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MINERAL RESOURCES DIVISION
Geological Survey Branch

ENVIRONMENTAL
GEOLOGY

OLIVINE POTENTIAL OF THE TULAMEEN ULTRAMAFIC COMPLEX

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SUMMARY

This report documents the geology and industrial mineral potential of an olivine deposit within the Tulameen ultramafic complex, southwestern British Columbia. Olivine occurs as dunite in the core of a zoned Alaskan-type ultramafic intrusion that is variably serpentinized. Detailed sampling has identified three zones of fresh rock. Foundry testing of the produced olivine sand has determined that it has similar quality and performance to other foundry sands imported from abroad. The olivine from the Tulameen complex compares favourably with other deposits worldwide and represents a development opportunity.

BACKGROUND INFORMATION

OLIVINE: THE MINERAL

Olivine is an essential mineral in ultramafic rocks and an accessory mineral in mafic rocks. As a major rock-forming mineral, it occurs as granular crystal aggregates or massive bodies in dunite and peridotite (harzburgite). As an accessory mineral in gabbro, lherzolite, wherlite, websterite, pyroxenite and basalt, olivine commonly occurs as free grains or small crystal aggregates. It also occurs as an alteration mineral in magnesian skarns in magnesian carbonate rocks. However, the most significant source of olivine is from dunite and related, partially serpentinized bodies.

In outcrop, massive olivine weathers a characteristic dun to red-tan colour. On fresh surfaces, dunite or peridotite is light to dark green with either a sugary or massive texture. Accessory minerals include orthopyroxene (enstatite), clinopyroxene (augite) and, rarely, plagioclase. Alteration minerals commonly present are serpentine (antigorite and lizardite), chrysotile (asbestos), talc, magnesian carbonate, magnesite, magnetite, brucite and sericite.

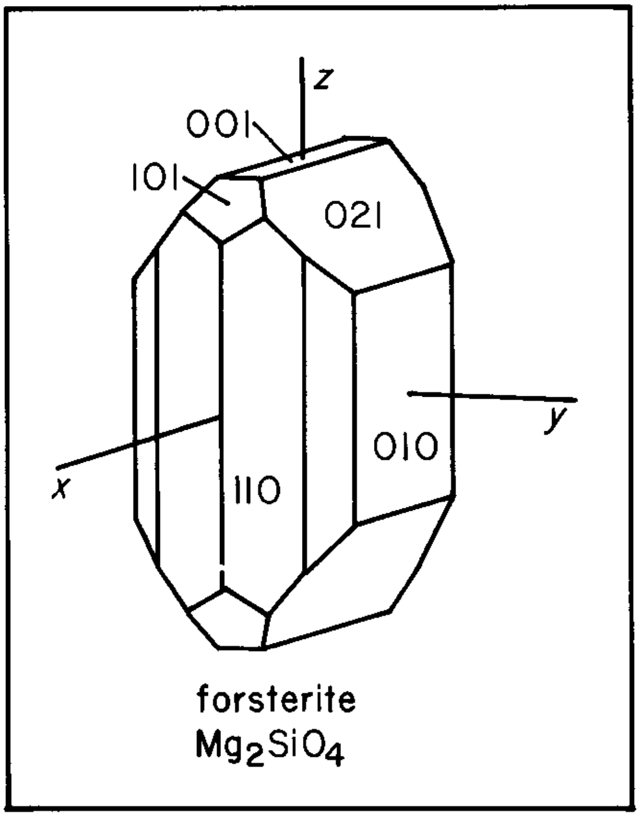

Figure 1. Diagram showing the crystal shape, faces and crystallographic axes of forsterite.

Specifically, olivine is a nesosilicate, paired silica tetrahedra, with a general composition of $(Mg, Fe)_2 SiO_4$. A continuous solid solution exists between forsterite, Mg_2SiO_4, and fayalite, Fe_2SiO_4. For industrial purposes, forsteritic olivine is preferred, containing a minimum of 45 weight per cent MgO and most producing deposits have magnesia contents nearer 50 weight per cent. Forsteritic olivine is light green to yellow-green in colour. It has a glassy to vitreous lustre, a Moh's hardness of 6.5 to 7 and a specific gravity of 3.27 to 4.37 (increasing with increasing iron content). It has a conchoidal fracture and no cleavage. Crystallographically, the mineral is orthorhombic with 2/m 2/m 2/m symmetry and a:b:c: = 0.467 : 1 : 0.586 (fo). Free grains are subequant in shape, formed by three pinacoids terminated by a diapiramid (*see* Figure 1).

USES FOR OLIVINE

The primary uses for olivine incorporate the refractory, chemical, strength, thermal conductivity and high density properties of the mineral. The major consumers of olivine are steel smelters and foundries. Secondary users are brick, tile, concrete, aggregate and abrasives manufacturers. Industry estimates of worldwide olivine consumption suggest a total of 9 million tonnes per annum. Included in this figure are some applications, primarily construction and aggregate, which incorporate the use of dunite and serpentinite. Not including these uses, a best estimate of 6.5 million tonnes per annum olivine consumption is projected worldwide.

Steel making accounts for approximately 75 per cent of the world consumption of olivine. There are several specific uses for the mineral in the smelting and casting processes. Primarily olivine as lump feed (up to 10 kg/t hot metal), sinter feed (1-2 % of feed) or olivine pellets (3-4 % of feed) is used as a slag conditioner. By increasing the magnesia content, slag is kept fluid in the furnace, is less sensitive to chemical and thermal changes and sulphur is retained in the slag. The addition of olivine introduces both magnesia and silica in equal proportions to the molten material and the basicity remains constant. This property favours olivine over other conditioners like dolomite. Addition of olivine also negates the need for alkali compounds that control other slag conditioners and create problems with melt quality, chemical stability and furnace control.

As use of the continuous casting process increases, there is a slight upward trend in demand for olivine sand as tundish backing lining. Olivine sand is used as a refractory layer between the hot and cold sides of a tundish. There is, however, strong competition for this purpose from recycled, crushed fire brick.

In addition to steel manufacture, olivine sand is used in speciality applications in foundries and this accounts for 10 to 15 per cent of world consumption. The common mold and core sands are silica blends, used in a variety of applications. Olivine sand is used for casting speciality metals, either as whole molds, cores or facing sand. Olivine flour is also used as a facing compound with silica molds, cores to improve the finish casting surface and eliminate mold-casting adhesion. The specifically desired properties of olivine are its high melting point, high strength, minimal grain attrition, recyclability, consistent performance with increased grain size and resistance to manganese, magnesium and aluminum steel alloy chemical attack. As well as steel and related alloy casting, olivine sand is used for bronze and aluminum casting. A significant consideration is that olivine sand is not compatible with most acid binding agents and so clay and bentonite binders are required. In some applications, use of acid binding agents precludes the use of olivine, and silica sand replaces it.

Following steel making and foundry usage, the other uses of olivine represent up to 10 per cent of world consumption. Individually these are small-tonnage markets that have fairly steady consumption. A modest demand for refractory brick, tile and castings still exists. Olivine is used where minimal thermal expansion, good thermal-shock resistance, high heat capacity and resistance to basic chemical attack are required. The products currently manufactured are either olivine or olivine-magnesite brick, tile and castings. The primary use for these products has been in blast furnaces but there is increased competition from magnesite, magnesite-chromite and dolomite materials. The main reason for the competition has been the lower price of the magnesite products. However, olivine ramming and gunning compounds are still well used. Olivine castings are commonly used in glass manufacture although this is a low-demand area. A few hundred tonnes of material are required for the initial manufacture of a facility and then only maintenance replacement of individual pieces is required.

In Europe, the high heat capacity of olivine brick is utilized in night heat-storage units. The brick is used in stored heat - heat exchanger units to provide lower cost domestic heating applications. This is a field that is currently undeveloped in North America. A growing market for olivine is in the abrasives field, specifically blasting sand. Olivine compares favourably with existing silica and copper-slag blasting materials. It has superior cutability and can be supplied in a large range of sizes compared to silica and slag. One of the major strong points of olivine is the lack of a silicosis hazard. Already in Europe there are stringent restrictions on allowable levels of free-silica in working atmospheres and olivine easily satisfies the free silica requirements. Also, olivine leaves a light-coloured dust which is often preferred over the dark dust from slag. With the current environmental trends, olivine may be able to capture a significant portion of the abrasives market.

Speciality markets developed by producers account for a small part of world consumption but can be quite significant on a local scale. An example of this is the manufacture of solid waste incinerators by Olivine Corp. Ltd. in Hamilton, Washington, U.S.A. The company produces modular olivine panels for the construction of incinerators. Many units have been installed in the Pacific Northwest and western Canada. The company has also examined the potential of olivine flour as a soil additive to supply magnesium (Johanson, 1973).

Other markets that have been developed in Europe and Japan and not in North America are construction material, aggregate, concrete additive and ballast. These products commonly incorporate serpentine and dunite with the specifications defined by end use and the customer. An example of the kind of market that exists in Japan, is provided by industry statistics showing that nonferrous use of olivine, dunite and serpentine is approximately 3 to 4 million tonnes per annum. The potential for a similar market in North America needs to be examined. Innovative uses could expand or open olivine markets in North America previously overlooked or uneconomical.

OLIVINE SPECIFICATIONS

At present there are few firm specifications for olivine in the marketplace as most are defined by the customer to fit individual applications. However, there are a few general considerations. Almost pure olivine is required for smelting and foundry use. The general test for alteration is loss on ignition, with acceptable levels below 2 per cent. High magnesium levels are preferred, with a minimum of 45 weight per cent MgO and most olivine produced averages 50 weight per cent. Finally, other oxides should be below 15 weight per cent in total and iron content below 10 per cent. Table 1 documents seven typical olivine ores and the olivine from the Tulameen ultramafic complex. There are no general specifications for use in refractories, abrasives, aggregates and construction material. Compositions, grain sizes and allowable impurities are highly variable depending on each customer. Details are worked out between the customer and producer on a product by product basis.

TABLE 1

COMPARISON OF CHEMICAL ANALYSES OF SOME COMMERCIAL OLIVINES WITH SAMPLE FROM THE TULAMEEN DEPOSIT

	1	2	3	4	5	6	7	8
MgO	47.5	43-44	49.0	47.7	46.4	46.9	48.09	47.1-48.9
SiO_2	40.4	24-35	42.6	40.8	42.5	40.8	40.28	39.3-40.0
Fe_2O_3	9.0	7.6-7.7	6.0	7.5	8.0	9.4	*9.13	*9.25
Other Oxides	2.5	0.7-0.8	1.8	1.9	2.4	3.2	1.51	0.84-3.46
Loss On Ignition	0.8	?	0.6	2.0	0.5	0.6	?	0.92

(after White, 1987)

1 *Ste. Anne des Monts, Quebec, Canada (Teague, 1983)*
2 *Leoben, Austria (Teague, 1983)*
3 *Aaheim, Norway (Teague, 1983)*
4 *Norddal, Norway (Teague, 1983)*
5 *Burnsville, North Carolina, U.S.A. (Teague, 1983)*
6 *Hamilton, Washington, U.S.A. (Teague, 1983)*
7 *Twin Sisters, Washington, U.S.A. (Olivine Corp., unpublished report)*
8 *Tulameen Ultramafic Complex, B.C., Canada (Findlay, 1969)*
*_Total iron calculated as_ Fe_2O_3

TABLE 2
LIST OF OLIVINE PRICES FOR TWO AMERICAN PRODUCERS

Grade	Container	Price $US per short ton FOB mine/plant
Foundry	bulk	53-85
	bag	65-105
Flour	bag	105
Aggregate	bulk	40-45

(after Griffiths, 1989)

**These prices are quoted for Hamilton, WA. and Burnsville/Aurora, N.C. sites of AIMCOR and Olivine Corp. and are only a guide.*

PRICES AND MARKETING

Prices, as raw olivine specifications, are negotiated directly between the customer and producer. They are product specific and price to the customer varies as transportation costs are significant. In North America, the two major producing companies are AIMCOR, in North Carolina and Olivine Corp. Ltd. in Washington. There are some small producers in the Eastern Townships of Quebec, but they are low-tonnage operations. Table 2 shows the most recent published figures for olivine prices, free on board mine or plant : Hamilton, WA., Burnsville and Aurora, N.C. These figures should only be considered a guide. Total production of olivine in the United States varies between 200 000 and 300 000 tonnes per annum (Smith, 1985). Total production from Washington State facilities is approximately 50 000 to 60 000 tonnes per annum (Lobdell, 1988).

It is essential to consider the costs of transportation in the total cost of olivine to consumers. The Washington state olivine products are only competitive with the North Carolina products west of the Mississippi River due to transportation cost, primarily trucking. Internationally, Norwegian olivine producers are close to tidewater and so can be competitive with other producers due to low bulk-shipping costs. Both American producers are well inland and this limits their market radius.

MARKET CONSIDERATIONS FOR GRASSHOPPER MOUNTAIN OLIVINE

As described in the preceding sections, careful evaluation of both the available market and product quality are very important. In the case of olivine from the Tulameen area, products would be in competition with those of Olivine Corp. Ltd. and the Twin Sisters deposit. However, as described in the following sections, the olivine at Grasshopper Mountain is of excellent quality. It remains for interested parties to determine the feasibility of olivine production from the Tulameen Complex.

ACKNOWLEDGMENTS

Gary White has completed the field component of this project. Also, we would like to acknowledge the excellent detailed examination of Grasshopper Mountain olivine by the Foundry Section of the Physical Metallurgy Research Laboratories of CANMET in Ottawa. Various industry sources provided helpful background information on olivine usage worldwide and David Lobdell provided the assessment of market potential.

GEOLOGY OF THE TULAMEEN ULTRAMAFIC COMPLEX

The Tulameen ultramafic complex is located about 30 kilometres west-northwest of Princeton, on the Tulameen River. Access is by good all-weather logging roads from Princeton via Coalmont or from Hope via Coquihalla Lakes. The complex is an Alaskan-type, zoned ultramafic intrusion and has been the source of most of the placer platinum production in British Columbia. It has also been a site of exploration for chromium and iron ore since the turn of the century.

The Tulameen ultramafite is an elongate body, 17 kilometres long and varying in width from 2.5 to 6.5 kilometres, oriented along a northwest trend. The country rocks to the intrusion are andesitic metavolcanics and metasediments of the Triassic Nicola Group, locally metamorphosed from greenschist to amphibolite grade. To the northwest and north, Eagle granodiorite of the Mount Lytton complex truncates the northern margin (Figure 2).

The Tulameen complex has a dunite core mantled by pyroxenites which are surrounded by a marginal gabbro phase. It is unusual compared to typical Alaskan complexes in that the mafic rocks are syenogabbros and syenodiorites rather than tholeiitic basalts (Findlay, 1963). The dunite core is composed of olivine with disseminated and nodular chromite. The platinum in the complex is concentrated with the chromite nodules. Individual olivine crystals are often less than 1 centimetre in diameter. Olivine is variably serpentinized and asbestiform serpentine joint and fracture fillings web the core. Peripheral to the dunite is an olivine clinopyroxenite zone composed of olivine and bright green diopside. In contrast with the core, this rock is much less serpentinized, generally less than 20 per cent altered. A hornblende clinopyroxenite unit, composed of diopsidic augite, hornblende and magnetite with minor amounts of biotite, apatite and vermiculite, surrounds the inner units. Syenogabbro is exposed at the southern and southeastern margins of the complex. The primary mineralogy is plagioclase (andesine), clinopyroxene, hornblende and potassium feldspar, with minor amounts of apatite and sphene.

The entire complex is cut by northwest-trending transcurrent strike-slip faults associated with the Fraser River - Straight Creek fault system (Monger, 1985). Northeast-trending extensional faults also transect the complex. All of the contacts of the intrusion with the Nicola country rocks appear to be high-angle faults or ductile shear zones, possibly grading to mylonite zones (Figure 2; Nixon and Rublee, 1988; Nixon *et al.*, 1990).

The dunite core of the complex is exposed on the slopes between Olivine and Grasshopper mountains and in the valley of the Tulameen River. It is roughly oval in shape and covers an area of about 6 square kilometres. Mapping by Findlay (1963) outlined areas of serpentinization that varied from less than 20 per cent to greater than 80 per cent as shown in Figure 3. The degree of serpentinization decreases, in general, from east to west. Essentially unaltered olivine is required for industrial purposes. Detailed mapping and sampling of the least altered zone of the core (less than 20 per cent serpentinized) was completed in 1986 by G.V. White of the British Columbia Geological Survey Branch. One hundred and ten 500-gram grab samples and

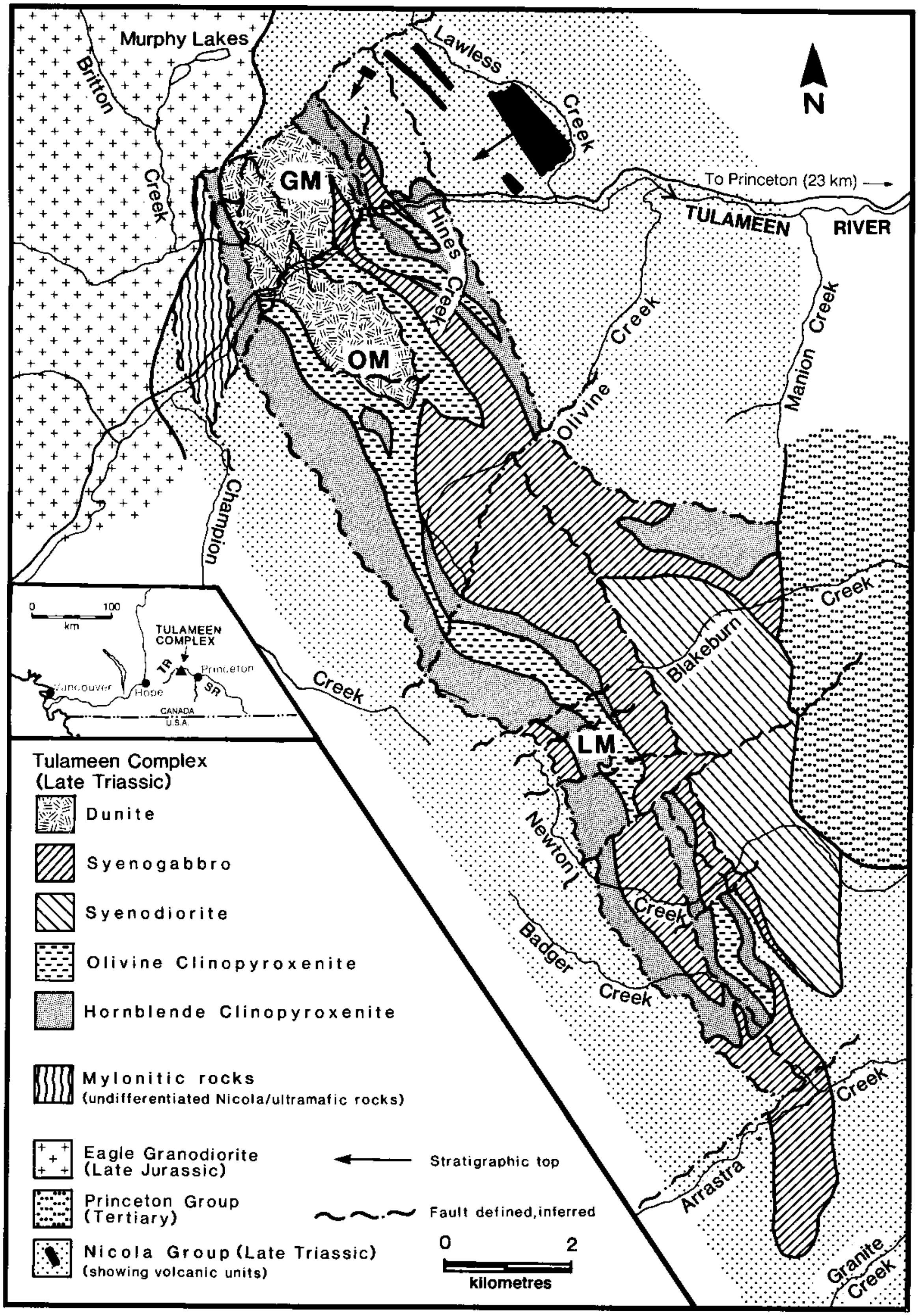

Figure 2. Regional setting of the Tulameen ultramafic complex (from Nixon *et al.*, 1990).

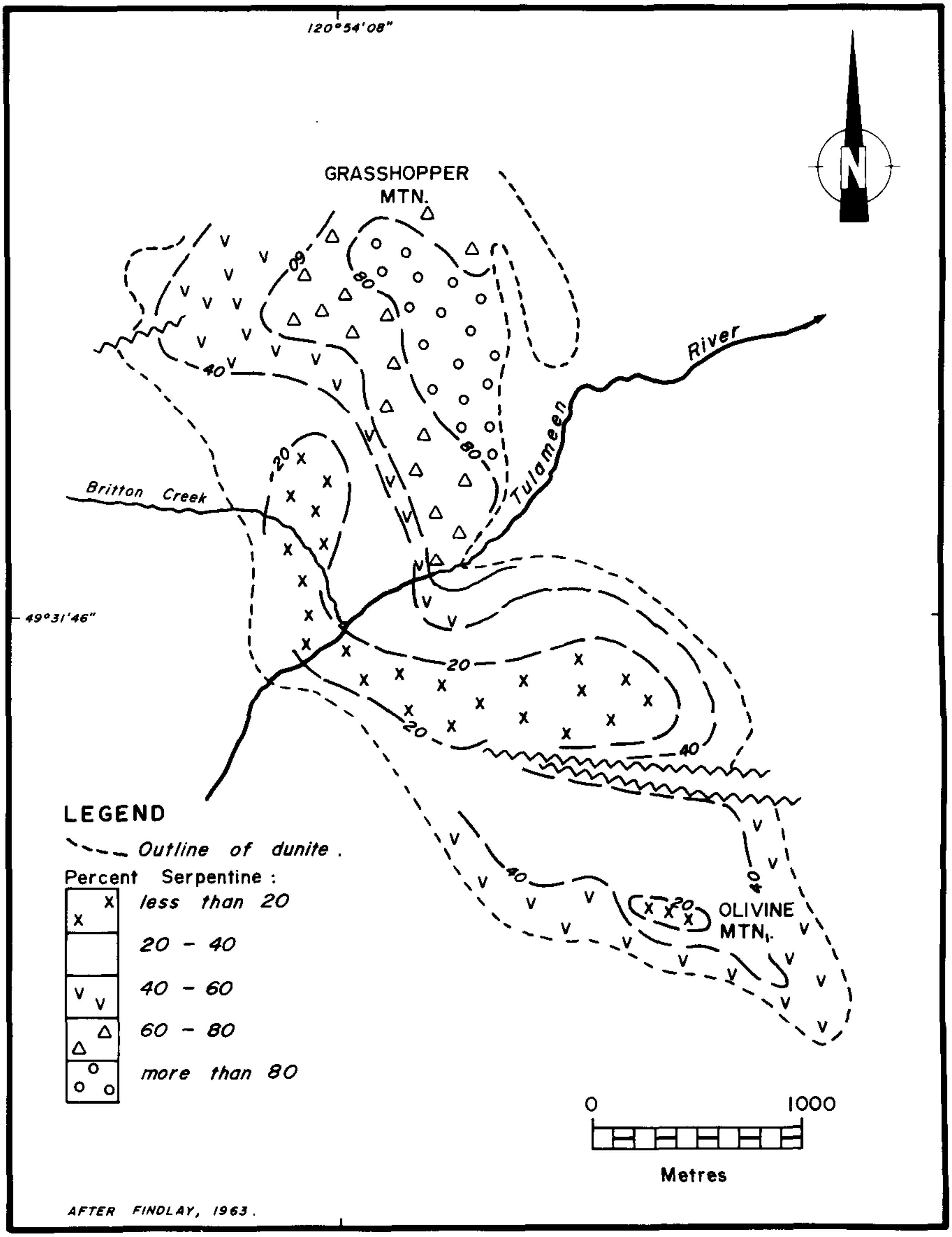

Figure 3. Map showing the variation of serpentinization in the dunite core (modified from Findlay, 1963).

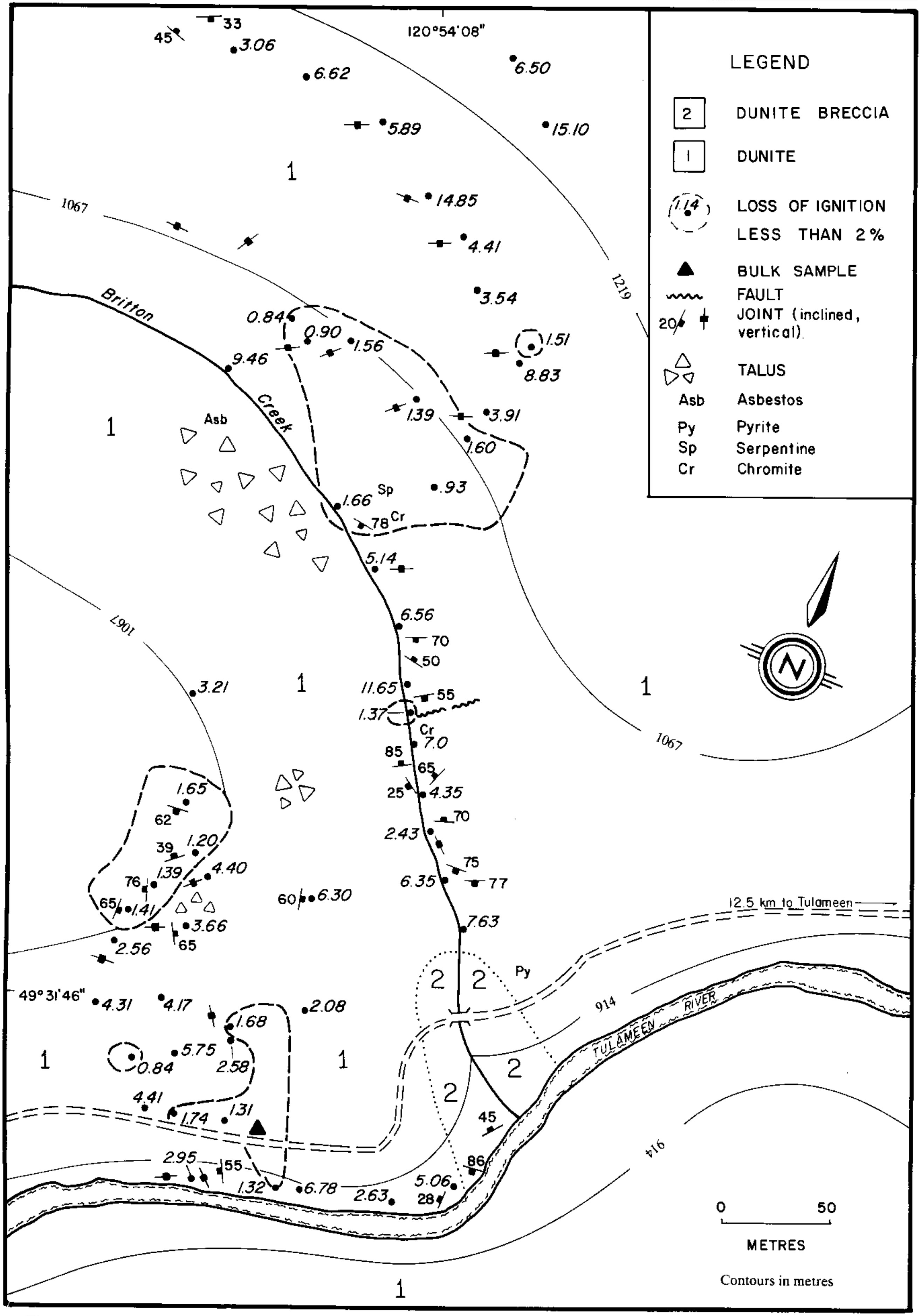

Figure 4. Map showing the location of the Tulameen deposit and the zones of fresh dunite (after Hora and White, 1988).

three 100-kilogram bulk samples were taken. Seventy four of the grab samples were tested for loss on ignition; nineteen returned values below 2 per cent. The 19 samples outlined three areas of "fresh" dunite on the lower slopes of Grasshopper Mountain that showed significant potential for raw olivine production. All the samples taken from Olivine Mountain had loss on ignition values in excess of 2 per cent. Figure 4 details the sample locations, loss on ignition values and the areas of unaltered olivine. The three zones are described by White (1987) as follows:

"Three zones with loss-on-ignition less than 2 per cent have been identified north of the Tulameen River on the southwest slopes of Grasshopper Mountain. The northern zone, approximately 100 metres long by 75 metres wide, is open to the east. A second, central zone is approximately 50 metres long by 40 metres wide and open to the west. The third, irregular zone, cut by the Tulameen River road, is approximately 100 metres long by 65 metres (maximum) wide."

Sampling was not carried out on the southeastern slopes of Grasshopper Mountain or the northeastern slopes of Olivine Mountain due to the difficulty of access. These areas are within the less than 20 per cent serpentinized zone as outlined by Findlay (1963) and a potential for more fresh olivine localities therefore exists. The bulk samples taken from the road zone were shipped to CANMET laboratories in Ottawa for further testing.

FOUNDRY SAND TESTING OF GRASSHOPPER MOUNTAIN OLIVINE BY CANMET

INITIAL SAMPLE

A 20-kilogram sample was tested in 1986 to determine if it would be suitable for foundry sand applications. The testing considered several properties including crushing and screening characteristics, mouldability, clay and water requirements, wet and dry compressibility and permeability. The results are presented in Table 3 and compared with other olivine and silica ores. The Grasshopper Mountain olivine sand performed well or adequately in all categories in the initial testing. Due to the favourable performance, a second, larger bulk sample was collected the following year for full-scale testing as foundry sand, (Szabo and Kular, 1987).

BULK SAMPLE ANALYSIS

In 1987, a 454-kilogram bulk sample of Grasshopper Mountain olivine was shipped to CANMET for detailed foundry sand testing. The examination included optimum crushing method and grain characteristics. Also examined were the greensand preparation including clay and water requirements, compactability, density, mould hardness and mouldability. Further, the casting performance was assessed for burn on, scabbing, surface finish and mould penetration. The performance of the sand with repeated use was tested by five sequential castings and the sand was examined for moisture content, clay demand, grain sizing and attrition as well as acid resistance and loss on ignition.

TABLE 3
PRELIMINARY COMPARISON
OF TULAMEEN SAMPLE OLIVINE
WITH COMMERCIAL SILICA AND
OLIVINE SANDS

Property	Standard Ottawa Silica	Commercial Crushed Olivine	Tulameen Sample Olivine
Clay Content %	6.5	6.5	6.5
Moisture %	3.3	3.1-3.2	3.2
Density	150	172	*179
Permeability	180-225	273-278	*86
Green Compression	8.5-10	7.6-7.9	*13.1
Dry Compression	58-82	46-56	*72

(after Szabo and Kular, 1987)

**Denotes average of three tests data for Ottawa Silica and Olivine from Physical Metallurgy Research Laboratories/ CANMET reports.*

The olivine test sand from Grasshopper Mountain performed well against an industry standard sand, IMC Olivine 50, from the United States. Most results were equivalent and little variation occurred between tests. This indicates that the olivine from Grasshopper Mountain could compete well against sands already available on the market (Whiting *et al.*, 1987).

DETAILED EXAMINATION

CRUSHING

Three 23-kilogram splits were taken from the bulk sample to test various crushing methods and the grain characteristics. The object of the crushing test was to determine the method which provided the optimum grain type and even sizing between -20 and +100 ASTM mesh with a minimum of flour. The three crushing methods tested were:

- jaw crusher; two passes, screened to -8 mesh and rolls; one pass
- pin mill; one pass, screened to -8 mesh
- hammer mill with 1/8 inch slotted grate; one pass, screened to -8 mesh.

TABLE 4
SIEVE ANALYSIS OF CRUSHED SAMPLE OLIVINE SHOWING BEST CRUSHING METHOD AND FINAL SAND BLEND

Sieve Analysis from the Three Crushing Processes

Mesh Size	Sample A* (jaw and rolls)		Sample B* (pin mill)		Sample C* (hammer mill)	
	15 min.	30 min.	15 min.	30 min.	15 min.	30 min.
+20	30.6	30.8	14.5	14.0	18.7	18.7
-20,+28	12.9	12.6	7.4	7.4	8.6	8.6
-28,+35	10.6	11.5	10.1	10.2	10.9	10.7
-35,+48	9.4	9.3	13.3	13.3	13.7	13.5
-48,+65	8.3	8.1	14.7	15.1	14.1	14.1
-65,+100	7.6	7.6	14.3	14.1	13.1	12.9
-100	20.6	20.1	25.7	25.9	20.9	21.5

Note: All data in per cent
**15 and 30 minute Rotap intervals*

Sieve Analysis - Blended Samples for Foundry Evaluation

Mesh Size	Target Olivine	B.C. Olivine		
		A	B	C
+28	6.9	7.8	7.8	9.4
-28,+35	27.4	18.7	18.7	22.6
-35,+48	28.3	23.5	23.5	28.4
-48,+65	29.0	24.3	24.3	29.3
-65,+100	7.3	19.0	6.3	7.6
-100	1.1	6.7	2.2	2.6

Note: All data in per cent *(after Whiting et al., 1987)*
A Hammer mill product screened at 20 and 100 mesh on Rotex.
B Product screened at 65 mesh, 1/3 of -65 reblended, remaining 2/3 discarded.
C Calculated sieve analysis of screened and reblended sample.

Two splits were taken from each crusher and screened, one for 15 minutes and one for 30 minutes. This test determined that the hammer mill process was the best method to provide a -20 to +100 mesh product. The standard IMC Olivine 50 is classed as a three-screen sand but the two shoulder screens retained 8 to 9 per cent sand thus making it more like a five-screen sand. The Grasshopper Mountain olivine sand classed as a four-screen sand with the fifth screen retaining 9 per cent sand. Table 4 documents the screening results and the five standard sieve intervals. Examination of the grain properties of the two sand types gave the IMC Olivine 50 sand an AFS/GFN rating of 43 and the Grasshopper Mountain sand a rating of 44. Microscopic analysis of the crushed product showed that the Grasshopper Mountain olivine consisted of individual subangular, subeuhedral grains. There were few composite grains and a minimum amount of broken grains. This was similar to the IMC Olivine 50 standard sand. Thus, after crushing, the two sands had similar grain sizes and distributions. Following crushing of the balance of the bulk sample by the hammer mill process, five separate 34-kilogram splits, -20 to +100 mesh, were used for foundry trials.

FOUNDRY TRIALS

A full series of tests was run on the five sand splits of the sample olivine and the industry standard. Twelve separate properties were examined while making the greensand moulds.

TABLE 5
GREENSAND PROPERTIES BEFORE AND AFTER EACH TRIAL

Casting Property	Sand Type	Casting Trial Number					
		1	2	3	4	5	
Sand Properties Before Each Casting Trial							
Compactability, %	IMC Olivine	44	45	48	44	49	
	Grasshopper Mountain	49	47	45	45	49	
Moisture, %	IMC Olivine	2.15	2.15	2.24	2.20	2.15	
	Grasshopper Mountain	2.16	2.21	2.14	2.13	2.23	
Density, g/cc	IMC Olivine	195	195	193	192	190	
	Grasshopper Mountain	186	185	185	185	183	
Permeability, AFS units	IMC Olivine	200	195	210	215	228	
	Grasshopper Mountain	249	240	240	243	253	
Green Compressive Strength, psi	IMC Olivine	30.0	27.1	29.0	30.2	28.9	
	Grasshopper Mountain	25.7	25.2	28.0	29.6	28.6	
Clay Additions, %	IMC Olivine	6.0	0.1	0.1	0.0	0.0	
	Grasshopper Mountain	6.0	0.3	0.15	0.05	0.2	
Methylene Blue Clay, %	IMC Olivine	6.1	6.1	6.3	5.8	5.8	
	Grasshopper Mountain	6.1	6.1	6.2	6.0	5.8	
Mould Hardness, B scale	IMC Olivine	88	88	88	90	88	
	Grasshopper Mountain	88	88	90	90	88	
AFS Grain Fineness Number	IMC Olivine	42.7					*50.6
	Grasshopper Mountain	44.3					*54.5
After Casting Trials							
Moisture, %	IMC Olivine	0.85	0.82	0.94	0.81	N/D	
	Grasshopper Mountain	0.93	0.83	0.98	0.85	N/D	
Methylene Blue Clay, %	IMC Olivine	5.9	5.9	6.1	6.1	N/D	
	Grasshopper Mountain	5.7	5.9	5.6	5.8	N/D	
AFS Clay, %	IMC Olivine	N/D	N/D	N/D	N/D	8.96	
	Grasshopper Mountain	N/D	N/D	N/D	N/D	8.48	

Additional Tests				
Acid Demand	at	pH 5	pH 7	
IMC Olivine	ml	9.6	8.5	
Grasshopper Mtn.	ml	33.6	30.5	
Loss On Ignition	at	500°C	700°C	975 °C
IMC Olivine	%	0.55	1.25	1.51
Grasshopper Mtn.	%	0.90	1.82	1.83

**After fifth trial and after washing for AFS clay test.*

(after Whiting et al., 1987)

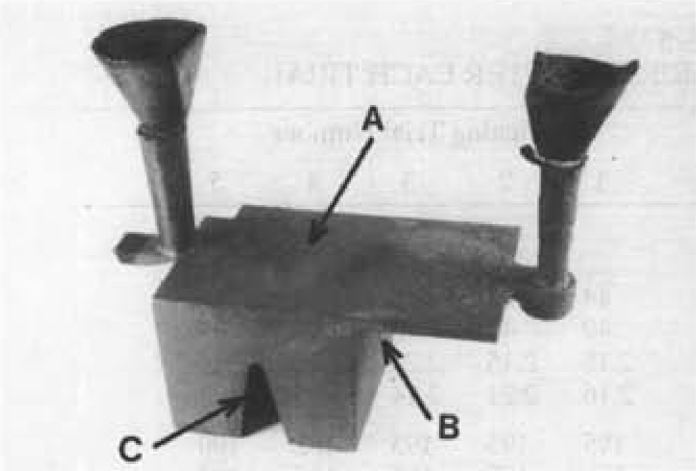

Plate 1. Surface of casting made with Grasshopper Mountain olivine sand showing no burn-on on top (A), side (B) and interior (C) surfaces (from Whiting *et al.*, 1987)

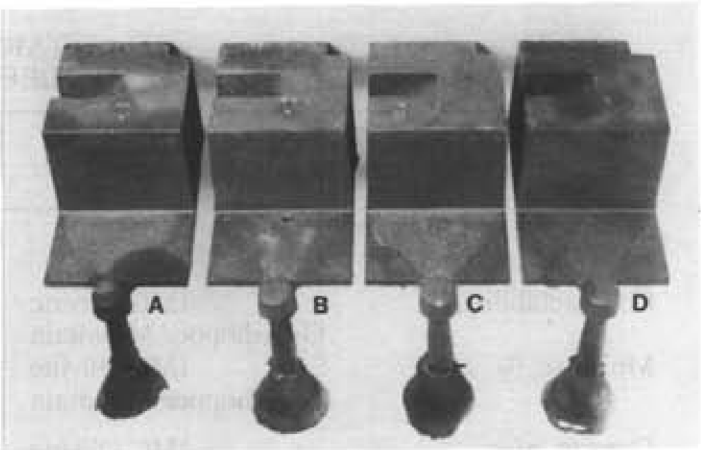

Plate 2. Burn-on and erosion on the bottom surfaces of scab blocks made in first and fifth castings. Blocks A and C are IMC Olivine 50, first and fifth castings respectively. Blocks B and D are Grasshopper Mountain olivine, first and fifth castings respectively (from Whiting *et al.*, 1987)

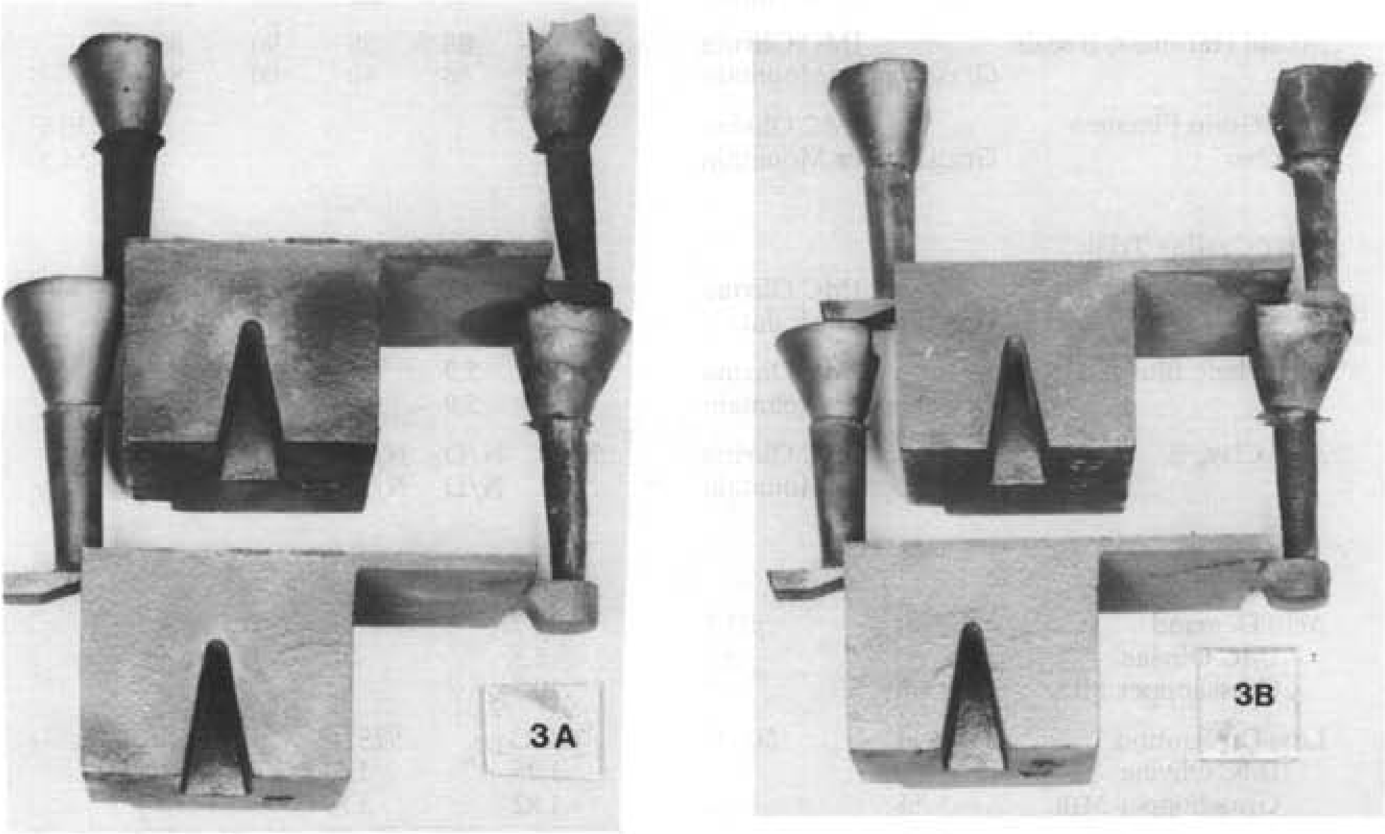

Plate 3. Scab blocks showing penetration in wedge, IMC Olivine 50 above Grasshopper Mountain castings. Plate 3a is first trial and plate 3b is fifth trial (from Whiting *et al.*, 1987).

TABLE 6
EVALUATION OF SCAB BLOCK CASTINGS

Casting Property	Sand Type	Casting Trial Number				
		1	2	3	4	5
Surface Finish	IMC Olivine	3	3	3	3	2
	Grasshopper Mountain	3	3	3	3	2
Scabbing	IMC Olivine	1	1	1	1	1
	Grasshopper Mountain	1	1	1	1	1
Burn On	IMC Olivine	2	2	2	2	2
	Grasshopper Mountain	2	2	2	2	2
Erosion	IMC Olivine	2	2	2	2	2
	Grasshopper Mountain	2	2	2	2	2
Penetration	IMC Olivine	2	2	2	2	2
	Grasshopper Mountain	2	2	2	2	2

(after Whiting et al., 1987)

Note: Each casting was rated subjectively for each property for every trial using a scale of 1 to 5 where 1 = good and 5 = bad.

Five separate metal castings were made to determine the performance of the sand with repeated use. Manganese steel test castings were made to test the chemical performance of the olivine sand. Each trial sequence began with forming molds from olivine sand, western bentonite and water. The greensand molds were evaluated for compactability, moisture content, density, permeability, compressive strength, active clay content and "B" scale mould hardness. Castings were made in pairs of standard sand and test sand. Pours were made alternately to compensate for differing temperatures between first and second pours of the molten steel. After casting, cooling and shakeout, the sand from each mold was carefully recovered and examined for moisture and active clay content with any lost material replaced. Following the last casting, the sand batches were dry mulled, sieved and examined to determine the amount of grain attrition. Acid demand of the sands and loss on ignition at high temperatures were also evaluated for each split. Table 5 details the properties measured during each trial and compares the test sand with the standard.

Each pair of castings, from Grasshopper Mountain and IMC Olivine 50 sand, were compared, subjectively, to examine the amount of burn on, scabbing, erosion, metal permeability and surface finish. The quality of the castings was very good and the individual castings were almost identical. No significant differences could be found. Plates 1 through 3 demonstrate the casting properties. The overall ratings of the castings were satisfactory to good. Table 6 shows the comparative ratings.

CONCLUSIONS

In each trial the Grasshopper Mountain olivine sand performed equally as well as the standard product available on the market. There are no significant variations and the notable, though small differences were that the test sand had slightly higher mould hardness and clay additions. The acid demand of the test sand is roughly three times higher than that of the commercial sand, but this is well within the limits of the various sands available internationally. Incompatability with most acid binding agents is a characteristic of olivine sand. Bentonite is the most common binding agent used for olivine. The olivine sand from Grasshopper Mountain has all the properties of a high-quality foundry sand.

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