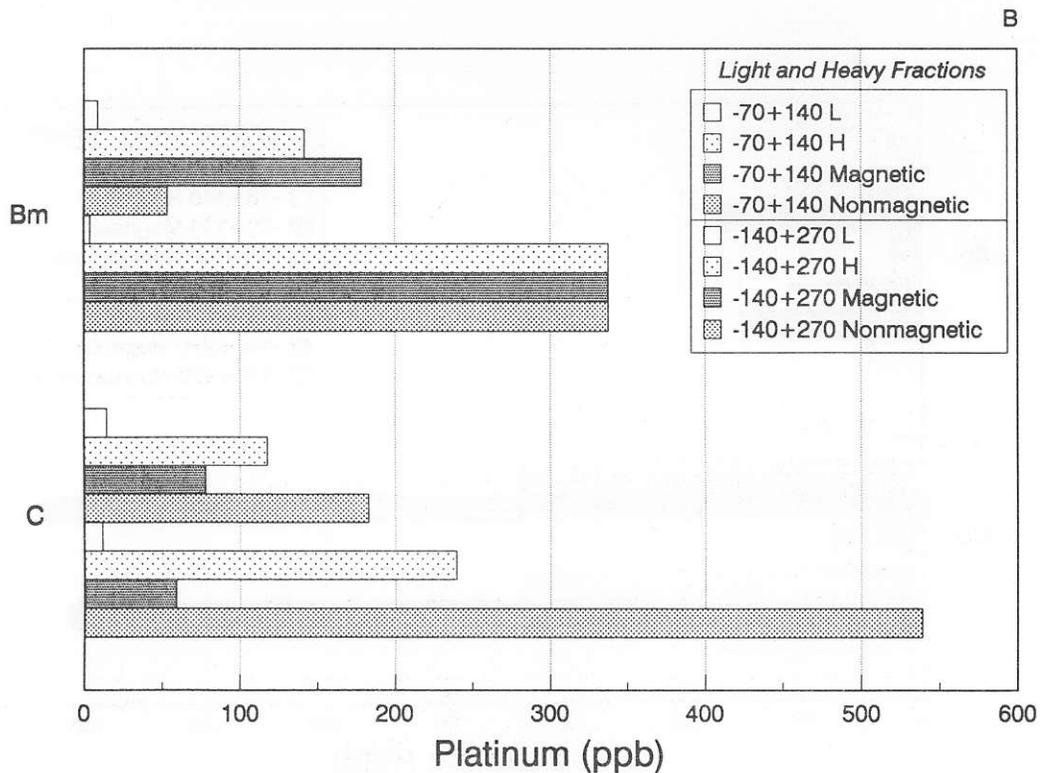
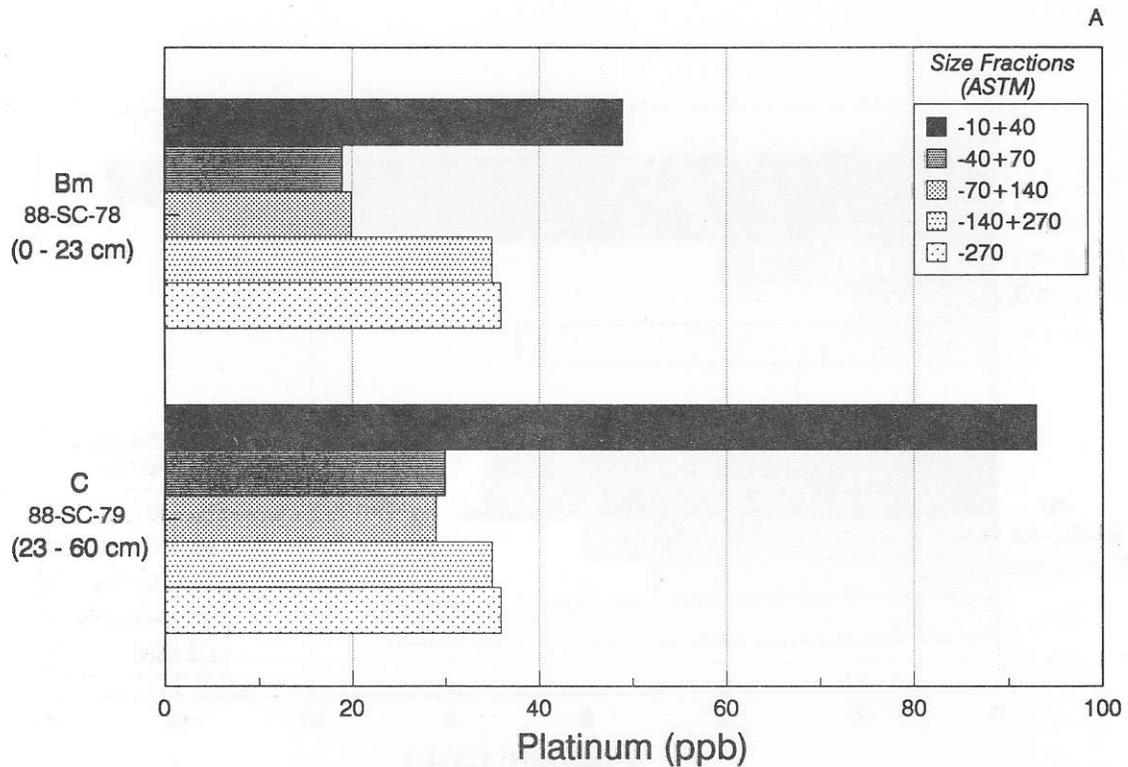
APPENDIX 9.1

PLATINUM DISTRIBUTION (ppb) IN MELANIC BRUNISOL (SOIL SITE 6) ON NON-DUNITIC TILL, SHOWING (A) PLATINUM CONTENT OF FIVE SIZE FRACTIONS AND (B) PLATINUM CONTENT OF LIGHT, HEAVY, HEAVY MAGNETIC AND HEAVY NONMAGNETIC MINERAL FRACTIONS OF THE -70 + 140 (BARS 1-4) AND -140 + 270 (BARS 5-8) MESH SIZE FRACTIONS



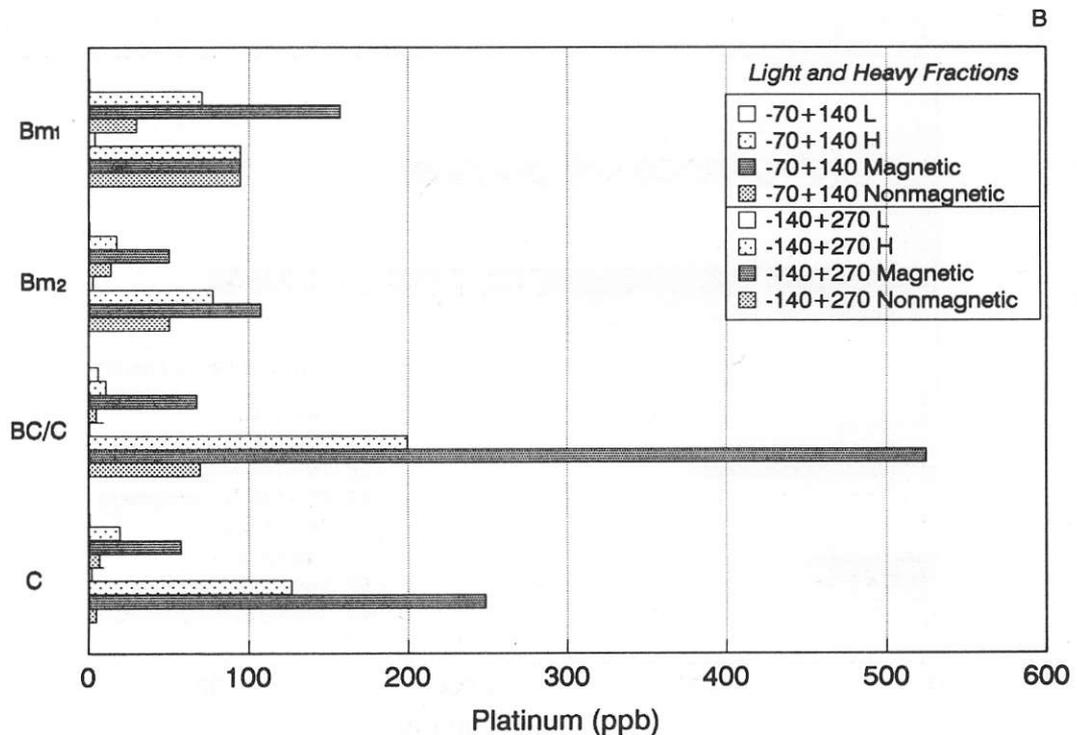
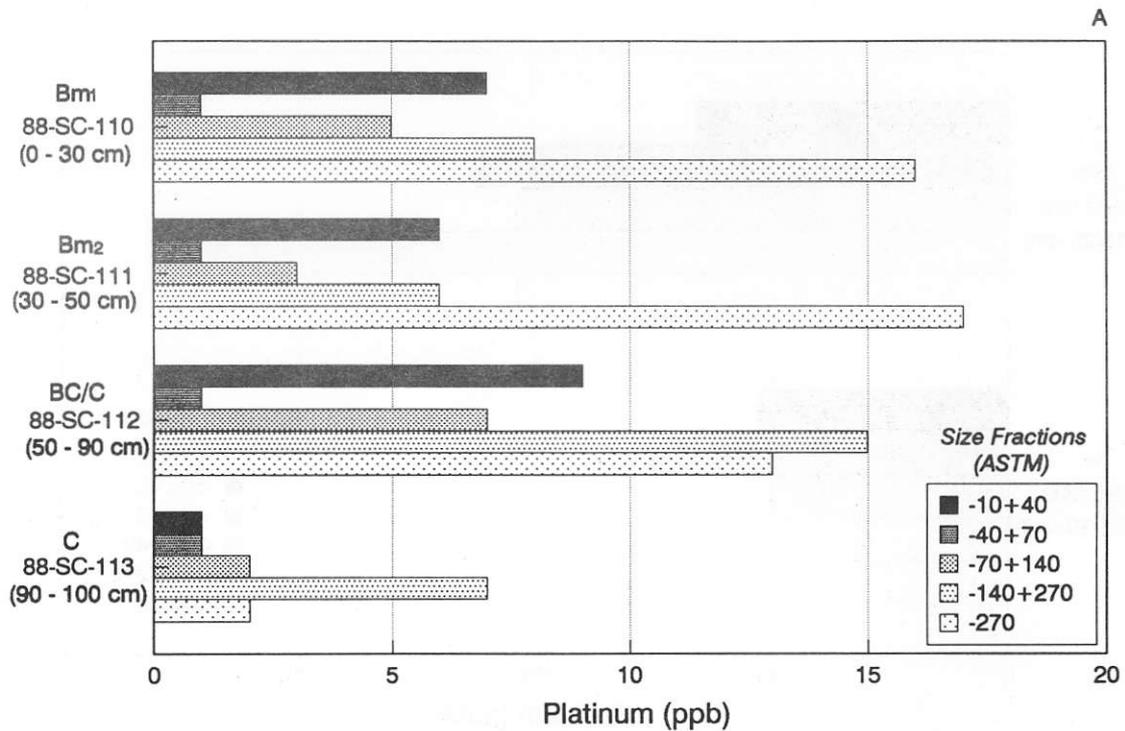
APPENDIX 9.2

PLATINUM DISTRIBUTION (ppb) IN EUTRIC BRUNISOL (SOIL SITE 33) ON DUNITIC TILL, SHOWING (A) PLATINUM CONTENT OF FIVE SIZE FRACTIONS AND (B) PLATINUM CONTENT OF LIGHT, HEAVY, HEAVY MAGNETIC AND HEAVY NONMAGNETIC MINERAL FRACTIONS OF THE -70 + 140 (BARS 1-4) AND -140 + 270 (BARS 5-8) MESH SIZE FRACTIONS



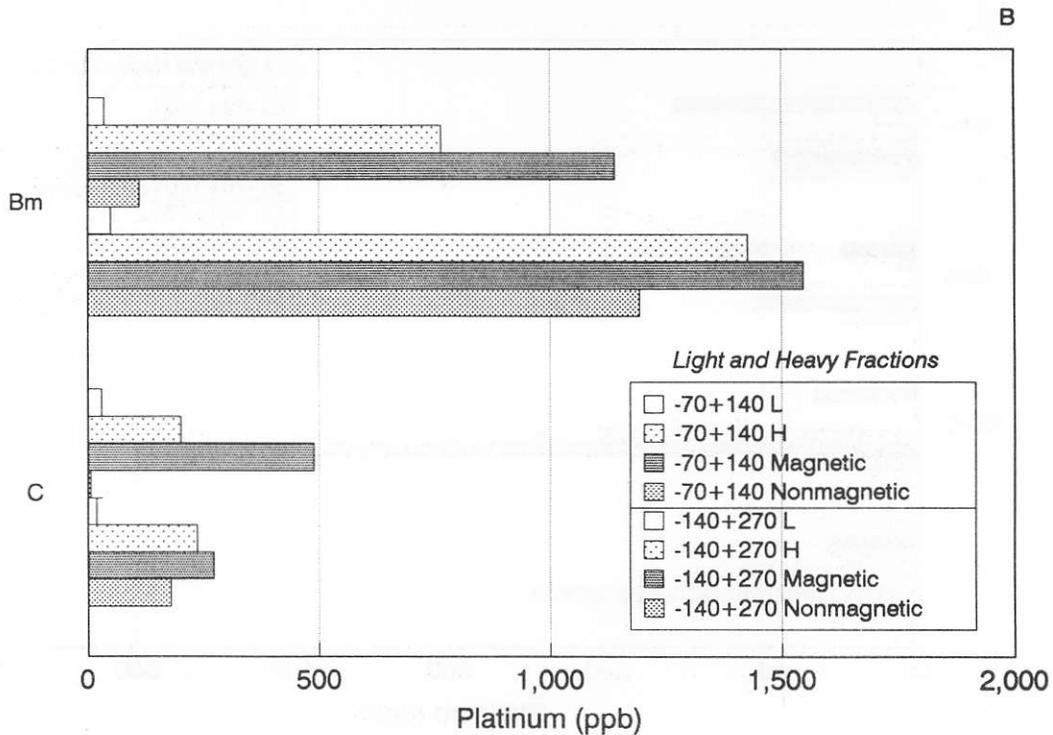
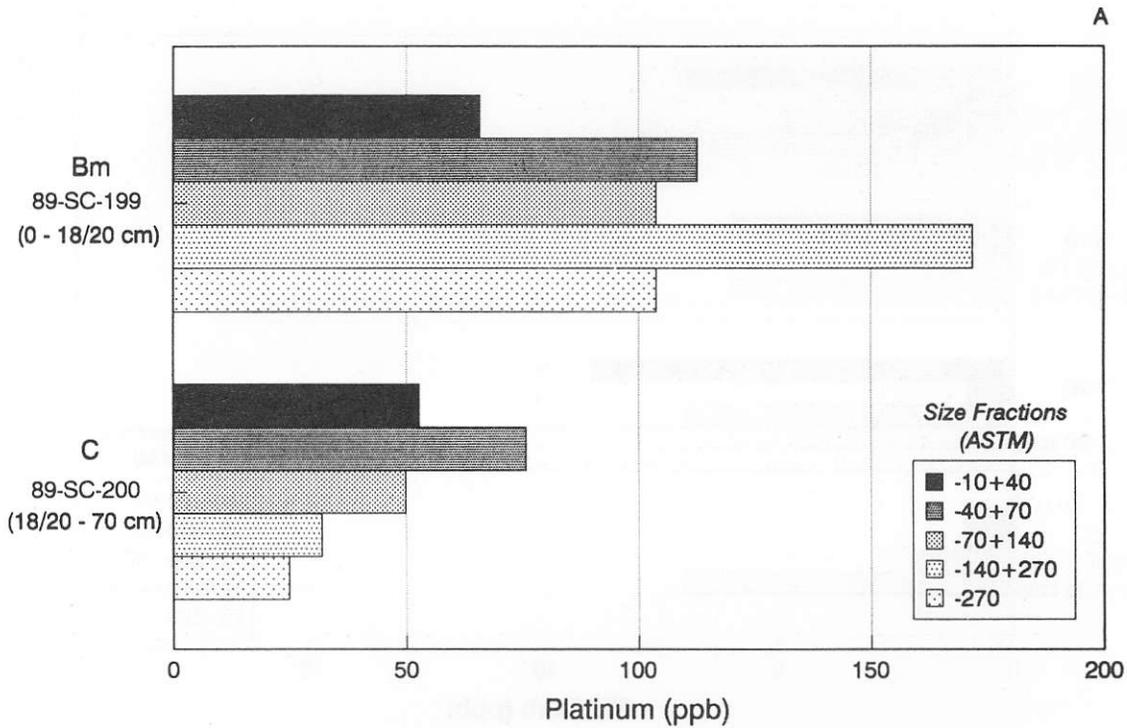
APPENDIX 9.3

PLATINUM DISTRIBUTION (ppb) IN COMPOSITE SOIL PROFILE (SOIL SITE 43) OF POSSIBLY GLACIOFLUVIALLY REWORKED DUNITIC TILL (B_m HORIZONS) ABOVE DUNITIC TILL (BC/C, C), SHOWING (A) PLATINUM CONTENT OF FIVE SIZE FRACTIONS AND (B) PLATINUM CONTENT OF LIGHT, HEAVY, HEAVY MAGNETIC AND HEAVY NONMAGNETIC MINERAL FRACTIONS OF THE -70 + 140 (BARS 1-4) AND -140 + 270 (BARS 5-8) MESH SIZE FRACTIONS



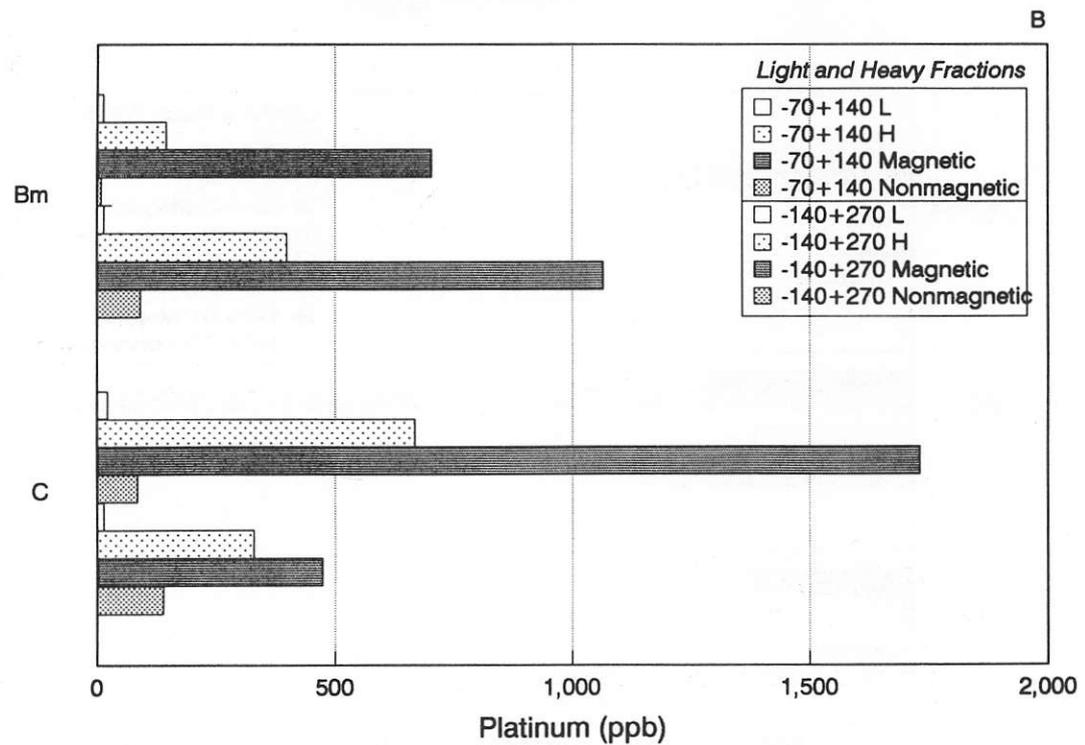
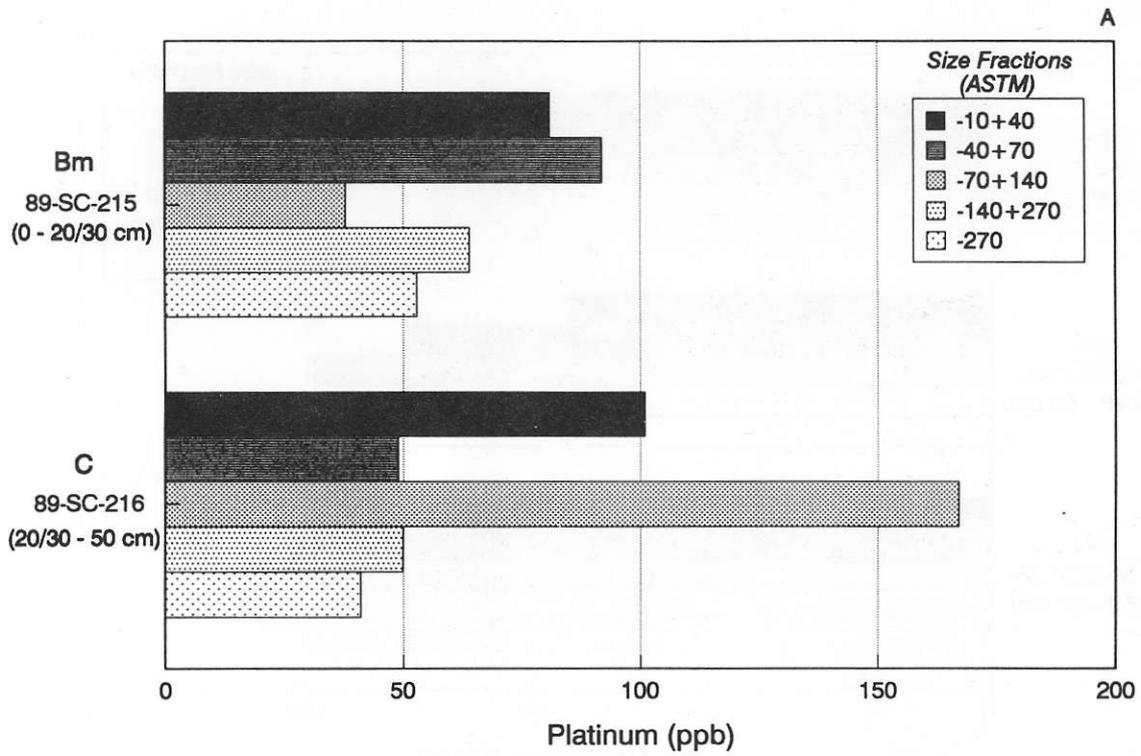
APPENDIX 9.4

PLATINUM DISTRIBUTION (ppb) IN EUTRIC BRUNISOL (SOIL SITE 69) ON DUNITIC TILL, SHOWING (A) PLATINUM CONTENT OF FIVE SIZE FRACTIONS AND (B) PLATINUM CONTENT OF LIGHT, HEAVY, HEAVY MAGNETIC AND HEAVY NONMAGNETIC MINERAL FRACTIONS OF THE -70 + 140 (-BARS 1-4) AND -140 + 270 (-BARS 5-8) MESH SIZE FRACTIONS



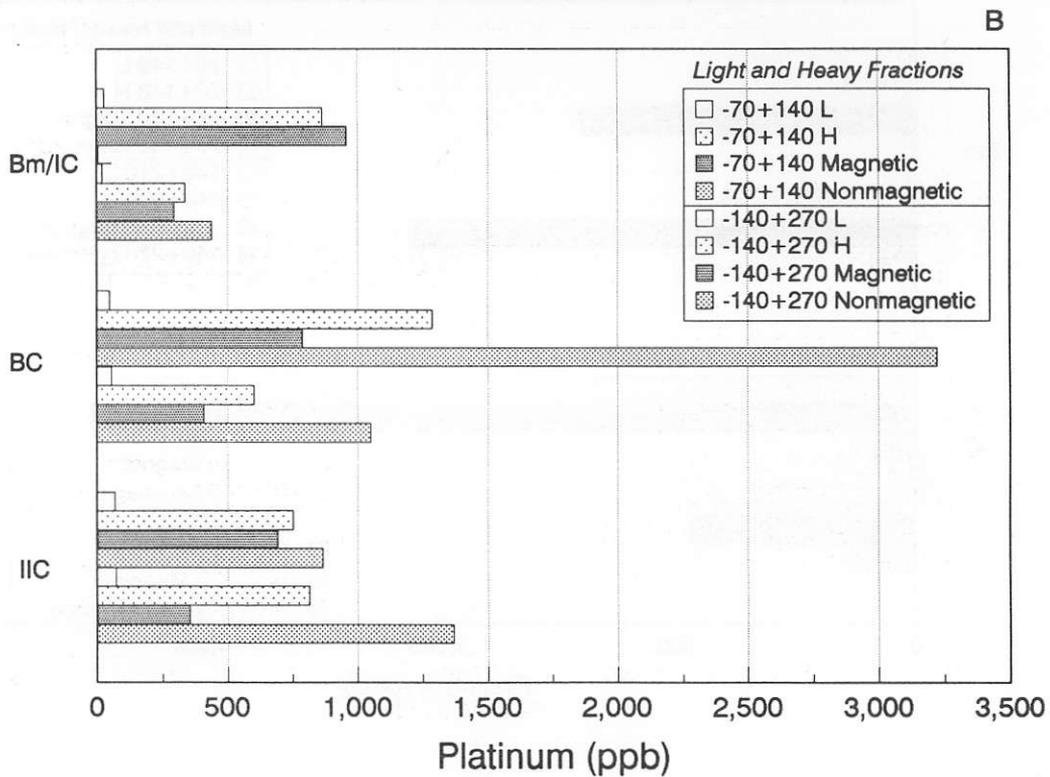
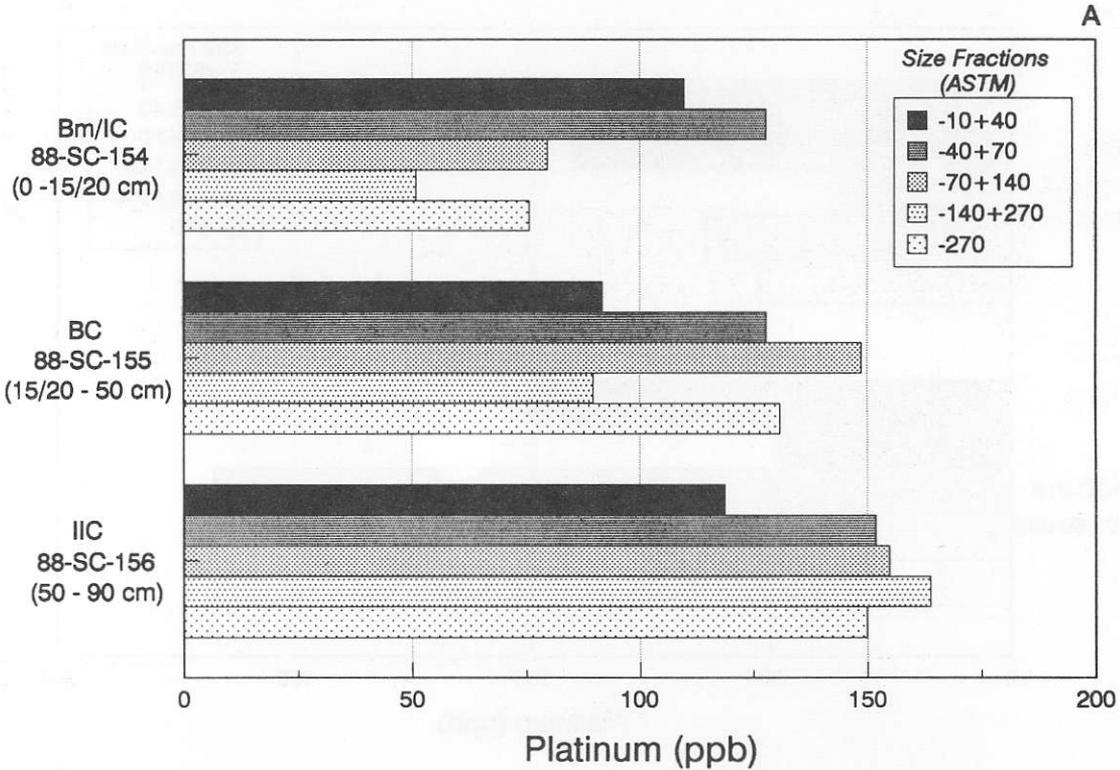
APPENDIX 9.5

PLATINUM DISTRIBUTION (ppb) IN EUTRIC BRUNISOL (SOIL SITE 73) ON DUNITIC TILL, SHOWING (A) PLATINUM CONTENT OF FIVE SIZE FRACTIONS AND (B) PLATINUM CONTENT OF LIGHT, HEAVY, HEAVY MAGNETIC AND HEAVY NONMAGNETIC MINERAL FRACTIONS OF THE -70 + 140 (BARS 1-4) AND -140 + 270 (BARS 5-8) MESH SIZE FRACTIONS



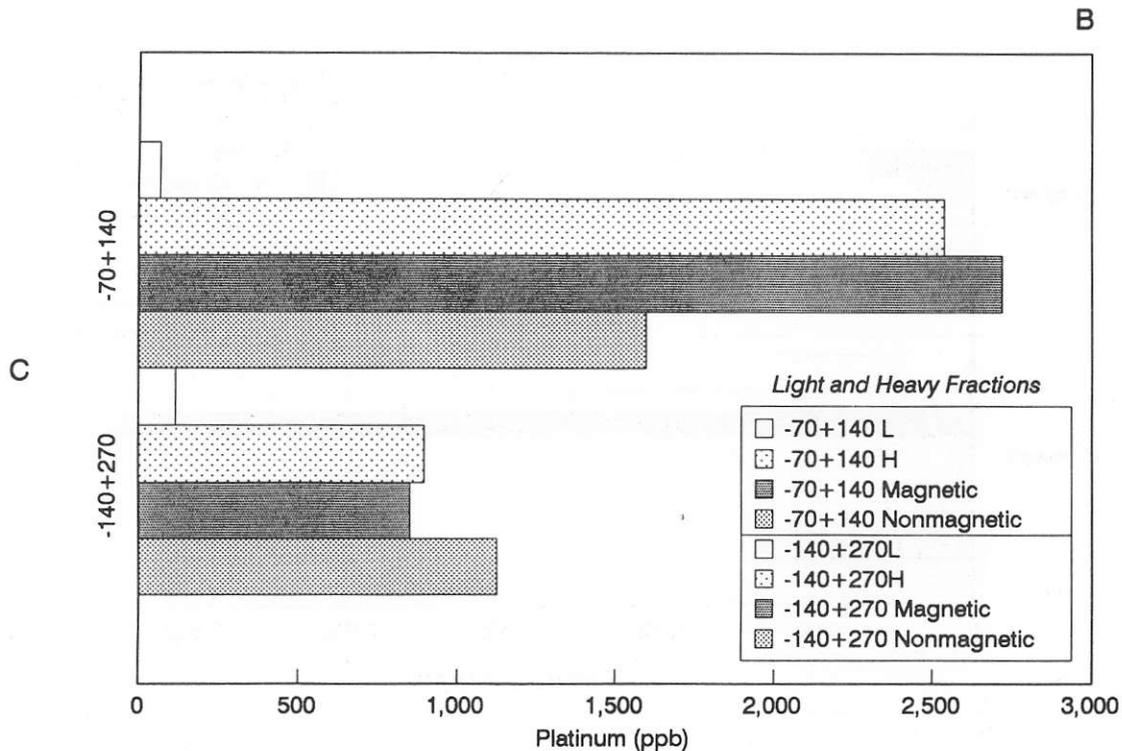
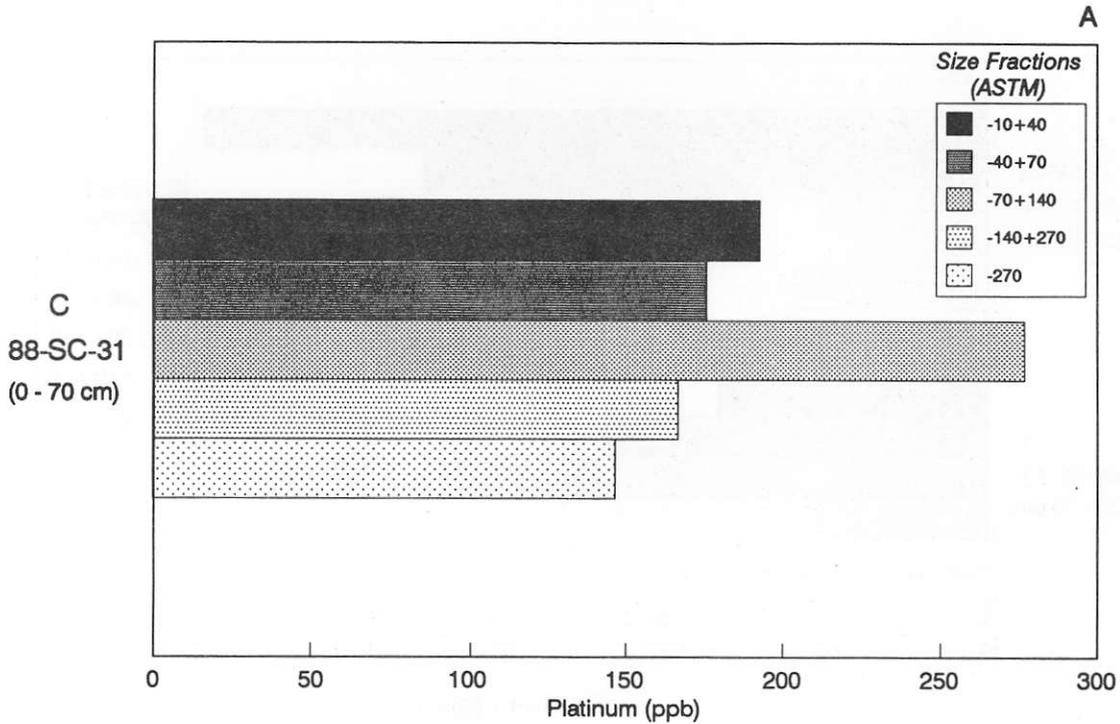
APPENDIX 9.6

PLATINUM DISTRIBUTION (ppb) IN EUTRIC BRUNISOL (SOIL SITE 57) WITH COLLUVIAL B_m HORIZON, ON DUNITIC TILL NEAR A-ZONE PGE OCCURRENCE, SECONDARY STUDY AREA, SHOWING (A) PLATINUM CONTENT OF FIVE SIZE FRACTIONS AND (B) PLATINUM CONTENT OF LIGHT, HEAVY, HEAVY MAGNETIC AND HEAVY NONMAGNETIC MINERAL FRACTIONS OF THE -70 + 140 (BARS 1-4) AND -140 + 270 (BARS 5-8) MESH SIZE FRACTIONS



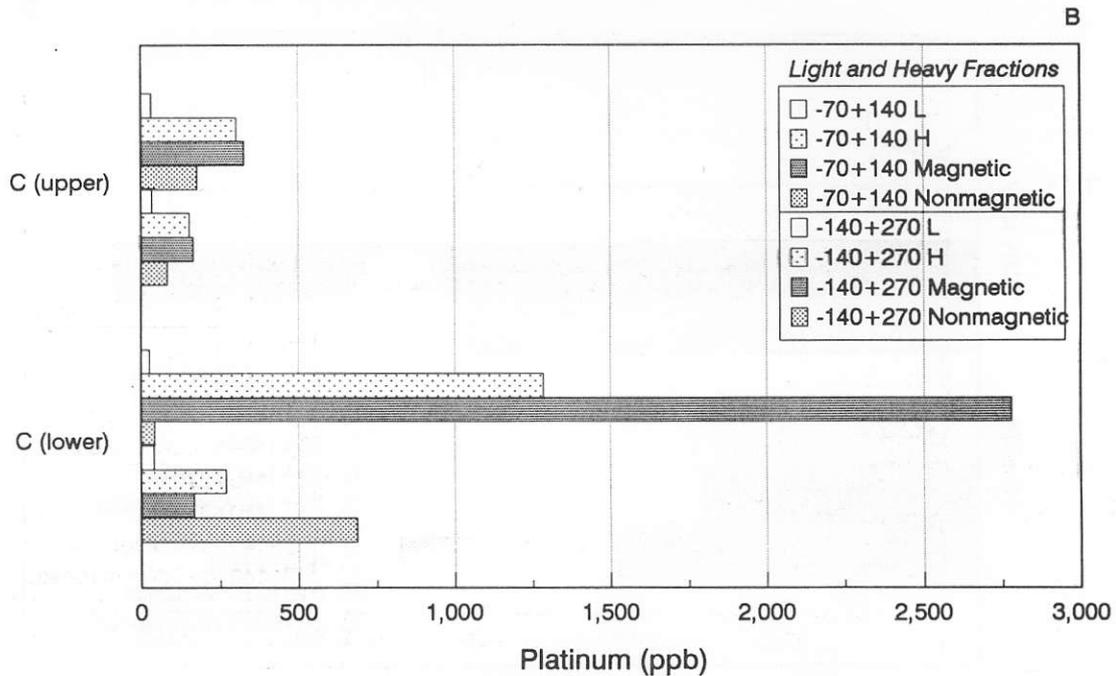
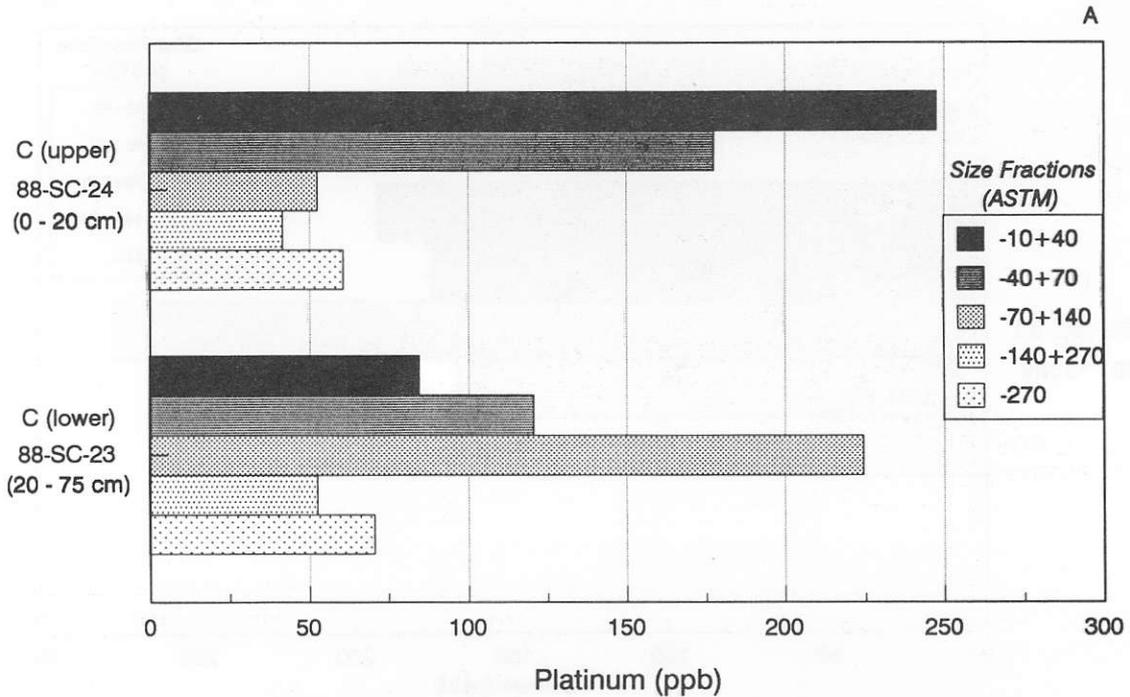
APPENDIX 9.7

PLATINUM DISTRIBUTION (ppb) IN ORTHIC REGOSOL (SOIL SITE 16) ON DUNITE COLLUVIUM BELOW CLIFF ZONE PGE OCCURRENCES, SHOWING (A) PLATINUM CONTENT OF FIVE SIZE FRACTIONS AND (B) PLATINUM CONTENT OF LIGHT, HEAVY, HEAVY MAGNETIC AND HEAVY NONMAGNETIC MINERAL FRACTIONS OF THE -70 + 140 (BARS 1-4) AND -140 + 270 (BARS 5-8) MESH SIZE FRACTIONS



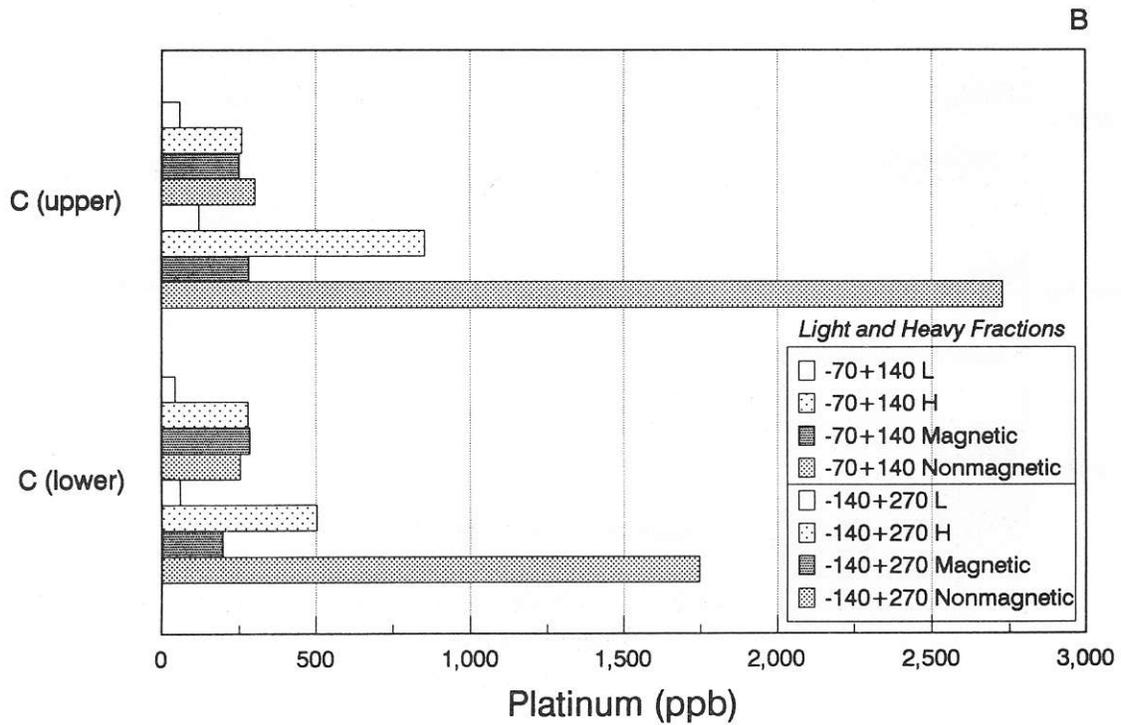
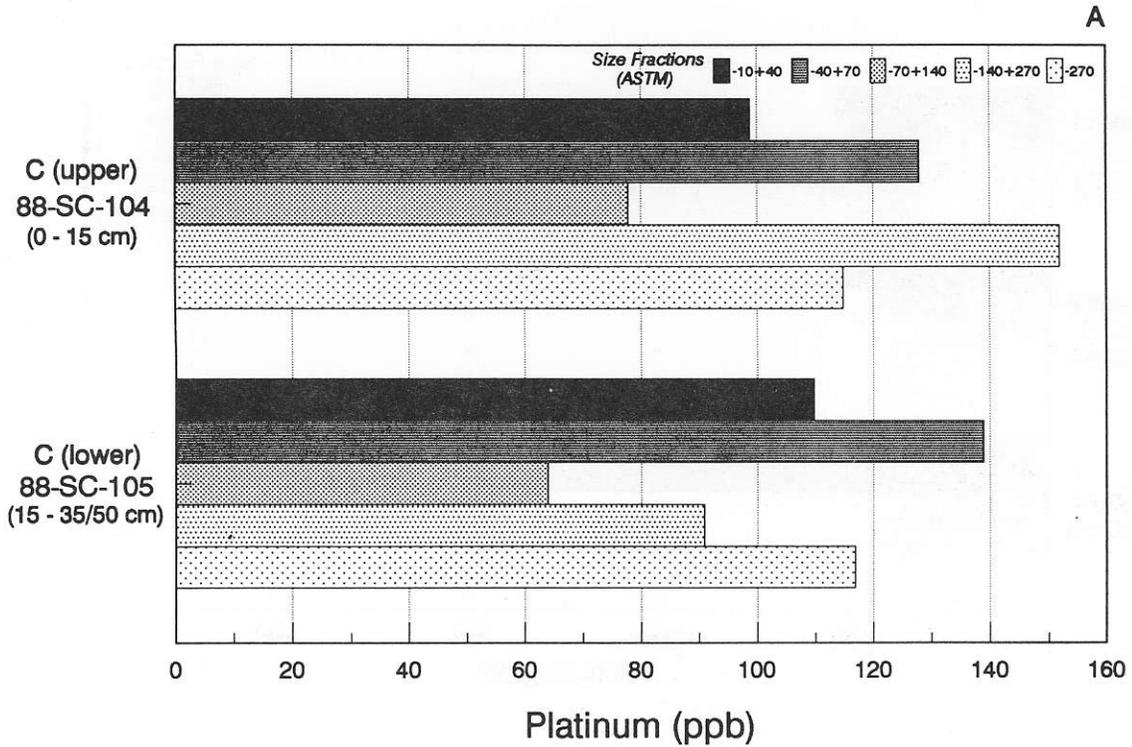
APPENDIX 9.8

PLATINUM DISTRIBUTION (ppb) IN ORTHIC REGOSOL (SOIL SITE 9) ON DUNITE COLLUVIUM BELOW CLIFF ZONE PGE OCCURRENCES, SHOWING (A) PLATINUM CONTENT OF FIVE SIZE FRACTIONS AND (B) PLATINUM CONTENT OF LIGHT, HEAVY, HEAVY MAGNETIC AND HEAVY NONMAGNETIC MINERAL FRACTIONS OF THE -70+140 (BARS 1-4) AND -140+270 (BARS 5-8) MESH SIZE FRACTIONS



APPENDIX 9.9

PLATINUM DISTRIBUTION (ppb) IN ORTHIC REGOSOL (SOIL SITE 42) ON SERPENTINE COLLUVIUM, SHOWING (A) PLATINUM CONTENT OF FIVE SIZE FRACTIONS AND (B) PLATINUM CONTENT OF LIGHT, HEAVY, HEAVY MAGNETIC AND HEAVY NONMAGNETIC MINERAL FRACTIONS OF THE -70 + 140 (BARS 1-4) AND -140 + 270 (BARS 5-8) MESH SIZE FRACTIONS



APPENDIX 9.10

PLATINUM DISTRIBUTION (ppb) IN ORTHIC REGOSOL (SOIL SITE 27) ON SERPENTINE COLLUVIUM, SHOWING (A) PLATINUM CONTENT OF FIVE SIZE FRACTIONS AND (B) PLATINUM CONTENT OF LIGHT, HEAVY, HEAVY MAGNETIC AND HEAVY NONMAGNETIC MINERAL FRACTIONS OF THE -70 + 140 (BARS 1-4) AND -140 + 270 (BARS 5-8) MESH SIZE FRACTIONS

