OFR 176-84

GEOLOGIC AND GEOCHEMICAL INVESTIGATION OF THE "NAIL" ALLOCHTHON, EAST-CENTRAL ALASKA

by D. D. Southworth,
Alaska Field Operations Center, Fairbanks, Alaska

***Open file report 176-84

UNITED STATES DEPARTMENT OF THE INTERIOR

Donald Paul Hodel, Secretary

ɩU OF MINES

:t C. Horton, Director

CONTENTS

FIGURE

TABLES

PLATE

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By
D.D. Southworth[1]

ABSTRACT

The ultramafic complex exposed in the vicinity of VABM "Nail" in the northwest Big Delta Quadrangle constitutes a 12-km-long, 610 m-thick tabular body of possible Permian age, which overlies a complex assemblage of Paleozoic(?) greenschist-facies metamorphic rocks. An extensive zone of carbonate alteration is present at the base of the ultramafic sheet, perhaps resulting from the movement of low temperature (<125°C) fluids, rich in CO_2, along the contact zone. The carbonate alteration probably occurred some time after the emplacement of the ultramafic body.

The geological and geochemical studies of Nail Ridge summarized in this report indicate that (1) the ultramafic rocks present do not appear to constitute a potential chromite resource, (2) significant concentrations of platinum-group elements or gold are not present in either the bedrock or as placer concentrations in the streams draining the area, (3) although a single occurrence of silica-carbonate rock was found to be very strongly anomalous in copper, antimony, arsenic, and silver, the very limited extent and mode of occurrence of the mineralization suggests that the likelihood of finding these elements in economic abundance is very low, and (4) although an extensive zone of magnesite-rich silica carbonate rock is present at Nail Ridge, the difficulty of access to the area coupled with the presence of other sources of magnesite in the U.S. including sea brines, makes the economic potential of the silica-carbonate rock very low.

INTRODUCTION

This report describes the geology of an area approximately 60 km^2 (24 mi^2) (60 km^2) in the northwestern portion of the Big Delta Quadrangle. Included are geochemical analyses of 50 rock samples, 29 stream sediment samples, and 29 pan concentrate samples from the area, which includes portions of the Big Delta C-2, C-3, D-2, and D-3 1:63,360 Quadrangles. Field efforts were completed during June, 1983 as an informal cooperative effort between the Alaska Division of Geological and Geophysical Surveys (DGGS), the U.S. Bureau of Mines (BOM), and the U.S. Geological Survey (USGS). This cooperative effort, the "Chena Project" was part of a joint effort by DGGS and the Mineral Industry Research Laboratory, University of Alaska to reexamine mineral districts in interior Alaska.

ACKNOWLEDGMENTS

The author wishes to personally thank all of the personnel involved in the "Chena Project" for their cooperation, advice, assistance and companionship. Special thanks go to T.E. Smith, for advice and encouragement and to

[1]U.S. Bureau of Mines, Fairbanks, Alaska.

F.R. Weber for helpful consultations on the metamorphic rocks. J.Y. Foley and M.D. Albanese kindly consented to review this report and each offered many helpful comments and suggestions. D. Dahlin of the Bureau of Mines Albany, Oregon Research Center conducted beneficiation tests on the chromian spinels. The author assumes responsibility for errors of fact or omission and welcomes criticism, comment, or correction by the reader.

LOCATION AND GENERAL GEOLOGY

The study area, about 60 km^2 (24 mi^2) lies in the northeastern portion of the Big Delta Quadrangle, Alaska, approximately 88.5 km (55 mi) N. 25° E. of Delta Junction, Alaska. The surrounding terrain is characterized by well-rounded hills and mountains. This portion of the Big Delta Quadrangle is included in the Yukon-Tanana Upland physiographic province (Wahrhaftig, 1965). Drainages are mature and well-developed. Elevations below 1,000 m (3,300 ft) are covered by dense brush and trees. Higher elevations are frequently tundra-covered, however most of the ridge (informally referred to as Nail Ridge in this report) is relatively unvegetated, due to its elevation [between 1,067 m (3,500 ft) and 1,685 m (5,531 ft)] and rock compositions, which are generally not conducive to plant growth. The creeks which drain the northwestern and western sides of Nail Ridge are tributaries of the North Fork of the Salcha River; those draining to the northeast or south empty into the main fork of the Salcha River.

The bedrock geology of the region, as discussed by Foster and others (1979), is dominated by a complex assemblage of greenschist- to amphibolite-facies metamorphic rocks that locally have been intruded by Mesozoic and Tertiary stocks of dioritic to granitic composition. Locally, Tertiary sedimentary and volcanic rocks overlie both the intrusives and the metamorphic complex. On the basis of lithologic similarities to Paleozoic sequences elsewhere in Alaska and the Yukon Territory of Canada, Foster and others (1979) believe that the greenschist facies rocks mentioned above are probably Paleozoic in age. The ultramafic rocks, which are the subject of this report, structurally overlie cherts that have yielded radiolaria and conodonts of Permian age (D.L. Jones, cited in Foster and others, 1979).

PREVIOUS INVESTIGATIONS

Although portions of the Big Delta Quadrangle were visited by H.T. Allen in 1885 (Allen, 1900), Brooks and Peters in 1898 (Brooks, 1900), and Prindle in 1903 (Prindle, 1905), the first published geologic description of the region was by Prindle (1906). Mertie's excellent compilation of the geology of the Yukon-Tanana region (Mertie, 1937) was published in 1937, and it remained the most detailed description of the area until 1978, when the Preliminary Geologic Map of the Big Delta Quadrangle (Weber and others, 1978) became available. This map was followed in 1979 by the publication of the results of the Alaska Mineral Resource Assessment Program (AMRAP) for the Big Delta Quadrangle (Foster and others, 1979). The Bureau of Mines visited the Nail Ridge area in 1964 (Thomas, 1965) and carried out a geochemical investigation of the 'Ricks prospect,' a reported copper-nickel occurrence (see also Cobb, 1972). The present study was done in conjunction with the DGGS mapping and geochemical sampling of the Upper Chena River area (Smith and others, in prep., and Albanese, 1984).

LOCAL GEOLOGY

The fresh and altered mafic and ultramafic rocks that form Nail Ridge constitute a thrust sheet measuring 12 km (8 mi) long and 610 m (2,000 ft) thick, which overlies a complex assemblage of greenschist-facies metamorphic rocks (pl. 1). Exposures of gabbro a few meters in maximum dimension are scattered along the crest of the ridge. The main rock types forming Nail Ridge, however, are ultramafic rocks and their alteration products including harzburgite, dunite, serpentinite, bright orange-weathering silica-carbonate rock, and massive, gray silica-carbonate rocks.

Gabbroic Rocks (Pgb)

Medium-grained gabbroic and dioritic rocks are found along the crest of Nail Ridge, usually occurring as patches of rubble a few meters in diameter. Larger boulders occur locally. Along the crest of the ridge these rock types are always surrounded by and overlie peridotite.

The gabbroic rocks are medium to dark gray in color. They are composed of subequal amounts of plagioclase and pyroxene with minor quartz, sphene, and chlorite. About one percent of fine magnetite is disseminated throughout, with trace amounts of chalcopyrite. In thin section, actinolite is seen to replace pyroxene, and clay alteration of the feldspar is pronounced. Similar gabbroic rocks are found in apparent fault contact with the ultramafic body along the south side of Nail Ridge, as well as at the western end of the ridge. At the eastern end, however, the dominant mafic mineral is hornblende, hence those rocks are more properly termed diorite.

Peridotite (mainly harzburgite) (Pu)

Most of the relatively unaltered ultramafic rock present at Nail Ridge is harzburgite, based on field estimates of relative percentages of olivine, orthopyroxene, and clinopyroxene. In both chromite content and degree of serpentinization, the harzburgite is very similar to the dunite, however the harzburgite typically contains 20 to 30 percent orthopyroxene (enstatite). On weathered surfaces the relatively resistant, coarse orthopyroxene grains stand out in relief against the more recessive-weathering olivine, resulting in a classic 'hobnail' texture. As with the dunite, harzburgite at Nail Ridge contains 0.25 to 4 percent coarse, disseminated chromite; however chromite schlieren were not observed in harzburgite.

In several outcrops one can observe mineral lineations defined by the alignment of orthopyroxene or chromite grains in harzburgite. Such lineations are narrow (<0.25 cm) and relatively long (up to 1.5 m). The blocky, rubbly nature of the outcrops at Nail Ridge, however, prevented tracing mineral lineations any great distance or for using them as structural indicators.

Enclosed within harzburgite are also rare, small vein-like segregations of clinopyroxene a few centimeters in size. Clinopyroxene appears to be restricted to these concentrations, and it is not a common mineral phase in most of the peridotite.

As exposed on the steeper north side of the ridge, the peridotite unit varies in thickness, from less than 15.25 m (50 ft) thick at the eastern and western ends of the ridge, to more than 245 m (800 ft) thick in the central portions.

Dunite

Dunite occurs as pods or lenses in harzburgite and constitutes an estimated 10 to 15 percent of the peridotite mass. In outcrop, dunite is distinguished from harzburgite primarily by an absence on weathered surfaces of the 'hobnail' texture common to the harzburgite.

The dunite is composed of medium- to coarse-grained olivine and 25 to 30 percent or more secondary serpentine minerals. Chromite (0.25 to 4 percent) is fairly evenly distributed, usually as individual grains, throughout the dunite; however rare schlieren and pods of chromite, a centimeter or two in maximum dimension, do occur. In addition, minor clinochrysotile asbestos (Weber and others, 1978) and finely-disseminated secondary magnetite are also present.

Serpentinite (Psp)

Over a vertical distance of a few meters, the degree of serpentinization increases dramatically until the original rock has become a massive, dark green to black serpentinite underlying the peridotite. Along the northern side of the ridge, this massive serpentinite forms an almost continuous zone roughly 30.5 m (100 ft) to over 90 m (300 ft) thick. Low angle fault surfaces within and at the base of the serpentinite are well-exposed on the north side of the ridge, where they can be seen dipping to the south at an angle of about 20° to 30°. Slickensides are common. Although these faults are not well exposed along the southern margin of Nail Ridge, they are observed at both the eastern and western ends of the ridge, where they also dip at low to moderate angles into the ridge.

Bright Orange Weathering Silica-Carbonate Rock (Psa)

Directly underlying the massive serpentinite in most places is a bright orange-weathering, silica-carbonate rock. This distinctive alteration type near the contact between rock types, the silica carbonate is occasionally found in the same specimen with massive serpentinite and is believed to represent silica-carbonate replacement of serpentinite. The carbonate present in these rocks has been identified as ankerite by W.L. Gnagy (1965). The silica is mostly quartz, with minor opal and chalcedony (fig. 1). Relict chromite grains are common and frequently occur with associated micaceous overgrowths on individual chromian-spinel grains; these overgrowths have been identified by Gnagy (1965) as fuchsite, a bright green, chromium mica resulting from the alteration of chromian spinel. Although fuchsite somewhat resembles malachite and is also easily mistaken for garnierite, a hydrous nickel silicate, both the copper and nickel content of these rocks is very low (table 3).

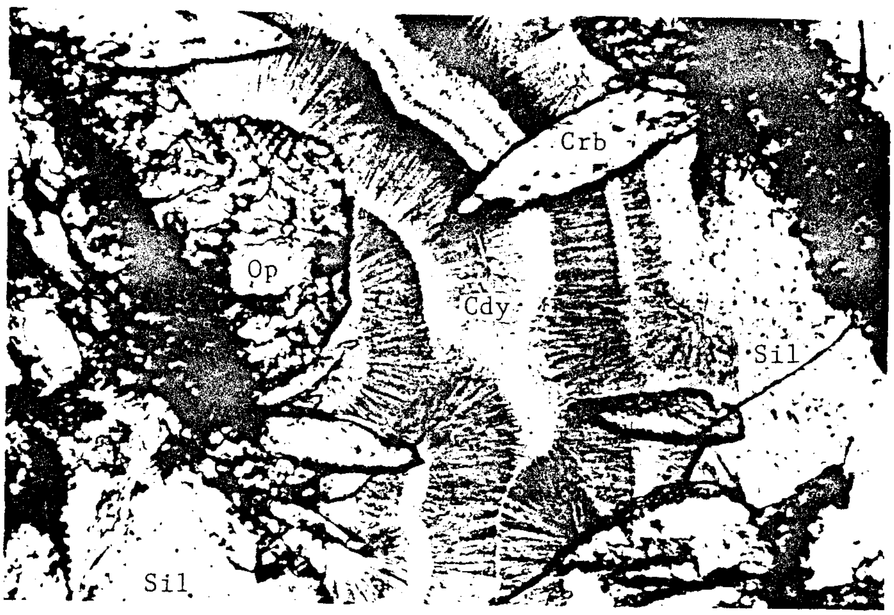

Figure 1. Photomicrograph of silica-carbonate rock. Cdy = chalcedony, Crb - carbonate, Op = opal, and Sil = silica. Distance across bottom of photograph is approximately 0.71 mm.

The bright orange-weathering unit forms a layer from 1 m (3 ft) to 50 m (55 ft) thick and is exposed along most of the length of the north side of the ridge. This same unit is also found locally on the other sides of the ridge at approximately the same relative position.

Gray Silica-Carbonate Rock (Psm)

For a distance of about 5.5 km (3 mi) in the central portion of the ridge, the orange-weathering quartz-ankerite rock is underlain by massive, gray silica-carbonate. This unit is easily mistaken for massive dolomite, however the carbonate has been identified by Weber and others (1978) as dominantly magnesite, with lesser dolomite. Patches of the orange silica-ankerite and relict grains of chromian spinel are present in some specimens near the contact with the orange-weathering unit. Chromian spinel content elsewhere in the massive gray unit is very low to nonexistent and fuchsite is absent. At one locality near the base of the gray carbonate unit small pods of malachite and azurite a few centimeters in diameter occur in the quartz and carbonate. The mineralization is unevenly distributed. Interestingly, the orange-weathering carbonate unit is absent above the mineralized outcrop but was present above the gray unit immediately to both the east and west.

Metamorphic Assemblage (Pzsg, Pgc)

Underlying and in fault contact with the ultramafic and altered ultramafic rocks is an undifferentiated assemblage of various rock types, including andesitic volcanic rocks, chert, calcareous black paper-shale, tan calc-phyllite, dark green quartz-chlorite schist, and tan to dark gray quartzite (Weber and others, 1978).

Along the northern side of Nail Ridge, dark-green quartz-chlorite schist is commonly found directly beneath the ultramafic sheet. Both foliation and crenulation axes within the quartz-chlorite schist are oblique to the overlying thrust fault surface and clearly pre-date emplacement of the ultramafic body. Limited outcrops of calcareous black paper shale and tan calc-phyllite occur between the quartz-chlorite schist and fine to medium grained quartzite. The quartzite locally contains minor chalcopyrite and pyrrhotite.

Minor chert is found underlying the altered ultramafic rocks at the extreme eastern end of Nail Ridge. Weber and others (1978) report that radiolaria and conodonts from these cherts have been dated as Permian by D.L. Jones of the USGS.

Vesicular andesite occurs in section 18 (T. 2 S., R. 14 E.) and may partially underlie the ultramafics (thrust sheet). At this location small slivers of strongly serpentinized peridotite are found intercalated with andesite about 2.4 km (1.5 mi) south of the main body of Nail Ridge.

MINERAL OCCURRENCES

A primary focus of the investigation was to examine the economic potential of the Nail Ridge area for:

1) concentrations of chromite associated with peridotites,
2) platinum-group metals associated with chromite concentrations,
3) nickel and cobalt mineralization,
4) copper, antimony, arsenic and silver in quartz-carbonate rock, and
5) magnesite.

The results of these mineral investigations are as follows.

Chromium

Four samples of dunite containing disseminated chromian spinel were collected along the crest of Nail Ridge for beneficiation and metallurgical tests by the Bureau of Mines Albany Research Center. The chromian spinel was assumed to be chromite prior to these tests, based on the common association of that mineral with dunite in ultramafic assemblages similar to those at Nail Ridge. Results of the metallurgical tests run on samples of chromite-bearing dunite by Albany Research Center, are listed in table 1. These results indicate that the chromian spinel present at Nail Ridge is, based on the proportions of Cr, Fe, Mg, and Al (Irving, 1965), a high-aluminum, high-magnesium chromite. A concentrate produced from the sample highest in chrome (EA20903) does not meet the requirements for industrial uses of chromian spinel, as specified by Papp (1983). The chromic oxide (Cr_2O_3) contents and chromium-to-iron ratios are too low to meet the requirements for metallurgical-grade (high-chromium), refractory-grade (high aluminum), or chemical-grade (high-iron) concentrates (Papp, 1983). Furthermore, because of the low chromian spinel content in the sample, only 26 percent of the chromium was recovered. The technical classification of this concentrate, therefore, is "submarginal high-aluminum" and would, at best, have limited uses as a refractory material for furnace lining in the metallurgical industry.

Platinum-group Metals and Gold

Significant levels of platinum-group metals or gold were not found in rock samples (table 3) collected from Nail Ridge nor in pan concentrate samples (table 2) collected from streams draining the ridge.

Nickel and Cobalt

Although portions of Nail Ridge were at one time staked for copper and nickel, the present investigation encountered no anomalous levels of nickel in any of the samples collected.

Similarly, the cobalt levels of samples collected from Nail Ridge are not greater than the average crustal abundance of cobalt in ultramafic rocks (150 ppm: Levinson, 1974, p. 43).

Copper, Antimony, Arsenic, and Silver

At one location (49, pl. 1) within the silica-magnesite unit, small (<.5 cm) pods of azurite- and malachite-stained rock were found, which proved to be strongly anomalous in Cu (1.14 percent), Sb (6,800 ppm), As (174 ppm), and Ag (24.6 ppm). The mineralized area represented by this selected sample,

Table 1. Analyses[1] of chromian spinel collected in the vicinity of VABM 'Nail,' Big Delta Quadrangle, Alaska.

Map No.	Sample	Type	Analysis, in pct					Cr recovery, pct	Cr:Fe ratio
			Cr_2O_3	Fe	Mgo	Al_2O_3	SiO_2		
A	EA20902	Bulk sample..	0.50	6.51	40.8	1.19	40.4		
B	EA20903	Bulk sample..	1.69	7.13	44.7	1.19	35.4		
C	EA20904	Bulk sample..	.53	6.60	39.4	1.38	39.1		
D	EA20905	Bulk sample..	.61	6.81	40.9	.57	34.6		
B	EA20903	Concentrate..	25.9	15.6	18.2	27.1	4.5	26	1.1

[1]Analyses performed by U.S. Bureau of Mines Albany, Oregon, Research Center. For description of analytical procedures, see U.S. Bureau of Mines information Circular 8916, 1983.

Table 2. Stream sediment samples collected in the vicinity of VABM 'Nail,'
Big Delta Quadrangle, Alaska.
(All analyses in ppm)

(All analyses in ppm)

Sample[1]	Ag	Au	As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Sb	Zn
1......	<0.1	<0.1	<10	<1	19	24	37,600	552	<1	66	12	<1	66
2......	<.1	<.1	<10	<1	17	27	33,500	458	<1	136	15	<1	70
7......	.1	<.1	<10	<1	13	24	30,800	431	<1	65	14	<1	71
11.....	.1	<.1	<10	<1	21	33	36,800	566	<1	221	12	<1	86
18.....	<.1	<.1	<10	<1	22	31	42,100	552	<1	136	16	<1	74
23.....	.1	<.1	31	<1	15	27	32,700	513	<1	35	14	7	84
26.....	.4	<.1	21	<1	17	23	34,300	418	<1	122	71	4	83
34.....	<.1	<.1	19	<1	26	26	44,000	629	<1	261	16	<1	77
36.....	<.1	<.1	34	<1	17	37	39,600	643	<1	41	21	<1	81
37.....	<.1	<.1	51	<1	17	33	38,000	649	<1	39	38	2	97
44.....	.1	<.1	90	<1	27	32	46,000	670	<1	254	19	21	94
54.....	.2	<.1	235	<1	13	30	37,800	252	<1	36	43	13	101
56.....	<.1	<.1	21	<1	19	28	34,900	548	<1	171	19	9	87
60.....	.1	<.1	11	<1	22	29	38,000	490	<1	197	12	4	80
62.....	<.1	<.1	<10	<1	19	20	29,600	312	<1	146	12	<1	58
63.....	<.1	<.1	<10	<1	17	25	33,800	525	<1	78	12	<1	76
66.....	<.1	<.1	20	<1	17	26	33,100	1,150	<1	63	10	<1	71
67.....	<.1	<.1	<10	<1	17	26	30,600	577	<1	123	21	<1	68
68.....	<.1	<.1	<10	<1	18	25	31,600	437	<1	156	9	1	85
69.....	<.1	<.1	<10	<1	16	27	29,800	248	<1	161	14	<1	70
70.....	<.1	<.1	<10	<1	77	22	50,500	709	<1	1,420	<1	<1	46
71.....	<.1	<.1	<10	<1	81	29	56,500	801	<1	1,550	<1	<1	55
76.....	<.1	<.1	<10	<1	34	24	47,900	769	<1	310	10	<1	91
77.....	<.1	<.1	<10	<1	36	19	34,700	480	<1	594	4	<1	63
80.....	<.1	<.1	<10	<1	19	33	37,000	433	<1	186	31	<1	138
81.....	<.1	<.1	<10	<1	45	37	50,600	742	<1	690	7	<1	74
95.....	<.1	<.1	<10	<1	22	22	26,600	302	<1	239	7	<1	60
96.....	<.1	<.1	<10	<1	35	38	40,900	786	<1	491	11	<1	68
97.....	.3	<.1	<10	<1	19	29	35,700	450	<1	171	15	1	54

[1] At each stream sediment sample location a separate pan concentrate sample (see table 3) was also collected.

Table 3. Analyses of pan concentrate samples collected in the vicinity of VABM 'Nail,' Big Delta Quadrangle, Alaska.

Sample[1]	Au, oz/ton	Pd, oz/ton	Pt, oz/ton
1......	0.002	<0.002	<0.002
2......	<.002	<.002	<.002
7......	<.002	<.002	<.002
11.....	<.002	<.002	<.002
18.....	<.002	<.002	<.002
23.....	<.002	<.002	<.002
26.....	<.002	<.002	<.002
34.....	<.002	<.002	<.002
36.....	<.002	<.002	<.002
37.....	.002	<.002	<.002
44.....	<.002	<.002	<.002
54.....	<.002	<.002	<.002
56.....	<.002	<.002	<.002
60.....	<.002	<.002	<.002
62.....	<.002	<.002	<.002
63.....	<.002	<.002	<.002
66.....	<.002	<.002	<.002
67.....	<.002	<.002	<.002
68.....	<.002	<.002	<.002
69.....	.002	<.002	<.002
70.....	<.002	<.002	<.002
71.....	<.002	<.002	<.002
76.....	<.002	<.002	<.002
77.....	<.002	<.002	<.002
80.....	<.002	<.002	<.002
81.....	<.002	<.002	<.002
95.....	<.002	<.002	<.002
96.....	.002	<.002	<.002
97.....	.002	<.002	<.002

[1]At each pan concentrate sample location a separate stream sediment sample (see table 2) was also collected.

Table 4. Geochemical analyses of rock samples collected in the vicinity of VABM 'Nail,' Big Delta Quadrangle, Alaska.

Sample	Au, oz/ton	Pt, oz/ton	Pd, oz/ton	Ag, ppm	As, ppm	Cd, ppm	Co, ppm	Cr, ppm	Cu, ppm	Fe, ppm	Mn, ppm	Mo, ppm	Ni, ppm	Pb, ppm	Sb, ppm	Zn, ppm
4....	<0.0005	<0.0007	<0.0007	0.3	11	<1	55	1224	12	39,400	505	<1	998	13	<1	13
6....	<.0004	<.0007	<.0007	.1	<10	<1	<10	1368	7	6,820	125	<1	76	6	1	10
8....	--	--	--	<.1	<10	<2	93	2400	11	41,400	630	<1	1,930	15	<1	36
9....	<.0004	<.0006	<.0006	<.1	<10	<1	20	80	34	61,200	821	<1	76	6	<1	100
10....	<.0004	<.0006	<.0006	<.1	<10	<1	11	48	26	60,300	984	<1	35	10	<1	95
12....	<.0004	<.0006	<.0006	<.1	<10	<1	27	96	68	58,100	1,100	<1	62	5	<1	49
13....	<.0004	<.0006	<.0006	<.1	<10	<1	<10	120	6	17,700	473	2	16	2	<1	15
16....	<.0004	<.0006	<.0006	<.1	<10	<1	29	48	70	59,800	1,130	1	63	6	<1	50
17....	<.0004	<.0006	<.0006	<.1	<10	<1	87	144	5	45,300	757	<1	19	8	<1	32
19....	<.0005	<.0007	<.0007	<.1	<10	<1	<10	1904	12	37,900	361	6	19	5	<1	31
20....	<.0004	<.0006	<.0006	<.1	<10	<1	11	344	44	85,800	766	3	12	8	<1	130
21....	<.0004	<.0006	<.0006	<.1	<10	<2	95	2168	8	47,700	733	<1	2,040	9	<1	39
22....	<.0004	<.0006	<.0006	<.1	<10	<2	105	2096	3	53,000	813	<1	2,230	18	<1	49
24....	<.0005	<.0008	<.0008	.1	<10	<1	<10	96	14	10,700	244	<1	37	13	<1	11
25....	<.0004	<.0006	<.0006	<.1	<10	<2	94	6048	5	45,400	698	<1	2,210	18	<1	39
27....	<.0004	<.0006	<.0006	<.1	<10	<1	<10	152	8	24,300	160	<1	57	11	<1	16
28....	<.0004	<.0006	<.0006	<.1	<10	<1	<10	24	11	4,430	618	<1	14	27	<1	8
29....	<.0004	<.0006	<.0006	.1	<10	<1	<10	24	13	4,990	538	<1	10	22	4	10
30....	<.0004	<.0006	<.0006	<.1	<10	<1	<10	48	9	3,930	563	<1	13	25	<1	7
31....	<.0004	<.0006	<.0006	<.1	<10	<1	42	400	74	78,300	1,270	<1	148	16	<1	94
32....	<.0008	<.001	<.001	<.1	<10	<1	32	216	27	64,200	803	<1	124	17	<1	65
33....	<.0004	<.0006	<.0006	.1	16	<1	<10	24	11	7,380	749	<1	<10	25	1	6
35....	<.0008	<.001	<.001	.1	<10	<1	15	96	31	43,900	956	<1	30	35	<1	71
38....	<.0007	<.001	<.001	<.1	<10	<1	12	96	23	34,100	484	<1	30	7	<1	50
39....	<.0004	<.0006	.007	<.1	<10	<1	55	1440	8	36,500	675	<1	1,040	15	1	11
40....	--	--	--	<.1	<10	<1	56	1320	38	53,800	537	<1	911	13	<1	42
41....	<.0004	<.0006	<.0006	<.1	186	<1	61	1536	7	35,200	572	<1	775	14	270	9
42....	<.0007	<.001	<.001	<.1	<10	<2	90	2424	6	49,100	729	<1	1,920	16	<1	37
43....	<.0004	<.0006	<.0006	<.1	12	<1	56	1240	12	35,800	630	<1	1,150	17	13	12
45....	<.0008	<.001	<.001	<.1	<10	<1	<10	168	40	38,700	130	<1	33	6	<1	55
46....	.001	<.0007	<.0007	<.1	<10	<1	17	80	25	40,600	914	<1	47	11	<1	79
47....	<.0004	<.0006	<.0006	<.1	234	<1	56	624	47	54,100	885	<1	599	8	<1	48
48....	<.0007	<.001	<.001	<.1	<10	<1	16	176	39	49,200	515	<1	53	16	<1	82
49....	<.0005	<.0007	<.0007	24.6	174	5	<50	56	>9999	9,160	537	<1	136	17	6,800	151
50....	<.0007	<.001	<.001	.7	<10	<1	<10	<8	46	4,250	655	<1	<10	26	69	16
51....	<.0004	.001	<.0006	<.1	<10	<1	<10	200	119	20,300	298	<1	38	15	<1	27
52....	<.001	<.002	<.002	<.1	<10	<2	97	2600	8	51,200	756	<1	2,070	18	<1	47
53....	.001	<.0006	<.0006	<.1	156	<1	40	1568	10	29,600	102	<1	630	5	157	10
55....	<.002	<.003	<.003	<.1	<10	<2	88	1736	14	47,700	618	<1	1,860	15	<1	35
57....	<.0005	<.0008	<.0008	<.1	344	<1	39	1216	10	29,600	494	<1	715	14	91	8
58....	<.0006	<.0009	<.0009	<.1	<10	<1	10	136	81	21,800	341	<1	46	10	<10	20
59....	<.0005	<.0007	<.0007	.1	<10	<2	86	1848	16	45,200	647	<1	1,880	15	<1	35
64....	<.0007	<.001	<.001	.1	104	<1	51	1384	11	31,200	443	<1	887	11	155	12
72....	<.0004	<.0006	<.0006	<.1	<10	<2	93	1872	18	48,300	724	<1	2,080	18	<1	38
73....	<.0004	<.0006	<.0006	.1	<10	<1	10	112	66	18,600	294	<1	32	11	<1	20
74....	<.0006	<.0009	<.0009	.1	<10	<2	104	3672	24	53,100	806	<1	2,260	16	<1	46
75....	<.0005	<.0008	<.0008	<.1	<10	<1	41	2016	36	29,200	452	<1	763	12	<1	23
78....	<.0006	<.0009	<.0009	<.1	<10	<1	10	184	70	17,800	913	<1	33	4	<1	17
82....	.001	<.0007	<.0007	<.1	<10	<2	89	2000	12	45,000	715	<1	1,930	9	<1	34
84....	<0.0004	<0.0006	<0.0006	<0.1	<10	<2	94	1984	9	47,900	723	<1	2,000	20	<1	41
85....	--	--	--	<.1	<10	<2	87	2128	14	45,300	701	<1	1,820	14	<1	31
87....	<.0004	<.0006	<.0006	<.1	<10	<1	22	112	48	65,800	864	3	28	5	<1	60
88....	<.0005	<.0008	<.0008	<.1	15	<1	20	240	40	39,900	858	<1	58	6	<1	33
89....	<.0004	<.0006	<.0006	<.1	<10	<1	<10	224	3	18,900	479	<1	16	2	<1	15
90....	<.0004	<.0006	<.0006	<.1	<10	<2	87	2496	16	43,700	644	<1	1,900	8	<1	32
91....	<.0004	<.0006	<.0006	<.1	<10	<2	99	2144	10	48,600	760	<1	2,110	16	<1	40
93....	<.0004	<.0006	<.0006	<.1	<10	<1	77	1864	6	39,900	603	<1	1,240	8	<1	20
94....	<.0004	<.0006	<.0006	<.1	<10	<1	22	24	42	73,100	988	<1	22	5	<1	75

NOTE. -- indicates sample was not analyzed for this element.

however, is less than a few square meters, and the mineralization is discontinuous. A few other samples of silica-carbonate rock (table 4) contained up to several hundred ppm Sb and/or As but nowhere approached economic tenor.

Magnesite

The massive gray silica-carbonate rock present for about 3.5 mi at the base of Nail Ridge contains up to 17 percent MgO. For comparison, pure magnesite ($MgCO_3$) has a theoretical MgO content of 47.6%. Similar magnesite-rich bodies formed by carbonate alteration of peridotite and serpentinite form mineable bodies elsewhere in the United States (Bodenlos, 1949). As such, Nail Ridge constitutes a speculative resource* of MgO. Currently, difficulty of access to mining and very low demand for additional domestic sources of MgO render the magnesite at Nail Ridge subeconomic.

DISCUSSION OF ALTERATION

Similar occurrences of silica-carbonate alteration of ultramafic rock are reported by other authors (Bailey and Everhardt, 1964, Barnes and others, 1973). Barnes and others (1973) give a brief overview and discussion of the literature on silica-carbonate alteration of serpentine, along with a detailed description of this type of alteration associated with the mercury deposits of northern California, and Abbott (1982) gives a brief description of similar alteration associated with asbestos-bearing serpentinites in nearby Yukon Territory. In each of these descriptions, the alteration products consist dominantly of quartz, chalcedony, opal, and magnesite with lesser ankerite (or ankeritic dolomite), dolomite and calcite. In contrast, at Nail Ridge the massive, gray silica-carbonate rock is composed dominantly of quartz, with lesser magnesite, opal, and chalcedony. Based on cross-cutting relationships and textures, the order of replacement appears to have been magnesite, quartz, opal, chalcedony.

In the silica-ankerite unit some serpentine veinlets still remain but are cross-cut by later veinlets of carbonate and silica. Relict grains of chromian spinel are also frequently preserved. It is apparent that carbonate replacement of serpentine occurred along the mesh of serpentine veinlets that replaced the original olivine in an earlier event. The fact that a few relict serpentine veinlets remain in the orange-weathering unit indicates that within that unit the alteration is not quite complete.

Further evidence that the alteration may not be complete in the upper portions of the silica-carbonate units is the preservation of the serpentinite texture, clearly evident on weathered surfaces of many of the silica-carbonate rocks examined. This strikingly preserved texture observed in similar rocks in California, suggests to Bailey and Everhart (1964) that the replacement involves a constant volume reaction. They conclude that this type of alteration involves the addition of CO_2, the loss of H_2O (and some MgO), and the retention of silica. The alteration fluid is not, according to Bailey and Everhart (1964), derived from the serpentine.

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* a 'speculative resource' is one that may occur in "deposits as yet unrecognized for their ecenomic potential". (see USGS circ. 831, 1980).

Barnes and others (1973) made a special study of the source of the fluids responsible for silica-carbonate alteration in mercury deposits of northern California and concluded that the source of the fluids was probably locally derived meteoric water with added metamorphic CO_2. Additionally, Barnes and others (1973) suggest that the fluids involved were at less than 100° C. No special study of similar fluids or their sources was made at Nail Ridge, and no conclusions can be reached, beyond pointing out that (1) the carbonate alteration clearly post-dates serpentinization, (2) the alteration is most pervasive at the base of the ultramafic sheet and hence, (3) the lower thrust fault contact may have served as the conduit for fluid migration.

At the base of the ultramafic sheet the alteration is most complete, with no serpentine textures or grains of chromian spinel preserved. As one approaches the orange-weathering, fuchsite-bearing horizon, both the serpentine textures and chromian spinel become more common. In the orange-weathering unit, chromian spinel is present in abundance similar to that of the relatively unaltered peridotite. The orange color probably results from higher Fe^{+2} content of the carbonate, ankerite or ankeritic dolomite, another indication that it is probably further from the main fluid conduit.

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APPENDIX A - SAMPLING AND ANALYTICAL PROCEDURES

Stream sediment and pan concentrate samples were collected by members of the DGGS staff, including J.W. Lindhorst, B.A. Doyle, D.A. Coleman, and T.D. Balog.

Stream sediment samples (table 1) were collected with a steel shovel from the finer sandy portion of the active channel or deepest most active part of a dry creek bed. Organic-rich material was avoided. Samples were air-dried before screening at minus-80 mesh. Float rock and stream characteristics were noted and recorded at each station.

At each stream sediment sample location, separate pan concentrate samples (table 2) were collected to enhance recognition of resistant minerals with high specific gravity. As with stream sediment samples, the pan concentrate samples were collected with a steel shovel from the silty, poorly sorted material in the active channel. One 16-in. gold pan was filled with material which had passed through a 0.25-in. mesh screen. This was panned to a 50 to 100 g sample.

Rock samples (table 3) were taken as random chip samples across a geologic unit of interest; for example a suspected mineralized area or a zone of alteration. The outcrop characteristics of the area covered by the chip sample were recorded. Each sample approximated 1 to 2 lb in weight.

Lead, gold, silver, molybdenum, antimony and arsenic were analyzed at the DGGS laboratory by atomic-absorption spectrophotometry on aqua-regia digest. Copper, zinc, cobalt, nickel, iron, manganese and cadmium were analyzed at the DGGS laboratory by inductively coupled plasma atomic-emission spectrophotometry on aqua-regia digests. Lower limits of detection were 1 ppm for lead, antimony, molybdenum, copper, zinc, and cadmium; 10 ppm for arsenic, cobalt, nickel, iron, and manganese; and 0.1 ppm for gold and silver. Chrome was analyzed on lithium metaborate digests with a lower limit of detection of 8 ppm.

Platinum, paladium, and gold were analyzed at the U.S. Bureau of Mines, Reno, Nevada, Research Center by fire assay preconcentration followed by inductively coupled plasma, atomic-emission spectrophotometry on aqua-regia digests.

APPENDIX B - SAMPLE NUMBER CROSS-REFERENCE LIST

MAP	BOM	DGGS
1.	21524P	5518P, 5519S
2.	21521P	5506P, 5505S
3.	21346	22746
4.	21344	22744
5.	21343	22743
6.	21320	22720
7.	21506P	5473P, 5472S
8.	21319	22719
9.	21345	22745
10.	21318	22718
11.	21504P	5469P. 5468S
12.	21369	22769
13.	21370	22770
14.	21349	22749
15.	21348	22748
16.	21371	22771
17.	21372	22772
18.	21512P	5486P, 5485S
19.	21373	22773
20.	21374	22774
21.	21356	22756
22.	21306	22706
23.	21527P	5547P, 5474S
24.	21327	22727
25.	21307	22707
26.	21500P	5461P, 5460S
27.	21308	22708
28.	21309	22709
29.	21326	22726
30.	21313	22713
31.	21314	22714
32.	21315	22715
33.	21316	22716
34.	21507P	5476P, 5475S
35.	21328	22728
36.	21515P	5493P, 5494S
37.	21514P	5491P, 5492S
38.	21364	22764
39.	21310	22710
40.	21325	22725
41.	21305	22711
42.	21305	22715
43.	21312	22712
44.	21508P	5478P, 5477S
45.	21360	22760
46.	21361	22761
47.	21362	22762
48.	21363	22763
49.	21333	22733
50.	21334	22734
51.	21304	22704

MAP	BOM	DGGS
52.	21303	22703
53.	21332	22732
54.	21519P	5501P, 5502S
55.	21329	22729
56.	21513P	5489P, 5488S
57.	21338	22738
58.	21337	22737
59.	21336	22736
60.	21505P	5471P, 5470S
61.	21335	22735
62.	21520P	5503P, 5504S
63.	21526P	5522P, 5523S
64.	22742	21342
65.	22740	21340
66.	21525P	5520P, 5521S
67.	21528P	5549P, 5548S
68.	21522P	5508P, 5543S
69.	21516P	5495P, 5496S
70.	21501P	5462P, 5463S
71.	21509P	5480P, 5479S
72.	21301	22701
73.	21302	22702
74.	21323	22723
75.	21324	22724
76.	21503P	5467P, 5466S
77.	21502P	5465P, 5464S
78.	21359	22759
79.	21358	22758
80.	21511P	5484P, 5483S
81.	21510P	5482P, 5481S
82.	21357	22757
83.	21355	22755
84.	21321	22721
85.	21322	22722
86.	21353	22753
87.	21368	22768
88.	21365	22765
89.	21366	22766
90.	21367	22767
91.	21317	22717
92.	21352	22752
93.	21351	22751
94.	21350	22750
95.	21517	5497P, 5498S
96.	21518	5499P, 5500S
97.	21523P	5510P, 5509S

P - Pan Concentrate sample
S - Stream Sediment sample
No suffix on rock samples

APPENDIX C - UNIT OF MEASURE ABBREVIATIONS

Abbreviation	Unit of measure	To convert to--	Multiply by--
cm	centimeter	inches	2.54
ft	foot	meters	.30
g	gram		
km	kilometer	miles	.622
km^2	square kilometers	square miles	.386
m	meter	feet	3.28
pct	percent		