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Podiform Chromite Occurrences in the Caribou Mountain and Lower Kanuti River Areas, Central Alaska

Part II: Beneficiation

By D. C. Dahlin, L. L. Brown, and J. J. Kinney

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

TABLES

PODIFORM CHROMITE OCCURRENCES IN THE CARIBOU MOUNTAIN AND LOWER KANUTI RIVER AREAS, CENTRAL ALASKA

Part II: Beneficiation

By D. C. Dahlin,[1] L. L. Brown,[2] and J. J. Kinney[3]

ABSTRACT

The Bureau of Mines has investigated podiform chromite deposits in three ultramafic bodies in the Caribou Mountain and lower Kanuti River areas of central Alaska. The investigation, reported in two parts, was done as part of the Bureau's mission to help insure an adequate supply of minerals to meet the Nation's needs. Part I describes an extensive field investigation and mineralogical studies by personnel from the Bureau's Alaska Field Operations Center. This report, part II, describes the mineralogy of 11 samples that were high-graded from surface exposures at 10 sites and presents the results of laboratory batch beneficiation tests designed to concentrate the chromite.

The 11 samples, peridotites and chromitites that consisted of variable amounts of chromite or chromium-bearing spinels, olivine, and serpentine, were beneficiated by grinding and sizing, gravity concentration, and electrodynamic separation. Three high-chromium chromite concentrates, two high-iron chromite concentrates, and one high-aluminum chromite concentrate were produced. Three other concentrates were marginal, and two were submarginal. Chromium recoveries ranged from 54 to 92 pct. These results indicate that the areas may be significant chromium resources.

Potential platinum association with the chromite was also investigated. Analysis of these 11 samples indicates that the areas are not good platinum resources.

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[1] Metallurgist.

[2] Group supervisor and geologist.

[3] Geologist.

All authors are with the Albany Research Center, Bureau of Mines, Albany, Oreg.

INTRODUCTION

The United States has no domestic production or economic reserves of chromite, the only commercial ore of chromium, and must rely on imports and on stockpiles to meet national needs. Although world reserves of chromite are adequate to meet forecast world demand, sensitive political and economic considerations, as well as geographical location, could conceivably make the United States vulnerable in an emergency.[4] The known large, high-grade chromite deposits are in the Eastern Hemisphere, and chromite imports have been primarily from the Republic of South Africa, the Soviet Union, the Philippines, Finland, and Turkey. As a means of meeting a potential emergency, the Bureau of Mines is characterizing potential domestic sources and developing processing technology.

Chromium is used primarily in the metallurgical industry, but also in the chemical and refractory industries. There are no economical substitutes for it in stainless steels and many other ferrous and nonferrous alloys. Chemical applications include plating, pigment production, and leather tanning. Chromite refractories are used in high-temperature applications such as furnace and kiln linings and as molding material in foundaries.

Identified U.S. chromite resources in Montana and the Pacific Coast States are small, low-grade, or both. The largest deposit is in the Stillwater Complex, Mont., and contains a high-iron variety of chromite. Laterites from northern California and southwestern Oregon are a large, low-grade resource that the Bureau is currently investigating for chromite recovery.[5]

Geologists at the Bureau's Alaska Field Operations Center have done reconnaissance investigations of three ultramafic complexes in the Caribou Mountain-Melozitna ultramafic belt in central Alaska. Their study is part I of this two-part investigation.[6] Geochemical sampling of the three complexes, identified as the Caribou Mountain, upper Kanuti River, and lower Kanuti River ultramafic bodies, was used to describe the occurrences of chromite and examine the significance of Cr, Ni, and Co anomalies reported by earlier workers. This report, part II of the investigation, describes the mineralogy and beneficiation of 11 chromite-bearing samples taken from 10 sites within the three ultramafic bodies.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of Jeff Foley, Mark McDermott, and Karen Clautice, geologists, Alaska Field Operations Center, Bureau of Mines, in obtaining samples for this investigation.

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[4] Morning, J. L., N. A. Matthews, and E. C. Peterson. Chromium. Ch. in Mineral Facts and Problems, 1980 Edition. BuMines Bull. 671, 1981, pp. 167-182.

[5] Kirby, D. E., D. R. George, and C. B. Daellenbach. Chromium Recovery From Nickel-Cobalt Laterite and Laterite Leach Residue. BuMines RI 8676, 1982, 22 pp.

[6] Foley, J. Y., and M. M. McDermott. Podiform Chromite Occurrences in the Caribou Mountain and Lower Kanuti River Areas, Central Alaska. Part I: Reconnaissance Investigations. BuMines IC 8915, 1983.

MINERALOGY

Each sample of chromite-bearing material that was studied was high-graded from surface exposures at the field site. The samples were high-graded to determine whether precious metals were associated with the chromite. The bulk samples of hard rock were collected from frost-riven rubble or from discontinuous pods and stringers in small outcrops and in shallow subcrops, usually along ridge crests. Sample weight ranged from 10 to 350 lb, and maximum rock size in each sample ranged from 1 to 15 in. in the largest dimension.

Representative specimens were selected from each sample for petrographic examination. The samples ranged from hard, unweathered, massive chromite to chromite that was disseminated sparsely to densely in lenses and stringers less than an inch to several inches thick. Most of the samples had surface alteration from weathering, and most were highly fractured.

All of the samples were mineralogically similar. They were peridotites and chromitites that consisted essentially of variable amounts of chromite or chromium-bearing spinels, olivine, and serpentine. Minor constituents included magnetite, chlorite, and ferromagnesian silicate minerals (pyroxenes and amphiboles). Six samples contained traces of pyrite, and a trace of maucherite (Ni_3As_2) was identified in sample E. Some of the olivine was altered to serpentine, and some of the serpentine and ferromagnesian silicates were altered to chlorite.

Head analyses of the samples are shown in table 1. The samples are identified by the letters A through K, as they are in part I. The Cr_2O_3 content of the samples ranged from 13.2 to 47.2 pct. Platinum was reported in the head analysis of sample B at a grade of 0.039 oz/ton, but the platinum analysis of the other head samples was less than the minimum detection level. The sensitivity of the precious-metals analyses depends on the chromium content of the sample being analyzed. The levels of detection are 0.01 oz/ton for Pt, Pd, and Ag, and 0.002 oz/ton for Au for a sample that contains more than about 20 pct Cr_2O_3. For a sample with less than about 20 pct Cr_2O_3, the levels of detection are improved to 0.004 oz/ton for Pt and Pd and 0.0008 oz/ton for Au, and remain at 0.01 oz/ton for Ag. All of the precious-metals analyses were done by a fire assay-atomic absorption technique.

In one case, samples taken from the same site were significantly different, as can be seen by comparing the analysis of sample I with that of sample J. Differences could also be seen in the hand specimens. The chromite in sample I was

TABLE 1. - Head analyses of 11 chromite-bearing samples from the lower Kanuti River and Caribou Mountain areas of central Alaska

Sample	Chromite occurrence[1]	Analysis, pct					Analysis, oz/ton			
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2	Pt	Pd	Au	Ag
A	3	17.0	8.5	34.5	4.1	26.8	<0.004	<0.004	<0.001	0.04
B	6	22.7	20.7	13.9	22.6	4.7	.039	.011	<.001	.10
C	7	14.8	9.3	28.1	8.4	26.0	<.004	<.004	.001	.05
D	12	31.1	12.5	22.1	7.5	14.9	<.01	<.01	<.002	.13
E	17	47.2	14.4	13.7	7.8	7.0	<.01	<.01	.003	.45
F	18	13.2	10.8	27.9	16.2	20.2	<.01	<.01	<.002	.03
G	19	44.4	18.6	12.8	7.6	7.3	<.01	<.01	<.002	.05
H	20	38.6	18.7	13.4	10.7	5.7	<.01	<.01	<.002	.05
I	21	24.8	15.8	15.6	30.5	2.8	<.01	<.01	.002	.04
J	21	15.6	9.4	27.2	8.9	25.8	<.004	<.004	<.001	.05
K	22	20.3	18.1	17.0	24.3	6.6	<.004	<.004	<.001	.05

[1] Chromite occurrence locations are shown in part I.

massive chromite, while in sample J, the chromite was disseminated in thin bands.

Detailed mineralogical examinations were done on table concentrates and tailings from sized fractions. Binocular and petrographic microscopy and magnetic separation techniques were used to determine the mineral composition of the samples. The composition of each sample appeared to be nearly uniform from one size fraction to the next. The 100- by 200-mesh fraction was studied because it was representative of the whole sample, and most of the mineral components were liberated in that size range. Table 2 shows the mineral composition, based on weight, of the samples, as calculated from the estimated compositions of the concentrates and tailings from the 100- by 200-mesh fraction.

High-purity chromite concentrates were prepared by carefully controlled magnetic separation of table concentrates that had been submitted for detailed mineralogical examination. Each sample was fractionated at several electromagnetic field settings on a laboratory-model isodynamic separator. The best concentrate, as determined with a binocular microscope, was submitted for chemical analysis. Table 3 shows the analyses of these high-purity concentrates from the samples. All were classified as magnesian aluminian chromites except samples B, F, I, and K. Those were identified as magnesian chromohercynites, iron-aluminum spinels ($FeAl_2O_4$) that contain significant amounts of chromium and magnesium substituted for aluminum and iron.

TABLE 2. - Estimated mineral composition of 11 lower Kanuti River and Caribou Mountain samples, weight-percent

Sample	Chromite	Olivine	Serpentine	Magnetics[1]	Chlorite	Ferromagnesian silicates	Sulfides
A	26	58	14	2	Trace	Trace	Trace
B	81	14	Trace	5	Trace	ND	ND
C	27	30	25	11	3	7	ND
D	60	20	16	3	Trace	Trace	ND
E	79	2	12	7	Trace	Trace	Trace
F	31	11	46	11	2	ND	Trace
G	74	Trace	19	6	Trace	ND	ND
H	74	ND	16	11	Trace	ND	Trace
I	82	Trace	5	10	3	ND	ND
J	31	23	34	10	Trace	2	Trace
K	62	13	15	10	Trace	ND	ND

ND Not detected. [1] Minerals removable with a hand magnet.

TABLE 3. - Analyses of high-purity concentrates prepared from 100- by 200-mesh size fractions

Sample	Analysis, pct							Cr:Fe ratio
	Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2	S	P	
A	51.6	15.6	12.4	12.0	2.58	0.009	0.06	2.3
B	24.8	22.4	12.0	24.9	1.79	.011	.05	.8
C	38.9	15.3	14.3	20.2	3.92	.011	.17	1.7
D	49.3	15.9	13.4	12.3	2.63	.006	.14	2.1
E	53.8	15.1	11.4	9.3	3.61	.009	.05	2.4
F	31.0	16.1	17.1	27.1	2.82	.012	.05	1.3
G	52.9	20.5	10.3	8.5	1.58	.009	.12	1.8
H	45.7	20.5	10.5	13.8	1.11	.006	.06	1.5
I	27.5	16.0	14.8	33.8	.18	.004	.07	1.2
J	39.8	15.8	13.9	20.2	3.62	.009	.09	1.7
K	24.7	20.0	11.4	31.6	1.57	.006	.07	.8

BENEFICIATION PROCEDURE

The beneficiation procedure that was used to produce a composite chromite concentrate was essentially the same for each of the 11 samples and is shown in figure 1. Minor variations were adopted to the procedure to suit each individual sample.

The samples, as received, consisted of hard, angular rock fragments from 1 to 15 in. in the largest dimension. Each sample was crushed in a jaw crusher and screened to minus 1/4 in. A head sample and several 20-lb splits for beneficiation tests were prepared from the minus 1/4-in material.

For each sample, a split was screened on 48, 100, and 200 mesh. The plus 48-mesh fraction was ground dry in a 13- by 25-in rodmill and a 7- by 9-in rodmill to pass 48 mesh and was sized at 100 and 200 mesh. Grinding was done in stages to minimize production of fines. Generally, the plus 48-mesh fraction from a 20-lb split was first ground in the

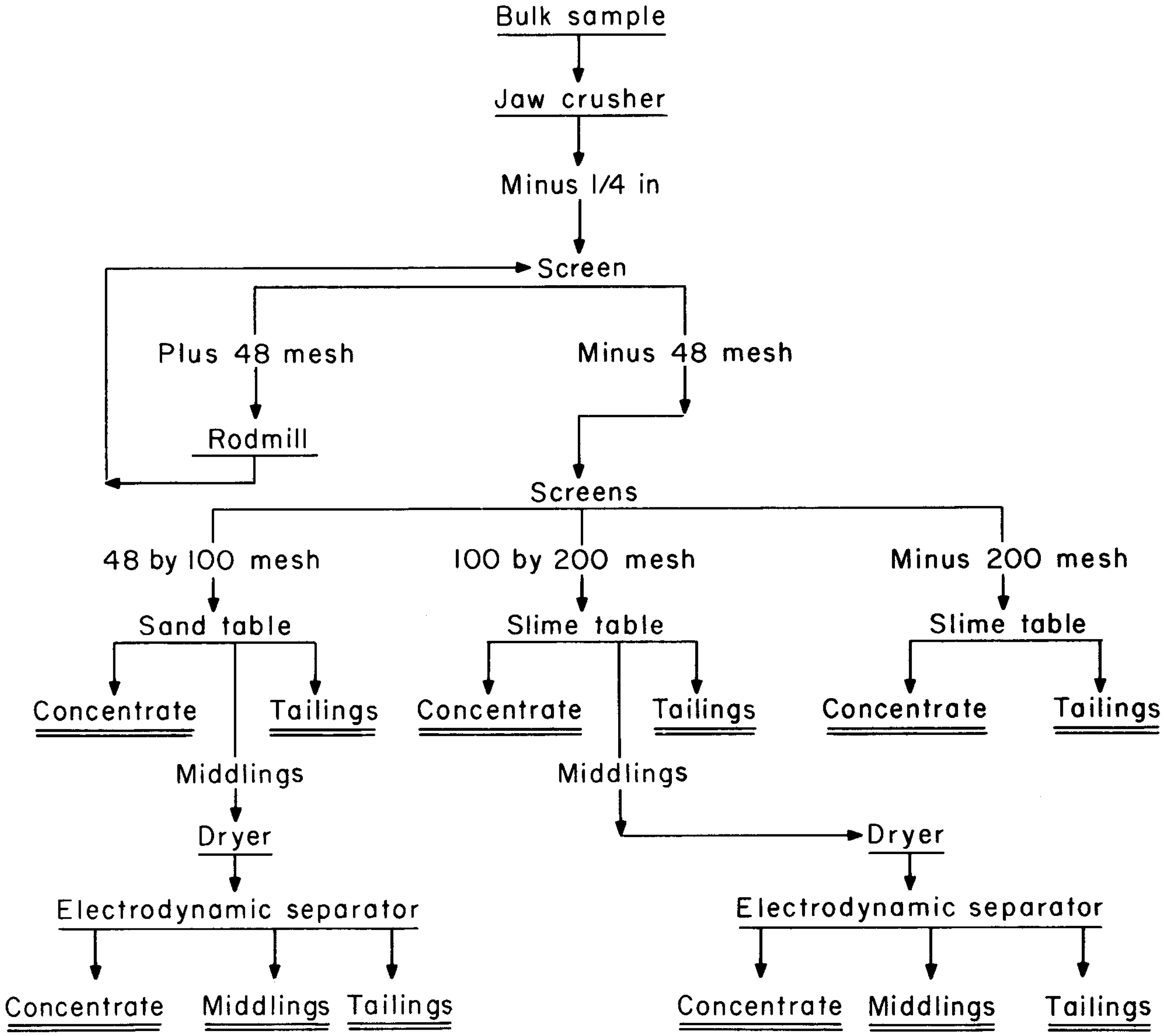

FIGURE 1. - General beneficiation procedure used to concentrate 11 lower Kanuti River and Caribou Mountain samples.

large mill in two stages of 5 and 3 min, and then, if needed, the remaining sample was ground in one to four stages of 3 min each in the small mill to reduce it to essentially 100 pct minus 48 mesh. The size splits were chosen because mineral liberation was good at 48 mesh and because 200 mesh approaches the lower practical limit of efficient separation by gravity and electrodynamic processing. The additional split at 100 mesh gave closely sized feed for gravity concentration.

The three products were passed separately over a 2- by 4-ft laboratory shaking table. The 48- by 100-mesh fraction was fed to a sand deck, and the 100- by 200-mesh fraction and the minus 200-mesh fraction were fed to a slime deck. A finished high-grade table concentrate was produced from each size fraction. Depending on the grade and separation characteristics of the sample, a middlings product, a tailings product, or both were collected for further processing to improve recovery. In the cases where a middlings product was separated, barren tailings were discarded. Only a high-grade concentrate and tailings were produced from the minus 200-mesh fraction. The minus 200-mesh concentrate contained only the coarser, high-specific-gravity particles of the size fraction. Several of the samples had relatively high chromite losses in the minus 200-mesh tailings because tabling becomes less effective in separating very fine-sized particles. The water that discharged off the tailings end of the table was dark brown, an indication that it contained very fine suspended chromite. Very fine chromite settled out in the tailings discharge tray.

Middlings products, and those tailings products from tests where no middlings products were taken, were dried and treated electrodynamically on a laboratory-model high-tension separator. A single layer of particles was fed onto a 14-in rotor by a vibratory feeder. The positions of the two electrodes were the same for all of the tests. The first electrode was oriented to give a combination pinning and lifting effect, and the second electrode was oriented to give a lifting effect. Chromite and other conductors present were thrown from the rotor, while the olivine, serpentine, and other nonconductor gangue minerals were pinned to the rotor. Rotor speed was varied, and the splitters were adjusted to produce good concentrate, middlings, and tailings products.

The general procedure for the electrodynamic separation is shown in figure 2. The dry feed was separated into a concentrate, middlings, and tailings. The middlings were retreated in two or more rougher steps. The concentrates from the three rougher passes were combined, and a cleaner step was done in which a cleaner concentrate and cleaner tailings were produced. The cleaner middlings were combined with the cleaner concentrate. The tailings from the three rougher passes were combined, and a scavenger step was done in which a scavenger concentrate and scavenger tailings were produced. The scavenger middlings were combined with the scavenger tailings. In industrial practice the scavenger concentrate, third rougher middlings, and cleaner tailings would probably be combined and recirculated to the head of the electrodynamic separation circuit.

The procedure for electrodynamic separation was modified to suit the samples.

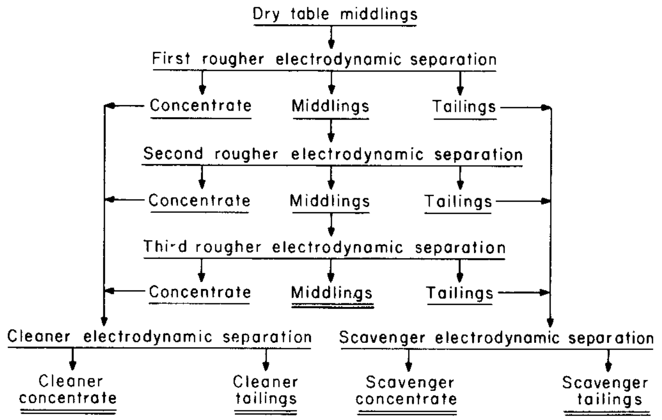

FIGURE 2. - General procedure for the electrodynamic separation step of the beneficiation procedure.

Three rougher steps were impractical on several middlings and tailings samples that were relatively small; one or two steps were sufficient. The cleaner and scavenger steps were omitted on several of the smaller samples. The minus 200-mesh table tailings were not treated electrodynamically because the process is not effective in that size range.

Electrodynamic separation was done primarily to give an indication of the increased recovery of chromite attainable from table middlings or tailings. Optimum separation parameters were not investigated. A limited number of variations in conditions were investigated for each sample, and those that gave good products, as determined visually, were used.

A magnetic separation step was not included in this process flowsheet, although low-intensity wet magnetic separation was considered as a means to improve the Cr:Fe ratio by removing magnetite. The mineralogy of the samples indicated that the table concentrates contained 2 to 15 pct magnetics as particles removable with a hand magnet. Attempts to remove a magnetic fraction from several table concentrates were ineffective with a laboratory-model concurrent wet drum magnetic separator with a permanent magnet. A very small percentage of the expected weight of magnetics was removed. A larger magnetic fraction could be removed with a higher intensity magnetic field at the expense of chromite recovery.

RESULTS AND DISCUSSION

The calculated composite chromite concentrates that were produced from the lower Kanuti River and Caribou Mountain ultramafics may be categorized in one of the following groups:[7]

1. High-chromium (metallurgical-grade) chromite that contains a minimum of 46 pct Cr_2O_3 with a Cr:Fe ratio greater than 2.0:1.

2. High-iron (chemical-grade) chromite that contains 40 to 46 pct Cr_2O_3 with a Cr:Fe ratio of 1.5:1 to 2.0:1.

3. High-aluminum (refractory-grade) chromite that contains more than 20 pct Al_2O_3 and more than 60 pct Al_2O_3 plus Cr_2O_3.

4. Marginal chromite that meets either the grade or Cr:Fe-ratio requirement for one of the classifications above and very nearly meets the other.

5. Submarginal chromite that fails to meet the above classifications.

Table 4 summarizes the results of beneficiation of the 11 samples using the procedure in figure 1. Complete metallurgical balances may be found in tables A-1 through A-11 in the appendix.

Samples A, D, and E were beneficiated to produce high-chromium chromite concentrates. The best concentrate was produced from sample E. The grade was 53.8 pct Cr_2O_3 with a Cr:Fe ratio of 2.4:1, and the chromium recovery was 87 pct. Sample A was concentrated to 48.7 pct Cr_2O_3 with a Cr:Fe ratio of 2.2:1 and 64 pct chromium recovery. The grade of the concentrate from sample D was 48.8 pct Cr_2O_3 with chromium recovery of 81 pct and a Cr:Fe ratio of 2.0:1.

Four samples were beneficiated to produce high-iron or marginal high-iron chromite concentrates. The grade of the concentrate from sample G was 50.1 pct Cr_2O_3, high enough to be considered a high-chromium chromite, but the Cr:Fe ratio was only 1.7:1; chromium recovery was 89 pct. Sample H was concentrated to 44.7 pct Cr_2O_3 with a Cr:Fe ratio of 1.5:1 and 87 pct chromium recovery. Concentrates from samples C and J met the Cr:Fe ratio requirement, but they were

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[7] Categories 1, 2, and 3 are from work cited in footnote 4.

TABLE 4. - Summary of the calculated composite concentrates from beneficiation of 11 chromite-bearing samples from the lower Kanuti River and Caribou Mountain areas

Chromite classification and sample	Wt-pct	Analysis, pct							Cr recovery, pct	Cr:Fe ratio
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2	S	P		
High-chromium:										
E	79.2	53.8	15.5	12.5	9.4	3.8	0.028	0.01	86.8	2.4
A	23.0	48.7	15.3	14.9	10.8	4.2	.020	.05	63.9	2.2
D	53.2	48.8	16.8	14.3	12.2	2.5	.021	.02	80.6	2.0
High-iron:										
G	76.6	50.1	20.6	10.4	7.9	2.4			88.5	1.7
H	76.9	44.7	21.0	11.7	13.7	1.6			87.3	1.5
Marginal high-iron:										
C	27.4	36.8	15.6	16.6	18.8	5.7			64.3	1.6
J	23.7	35.8	16.1	16.3	19.1	5.8			53.7	1.5
High-aluminum:										
I	81.1	27.5	16.8	16.5	33.0	1.0			86.0	1.1
Marginal high-aluminum: F	27.9	33.6	16.3	15.8	26.2	3.3			73.8	1.4
Submarginal:										
B	84.1	25.3	22.7	14.2	24.4	2.0			91.7	.8
K	73.5	23.5	20.3	15.9	28.6	2.3			83.7	.8

NOTE.--Absence of data indicates no analysis.

significantly below the grade requirement of 40 pct Cr_2O_3. The metallurgical balances in tables A-3 and A-10 show that the electrodynamic concentrates could possibly be improved enough, with some sacrifice in recovery, to raise the composite grade to near 40 pct Cr_2O_3.

Two samples were beneficiated to produce high-aluminum or marginal high-aluminum chromite concentrates. The concentrate from sample I was a high-aluminum product with a grade of 27.5 pct Cr_2O_3 and 33.0 pct Al_2O_3 and a chromium recovery of 86 pct. The concentrate from sample F was a marginal high-aluminum product with 33.6 pct Cr_2O_3 and 26.2 pct Al_2O_3 with chromium recovery of 74 pct.

Concentrates from samples B and K had Al_2O_3 contents of more than 20 pct, but the combination of Cr_2O_3 and Al_2O_3 was significantly below 60 pct. The metallurgical balances in tables A-2 and A-11 show that the concentrates cannot be upgraded enough to meet the marginal high-aluminum classification. They were classified as submarginal chromites.

The gravity concentration products from each of the 11 samples were analyzed for precious-metals content. Only the table concentrates from samples B and G contained platinum at a level above the minimum detection limit of 0.01 oz/ton. The head analysis of sample B indicated the presence of 0.039 oz/ton Pt. The calculated analysis of the composite concentrate was 0.022 oz/ton Pt, and the calculated head was 0.021 oz/ton Pt. The analyses indicate that the platinum is not uniformly distributed in the rock and that it may be associated with both the chromium mineral and gangue. The head analysis of sample G was less than 0.01 oz/ton Pt, and the calculated analysis of the composite concentrate was 0.01 oz/ton Pt. Examination of these 11 samples indicated that the chromite-bearing areas of the lower Kanuti River and Caribou Mountain ultramafics are not significant resources for platinum.

SUMMARY AND CONCLUSIONS

Eleven samples of chromite-bearing materials were collected from three ultramafic bodies in the Caribou Mountain-Melozitna ultramafic belt of central Alaska. These samples were characterized mineralogically and beneficiated to produce chromite concentrates.

The samples ranged from hard, unweathered, massive chromite to chromite disseminated in lenses and stringers. All were peridotites or chromitites that consisted essentially of variable amounts of chromite or chromohercynite, olivine, and serpentine.

A beneficiation process was designed to treat the samples that included grinding and sizing, gravity concentration, and electrodynamic separation. Three high-chromium (metallurgical-grade) chromite concentrates, two high-iron (chemical-grade) chromite concentrates, and one high-aluminum (refractory-grade) chromite concentrate were produced. Three other concentrates were marginal, and two concentrates were submarginal. Recoveries ranged from 54 to 92 pct Cr_2O_3.

Potential platinum association with the chromite was investigated. No platinum-group minerals were observed in the mineralogical examinations, although in one sample the calculated platinum content of the gravity concentrate was 0.022 oz/ton. The platinum content of the other concentrates was at or below the detection limit of 0.01 oz/ton.

This investigation was a preliminary evaluation of the chromite and platinum resource potential of the lower Kanuti River and Caribou Mountain ultramafic bodies. Although all of the samples were high-graded from surface exposures, they indicate that the areas may be significant chromium resources. They do not indicate good platinum resources.

APPENDIX.--METALLURGICAL BALANCES

TABLE A-1. - Gravity concentration and electrodynamic separation of sample A

Product[1]	Wt-pct	Analysis, pct							Cr distribution, pct	Cr:Fe ratio
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2	S	P		
48 by 100 mesh:										
Table concentrate*..........	2.7	51.2	16.0	13.2	11.0	2.1	0.016	0.16	7.9	2.2
Table middlings............	32.6	24.7	10.1	31.3	6.6	21.7				
Electrodynamic separation:										
Cleaner concentrate*....	12.1	46.3	14.6	16.6	10.2	5.9	.022	.02	32.0	2.2
Cleaner tailings........	.4	35.4	12.0			16.0			.8	
3d rougher middlings....	3.7	36.2	12.1			13.9			7.6	
Scavenger concentrate...	.6	38.0	12.3			13.4			1.3	
Scavenger tailings......	15.8	4.9	5.9			36.1			4.4	
Table tailings.............	11.0	4.1	5.5			36.7			2.6	
100 by 200 mesh:										
Table concentrate*..........	3.4	52.9	15.8	13.3	11.4	2.5	.018	.01	10.3	2.3
Table middlings............	13.6	13.5	7.6	42.8	3.1	30.5				
Electrodynamic separation:										
Cleaner concentrate*....	1.9	48.1	15.4	13.7	11.3	3.9	.023	.02	5.2	2.1
Cleaner tailings........	.3	43.0	13.7			8.0			.7	
2d rougher middlings....	.6	33.0	12.4			15.2			1.1	
Scavenger concentrate...	.4	43.3	14.1			7.3			1.0	
Scavenger tailings......	10.4	3.7	5.7			37.5			2.2	
Table tailings.............	8.3	2.4	5.1			38.1			1.1	
Minus 200 mesh:										
Table concentrate*..........	2.9	51.4	16.7	12.4	11.9	1.7	.014	.11	8.5	2.1
Table tailings.............	25.5	9.1	6.5			32.5			13.3	
Composite or total........	100.0	17.5	8.5			26.9			100.0	
Calculated composite concentrate[1]...............	23.0	48.7	15.3	14.9	10.8	4.3	.020	.05	63.9	2.2

[1] Products with asterisks have been mathematically combined to give the calculated composite concentrate.

TABLE A-2. - Gravity concentration and electrodynamic separation of sample B

Product[1]	Wt-pct	Analysis, pct					Cr distribution, pct	Cr:Fe ratio
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2		
48 by 100 mesh:								
Table concentrate*..............	35.2	25.3	23.0	12.9	23.6	1.5	38.5	0.8
Table tailings..................	13.3	19.6	20.0			9.3		
Electrodynamic separation:								
Cleaner concentrate*.........	9.3	23.5	22.0	15.3	27.2	2.6	9.5	.7
Cleaner tailings.............	.2	11.0	14.3			21.0	.1	
3d rougher middlings.........	1.3	16.5	17.4			13.1	.9	
Scavenger concentrate........	.2	20.3	20.6			7.3	.2	
Scavenger tailings...........	2.3	2.4	8.8			33.6	.2	
100 by 200 mesh:								
Table concentrate*..............	20.4	26.3	22.6	15.1	23.0	2.0	23.2	.8
Table tailings..................	4.2	14.8	16.5			16.2		
Electrodynamic separation:								
Concentrate*................	1.3	23.8	22.6	14.8	27.8	2.5	1.3	.7
Middlings...................	1.7	15.8	17.3			13.9	1.2	
Tailings....................	1.2	2.2	8.0			33.8	.1	
Minus 200 mesh:								
Table concentrate*..............	17.9	24.8	22.6	15.2	26.0	2.8	19.2	.8
Table tailings..................	9.0	14.4	15.6			17.1	5.6	
Composite or total............	100.0	23.1	21.4			4.9	100.0	
Calculated composite concentrate[1].....................	84.1	25.3	22.7	14.2	24.4	2.0	91.7	.8

[1] Products with asterisks have been mathematically combined to give the calculated composite concentrate.

TABLE A-3. - Gravity concentration and electrodynamic separation of sample C

Product[1]	Wt-pct	Analysis, pct					Cr distribution, pct	Cr:Fe ratio
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2		
48 by 100 mesh:								
Table concentrate*	6.7	40.3	16.1	14.9	20.5	2.7	17.2	1.7
Table middlings	22.3	23.2	11.8	25.6	12.4	18.5		
Electrodynamic separation:								
Cleaner concentrate*	10.4	31.4	14.4	19.0	16.7	10.2	20.9	1.5
Cleaner tailings	.4	24.1	11.8			17.9	.6	
3d rougher middlings	5.3	29.4	12.0			14.3	9.9	
Scavenger concentrate	.5	24.1	11.7			17.8	.8	
Scavenger tailings	5.7	5.4	6.2			37.3	2.0	
Table tailings	16.7	4.2	5.9			36.1	4.4	
100 by 200 mesh:								
Table concentrate*	3.9	41.8	16.3	15.0	20.7	2.1	10.4	1.8
Table middlings	10.5	16.8	9.8	32.6	9.7	25.7		
Electrodynamic separation:								
Cleaner concentrate*	3.1	36.2	16.2	16.1	18.4	5.6	7.2	1.5
Cleaner tailings	.4	29.4	13.6			12.4	.8	
3d rougher middlings	.3	26.3	13.1			15.5	.5	
Scavenger concentrate	.7	32.3	14.1			9.8	1.4	
Scavenger tailings	6.0	5.0	6.3			37.3	1.9	
Table tailings	8.4	2.4	4.7			38.7	1.3	
Minus 200 mesh:								
Table concentrate*	3.3	41.1	17.3	15.0	20.3	2.2	8.6	1.6
Table tailings	28.2	6.7	6.6			34.7	12.1	
Composite or total	100.0	15.7	9.2			26.1	100.0	
Calculated composite concentrate[1]	27.4	36.8	15.6	16.6	18.8	5.7	64.3	1.6

[1] Products with asterisks have been mathematically combined to give the calculated composite concentrate.

TABLE A-4. - Gravity concentration and electrodynamic separation of sample D

Product[1]	Wt-pct	Analysis, pct							Cr distribution, pct	Cr:Fe ratio
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2	S	P		
48 by 100 mesh:										
Table concentrate*	10.6	49.7	17.1	13.9	12.6	1.8	0.019	0.01	16.3	2.0
Table middlings	27.3	41.7	15.1	18.8	10.5	8.0				
Electrodynamic separation:										
Cleaner concentrate*	19.7	47.6	16.5	14.7	12.1	2.9	.020	.03	29.1	2.0
Cleaner tailings	.3	39.5	14.8			9.0			.4	
3d rougher middlings	2.6	46.6	16.0			3.9			3.8	
Scavenger concentrate	.6	42.4	15.1			6.8			.8	
Scavenger tailings	4.1	6.9	6.7			33.8			.9	
Table tailings	8.5	4.2	5.7			34.8			1.1	
100 by 200 mesh:										
Table concentrate*	6.4	50.6	17.1	13.8	12.4	1.5	.018	.01	10.0	2.0
Table middlings	12.2	34.2	13.2	25.0	8.6	13.9				
Electrodynamic separation:										
Cleaner concentrate*	7.1	49.1	16.6	14.0	11.8	2.5	.024	.02	10.8	2.0
Cleaner tailings	.4	40.0	13.6			11.7			.5	
2d rougher middlings	.4	36.4	14.5			9.1			.4	
Scavenger concentrate	.3	44.0	15.2			5.9			.4	
Scavenger tailings	4.0	6.2	6.6			34.8			.8	
Table tailings	5.1	2.3	5.1			35.7			.4	
Minus 200 mesh:										
Table concentrate*	9.4	49.3	16.8	14.5	12.3	2.9	.026	.01	14.4	2.0
Table tailings	20.5	15.5	8.5			26.7			9.9	
Composite or total	100.0	32.2	12.7			14.6			100.0	
Calculated composite concentrate[1]	53.2	48.8	16.8	14.3	12.2	2.5	.021	.02	80.6	2.0

[1] Products with asterisks have been mathematically combined to give the calculated composite concentrate.

TABLE A-5. - Gravity concentration and electrodynamic separation of sample E

Product[1]	Wt-pct	Analysis, pct							Cr distribution, pct	Cr:Fe ratio
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2	S	P		
48 by 100 mesh:										
Table concentrate*	42.1	53.8	15.5	12.7	9.5	3.9	0.029	0.01	46.1	2.4
Table tailings....	7.8	34.3	10.7			16.9				
Electrodynamic separation:										
Cleaner concentrate*....	4.5	47.1	14.0	14.9	8.7	7.3	.039	.02	4.3	2.3
Cleaner tailings.........	.1	36.8	11.4			14.2			.1	
3d rougher middlings....	1.6	28.1	9.1			20.2			.9	
Rougher tailings.........	1.6	8.0	4.4			34.7			.3	
100 by 200 mesh:										
Table concentrate*	16.2	55.0	15.6	12.4	10.1	3.2	.025	.02	18.1	2.4
Table tailings....	3.5	24.3	8.2			23.0				
Electrodynamic separation:										
Concentrate*..	.2	32.4	10.6	23.3	6.3	17.6	.082	.20	.1	2.1
Middlings.....	2.6	28.4	9.5			19.9			1.5	
Tailings......	.7	5.5	3.5			36.0			.1	
Minus 200 mesh:										
Table concentrate*	16.2	55.1	15.8	11.3	8.5	3.0	.023	.01	18.2	2.4
Table tailings....	14.2	35.5	11.1			15.9			10.3	
Composite or total..........	100.0	49.1	14.3			6.9			100.0	
Calculated composite concentrate[1].........	79.2	53.8	15.5	12.5	9.4	3.8	.028	.01	86.8	2.4

[1] Products with asterisks have been mathematically combined to give the calculated composite concentrate.

TABLE A-6. - Gravity concentration and electrodynamic separation of sample F

Product[1]	Wt-pct	Analysis, pct					Cr distribution, pct	Cr:Fe ratio
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2		
100 by 200 mesh:								
Table concentrate*...	18.3	33.9	15.6	15.9	27.9	3.0	49.0	1.5
Table tailings.......	34.5	4.2	7.4			27.7		
Electrodynamic separation:								
Concentrate*.....	1.4	24.4	15.4	19.9	23.5	8.1	2.7	1.1
Middlings........	5.8	10.3	9.7			21.7	4.7	
Tailings.........	27.3	1.9	6.4			29.4	4.1	
Minus 200 mesh:								
Table concentrate*...	8.2	34.2	18.1	15.0	22.9	3.3	22.1	1.3
Table tailings.......	39.0	5.6	7.9			26.3	17.4	
Composite or total.	100.0	12.7	9.9			20.5	100.0	
Calculated composite concentrate[1].	27.9	33.6	16.3	15.8	26.2	3.3	73.8	1.4

[1] Products with asterisks have been mathematically combined to give the calculated composite concentrate.

TABLE A-7. - Gravity concentration and electrodynamic separation of sample G

Product[1]	Wt-pct	Analysis, pct							Cr distribution, pct	Cr:Fe ratio
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2	S	P		
48 by 100 mesh:										
Table concentrate*..........	34.4	49.5	20.4	10.7	7.4	2.6	0.020	0.01	39.2	1.7
Table tailings.............	6.1	22.7	12.3			21.4				
Electrodynamic separation:										
Cleaner concentrate*....	2.2	42.8	19.0	13.3	7.8	7.3	.041	.13	2.2	1.5
Cleaner tailings........	.1	31.6	15.0			15.8			.1	
2d rougher middlings plus scavenger concentrate[2].................	2.3	18.6	11.0			24.3			1.0	
Scavenger tailings......	1.5	4.3	6.5			34.6			.1	
100 by 200 mesh:										
Table concentrate*..........	21.6	51.0	20.7	10.2	8.3	2.0	.018	.01	25.4	1.7
Table tailings.............	4.8	17.4	10.6			25.4				
Electrodynamic separation:										
Concentrate*...........	.8	41.7	18.3	14.1	7.9	7.7	.040	.03	.8	1.6
Middlings..............	1.1	32.7	15.5			14.2			.8	
Tailings...............	2.9	3.1	6.9			33.4			.2	
Minus 200 mesh:										
Table concentrate*..........	17.6	51.6	21.1	9.4	8.2	1.7	.017	.01	20.9	1.7
Table tailings.............	15.5	26.2	13.3			19.0			9.3	
Composite or total........	100.0	43.4	18.6			7.0			100.0	
Calculated composite concentrate[1]...............	76.6	50.1	20.6	10.4	7.9	2.4	.020	.01	88.5	1.7

[1] Products with asterisks have been mathematically combined to give the calculated composite concentrate.

[2] 2d rougher middlings, 95 pct; scavenger concentrate, 5 pct.

TABLE A-8. - Gravity concentration and electrodynamic separation of sample H

Product[1]	Wt-pct	Analysis, pct					Cr distribution, pct	Cr:Fe ratio
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2		
48 by 100 mesh:								
Table concentrate*...............	39.8	43.8	20.8	11.9	12.4	1.8	44.3	1.4
Table tailings..................	5.0	22.4	13.0			19.2		
Electrodynamic separation:								
Cleaner concentrate*.........	1.2	39.2	19.5	13.6	11.9	5.3	1.2	1.4
Cleaner tailings............	.6	29.5	15.7			13.2	.4	
3d rougher middlings plus scavenger concentrate[2]......	1.0	34.5	17.5			8.9	.9	
Scavenger tailings..........	2.2	5.3	6.4			33.0	.3	
100 by 200 mesh:								
Table concentrate*...............	20.7	46.0	21.3	11.8	15.0	1.2	24.2	1.5
Table tailings..................	4.1	14.3	9.5			26.5		
Electrodynamic separation:								
Concentrate*................	.3	37.6	18.9	15.3	12.4	6.3	.3	1.4
Middlings...................	.9	29.7	16.0			12.5	.7	
Tailings....................	2.9	7.6	6.9			31.5	.6	
Minus 200 mesh:								
Table concentrate*...............	14.9	45.7	21.2	10.6	15.7	1.1	17.3	1.5
Table tailings..................	15.5	25.0	14.0			16.9	9.8	
Composite or total............	100.0	39.4	19.1			5.8	100.0	
Calculated composite concentrate[1]......................	76.9	44.7	21.0	11.7	13.7	1.6	87.3	1.5

[1] Products with asterisks have been mathematically combined to give the calculated composite concentrate.

[2] 3d rougher middlings, 93 pct; scavenger concentrate, 7 pct.

TABLE A-9. - Gravity concentration and electrodynamic separation of sample I

Product[1]	Wt-pct	Analysis, pct					Cr distribution, pct	Cr:Fe ratio
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2		
48 by 100 mesh:								
Table concentrate*	47.4	26.7	16.8	16.5	32.5	1.0	48.8	1.1
Table tailings	6.4	17.8	12.3			11.5		
Electrodynamic separation:								
Concentrate*	.8	24.6	16.0	17.4	31.5	3.2	.8	1.0
Middlings	3.9	22.8	14.9			5.5	3.4	
Tailings	1.7	2.8	4.1			28.7	.2	
100 by 200 mesh:								
Table concentrate*	19.4	29.2	16.7	16.7	34.5	1.1	21.8	1.2
Table tailings	2.5	17.1	11.6			13.5		
Electrodynamic separation:								
Concentrate*	.5	25.7	16.6	16.3	32.9	1.9	.5	1.1
Middlings	1.0	21.9	14.8			6.4	.8	
Tailings	1.0	4.2	5.1			28.5	.2	
Minus 200 mesh:								
Table concentrate*	13.0	28.1	17.1	16.1	32.5	.7	14.1	1.1
Table tailings	11.3	21.6	14.6			9.3	9.4	
Composite or total	100.0	26.0	16.1			2.9	100.0	
Calculated composite concentrate[1]	81.1	27.5	16.8	16.5	33.0	1.0	86.0	1.1

[1] Products with asterisks have been mathematically combined to give the calculated composite concentrate.

TABLE A-10. - Gravity concentration and electrodynamic separation of sample J

Product[1]	Wt-pct	Analysis, pct					Cr distribution, pct	Cr:Fe ratio
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2		
48 by 100 mesh:								
Table concentrate*	4.9	39.5	16.8	14.5	20.7	2.4	12.2	1.6
Table middlings	21.7	25.7	13.0	23.0	11.4	15.9		
Electrodynamic separation:								
Cleaner concentrate*	11.1	32.6	15.2	18.1	17.3	8.9	22.9	1.5
Cleaner tailings	.5	27.3	13.9			14.1	.9	
3d rougher middlings	5.2	25.9	11.8			17.1	8.5	
Scavenger concentrate	.8	28.9	14.0			12.5	1.5	
Scavenger tailings	4.1	9.5	7.4			33.6	2.5	
Table tailings	16.4	5.4	6.4			34.9	5.6	
100 by 200 mesh:								
Table concentrate*	3.8	39.0	17.3	14.0	21.3	2.2	9.4	1.5
Table middlings	13.0	15.5	10.2	32.2	8.8	26.1		
Electrodynamic separation:								
Cleaner concentrate*	2.5	35.8	16.6	16.0	20.2	5.2	5.7	1.5
Cleaner tailings	.5	31.3	15.0			9.7	1.0	
2d rougher middlings	1.2	24.6	12.9			16.9	1.9	
Rougher tailings	8.8	7.8	7.5			34.5	4.3	
Table tailings	6.9	2.1	4.9			38.5	.9	
Minus 200 mesh:								
Table concentrate*	1.4	39.9	17.3	15.0	20.3	3.4	3.5	1.6
Table tailings	31.9	9.5	7.8			32.3	19.2	
Composite or total	100.0	15.8	9.7			25.8	100.0	
Calculated composite concentrate[1]	23.7	35.8	16.1	16.3	19.1	5.8	53.7	1.5

[1] Products with asterisks have been mathematically combined to give the calculated composite concentrate.

TABLE A-11. - Gravity concentration and electrodynamic separation of sample K

Product[1]	Wt-pct	Analysis, pct					Cr distribution, pct	Cr:Fe ratio
		Cr_2O_3	Fe	MgO	Al_2O_3	SiO_2		
48 by 100 mesh:								
Table concentrate*........	39.4	23.7	20.4	16.0	28.5	2.3	45.0	0.8
Table tailings............	10.5	14.9	15.9			14.3		
Electrodynamic separation:								
Cleaner concentrate*..	5.8	22.9	19.7	16.7	29.8	3.4	6.4	.8
Cleaner tailings......	.1	16.8	16.6			12.1	.1	
3d rougher middlings..	1.9	9.7	12.8			22.4	.9	
Scavenger concentrate.	.2	19.7	18.0			8.1	.2	
Scavenger tailings....	2.5	2.0	8.4			33.4	.2	
100 by 200 mesh:								
Table concentrate*........	16.4	23.2	20.3	16.3	29.2	2.5	18.4	.8
Table tailings............	7.4	14.6	15.7			14.9		
Electrodynamic separation:								
Cleaner concentrate*..	4.0	22.8	20.0	15.7	30.1	2.8	4.4	.8
Cleaner tailings......	.2	17.8	17.2			10.3	.2	
3d rougher middlings..	.3	11.0	14.4			20.1	.2	
Scavenger concentrate.	.2	19.3	18.0			8.0	.2	
Scavenger tailings....	2.7	2.2	8.5			33.2	.3	
Minus 200 mesh:								
Table concentrate*........	7.9	24.8	20.8	14.2	32.0	1.3	9.5	.8
Table tailings............	18.4	15.8	15.8			13.9	14.0	
Composite or total......	100.0	20.7	18.7			6.6	100.0	
Calculated composite concentrate[1]..........	73.5	23.5	20.3	15.9	29.2	2.4	83.7	.8

[1] Products with asterisks have been mathematically combined to give the calculated composite concentrate.

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