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ECONOMIC POTENTIAL FOR CHROMIUM, PLATINUM, AND PALLADIUM IN THE MOUNT HURST ULTRAMAFICS, WEST-CENTRAL AREA, ALASKA

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UNITED STATES DEPARTMENT OF THE INTERIOR

William P. Clark, Secretary

REAU OF MINES

bert G. Horton, Director

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ft^3	cubic feet
ft	feet, foot
in.	inch(s)
mm	millimeter(s)
cm	centimeter(s)
%	percent
ppm	parts per million

ECONOMIC POTENTIAL FOR CHROMIUM, PLATINUM, AND PALLADIUM IN THE MOUNT HURST ULTRAMAFICS, WEST-CENTRAL AREA, ALASKA

By William S. Roberts [1]

ABSTRACT

Platinum, palladium, and chromite potential of the ultramafic rocks of Mt. Hurst, Ophir Quadrangle, in west-central Alaska was investigated in 1981 by the Bureau of Mines as part of a critical and strategic minerals program. Analyses of rock, stream sediment, soil, and panned concentrate samples indicate a low potential for lode and placer deposits of platinum, palladium, and chromite. The potential for paleo-placers is unknown. The ultramafic rocks consist of peridotites and pyroxenites of ophiolitic origin. Comparison of these ultramafic rocks to other known occurrences provides a general framework for predicting size and quality of deposits. The upper limit for lode chromite ore is about 1,000,000 tons. A greater probability exists for deposits containing less than 1,000 tons. The discontinuous character of the ultramafic rocks and the chemical variability of the chromite also suggest the unliklihood of economically significant platinum and palladium or chromite lode deposits. Placer potential for these metals is limited because of the relative absence of alluvial deposits in the first order drainages. Placer potential in larger adjacent drainages is unknown except for the apparent negative results of historical prospecting. The detection of platinum and

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palladium in selected chromite and panned concentrate samples suggest a source for the nearby Boob Creek placer platinum occurrence reported by previous investigators.

ACKNOWLEDGMENTS

Jeff Drake (geologist, USBM, Juneau Alaska), Jeffrey Y. Foley (geologist, USBM, Fairbanks, Alaska), Cory J. Samia, (technical editor, USBM, Juneau), and Tom C. Mowatt (consulting mineralogist, Denver, Colorado) provided ideas and recommendations that were incorporated into this study. G. Steven Will assisted in the collection of samples.

Thomas K. Bundtzen (mining geologist, Fairbanks, Alaska, Department of Geological and Geophysical Surveys, State of Alaska) provided logistical support while conducting field investigations in the general area.

The Mt. Hurst area was selected for investigation because of geological reports and information provided by the U. S. Geological Survey. W. W. Patton, Jr. (geologist, U. S. Geological Survey, Menlo Park, California), provided information and maps on the geology of the Mt. Hurst area.

INTRODUCTION

This investigation represents a portion of an Alaska critical and strategic minerals program initiated by the Bureau of Mines during 1981. This report presents the results of a reconnaissance field project designed to identify general targets which have a decided potential for chromium and platinum-group elements (PGE).

Field work in the Mt. Hurst area was initiated because 1) published reports indicated placer platinum was produced from nearby Boob Creek (fig. 2) and 2) a recent communication indicated William W. Patton, Jr. and R.M. Chapman (USGS) had recently mapped an ultramafic occurrence on Mt. Hurst (1).

The close spatial relationship of Boob Creek to the ultramafics and the known genetic association of PGE to ultramafic and/or mafic complexes suggest the Mt. Hurst ultramafics may be the source for the placer platinum, and 3) published information on the geology and mineral occurrences of Mt. Hurst is at present unavailable.

One important step in assessing mineral potentials of ultramafic occurrences is to characterize the rocks and compare to known deposits elsewhere. There is a direct relationship between the genetic origin of an ultramafic complex and its potential for hosting economic deposits of chromium, platinum, and palladium. Genetically classifying Mt. Hurst, at least within an established general framework, requires the integration of representative sampling, mapping of field relationships, petrology, and trace element geochemistry. A resulting genetic classification establishes a general framework for evaluating and predicting the critical and strategic mineral potential of the ultramafic rocks of Mt. Hurst.

PHYSIOGRAPHY, LAND STATUS, AND ACCESS

Mt. Hurst, located on the western margin of the Kuskokwim Mountains Section of the Western Alaska Physiographic Province, is about 25 miles northwest of Ophir(25)[2/] (fig. 1 and 2). At 2882 ft, Mt. Hurst is the highest prominence within 20 miles of the low hilly terrain that lies between the north flowing Innoko and Dishna Rivers. Hurst Creek, which transects the Mt. Hurst ultramafics, flows northerly to Mastodon Creek which in turn flows to

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[2/] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Tolstoi Creek, a tributary of the Dishna River. The nearest town is McGrath, which lies about 92 miles to the southeast. Ophir is the nearest active mining community.

The upland terrain typically consists of rounded hilltops and ridges except where resistant bedrock outcrops as jagged exposures. Except for Mt. Hurst itself relief is between 1000 and 1500 ft with ridge elevations varying between 1500 and 2000 ft To the west of the project area lie the Innoko Lowlands with meandering streams and wet lowlands with elevations generally less than 500 ft

Treeline on Mt. Hurst is approximately 1500 ft, so much of the study area is forested. The vegetative cover consists primarily of black spruce with a thick sphagnum moss mat and valley floors covered with deciduous alder brush with subordinate spruce. Weathered outcrops and steep talus slopes consisting of dunite are characteristically devoid of vegetation. The gentler slopes and ridges are variably covered with a thick vegetative mat. The best bedrock exposure is at higher elevations along ridge crests.

The area around Mt. Hurst is best reached by helicopter (there are no roads in the area). The nearest fixed wing airstrip to the study area is Tolstoi, a small mining camp located at the confluence of the Mastodon Creek and Tolstoi Creek, about 36 miles north of Mt. Hurst.

The Mt. Hurst area, specifically T 26 S, R 10 E Kateel River Meridian, has been selected by the state. It is presently administered by the U.S. Department of Interior, Bureau of Land Management (BLM) until temporary approval is given for the state selection.

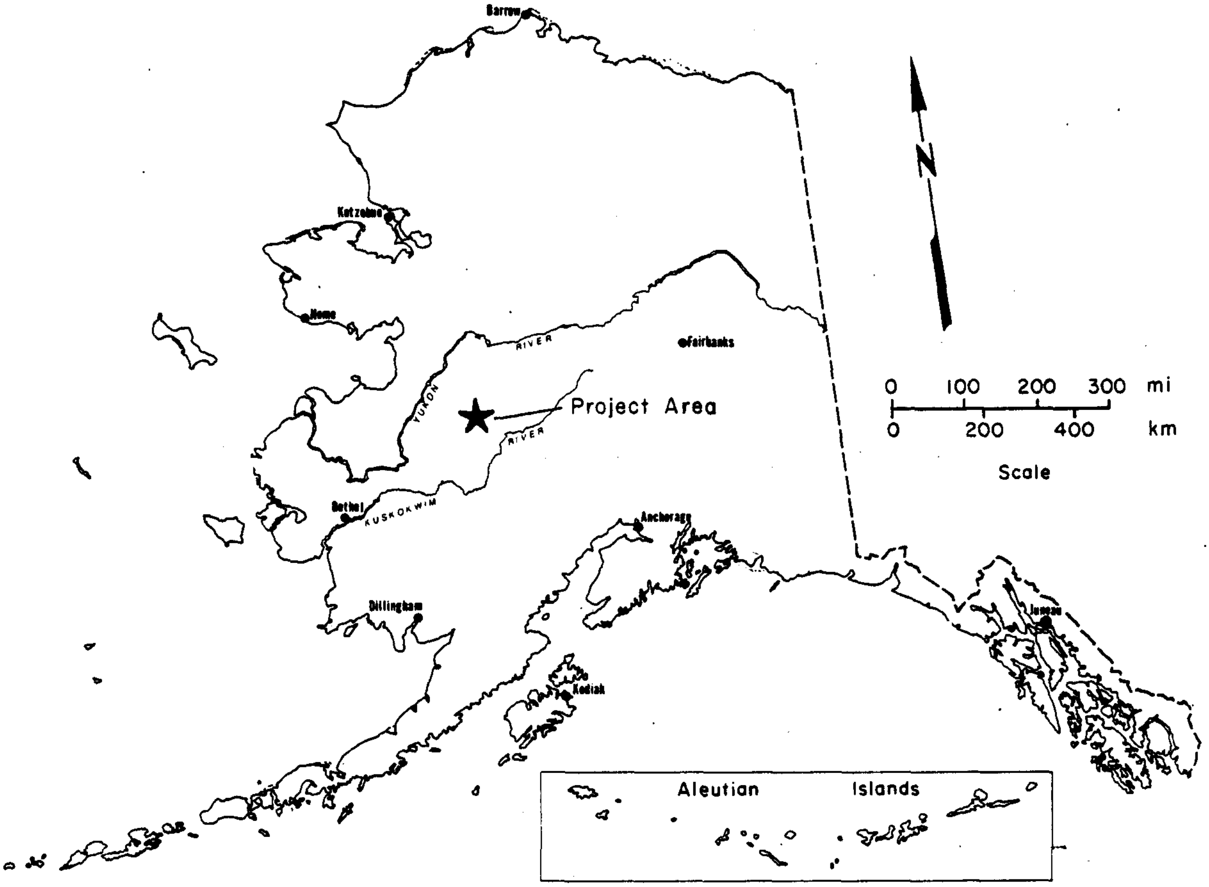
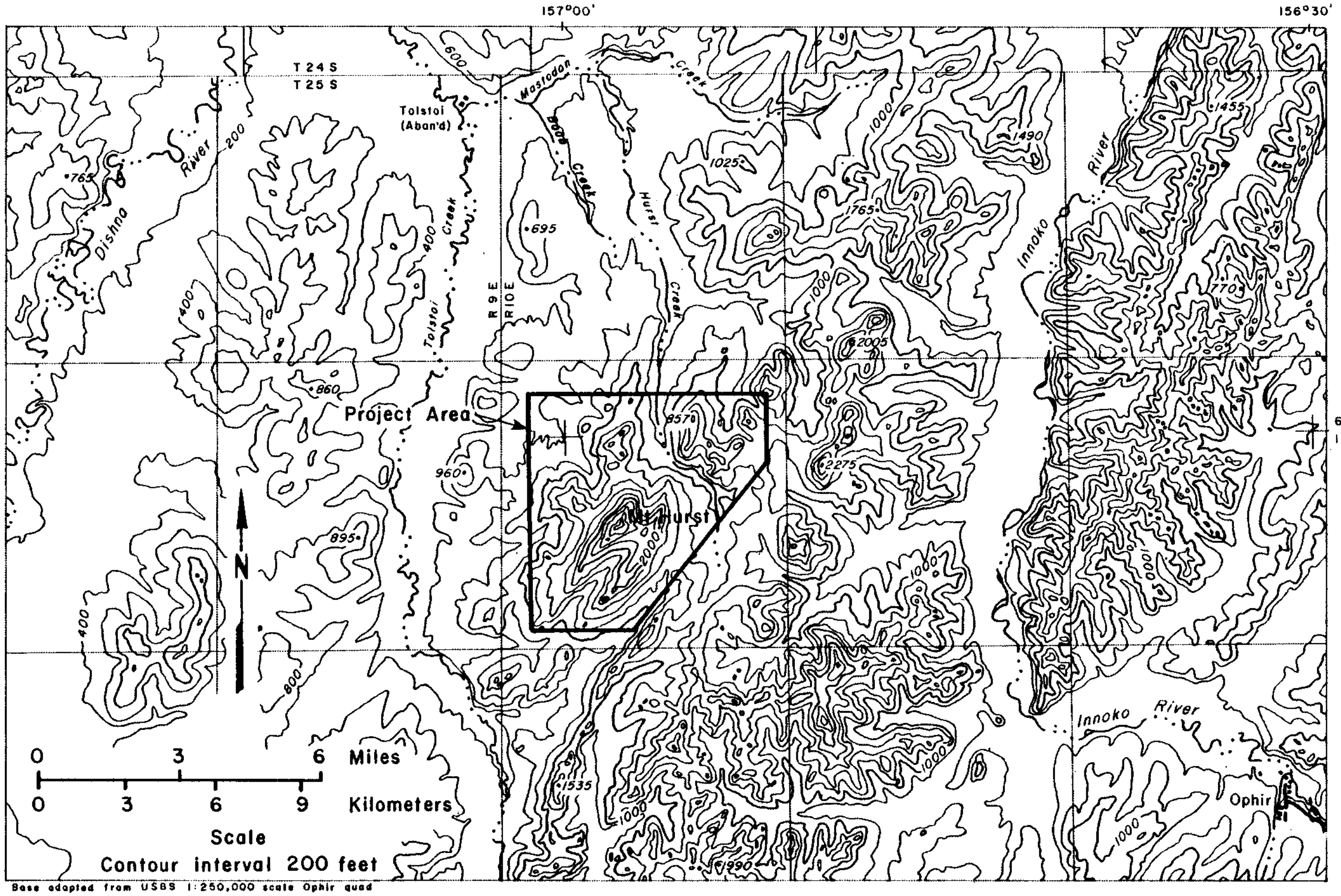


FIGURE 1. Location of project area in Alaska.



Base adapted from USGS 1:250,000 scale Ophir quad

FIGURE 2. Map of Mt. Hurst and adjacent areas.

PREVIOUS WORK

Published geologic data for the Mt. Hurst area are limited. The most complete report on the area is Harrington's 1919 U.S. Geological Survey Bulletin 692 entitled "The Gold and Platinum Placers of the Tolstoi District"(10). This report includes a generalized geologic sketch map which was based on a two week reconnaissance survey. Even though the report is based on a relatively short traverse during a time when access and mobility required a monumental effort, it still represents the single most authoritative report available to date. General references to the Tolstoi area are made by Maddren (13)(14), Eakin (6), and Mertie Jr. and Harrington (16). A more recent summary includes a report by Mertie, Jr. (15). A geologic investigation by Patton, Chapman, and Moll of the U.S. Geological Survey in the Ophir Quadrangle is currently underway. A summary report (U.S. Geolgical Survey Circular 844) outlining their 1980 field work is recently available (3).

A consulting group visited and conducted aeromagnetic surveys of the Mt. Hurst area during the summer of 1981. No follow-up staking was done.

MINING HISTORY

Economic concentrations of placer gold in the Innoko mining district were first found in 1906 near the present site of Ophir (14). This discovery spurred prospecting of the tributaries of Tolstoi Creek and drainages of the Mt. Hurst area. Numerous prospects were located on Madison and Mastodon Creeks

in 1907 (13). After an initial period of claim staking, interest in the area apparently waned. Extensive prospecting resumed in 1916, with minor production from Boob Creek, a tributary of Mastodon Creek. In 1917, five mining operations on Boob Creek produced most of the placer gold from the Tolstoi area. Harrington (10)reports that about 1% of the gold taken out of Boob Creek consisted of platinum. For the year 1917 this amounts to a total production of about 30 troy oz. of platinum. Records of production of precious metals from Boob Creek since 1917 are unavailable. Small nonfloat operations existed in the general area between World War II and 1965 (4). There is currently active prospecting taking place
on Boob Creek.

REGIONAL GEOLOGY

Ultramafic rocks at Mt. Hurst lie within lower Paleozoic rocks consisting of crystalline limestone, schist, slate, phyllite, quartz, and chert. Younger, unnamed Cretaceous sequences occur near the Paleozoic units (3).Mt Hursts close proximity to a late Paleozoic sequence consisting of greenstones, metavolcanics, tuffs, and chert-bearing sedimentary rocks suggests the ultramafic rocks may be of ophiolitic origin (fig. 3).

The ultramafic rocks at Mt. Hurst lie within an extension of the Yukon-Koyukuk ophiolite belt (18). Patton and others suggest the ophiolite bodies within the Yukon-Koyukuk trend represent erosional remnants of a continuous, though allocthonous, sheet consisting of an ophiolite assemblage. Partial evidence for this statement include the klippen-like bodies on the Ruby geanticline and the abundance of ophiolite debris in the marginal

Cretaceous conglomerates along the geanticline.

Furthermore, field relationships and petrographic descriptions reported by Foley and McDermott (7) suggest the Kanuti and Kilolitna Rivers ultramafic plutons, which are a part of the same Yukon-Koyukuk belt, have petrogenetic relationships indicative of ophiolite peridotites.

BUREAU OF MINES RECONNAISSANCE

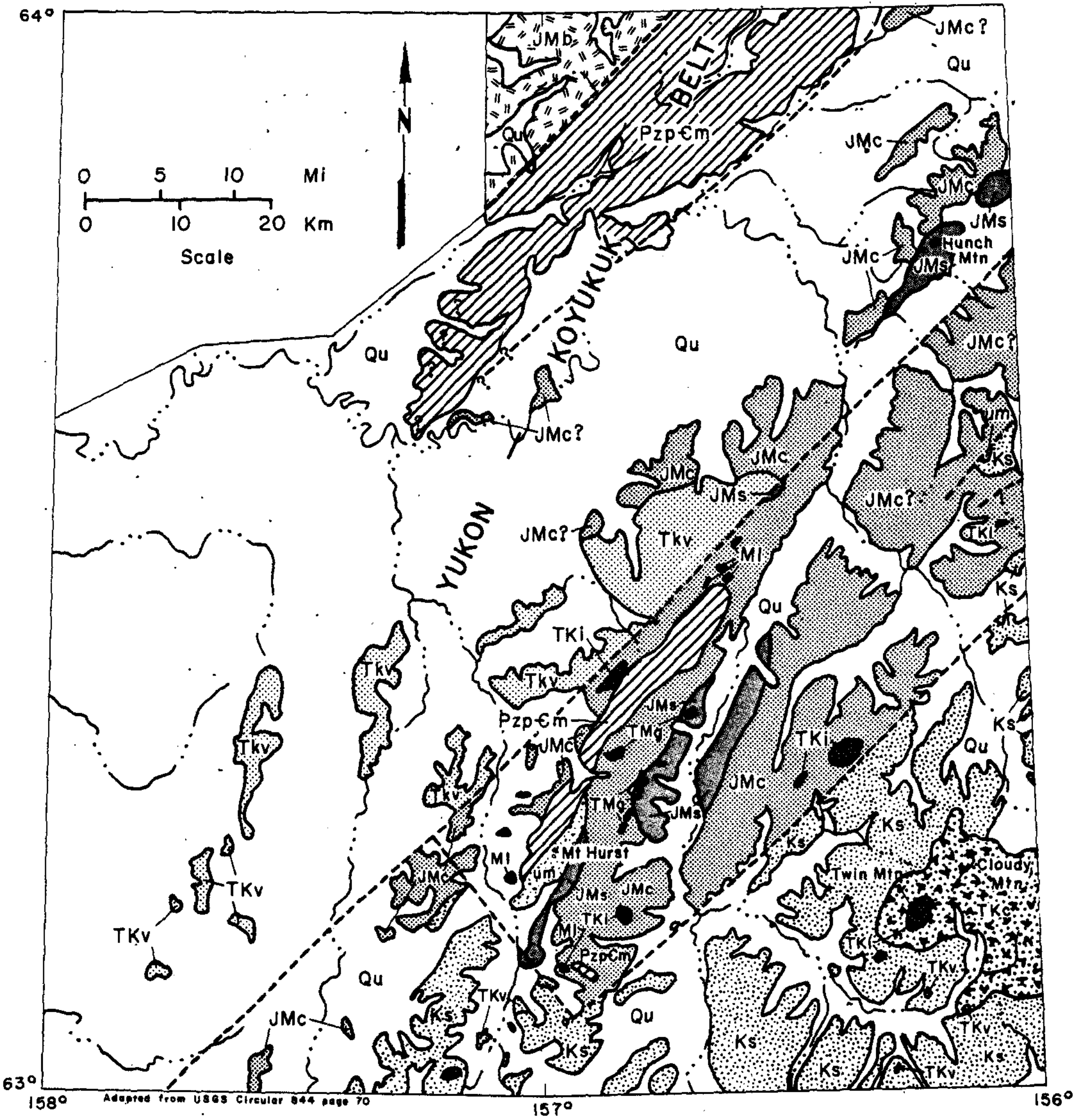
Field work at Mt. Hurst was planned with two limiting factors: 1) a limited budget and 2) remoteness of the project site. A state of Alaska (DGGS) field investigation was being conducted in the Beaver Mountains approximately 25 miles to the south of Mt. Hurst. The DGGS generously permitted the Bureau of Mines access to their contracted helicopter for logistical support between McGrath and Mt. Hurst. This permitted the Bureau, on a reduced budget, to visit Mt. Hurst on a limited basis.

The Boob Creek placer area was not visited because of logistical limitations . The visit was low priority because the 2 to 4 ft thick auriferous gravels are reported to lie beneath 25 to 35 ft of frozen muck (10).

The author and a field assistant G. Steven Will spent a total of 7 days investigating Mt. Hurst in July, 1981. Poor weather, including heavy wind and rain, hampered field work for 3 days. A helicopter supported base camp was located on the north side of Mt. Hurst at the 1300 ft elevation near a small tributary of Hurst Creek.

PROCEDURES, SAMPLING, AND ANALYTICAL TECHNIQUES

The field work at Mt. Hurst was designed, insofar as time and funding allowed, to 1) obtain lithogeochemical samples of the distinct rock types, 2)



LEGEND

Qu	Unconsolidated deposits (Quaternary)	JMc	Chert, Tuff, Argillite, and Basalt (Jurassic? to Mississippian)
TKv	Volcanic Rocks (Tertiary and (or) Cretaceous)	JMs	Sandstone, Grit, and Argillite (Jurassic? to Mississippian)
TKc	Volcanic and Plutonic Complex (Tertiary and (or) Cretaceous)	Ml	Limestone (Mississipian?)
TKi	Intermediate and Felsic Plutonic Rocks (Tertiary and (or) Cretaceous)	Pzp€m	Metamorphic Rocks (early Paleozoic and Precambrian?)
TMg	Gabbro (Tertiary to Mississippian)	um	Ultramafic Rocks (age uncertain)
Ks	Sandstone and Shale (Cretaceous)	╱	Contact, approximately located
JMb	Basaltic Rocks (Jurassic to Mississippian)	╌	Inferred fault

FIGURE 3. General geology of the Mt. Hurst area.

collect panned concentrates and stream sediment samples from first order drainages on Mt. Hurst, 3) map any chrome spinel or sulfide occurrences, and 4) bulk sample any significant spinel or sulfide occurrences.

In this report igneous rock terms follow the classification and nomenclature recommended by the International Union of Geological Sciences subcommission on the Systematics of Igneous Rocks (11). Ultramafic textural and fabric descriptions are derived from a variety of sources including Wager and Brown (24), Coleman (5), Thayer (21), and Jackson (12). Chromium bearing spinels will be referred to as "chrome spinels" unless diffraction and chemical data allow a more specific term, after Haggerty (9).

One bulk chrome spinel sample was collected and forwarded to the Bureau of Mines Albany Research Center (ALRC) in Albany Oregon for metallurgical analysis. The metallurgical data will be reported in a forthcoming publication released by ALRC.

The panned concentrate samples represent screened (-1/4 in.) stream gravels concentrated by panning in a 16 X 4 in. pan. The original volume equaled approximately 0.5 ft^3 of unconsolidated material.

The analytical results, presented in appendix A, tables A-1 and A-2, were generated using a variety of analytical techniques. Stream sediment samples were tested by atomic absorption (AA), while panned concentrates and rock samples were analyzed for precious metals using fire-assay combined with inductively coupled argon plasma spectroscopy (ICAP) method.

The atomic absorption data were produced for the Bureau by contract at Technical Service Laboratories (TSL) of Spokane, Washington using standard spectrophotometric techniques. The fire assay-ICAP data were generated by the Reno Research Center with the fire-assay pre-concentration done by C.W. Merrill, geologist, at AFOC, Juneau.

Optical emission spectrographic data, also generated by TSL Laboratories, are tabulated in table A-2, appendix A.

In addition to the above analytical techniques, selected samples were analyzed using energy dispersive X-ray fluorescence and X-ray diffraction techniques. This work was done at the USBM, Alaskan Field Operations Center, Juneau, Alaska.

The largest chrome spinel occurrence observed at Mt Hurst was mapped using brunton and tape.

GEOLOGY AND MINERALOGY

The Mt. Hurst ultramafics are distinctly, although crudely, layered igneous rocks with certain layered zones traceable for more than 2 miles. Igneous rock types include dunite, harzburgite, lherzolite, and clinopyroxenite.

Igneous layering is due to compositional and/or textural layering including cumulate olivine, chrome spinel, and orthopyroxene, and occasionally gradational chrome spinel textures suggestive of gravitative settling. Rare evidence of current scouring and truncated layering, combined with mildly deformed layering and the intimate interbedded relationships of wehrlite + dunite + chromitite suggest a relatively dynamic crystallization history. Lineation of minerals suggesting metamorphosis of the ultramafics is notably absent. One outcrop of altered dunite consisting of carbonate + quartz + talc indicates low grade metamorphism.

Immediately west and north of the Mt. Hurst ultramafics are carbonates (dolomitic), chert, gabbro, and basalt (fig. 4). The carbonates appear to be recrystallized. One small outcrop had peculiar faint hemispherical layering and fracturing which suggest an algal origin. Light green silty chert, apparently lacking in diatom tests, is also present in minor amounts in the carbonate. Light brown crenulated phyllite, observed as float, was found in saddles and on slopes adjacent to carbonate knobs.

Two minor occurrences of basalt were noted, as well as one outcrop of gabbro. Contacts were not clearly visible, but the coarse textured carbonatized gabbro is probably a tectonic sliver. Analyses of the gabbro indicate no anomalous metal values (for example, see sample KW19867 in table 1).

Semi-quantitative analyses of the various rock types sampled during the field investigation are presented in table 1.

DESCRIPTION OF ROCK UNITS

Five distinct rock types or assemblages of rock types are differentiated within the ultramafic rocks of Mt. Hurst. The five assemblages or rock types are herein informally referred to as "units." The distribution of the five units are presented in figure 4, and these units are summarized as follows:

Unit	Rock Types
1	Dunite interbedded with harzburgite ± lherzolite
2	Clinopyroxenite±wehrlite interbedded with dunite
3	Pyroxenite veins, sills, and dikes
4	Altered dunite zones
5	Metamorphosed dunite consisting of magnesite + quartz + talc

Unit 3 is not plotted on figure 4 because of the small map scale and the variable and discontinuous character of the dikes and sills.

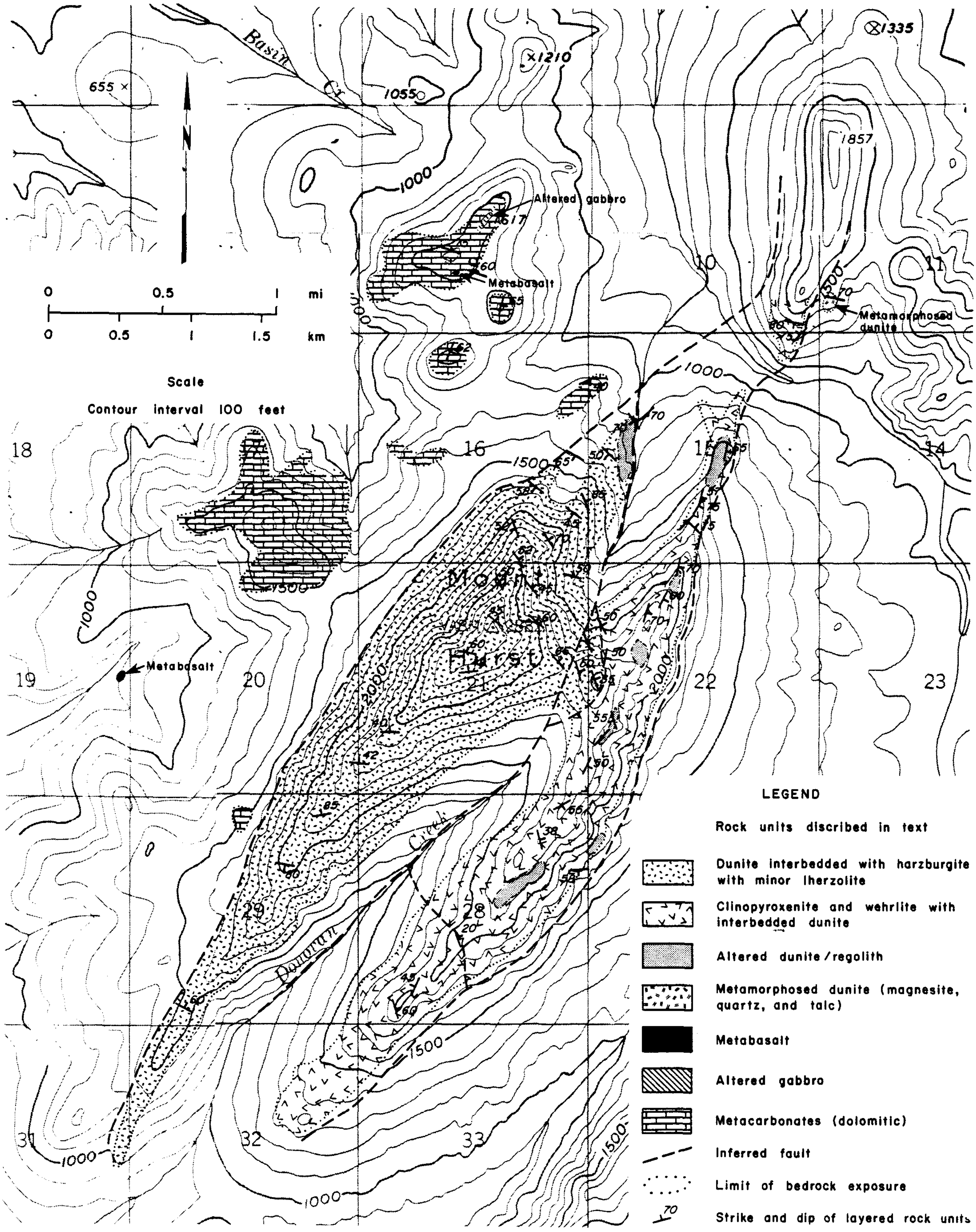


FIGURE 4. Reconnaissance geologic map of Mt. Hurst.

TABLE 1.- Semi-quantitative major oxide and trace element analyses of select rock samples.[1]

Major oxides, %

	Sample [2]								
Oxide	474	472	481	483	866	867	870	871	873
SiO_2	46.0	47.0	40.0	50.0	46.0	52.0	52.0	43.0	52.0
Al_2O_3	----	----	----	1.5	14.0	14.0	1.3	----	1.5
Fe_2O_3	9.3	9.9	10.0	7.0	17.0	18.0	7.8	10.0	4.6
MgO	43.0	41.0	40.0	23.0	5.2	3.7	25.0	39.0	23.0
Cr_2O_3	0.35	0.36	12.0	0.75	----	----	0.39	0.55	0.79
CaO	1.1	1.1	0.11	18.0	9.1	12.0	14.0	3.0	17.0
K_2O	----	----	----	----	3.0	2.3	----	0.18	----
TiO_2	----	----	----	----	1.3	1.6	----	----	----
MnO	NA	NA	NA	NA	0.03	0.04	NA	NA	NA
Trace elements, (ppm)									
Ni	2200	2400	1800	170	110	140	440	1800	250
Cu	----	----	----	----	190	210	----	----	----
Zn	26	37	71	----	110	120	21	45	----
As	----	----	----	----	----	----	----	610	----
Sb	----	----	----	----	----	----	----	40	----
Sr	----	----	----	31	197	390	----	1500	----

Rock Types

474 - Dunite
472 - Harzburgite
481 - Dunite + Chromite
483 - Clinopyroxenite Dike
866 - Metabasalt
867 - Carbonatized Gabbro
870 - Wehrlite
871 - Metamorphosed Dunite
873 - Clinopyroxenite Dike

NA	Not analyzed
---	Less than minimum detection limit

1/ See figure 12 for sample locations
2/ All samples have KW19 prefix

NOTE.-Analyses by X-ray fluorescence spectrometry on bulk grab samples, USBM, AFOC, Juneau, Alaska. Analyses presented to two significant figures ± 25% relative error

Surficial geology was not mapped, and no glacial erratics or moraines were observed. Peri-glacial features such as frost riven bedrock and minor solifluction lobes are present.

The rock units are discussed in terms of their field occurrence, petrography, and chemistry. Incomplete analytical data and sampling prevent a thorough characterization of the rocks. The maps represent data collected during a reconnaissance oriented field project and are presented as such.

Unit 1 - Dunite + Harzburgite

The rocks in unit 1 include interlayered dunite and harzburgite (olivine + orthopyroxene). Locally the dunite occurs as massive pyroxene free layers with sharp phase contacts with adjacent harzburgite (olivine + orthopyroxene ± clinopyroxene). The dunite commonly grades vertically into harzburgite, making detailed mapping difficult. Specific dunite layers can rarely be traced laterally for more than 15 to 30 ft Pyroxene-free or pyroxene-rich zones may, however, persist for hundreds of feet (fig. 5).

Weathered sufaces on dunite and harzburgite reveal the concentration and distribution of pyroxenes present in the peridotites. The olivine typically weathers light tan to orange brown in color ("buff") and is less resistant to erosion than the chrome spinels and pyroxenes which are also present. There is no significant mineral lineation due to metamorphism within either the dunite or harzburgite. Phase layering is displayed by pyroxene-rich segregations and evenly disseminated pyroxene grains which weather more resistantly than the olivine. Lateral persistance of pyroxene ± olivine phase layering is weak. Individual layers, often consisting of one to five in. thick accumulations of orthopyroxene + olivine, are traceable laterally on the order of a few feet. Lateral and vertical variability of phase layering, consisting of olivine, pyroxene, and chrome spinel phases, is the rule rather than the exception.

Pinching and swelling (fig. 5) of layers with lateral gradational phase changes, and truncated or displaced layering (fig. 6) suggest a relatively quiescent, but variable, emplacement history. Exposure is excellent on the north flank of Mt. Hurst. Traverses along and across strike revealed no consistent change or pattern within the dunites and harzburgites in unit 1. Dunite persists north of Mt. Hurst within unit 1, although a significant amount of disseminated pyroxene grains of variable concentration precludes lumping the area into a dunite classification at the scale mapped. To the south of Mt. Hurst, the rocks consist of interbedded dunite and harzburgite, similar to the rocks to the north except that a stronger presence of disseminated to layered pyroxene phases was noted.

Chrome spinel was conspicuously absent on weathered dunite. Transmitted light microscopy indicates the presence of less than 1.0% (by volume) chrome spinel with mean grain sizes on the order of 0.2 mm diameter. The accessory spinels are generally subhedral to anhedral equant grains, although some elongated grains are present. The spinels tend to be reddish-brown in plane light and occur along grain boundaries. Two very minor occurrences of chrome spinel layers were found as float within unit 1, but considering the excellent exposure it is significant more was not seen.

Serpentinization appears to be variable with serpentine minerals

Figure 5. - Interlayered relationship of dunite and harzburgite. Note hammer for scale.

Figure 6. - Pinch, swell, and truncation of pyroxene-rich layers in harzburgite.

ranging, in volume, from 5 to 60% of the sample. The dunites have "mesh-textures", a result of incipient serpentinization beginning along the anastomosing fracture framework typically found in olivine (fig. 7).

Olivine grain sizes and textures vary from small, rounded, equant grains up to 1 or 2 mm in diameter to very large, optically continuous grains 15 to 20 mm in diameter. The smaller grains, occluded within large oikocrystic grains of olivine, suggest a cumulus texture. The textural nature of the large olivine grains is difficult to characterize without petrographic analysis of more samples. The bimodal grain size distribution may be more apparent than real due to limited petrographic work. (fig. 8).

Embayment of olivine grains at olivine-orthopyroxene boundaries was also noted. This indicates chemical reaction existed between the pyroxene melt and olivine grains.

Orthopyroxene grains tend to be interstitial with olivine and are generally less than 3 mm in diameter. Texturally they occur as anhedral interstitial grains or as a subhedral to euhedral cumulus phase. The orthopyroxene tends to show undulatory extinction suggesting a significant strain history. Cataclastic textures and sub-parallel fracturing extending at least 1 cm are also evidence of an energetic, post-emplacement stress history.

Unit 2 -Wehrlite and/or Clinopyroxenite + Dunite

Unit 2 consists of light grey-green wehrlite and clinopyroxenite interlayered with sharply contrasting orange-brown dunite to dull brown altered dunite. This unit is found primarily on a northeast-southwest ridge with a central spine made up of erosionally resistant wehrlite and clinopyroxenite (fig. 4). The dunite and wehrlite contacts are distinct phase boundaries with no evidence of any relative movement.

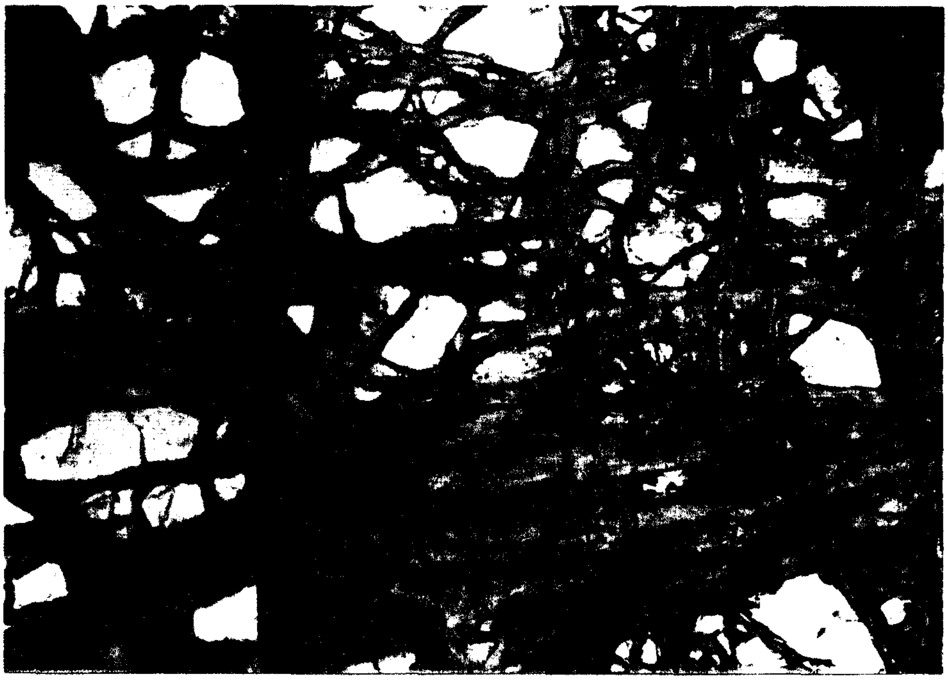


FIGURE 7. - Olivine partially altered to serpentine. Dark brown serpentine (left side of photomicrograph) indicates weathering effect. Field of view = 1.1 x 1.7 mm. Sample KW19875.

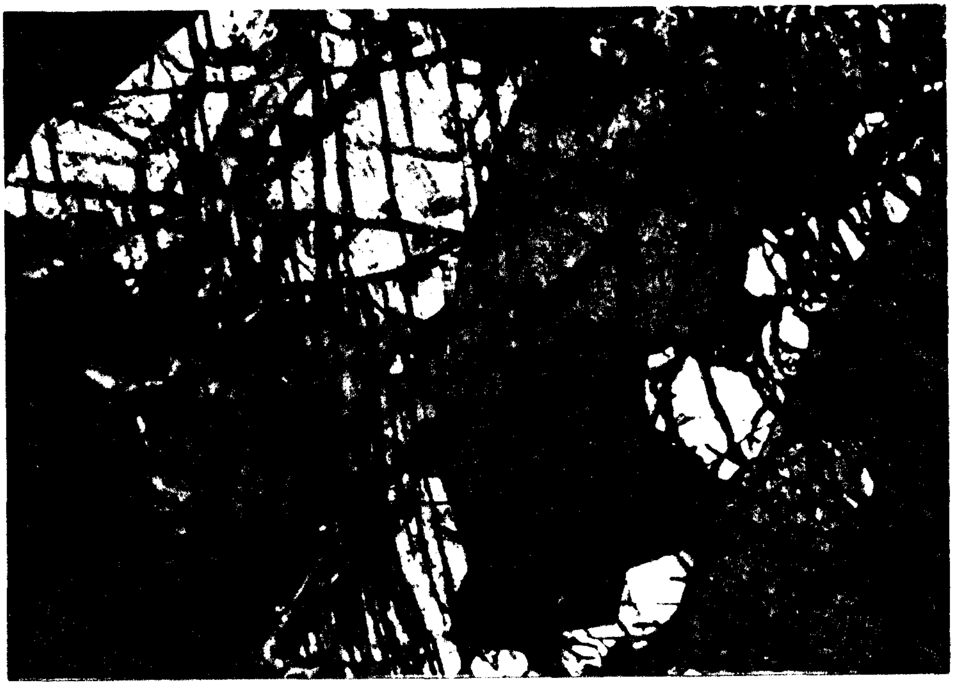


FIGURE 8. - Photomicrograph of harzburgite. Note rounded olivine grain occluded within orthopyroxene. Field of view = 1.1 x 1.7 mm. Sample KW19471B.

The wehrlite and clinopyroxenite are characterized by distinctive phase layering which is visible from a distance. Poorly developed lateral continuity of the layers makes it difficult to trace individual layers for more than 10 or 20 ft

Within the wehrlite and clinopyroxenite are numerous, discontinuous layers of dunite with minor chrome spinel from 1 to 10 ft thick, and which commonly pinch and swell over a lateral distance of 20 to 50 ft For example, a 5 ft thick layer of dunite pinches out in wehrlite over a distance of 30 ft The largest chrome spinel occurrence was found in one of these dunite layers. These occurrences will be discussed in more detail later. Certain dunite zones have been altered to an unconsolidated regolith or saprolite.

Petrographic examination of rocks from this unit are as follows. Within the wehrlite-clinopyroxenite unit, the clinopyroxenite grains are commonly 0.5 to 2.0 mm in diameter but may range in size up to 5 mm. They tend to anhedral, irregularly shaped and appear to have crystallized after olivine. Petrographic examinations show granulated zones and cataclastic textures. Rounding of select clinopyroxene grains has resulted from this cataclasis (fig. 9). Crushed and fragmented clinopyroxene grains along twin planes and undulatory extinction confirm a compressional and/or translational stress history. Subparallel fractures extending through clinopyroxene and chrome spinel grains in the dunite layers suggest a tensional component in the stress history (fig. 10).

Optical data suggest the clinopyroxene in the wehrlite is augitic. No chemical data allow a more specific determination, however the presence of 10% calcium in major oxide analyses (samples KW19873 and KW19483,

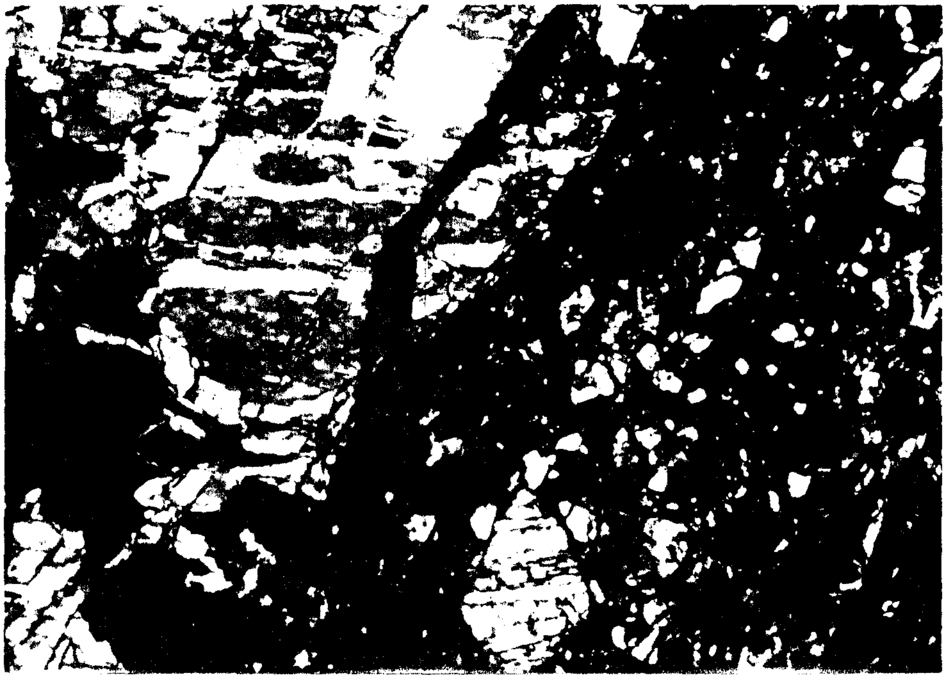


FIGURE 9. - Cataclastic texture in wehrlite. Field of view = 1.1 x 1.7 mm. Sample KW19877.

FIGURE 10. - Evidence for a translational/tensional component in stress history. Field of view = 1.1 x 1.7 mm. Sample Kw19476.

table 1) supports the optical determinations. Diallage is commonly developed within the clinopyroxene. Well developed multiple twinning of clinopyroxene is present. Fine exsolution lamellae are noticeable upon extinction of the clinopyroxene under crossed nicols.

Olivine is present as rounded, equant grains up to 2 mm in diameter. Cataclasis is the dominant textural modifier. The equant, rounded olivine grains suggest a cumulus texture.

Alteration is primarily restricted to serpentine-filled fractures, relict olivine grains, and embayed portions of clinopyroxene grains. Cross fiber serpentine within fractures is common. Also common is an irregular mat of serpentine which indicates altered olivine grains.

Only accessory amounts of chrome spinels and other opaque minerals are present within the wehrlite. In contrast the interlayered dunite layers host all of the chrome spinel bands that range from weakly disseminated to massive in character. These chromite occurrences are described later in the report.

Unit 3 - Pyroxenite Veins-Dikes-Sills

Unit 3 consists of at least three types of pyroxenite veins, dikes or sills. The three types of pyroxenite veins include those composed of orthopyroxene, clinopyroxene, and pegmatoidal textured clinopyroxene.

The clinopyroxenite veins and sills are generally light green in color. A blackening of the green colored pyroxenite veins is thought to be due to local, intense serpentinization. The orthopyroxene dikes weather to a peculiar golden-brown sheen (schiller bastite?). Clinopyroxene is invariably present as discreet grains with the orthopyroxene. No orthopyroxene dikes were noticed in unit 2 and they seem to be relatively uncommon in unit 1.

The mutually cross cutting clinopyroxenite dikes range in thickness from 1 to less than 5 in. Pegmatoidal sills or dikes up to 6 ft thick, were observed mainly on the spur NE of Mt. Hurst in unit 1. These sills or dikes consist of partially serpentinized clinopyroxene.

Textural relationships in the narrow light-green clinopyroxenite veins indicate that emplacement occurred during the early cooling stages of the hosting peridotite. No textural gradations are discernible in the narrow veins, indicating little chilling effect at the rock-vein contact.

Pegmatoidal textures of clinopyroxenite sills or dikes are unusual in contrast to the coarse grained wehrlite and interbedded dunite and chrome spinels. No evidence of faulting, tectonic stressing, or contact alteration is noticeable at the sharp sill-host rock contacts. A definite pinching and swelling of the pegmatoidal sills are generally conformable to layering, although exposures are limited.

Samples KW19873 and KW19484 were collected from pegmatoidal clinopyroxenite sills have a molecular composition of $Mg_{60}Ca_{32}Fe_8$ (endiopside) as plotted on a clinopyroxene composition quadralateral (19).

No sulfide minerals were observed in hand specimens of the dikes and sills.

Unit 4 - Altered Dunite Zones

The distribution of altered dunite zones is shown in figure 4. These zones appear as rounded knobs or saddles and consist of a loose, light-brown regolith (fig. 11). Fragments of chromitite, typically 1 to 6 in. thick, can be found weathered out on the surface. The altered zones on the northeast striking ridge east of Mt. Hurst are generally aligned along strike of the exposed layering in the wehrlite. This alignment indicats these altered zones may represent pinching and swelling dunite layers within the

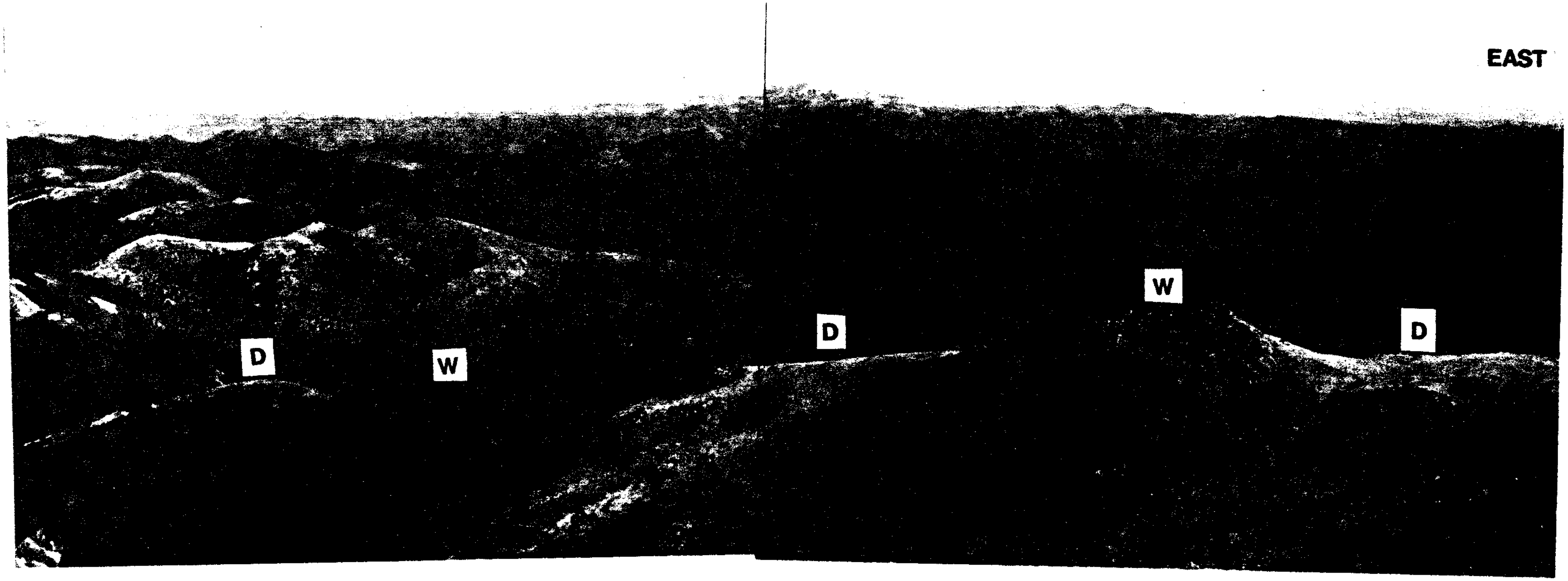


Figure 11. - View to the northeast from Mt. Hurst showing rounded regolithic knobs or saddles consisting of altered dunite (D). Resistant rocks consist of wehrlite (W).

wehrlite-pyroxenite unit.

The usual presence of chromitite, serpentine fragments, and minor serpentinized dunite weathered out on and in the regolith suggest altered dunite. They probably represent "pods" of dunite that has been intensely altered and tectonized along a zone of relative weakness within the wehrlite-pyroxenite host.

Unit 5 - Metamorphosed Dunite

A bright orange-colored anomaly on the north side of Hurst Creek was briefly examined. A weathered carbonate surface speckled with apparently unaltered chrome spinels led the writer to conclude the rocks were silicified metamorphosed dunite (fig. 4). Geochemical analyses, listed as samples KW19871 and KW19872 in table A-1, appendix A, indicate elevated nickel and chromium values, thus supporting the field interpretation.

X-ray diffraction of the samples KW19871 and KW19872 confirmed the presence of a quartz + magnesite + talc assemblage. This assemblage is assumed to be in equilibrium. Such an assemblage has the following temperature-pressure relationships. A quartz + magnesite + talc (Q+M+T) assemblage is a metamorphic assemblage typical of low grade metamorphism of serpentine in the presence of carbon dioxide (CO_2). Isobaric equilibrium curves, as presented by Winkler (27, p.158), indicate metamorphic temperatures in the range of 300° to 450° C at between 1 and 4 Kbars pressure for low XCO_2 (X=partial pressure). Other equilibrium curves indicate the assemblage is stable up to about 500° C at high XCO_2 (27). The abundance of magnesite in the samples suggest a high XCO_2, so 300° C probably represents a lower limit.

Three possible explanations for the mineral assemblage are that:

1) hydrothermal fluids from an unknown source supplied necessary heat + XCO_2 for alteration.
2) a hot igneous slab was tectonically thrust adjacent to carbonates.
3) a cool igneous slab was thrust adjacent to carbonates with subsequent regional low-grade metamorphic event.

Explanation 1 is the most logical given the following evidence. Semi-quantitative analyses of metamorphosed dunite samples by X-ray fluorescence indicates the presence of 610 ppm As and 40 ppm Sb. The presence of As and Sb, combined with an elevated Ag content, strongly indicate hydrothermal alteration of the rocks.

Explanation 2 fits proposed ophiolite emplacement models (5, 18). The tectonics associated with ophiolitic ultramafics are well documented and Jurassic carbonates are present within the immediate area. Thus a mechanism and source for CO_2 are logically accounted for.

Explanation 3 is plausible if one considers the recrystallized dolomite and phyllite present in the immediate area. However, the close proximity of carbonates on the west margin of Mt. Hurst and attendant lack of quartz + magnesite in the adjacent ultramafic rocks cast doubt on the metamorphism of the rocks in their present field relations.

RESULTS

The sample locations and analytical results are reviewed with some geological inferences made concerning the economic potential of the ultramafic rocks. A discussion on the locations and descriptions of chrome spinel occurrences will be followed by a characterization of their mineralogy and chemistry. Of significance is the genetic classification of the Mt. Hurst ultramafics. With a general genetic classification a framework is established for assessing mineral potential based on worldwide occurrences of genetically similar rocks.

SAMPLE LOCATIONS AND ANALYTICAL RESULTS

Sample locations are presented in figure 12, and the analytical results are listed in appendix A.

Chromitite samples collected during this investigation contain anomalous concentrations of platinum (Pt) and palladium (Pd) (table 5). Wehrlite sample kw19870 (table A-1) also contained minor platinum. Altered dunite samples KW19871 and KW19872 (table A-1) contain elevated concentrations of mercury (Hg), antimony (Sb), arsenic (As), and silver (Ag).

An analysis of the wehrlite sample (KW19870) taken north of Hurst Creek indicates a concentration of platinum near the minimum detection limit of the FA-ICAP analytical technique. The sample has no visible sulfides and shows evidence of cataclasis in thin section.

Data from samples KW19871 and KW19872 indicate enrichment of certain metals in the metamorphosed dunite, but, the apparent limited areal extent of altered rock (approximately several acres) and the apparent lack of significant localized mineralization suggest the occurrence is relatively unimportant. No other color anomalies were noted in the study area.

The stream sediment samples collected in the vicinity of Mt. Hurst indicate geochemical concentrations typical of sediments derived from

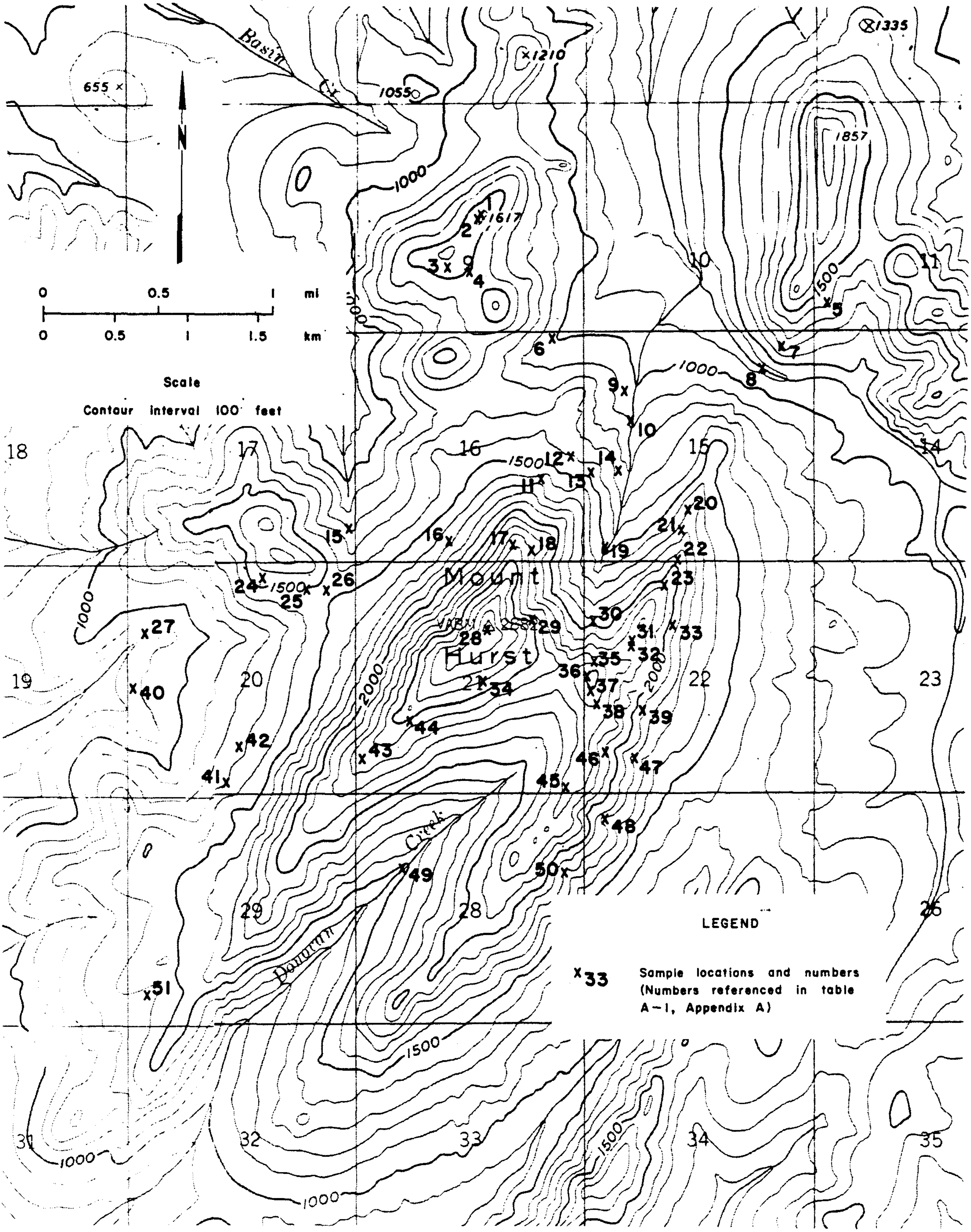


FIGURE 12. Sample locations in the Mt. Hurst study area.

ultramafic rocks. As expected the nickel (Ni) and chromium (Cr) values are relatively high compared to copper (Cu), lead (Pb), and zinc (Zn).

Stream sediment samples KW19882, KW19890, and KW19888 (table A-1) indicate relatively high values of Zn. These values may be reflecting the proximity of meta-sediments.

Three of five panned concentrate samples taken mainly from the first order drainages on Mt. Hurst have detectable platinum and palladium. Samples KW19892 and KW19500, (table A-1), have values of about 0.04 oz.troy/ton platinum, and less than 0.005 oz. troy/ton palladium. A 1919 analysis of a Boob Creek platinum nugget also indicated very little palladium (10,p.106). A panned concentrate contains a mixture of various phases unlike a single platinum nugget so a direct comparison has to be made with caution. Gold was also detected in four of the pans, but, no obvious relationship among the precious metals can be proposed on the basis of the small number of samples.

CHROME SPINEL

The mapped locations of chrome spinel, their mineralogy, and their precious metal content are discussed in the following three sections.

Occurrences

Coalescent or banded chrome spinel are found almost exclusively in dunite layers hosted by wehrlite (unit 2). Chrome spinel occurrences are shown on figure 13 with abbreviated descriptions appearing in table 2. Float or bedrock occurrences are differentiated. None of the occurrences are significant either in tonnage or grade. Chromite banding in the dunite and/or harzburgite in unit 1 occurs only as sparse disseminations and very minor wispy banding.

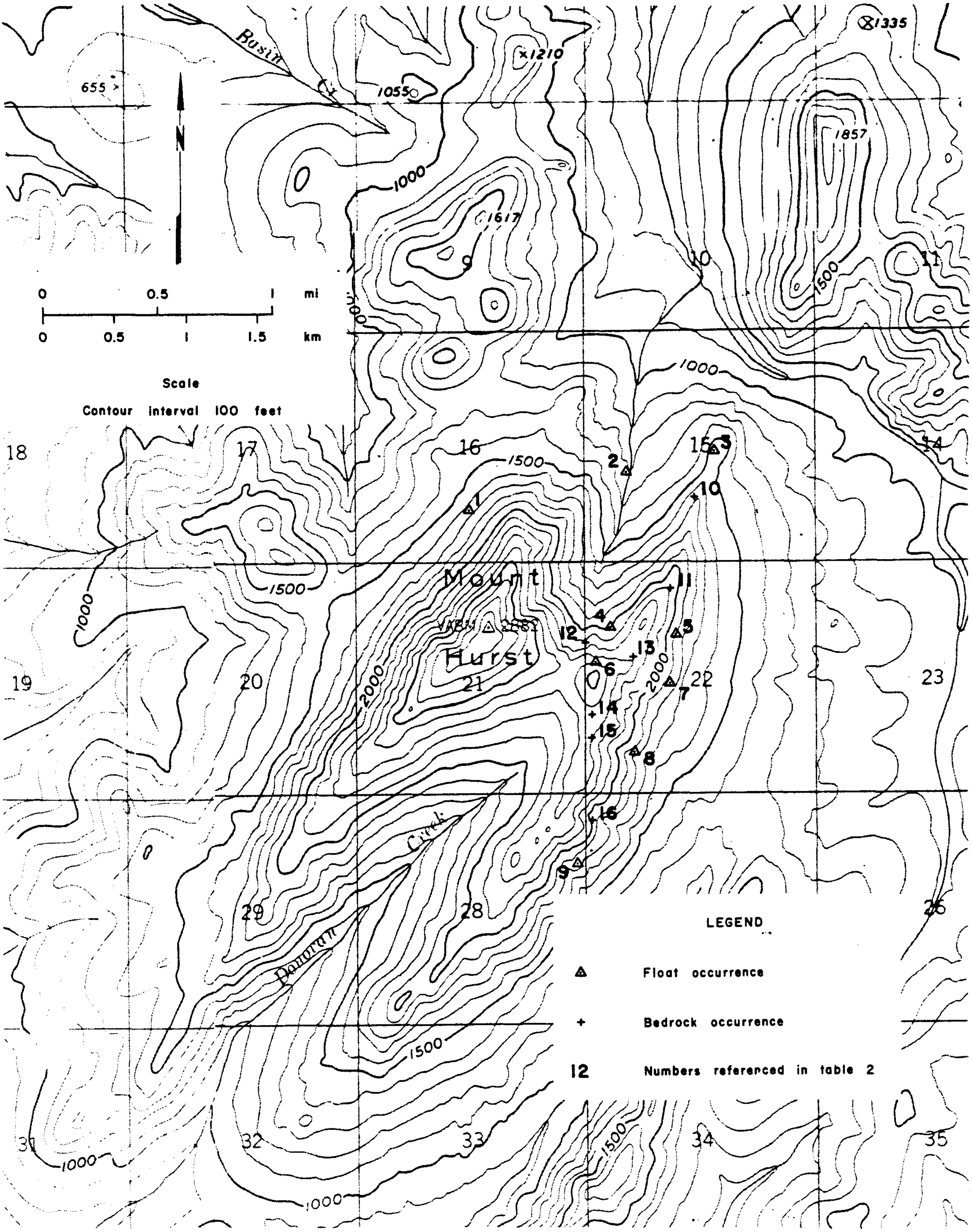


FIGURE 13. Float and bedrock occurrences of chrome spinel.

TABLE 2.- Mt. Hurst chromite occurrences[1/]

Figure-map number	Sample	Comments
		Float
13- 1.	--	Orange-brown dunite with discontinuous chromite bands (0.5 cm thick).
13- 2.	KW19873	Dull brown altered dunite, thin sparse chromite bands.
13- 3.	--	Weathered dunite regolith with chromitite bands up to 1 cm thick.
13- 4.	--	Altered brown "cuspy" dunite, discontinuous spinel bands (0.5 cm thick).
13- 5.	--	Minor bands consisting of disseminated chromite
13- 6.	KW19475	Dunite with minor, wispy chromite bands.
13- 7.	--	Minor occurrence, disseminated chromite bands
13- 8.	--	Minor occurrence, disseminated chromite bands
13- 9.	KW19490	Minor occurrence, disseminated chromite bands
		Bedrock Occurrences
13-10.	KW19868 & KW19869	Largest chromite occurrence located in study area. Orange brown dunite hosts irregular chromite seam from 15 to 81 cm thick - exposed for 8 m along strike.
13-11.	KW19482	Weathered orange-brown dunite with chromite bearing zones approx. 0.5 m thick with individual bands up to 5 cm thick.
13-12.	--	Very minor occurrence of spinels (0.5 cm thick) hosted in altered light tan dunite.
13-13.	KW10476 & KW19477	Disseminated chromite (less than 1/2%), with minor chromite banding generally less than 0.5 cm thick. Float indicates individual chromite bands up to 3 cm thick.
13-14.	--	Light to dark brown altered dunite with very minor amounts of disseminated chrome spinel or wispy, thin chrome spinel bands.
13-15.	--	Similar to location 13-14 .
13-16.	--	Subparallel, thin bands of chromite in dunite. Associated float indicates chromitite bands up to 20 cm thick.

[1/] Map location numbers refer to chromite occurrences as mapped on figure 13. Example: Map location 13-1 refers to location 1 on figure 13.

-- No sample taken.

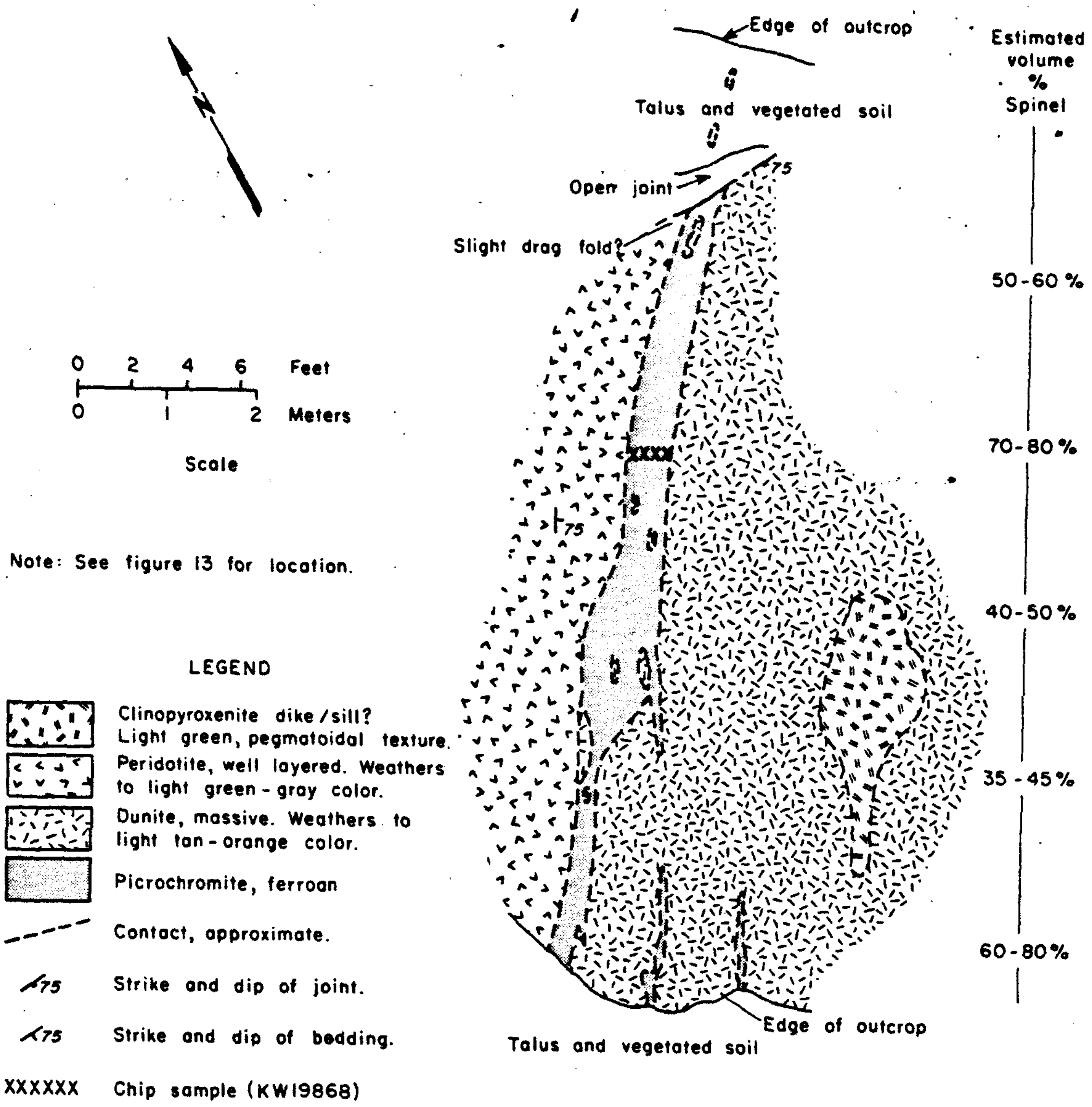


FIGURE 14. Geologic sketch map of chrome spinel occurrence 10.

Although many dunite layers appeared to be totally devoid of chrome spinels, limited transmitted light microscopy indicates the presence of chrome spinels in accessory amounts.

Chrome spinel location number 10 (fig. 13) was the largest occurrence found within the study area. A brunton-tape survey was made of the chromite band with the results presented as a geologic sketch map in figure 14. The chromite band occurs in a light orange-brown dunite lens hosted by well layered, light-green wehrlite. The chromite band is exposed on the west side of a steeply eroded wehrlite outcrop that forms a resistant spine down the northeast spur of Mt. Hurst. The chromite band is exposed along strike for about 30 ft, with the south end disappearing beneath vegetated soil and talus. The north end is truncated by an open joint. Digging into talus north of and on strike with the chrome spinel band suggested the occurrence continued sparingly as satellite stringers or pods. The chrome spinel band is very discontinuous in at least two dimensions. The band pinches and swells from 6 to 30 in thick over a 30 ft distance. The chrome spinel concentration varys from 30 to over 80% by volume. The dunite and chrome spinel layers are both parallel or subparallel to the layering in the wehrlite and have clean phase contacts. These contacts are devoid of any obvious evidence of tectonism. It is difficult to reconcile the intimate, interlayered igneous relationship of chrome spinel + dunite + wehrlite. The presence of phase layering suggests emplacement of the olivine + chrome spinel phases early in the crystallization history of the wehrlite. The texture of the cumulus phases in the chrome spinels is significantly different from the strained clinopyroxene in the wehrlite. This suggests different crystallization histories which are difficult to explain with the present field relations.

Gradational textures of chrome spinels were noticed only in a few select samples. In general, textural variations in chrome spinel exposures show no obvious or consistent pattern such as gradational textures or rhythmic layering. In thin section, such as sample number KW19476, occasional "trains" of chrome spinels were noticed. Spinel "trains", as discussed by Thayer (22), are texturally characteristic of ophiolitic ultramafic rocks containing chrome spinels.

Chemistry and Mineralogy

Five grab samples of chromitite from four different localities were analyzed by X-ray fluorescence spectrometry. Prior to analysis the five chromitite samples were also cleaned of magnetite and silicates using a Franz isodynamic magnetic separator and hydrofluoric acid. In addition, one bulk sample was metallurgically tested by USBM Albany Research Center by wet chemical methods. The results are summarized in tables 3 and 4.

The geochemistry of the chromitite samples indicates considerable chemical variability. The cleaned samples ranged in chromic oxide (Cr_2O_3) content from about 33% to as much as 60%. Samples KW19868 and KW19869, (location 10, fig. 13) have a Cr/Fe ratios of approximately 1:1 with Cr_2O_3 contents of about 30%. These samples are marginal chromium ores because of the high magnesium (Mg) and iron (Fe) contents with reciprocally low chromium (Cr) and aluminum (Al) concentrations. The chromite samples with highest concentrations of Cr are from the smaller chrome spinel occurrences. Figure 15 represents a plot, in terms of mole %, of the Fe, Mg, Al, and Cr components of the cleaned chromitite. Analysis by X-ray fluorescence yields total concentrations but

TABLE 3.- Partial analyses of chromitite grab samples, %1/

Oxide	Sample no.2/					
	477	482	868	869	881	869b
Fe_2O_3	15.0	20.0	28.0	30.0	16.0	31.2
Cr_2O_3	44.0	22.0	28.0	31.0	43.0	32.2
Al_2O_3	9.1	6.4	19.0	23.0	6.9	23.1
MgO	22.0	33.0	20.0	13.0	26.0	13.6
CaO	0.25	0.84	—	—	0.36	NA
TiO_2	.32	.24	0.39	0.46	.38	NA
SiO_2	5.6	10.6	4.0	2.5	5.9	2.52
NiO	.27	.36	.21	.19	.33	NA
ZnO	.026	.034	.057	.067	.022	NA
Cr/Fe	3.0	1.1	1.0	1.0	2.6	1.0

NA Not analyzed
— Less than minimum detection limit

1/ All samples have KW19 prefix
2/ See figure 12 for sample locations
NOTE. - Analyses by X-ray fluorescence spectrometry (except sample 869b) on chromite grab samples, USBM, AFOC, Juneau, Alaska. Sample 869b, analyzed by USBM, Albany Research Center was by wet chemical methods (metallurgist D.C. Dahlin). The Cr and Fe were reported as elemental values, but for ease of comparison they are reported here as oxides.

TABLE 4.- XRF[1] analyses of cleaned chromite samples[2], %, normalized to 100

Oxide	Sample no.[3]				
	477	868	881	482	869
Fe_2O_3	3.70	11.20	1.00	9.00	13.10
FeO	12.70	16.10	16.10	9.90	15.70
Cr_2O_3	59.80	34.20	61.10	46.40	33.80
Al_2O_3	9.20	24.10	9.60	16.90	23.00
MgO	13.30	12.40	11.20	15.70	12.50
CaO	—	—	—	—	—
TiO_2	0.30	0.40	0.30	.30	.40
V_2O_5	.10	.30	—	—	.20
SiO_2	.70	1.00	.50	1.50	.90
P_2O_5	.06	.10	.06	.10	.10
NiO	.09	.08	.10	.07	.10
CuO	—	—	—	—	.01
ZnO	.06	.10	.06	.07	.10
Total	100.01	99.98	100.02	99.94	99.91
Cr/Fe	3.3	1.1	3.2	2.3	1.1
Molecular Proportions:					
$Fe^{2+}/Fe^{2+} + Mg =$	0.35	0.42	0.45	0.26	0.41
$Cr/Cr + Al =$	0.81	0.49	0.81	0.65	0.50

NA Not Analyzed

— Less than minimum detection limit

[1] XRF = X-ray fluorescence

[2] See figure 12 for sample locations

[3] All samples have KW19 prefix

NOTE. - Analyses by X-ray fluorescence spectrometry using NBS 103 standard, USBM, AFOC, Juneau, Alaska. Samples were cleaned with isodynamic magnetic separator and hydrofluoric acid to remove silicates. Fe oxide calculations are based on assumption of stoichiometric proportions.

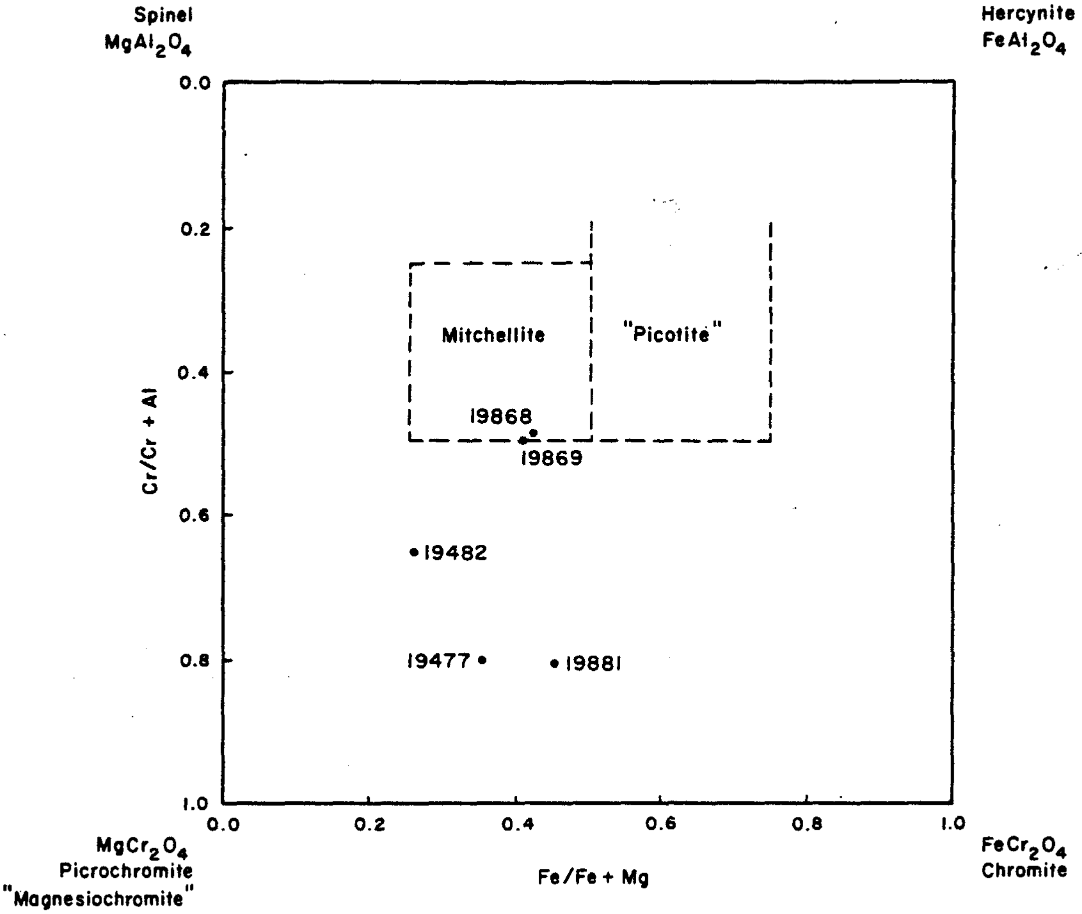


FIGURE 15. Molecular proportion plot of chrome spinels characterizing cleaned chromitite samples.

does not differentiate the oxidation states. The diagram ignores the titanium (Ti) component which in these samples is less that 0.01 mole %.) The plots suggest compositional variation of the chrome spinels, which can be termed picrochromites or mitchellite chromites, depending upon the chemistry. The terminology used here is based on spinel compositional diagrams presented by Haggerty (9).

Platinum Bearing Chrome Spinels

Four analyses of sample KW19869 (table 5), from chromite occurrence 10 (figures 13 and 14), indicate a platinum concentration between 0.014 and 0.026 oz. troy/ton. Three other chromitite grab samples were submitted for platinum and palladium analysis. Sample KW19868 (table A-1) contains minor platinum and palladium concentrations (0.008 and 0.003 oz. troy/ton, respectively). These data suggest, at least in the samples analyzed, that the platinum and palladium are associated with or related to the chrome spinel rocks. Platinum and palladium were detected in samples from the largest chrome spinel occurrence. The much smaller chromite occurrences did not contain detectable platinum or palladium.

Reflected light microscopy on polished sections of chromitite samples suggest that more than one reflective phase is present within the chrome spinel grains. Typically these inclusions are small (1 to 4 microns) anhedral to subhedral grains, and they appear to be anisotropic with a yellow-white reflectance. They often appear to be associated with small plucked out zones, probably attributable to the polishing process and general hardness of the

TABLE 5.-Analyses of platinum bearing chromitite samples

(Mt. Hurst, Ophir Quadrangle, Alaska)

Quantitative Analyses (oz. troy/ton)

PGE	Sample no.[1/] 869a	869b	869c	869d
Pt	0.026	0.021*	0.018*	0.014*
Pd	NA	NA	.01	.01
Au	.003	.002	.002	.002
Ag	.1	.1	NA	NA

869a,869 inquarted with Pd.
869b,duplicate analysis of 869a inquarted with Pd.
869c, 869, inquarted with Ag.
869d duplicate analysis of 869c inquarted with Ag.

NA Not Analyzed
* Indicates result is near detection limit and must be interpreted accordingly.

[1/] All samples have KW19 prefix.

NOTE. - Analyses by U.S.B.M. Reno Research Center utilizing inductively coupled plasma emission spectroscopy(ICAP) on preconcentrated samples. Chromitite heads prepared by Albany Research Center, (D.C. Dahlin, Metallurgist).

mineral. Several polished thin sections were microprobed by James Sjoberg, mineralogist, Reno Research Center. The analyses indicated the grains are an iron-nickel phase. No platinum or palladium minerals were identified.

The platinum and palladium analyses (table 5) are similar to an analysis of a placer platinum nugget produced from Boob Creek. Harrington (10) reported that the nugget consisted primarily of palladium with very little other PGE content. The analyses of the chromitite samples from Mt. Hurst indicate the platinum:palladium ratio to be about 2:1. Panned concentrate data, discussed under sample locations and analyses, agree with the Boob Creek data better than with the chromitite analyses. This is probably due to the effect of weathering and transportation on the PGE phases.

ECONOMIC CONSIDERATIONS

The potential for economic deposits of chromite, platinum, and palladium, both lode and placer, are discussed in the following respective sections.

CHROMITE

Field mapping and sampling indicate limited potential for chromite deposits, both lode and placer. An economic evaluation must take the following into account:

1) Field relationships indicate a relatively limited extent of ultramafic host rock and limited alluvium derived from the ultramafics is present in the first order drainages.

2) Field evidence, including lithologic discontinuities , pinch and swell of layers suggest the rocks have crystallized under less than stable pressure-temperature-composition (P-T-X) conditions. This limits the

possibility for large magmatically derived ore deposits.

3). Field and laboratory evidence, combined with published regional geologic interpretations, suggest the Mt. Hurst ultramafic rocks represent a dismembered portion of an ophiolite. This information provides a general framework for predicting potentials for occurrence of chromite, platinum and palladium deposits.

4) A poorly developed infrastructure within the Mt. Hurst area would demand relatively high tonnages and/or grade for an economically viable deposit.

These factors suggest a relatively limited potential for lode chromite deposits. Chromite deposits located in ophiolitic rocks are typically insignificant relative to stratiform chromite deposits, and would supply only a fraction of the annual U. S. consumption (898,000 tons in 1981). Most podiform chromite deposits yield less than a 1,000 tons of ore; some yield up to about 1,000,000 tons, but only 12 podiform chromite deposits are known to have contained more than 1,000,000 tons of ore (23).

The chrome spinel occurrences observed on Mt. Hurst are very sparse and these are variable in size and quality. Irregular morphology of the chrome occurrences is an important characteristic.

The Mt. Hurst chromite resources are near the lower end of the range of tonnage stated above. These observations and Mt. Hurst's remote location, make it a poor target for developing lode chrome deposits.

Placer deposits of chromite are probably of relatively limited extent, based on the paucity of bedrock chromitie occurrences and relative sparseness of alluvial deposits in the immediate Mt. Hurst area. The first order drainages on Mt. Hurst consist largely of poorly developed alluvium lying on near-surface bedrock. Larger nearby drainages (such as lower Hurst Creek) have considerably more alluvium but their potential for placer chrome is unknown.

PLATINUM AND PALLADIUM

The potential for occurrence of both lode and placer deposits of platinum and palladium in the immediate Mt. Hurst area is low. A potential of unknown magnitude exists for paleo-placers in sediments derived from ophiolitic ultramafic rocks.

An assessment of the platinum and palladium potential in the immediate Mt. Hurst area must take into account the following facts:

1) Recorded production of PGE from nearby Boob Creek is low; only about 1% of the precious metals recovered from gold placer operations were platinum with minor palladium.
2) Alluvial deposits within the immediate map area are of relatively limited extent and depth.
3) The alluvium and colluvium remain largely untested, except by unrecorded prospectors who had undoubtedly sampled the area with apparently negative results.
4) Rock samples with detectable platinum and palladium are of low grade and are associated with small, discontinuous chromite deposits.
5) The ultramafic rocks are discontinuous in form and appear to have crystallized in a relatively dynamic environment thereby limiting the occurrences of magmatically segregated ore deposits.

The potential for placer deposits of platinum and palladium is relatively low within the immediate area of Mt. Hurst because of limited alluvial and/or colluvial deposits and apparent limited areal extent of the ultramafic rocks. The potential for occurrence of PGE placers in adjacent, larger alluvial systems (such as lower Hurst Creek), is unknown.

Chromitite samples that contain detectable platinum are characteristically discontinuous in morphology. Mining the chromite would be costly because of limited tonnage, low grade, and remote location. Recovery of platinum and palladium from chromite would be difficult because of the low concentrations of precious metals. Other potential hosts such as the dunite, harzburgite, and lherzolite are equally discontinuous in form; thus mining would be expensive and ore extensions unlikely. These factors, in conjunction with the knowledge that economic lode deposits of platinum and/or palladium have not been found in similar rocks elsewhere, support an estimate of low potential for lode platinum and palladium.

The presence of detectable platinum and palladium in present-day sediments derived from the ultramafic rocks indicates a potential for paleo-placers, given adequate source rock and concentration by the fluvial process. Regional investigations indicate that the ultramafic rocks of the Mt. Hurst area are erosional remnants of broad allocthonous sheets (18). Subsequent erosion of these sheets may have produced PGE placer deposits. Based on these assumptions one can conclude there is a potential of unknown magnitude for paleo-placers in sediments derived from ophiolitic ultramafic rocks.

CONCLUSIONS

The following conclusions are based on this reconnaissance field investigation of recently discovered ultramafic rocks in the Ophir Quadrangle:

1). The Mt. Hurst ultramafic rocks consist of a crudely layered assemblage of dunite, wehrlite, harzburgite, and clinopyroxenite.

2). Field relationships,along with petrographic, and chemical data support Patton and others' interpretation that the rocks are ophiolitic.

3). The potential for occurrence of economic lode deposits of chromite is very low.

4). Platinum and palladium bearing chromitites were defined indicating a possible lode source for the platinum recovered from gold placers from nearby Boob Creek. The potential for platinum and palladium in lode deposits is judged to be low due to the discontinuous character of the rocks.

5). Analyses of samples show the platinum and palladium appear to be associated with chromitite.

6). Platinum and palladium were recovered in panned concentrates collected from the first order drainages on Mt. Hurst.

7). The potential for occurrence of significant deposits of placer PGE and chromite are judged to be low in the immediate Mt. Hurst area because of a lack of alluvium in the first order drainages. The potential for occurrence of PGE and chromite placer deposits in larger, adjacent alluvial deposits is unknown.

8). An unknown potential exists for paleo-placer deposits derived from eroded allocthonous sheets containing chrome spinel and PGE bearing ultramafic rocks.

RECOMMENDATIONS

No futher work specifically directed toward the economic potential of PGE and chromite lode deposits located on Mt. Hurst is recommended. Work on PGE and chromite bearing placer deposits should focus on adjacent alluvial systems that have significant deposits of alluvium such as lower Hurst Creek. An investigation to determine the potential for paleo-placer deposits of PGE in post-Jurassic (?) sedimentary rocks containing ophiolitic debris is also recommended.

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Appendix A

TABLE A-1.- Analytical results of rock, soil, stream sediment, and panned concentrates

			Analyses											
Map[1] no.	Sample no.	Sample type	oz./ton[2]			(ppm)[3]								Comments
			Au	Pt	Pd	Ag	Cu	Ni	Co	Pb	Zn	Hg	Cr	
2	KW19867	Rock	L0.0002	L0.001	L0.001	0.4	155	26	27	63	10	0.1	NA	Altered gabbro carbonatized
3	KW19866	Rock	NA	NA	NA	0.4	150	30	28	64	12	0.1	NA	Meta basalt
4	KW19865	Rock	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Gy to lt bn marble
5	KW19871	Rock	L0.0002	L0.001	L0.001	9.7	7	800	60	22	19	0.8	NA	Altered silicified dunite
5	KW19872	Rock	L0.0002	L0.001	L0.001	NA	6	930	54	18	25	NA	2100	do.
6	KW19882	SS	NA	NA	NA	0.1	13	245	41	17	370	0.1	1800	
7	KW19870	Rock	L0.0002	0.002*	L0.001	NA	6	310	43	14	21	NA	NA	Wehrlite
8	KW19883	SS	NA	NA	NA	0.1	22	61	20	12	100	0.2	2800	
8	KW19884	PC	L0.0008	L0.004	L0.004	NA	NA	NA	NA	NA	NA	NA	NA	
9	KW19890	SS	NA	NA	NA	0.1	9	475	46	16	150	0.1	1150	
10	KW19891	SS	NA	NA	NA	0.1	15	690	57	13	76	0.1	6100	
10	KW19892	PC	0.004	0.043	0.002*	NA	NA	NA	NA	NA	NA	NA	NA	
11	KW19470A	Rock	L0.0002	L0.001	L0.001	NA	8	395	43	14	17	NA	4300	C grained pyrox dike
12	KW19469	Rock	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Weathered altered dunite
13	KW19874	Rock	L0.0002	L0.001	L0.001	NA	NA	NA	NA	NA	NA	NA	NA	Serpentinized dunite
14	KW19873	Rock	L0.0002	L0.001	L0.001	NA	NA	NA	NA	NA	NA	NA	NA	Serpentinized peridotite
15	KW19499	SS	NA	NA	NA	1.8	105	640	45	16	69	0.1	1600	
15	KW19500	PC	0.071	0.044	L0.005	NA	NA	NA	NA	NA	NA	NA	NA	
16	KW19498	SS	NA	NA	NA	0.3	13	125	19	14	59	0.2	380	
17	KW19470B	Rock	L0.0002	L0.001	L0.001	NA	3	550	30	12	21	NA	3200	Altered pyrox dike
18	KW19475	Rock	L0.0002	L0.001	L0.001	NA	NA	NA	NA	NA	NA	NA	NA	Dunite
19	KW19485	Soil	NA	NA	NA	0.1	17	700	61	13	49	0.1	8300	
19	KW19486	PC	0.011	L0.002	L0.002	NA	NA	NA	NA	NA	NA	NA	NA	
20	KW19868	Rock	L0.0002	0.008	0.003	0.2	24	201	18	66	6	0.4	19.5%	Chip sample of chromitite
20	KW19869	Rock	NA	NA	NA	NA	56	140	14	8	14	NA	15.5%	Bulk chromite sample
21	KW19483	Rock	L0.0002	L0.001	L0.001	0.6	6	111	17	45	9	0.1	NA	Pegmatoidal pyrox dike
22	KW19878	Rock	L0.0002	L0.001	L0.001	0.2	7	155	20	25	8	0.1	NA	C grained pyrox dike
23	KW19482	Rock	L0.0002	L0.001	L0.001	1.3	17	800	29	21	12	0.1	NA	Chromite-rich dunite
24	KW19863	Rock	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Lt. gy dolomite
25	KW19864	Rock	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Lt. gn chert
26	KW19484	Rock	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Lt. gy phyllite
27	KW19888	SS	NA	NA	NA	0.1	16	180	27	19	260	0.1	880	
28	KW19471	Rock	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Serpentinized dunite
29	KW19876	Rock	NA	NA	NA	NA	6	1100	58	19	41	NA	2500	Pyrox dike
30	KW19487	Rock	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	do.

See footnotes at end of table A-1

TABLE A-1.- Analytical results of rock, soil, stream sediment, and panned concentrates

Map1/	Sample	Sample	Analyses											Comments
			oz./ton2/		(ppm)3/									
no.	no.	type	Au	Pt	Pd	Ag	Cu	Ni	Co	Pb	Zn	Hg	Cr	
31	KW19476	Rock	L0.0002	L0.001	L0.001	0.5	5	850	33	16	10	0.1	26%	Dissem. chromite in dunite
32	KW19477	Rock	NA	NA	NA	0.1	5	520	7	10	5	0.1	NA	do.
32	KW19478	Rock	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Peridotite
33	KW19493	Soil	NA	NA	NA	0.1	11	960	83	13	60	0.1	36000	
34	KW19474	Rock	L0.0002	L0.001	L0.001	0.1	28	1550	82	31	21	0.1	NA	Serpentinized dunite
35	KW19475	Rock	L0.0002	L0.001	L0.001	NA	NA	NA	NA	NA	NA	NA	NA	Peridotite
36	KW19481	Rock	L0.0002	L0.001	L0.001	0.1	13	1250	47	51	17	0.1	NA	Chrome banded dunite
37	KW19479	Rock	L0.0002	L0.001	L0.001	NA	3	340	46	13	34	NA	2300	Peridotite
38	KW19480	Rock	L0.0002	L0.001	L0.001	NA	5	610	73	22	19	NA	2300	Dunite with pyrox vein
39	KW19494	Soil	NA	NA	NA	0.1	11	680	72	15	55	0.1	1700	
40	KW19889	Rock	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Metabasalt
41	KW19886	Soil	NA	NA	NA	0.1	7	325	44	12	43	0.1	120	
42	KW19887	SS	NA	NA	NA	0.1	13	440	43	15	87	0.1	1400	
43	KW19472	Rock	NA	L0.001	L0.001	0.1	21	1400	86	18	34	0.1	2450	Fe stained peridotite
44	KW19473	Rock	L0.0002	L0.001	L0.001	NA	5	305	17	9	13	NA	4100	Altered C grained pyrox
45	KW19877	Rock	L0.0002	L0.001	L0.001	NA	24	340	42	14	25	NA	2400	V.C. grained pyrox dike
46	KW19879	Rock	0.001	L0.001	L0.001	NA	24	365	47	16	17	NA	2100	Serpentinized peridotite (?)
46	KW19881	Rock	L0.0002	L0.001	L0.001	0.4	4	484	7	4	6	0.1	32%	Chromite
47	KW19495	SS	NA	NA	NA	0.1	8	970	91	14	63	0.1	9400	
48	KW19496	SS	NA	NA	NA	0.1	7	890	85	14	72	0.1	8200	
49	KW19488	Soil	NA	NA	NA	NA	23	1100	94	16	29	0.1	12500	
49	KW19489	PC	0.078	0.003*	L0.002	NA	NA	NA	NA	NA	NA	NA	NA	
49	KW19490	Rock	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Serpentinized dunite
50	KW19497	Soil	NA	NA	NA	0.1	10	990	84	15	110	0.1	2300	
51	KW19885	Soil	NA	NA	NA	0.1	7	220	37	13	145	0.1	1300	

NA Not analyzed

L Less than

* Near detection limit; interpret with caution

1/ Map numbers keyed to Figure 12

2/ Fire assay/ICAP analyses done by Bureau of Mines. Pre-concentration done by C.W. Merrill, Jr. AFOC. ICAP by W. Barry, Reno Research Center

3/ A.A. analyses by TSL Laboratories, Spokane WA

NOTE: Sample map location number 1 was deleted.

Abbreviations used:

SS – Stream sediment	lt – light	gn – green
PC – Panned concentrate	C – coarse	pyrox – pyroxene
gy – gray	VC – very coarse	dissem – disseminated

Appendix A - Continued

Table A-2. - Results of selected samples analyzed by optical emission spectroscopy, %

Element	Sample numbers						
	KW 19483	KW19866	KW19867	KW19868	KW19871	KW19878	KW19881
Aluminum (Al_2O_3)	2	8	8	15	0.1	2	6
Antimony	ND	ND	ND	ND	ND	ND	ND
Arsenic	ND	ND	ND	ND	ND	ND	ND
Barium	ND	ND	ND	ND	ND	ND	ND
Beryllium (BeO)	ND	ND	ND	ND	ND	ND	ND
Bismuth	ND	ND	ND	ND	ND	ND	ND
Boron	ND	0.005	0.002	ND	ND	ND	ND
Calcium (CaO)	G 5	5	5	ND	0.5	G 5	ND
Cadmium	ND	ND	ND	ND	ND	ND	ND
Chromium	0.8	.01	.01	G 1	.3	.8	G 1
Cobalt	.002	ND	ND	.02	ND	ND	.01
Columbium (Cb_2O_3)	ND	ND	ND	ND	ND	ND	ND
Copper	.005	.02	.02	.002	ND	ND	.001
Gallium	ND	.002	.002	.003	ND	ND	ND
Iron (Fe)	5.00	6.00	6.00	8.00	2.00	3.00	6.00
Lanthanum (La_2O_3)	ND	ND	ND	ND	ND	ND	ND
Lead	ND	ND	ND	ND	ND	ND	ND
Lithium (Li_2O)	ND	ND	ND	ND	ND	ND	ND
Manganese	.04	.04	.05	.05	.02	.04	.04
Magnesium (MgO)	G 3.00	2.00	2.00	G 3.00	G 3.00	G 3.00	G 3.00
Molybdenum	ND	ND	ND	.001	ND	ND	ND
Nickel	.04	.004	.003	.1	.04	.04	.1
Phosphorous	ND	ND	ND	ND	ND	ND	ND
Silver	ND	ND	ND	ND	ND	ND	ND
Silicon (SiO_2)	G2 .00	G2 .00	G2 .00	3.00	15.00	G2 .00	5.00
Sodium (Na_2O)	ND	2.00	3.00	ND	ND	ND	ND
Strontium	ND	ND	ND	ND	ND	ND	ND
Tantalum (Ta_2O_3)	ND	ND	ND	ND	ND	ND	ND
Tin	ND	ND	ND	ND	ND	ND	ND
Titanium	.01	.4	.3	.06	ND	.02	.04
Vanadium	.01	.03	.03	.1	ND	.02	.04
Yttrium (Y_2O_3)	ND	0.002	0.001	ND	ND	ND	ND
Zinc	ND	ND	ND	ND	ND	ND	ND
Zirconium	ND	ND	ND	ND	ND	ND	ND
Gold	ND	ND	ND	ND	ND	ND	ND
Hainium	ND	ND	ND	ND	ND	ND	ND
Indium	ND	ND	ND	ND	ND	ND	ND
Platinum	ND	ND	ND	ND	ND	ND	ND
Rhenium	ND	ND	ND	ND	ND	ND	ND
Tellurium	ND	ND	ND	ND	ND	ND	ND
Thallium	ND	ND	ND	ND	ND	ND	ND
Scandium	ND	ND	ND	ND	ND	ND	ND

See Footnotes at end of table A-2

Table A-2. - Results of selected samples analyzed by optical emission spectrometry, % (cont.)

Element	Sample Number KW 19474	KW19476	KW19477	KW19481	KW19482	KW19472
Aluminum (Al_2O_3)	0.06	4	6	2	6	0.5
Antimony	ND	ND	ND	ND	ND	ND
Arsenic	ND	ND	ND	ND	ND	ND
Barium	ND	ND	ND	ND	ND	ND
Beryllium (BeO)	ND	ND	ND	ND	ND	ND
Bismuth	ND	ND	ND	ND	ND	ND
Boron	ND	ND	ND	ND	ND	ND
Calcium (CaO)	1	ND	ND	ND	0.4	0.8
Cadmium	ND	ND	ND	ND	ND	ND
Chromium	.2	G 1.00	G 1.00	G 1.00	G 1.00	.1
Cobalt	.008	0.02	0.02	0.01	0.02	.01
Columbium (Cb_2O_3)	ND	ND	ND	ND	ND	ND
Copper	.004	.003	.001	.003	.004	.004
Gallium	ND	ND	.002	ND	.003	.003
Iron (Fe)	3.00	6.00	6.00	5.00	6.00	6.00
Lanthanum (La_2O_3)	ND	ND	ND	ND	ND	ND
Lead	ND	ND	ND	ND	ND	ND
Lithium (Li_2O)	ND	ND	ND	ND	ND	ND
Manganese	.03	.03	.03	.03	.04	.03
Magnesium (MgO)	G 3.00	G 3.00	G 3.00	G 3.00	G 3.00	G 3.00
Molybdenum	ND	.004	ND	ND	ND	ND
Nickel	.2	.1	.1	.1	.1	.2
Phosphorous	ND	ND	ND	ND	ND	ND
Silver	ND	ND	ND	ND	ND	ND
Silicon (SiO_2)	G20.00	5.00	3.00	10.00	10.00	20.00
Sodium (Na_2O)	ND	ND	ND	ND	ND	ND
Strontium	ND	ND	ND	ND	ND	ND
Tantalum (Ta_2O_3)	ND	ND	ND	ND	ND	ND
Tin	ND	ND	ND	ND	ND	ND
Titanium	ND	.02	.03	.01	.03	.008
Vanadium	ND	.03	.04	.02	.05	.003
Yttrium (Y_2O_3)	ND	ND	ND	ND	ND	ND
Zinc	ND	ND	ND	ND	ND	ND
Zirconium	ND	ND	ND	ND	ND	ND
Gold	ND	ND	ND	ND	ND	ND
Hainium	ND	ND	ND	ND	ND	ND
Indium	ND	ND	ND	ND	ND	ND
Platinum	ND	ND	ND	ND	ND	ND
Rhenium	ND	ND	ND	ND	ND	ND
Tellurium	ND	ND	ND	ND	ND	ND
Thallium	ND	ND	ND	ND	ND	ND
Scandium	ND	ND	ND	ND	ND	ND

See footnotes at end of table A-2

Appendix A - Continued

Table A-2. - Results of selected samples analyzed by optical emission spectroscopy, %

Element	Sample Number			
	KW 19872	KW19888	KW19877	KW19879
Aluminum (Al_2O_3)	0.05%	0.4%	3%	3%
Antimony	ND	ND	ND	ND
Arsenic	ND	ND	ND	ND
Barium	ND	ND	ND	ND
Beryllium (BeO)	ND	ND	ND	ND
Bismuth	ND	ND	ND	ND
Boron	.002	ND	ND	ND
Calcium (CaO)	.2	2.00	G 5.00	G 5.00
Cadmium	ND	ND	ND	ND
Chromium	.1	.2	0.1	0.1
Cobalt	.004	.01	.006	.006
Columbium (Cb_2O_3)	ND	ND	ND	ND
Copper	ND	ND	.002	.002
Gallium	ND	ND	ND	ND
Iron (Fe)	4.00	5.00	5.00	5.00
Lanthanum (La_2O_3)	ND	ND	ND	ND
Lead	ND	ND	ND	ND
Lithium (Li_2O)	ND	ND	ND	ND
Manganese	.03	.04	.04	.04
Magnesium (MgO)	G 3.00	G 3.00	G 3.00	G 3.00
Molybdenum	ND	ND	ND	ND
Nickel	.1	.1	.02	.02
Phosphorous	ND	ND	ND	ND
Silver	ND	ND	ND	ND
Silicon (SiO_2)	20.00	G20.00	G 20.00	G 20.00
Sodium (Na_2O)	ND	ND	ND	ND
Strontium	ND	ND	ND	ND
Tantalum (Ta_2O_3)	ND	ND	ND	ND
Tin	ND	ND	ND	ND
Titanium	ND	.001	.08	.06
Vanadium	ND	.01	.02	.02
Yttrium (Y_2O_3)	ND	ND	ND	ND
Zinc	ND	ND	ND	ND
Zirconium	ND	ND	ND	ND
Gold	ND	ND	ND	ND
Hainium	ND	ND	ND	ND
Indium	ND	ND	ND	ND
Platinum	ND	ND	ND	ND
Rhenium	ND	ND	ND	ND
Tellurium	ND	ND	ND	ND
Thallium	ND	ND	ND	ND
Scandium	ND	ND	ND	ND

See footnotes at end of table A-2

Appendix A - Continued

Table A-2. - Results of selected samples analyzed by optical emission spectroscopy, %

Element	Sample Number						
	KW 19470A	KW19470B	KW19473	KW19479	KW19480	KW19469	KW19870
Aluminum (Al_2O_3)	2%	0.7%	0.7%	2%	1%	20%	3%
Antimony	ND	ND	ND	ND	ND	ND	ND
Arsenic	ND	ND	.1	ND	ND	1	ND
Barium	ND	ND	ND	ND	ND	ND	ND
Beryllium (BeO)	ND	ND	ND	ND	ND	ND	ND
Bismuth	ND	ND	ND	ND	ND	ND	ND
Boron	ND	ND	ND	ND	ND	ND	ND
Calcium (CaO)	G 5.00	.8	.5	G 5.00	G 5.00	0.1	G 5
Cadmium	ND	ND	ND	ND	ND	ND	ND
Chromium	0.2	.2	.4	0.1	0.1	G 1.00	0.2
Cobalt	.01	.02	.01	.01	.01	0.05	.01
Columbium (Cb_2O_3)	ND	ND	ND	ND	ND	ND	ND
Copper	.002	ND	ND	ND	ND	.004	ND
Gallium	ND	ND	ND	ND	ND	ND	ND
Iron (Fe)	4.00	5.00	5.00	4.00	5.00	G 10.00	5.00
Lanthanum (La_2O_3)	ND	ND	ND	ND	ND	ND	ND
Lead	ND	ND	ND	ND	ND	ND	ND
Lithium (Li_2O)	ND	ND	ND	ND	ND	ND	ND
Manganese	.04	.04	.04	.04	.04	.06	.04
Magnesium (MgO)	G 3.00	G 3.00	G 3.00	G 3.00	G 3.00	G 3.00	G 3.00
Molybdenum	ND	ND	ND	ND	ND	0.002	ND
Nickel	.04	.1	.08	.04	.06	.1	.04
Phosphorous	ND	ND	ND	ND	ND	ND	ND
Silver	ND	ND	ND	ND	ND	ND	ND
Silicon (SiO_2)	G20.00	G20.00	G20.00	G 20.00	G 20.00	7.00	G 20.00
Sodium (Na_2O)	ND	ND	ND	ND	ND	.4	ND
Strontium	ND	ND	ND	ND	ND	ND	ND
Tantalum (Ta_2O_3)	ND	ND	ND	ND	ND	ND	ND
Tin	ND	ND	ND	ND	ND	ND	ND
Titanium	.02	.001	.001	.01	.01	.1	.04
Vanadium	.01	.01	.01	.02	.01	.2	.03
Yttrium (Y_2O_3)	ND	ND	ND	ND	ND	ND	ND
Zinc	ND	ND	ND	ND	ND	ND	ND
Zirconium	ND	ND	ND	ND	ND	ND	ND
Gold	ND	ND	ND	ND	ND	ND	ND
Hainium	ND	ND	ND	ND	ND	ND	ND
Indium	ND	ND	ND	ND	ND	ND	ND
Platinum	ND	ND	ND	ND	ND	ND	ND
Rhenium	ND	ND	ND	ND	ND	ND	ND
Tellurium	ND	ND	ND	ND	ND	ND	ND
Thallium	ND	ND	ND	ND	ND	ND	ND
Scandium	ND	ND	ND	ND	ND	ND	ND

ND - Not detected
G - Greater than

Samples analyzed by TSL Laboratories, Spokane, WA

Appendix B

Appendix B.- Distribution of Nickel

The spatial relationships of the peridotites and clinopyroxenite dikes suggest a common origin, a hypothesis supported by the distribution of nickel (Ni) in the ultramafic rocks. The peridotites from unit 1 (dunite and harzburgite) consistently indicate a Ni concentration greater than 0.15%. The unit 2 ultramafics (wehrlite-clinopyroxenite) commonly have less than 0.05%, while the crosscutting late stage pyroxenite dikes of unit 3 contain less than 0.025% Ni.

The distribution of trace amounts of Ni has a genetic implication and several inferences may be drawn with respect to the cooling history of the parent magma. According to crystal field stabilizing energy theory one can consider the six-fold octahedral sites available for Ni^{2+} substitution in forsterite, hypersthene, picrochromite, and diopside on a mole basis . A proportionate Ni concentration in each mineral should be present in each phase with respect to the relative sites available. This assumes an open system because, as Ni^{2+} is removed from the melt by assimilation in early formed minerals, it is replenished from an outside source. If a closed system is assumed, progressive depletion of Ni^{2+} in the melt should be reflected in non-proportional ratios with respect to the minerals' six-fold octahedral sites.

If all six-fold octahedral sites were filled with Ni^{2+} ions the nickel content (weight %) of olivine, hypersthene, magnesiochromite, and diopside would be 56, 43, 34, and 23%, respectively. Normalized to weight % of Ni in olivine, the respective ratios would be about 1.0:0.77:0.61:0.41. If the various minerals had crystallized from a magma with the same Ni^{2+} concentration then the proportional ratios would be approximately as indicated. In a similar analogy, corresponding rocks such as dunite, chromite, wehrlite (consisting of 60% clinopyroxene and 40% olivine), and clinopyroxenite would consist of 56,34,36, and 23%, respectively byweight if all six-fold octahedrally coordinated sites were filled by nickel. Thus the predicted ratios of dunite:chromite:wehrlite: clinopyroxenite normalized to dunite, would be approximately 1.0:0.60:0.64:0.41. The apparent ratios, based on analytical data, indicate a 1.0:0.60:0.22:0.10 ratio.

The gap between predicted and actual Ni ratios can be explained if 1) the dunite and chromitite fractionated early in the differentiation history or they had little mutual effect on the nickel concentration, and if 2) the wehrlite and clinopyroxenite crystallized relatively late with respect to the dunite and chromite, the magma becoming progressively depleted with time. The clinopyroxenite ratio indicates a greater apparent depletion than the wehrlite ratio thereby suggesting the former crystallized post-wehrlite, exactly as field relations indicate. These conclusions assume a closed system and ignore discrete (although minor) nickel phases identified in chrome spinel samples. These data corroborate with field evidence which implies:

1) Units 1 (dunite), 2 (wehrlite), and 3 (clinopyroxenite) are genetically related

2) The units fit a model for a fractionating magma which may have given rise to magmatically segregated ores.