THE WEBSTER-ADDIE ULTRAMAFIC RING, JACKSON COUNTY, NORTH CAROLINA, AND SECONDARY ALTERATION OF ITS CHROMITE*

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Abstract

The structure of the Webster-Addie ultramafic ring in Jackson County, North Carolina, is discussed briefly. The ultramafic ring is almost everywhere concordant with the enclosing and enclosed gneiss and is thought to have been intruded as a sheet-like mass and subsequently deformed.

The mineralogy of the dunite, websterite, and enstatite pyroxenite is discussed. A table is presented showing that the Fe_2SiO_4 content of nine olivines from the ultramafic ring varies only $1\frac{1}{4}\%$ and shows no "trend" across three quarters of the thickness of the mass. Chemical analyses are given for the two types of enstatite from the enstatite pyroxenite, and for two chromite samples and one kammererite sample. The hydrothermal alteration of chromite to kammererite is described and photomicrographs presented to illustrate the progression of this reaction toward an ideal chromite-magnetite solid solution.

General Geology

The Webster-Addie ultramafic ring lies in Jackson County, North Carolina, fifty miles southwest of Asheville. The ring, comprised of dunite, websterite, and enstatite pyroxenite, is an ellipse with a maximum dimension of six miles and a minimum dimension of three and a half miles. The greatest width of outcrop of the ultramafic rocks, just south of the town of Addie, is a little under four tenths of a mile.

Except for very local areas, the Webster-Addie ultramafic rocks are concordant with the enclosing and enclosed gneiss. The gneiss forms a dome on the flanks of which lies the thin band of dunite (Fig. 1). The position of the dome itself probably was determined by original structures in the Carolina gneiss, and its present form was brought about by the interaction of lateral compression and vertical uplift during recurring periods of deformation in Paleozoic time. The dip of the gneiss and ultramafic rocks varies from 23 degrees near the center of the dome to vertical at several localities on the flanks of the dome, but in general it is steeper away from the long northeast-southwest axis (Fig. 2).

The extreme granulation of the dunites in the Webster-Addie ring and the prevalent faulting along dunite-country rock contacts indicates great post-intrusion deformation. The actual magnitude of this deformation cannot be determined because of the recurrent character of the deformation and the impossibility of dating precisely the ultramafic rocks them-

WEBSTER-ADDIE ULTRAMAFIC RING
JACKSON CO,N.C.

Surfaced roads
Graded roads
Dirt roads
Wagon roads
Dip & strike of banding & foliation
R Miller 1950

Scale in miles

Ultramafic rocks
Carolina gneiss
Rivers & streams
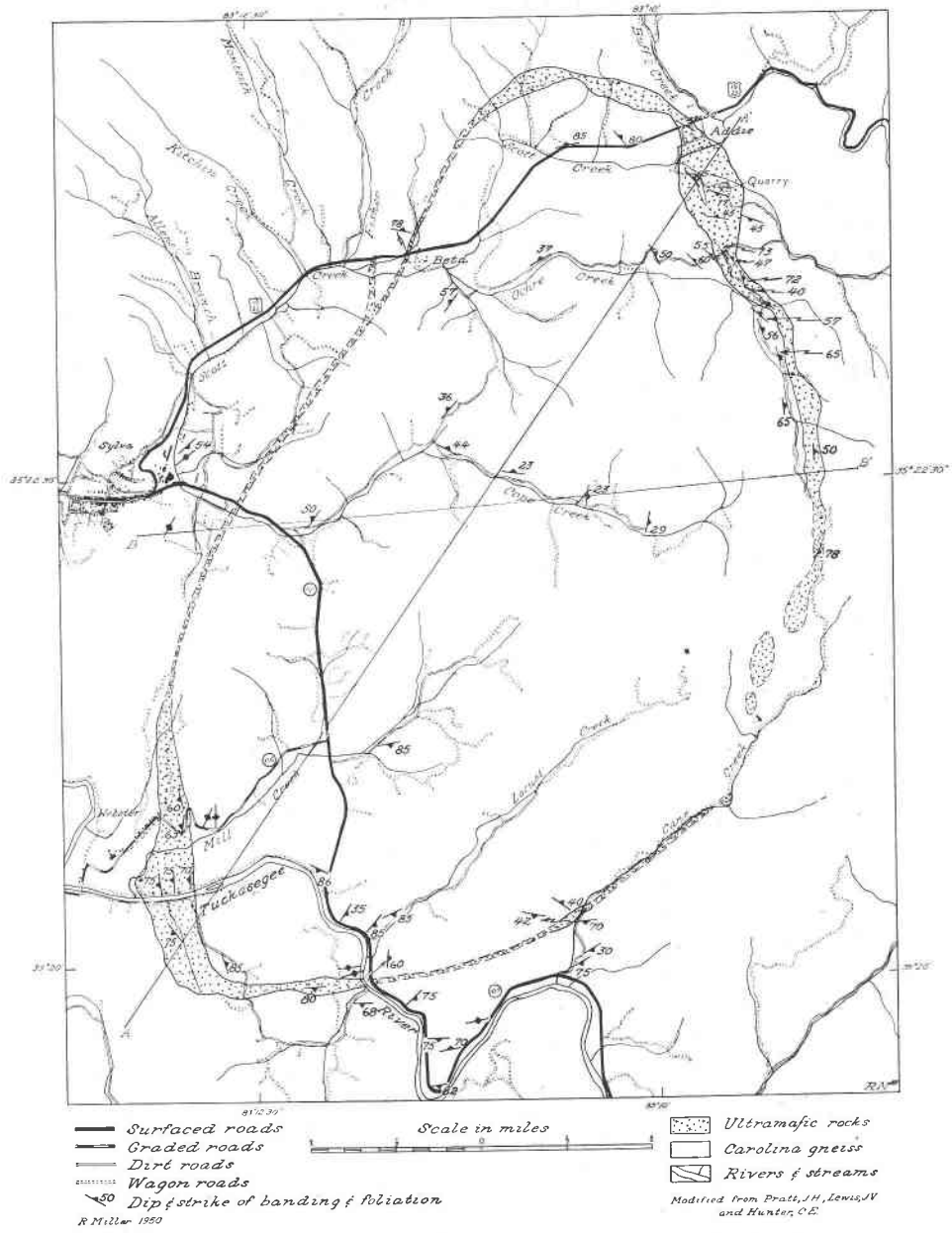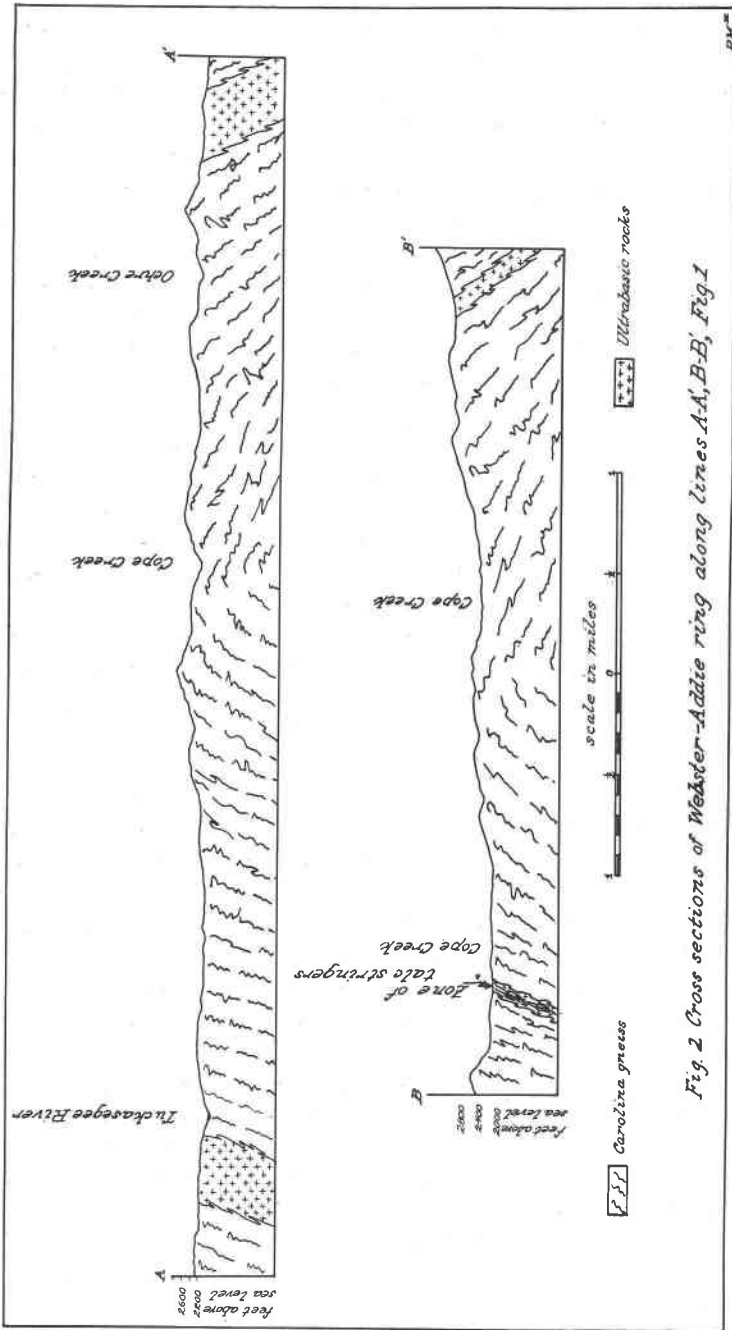Modified from Pratt, J.H., Lewis, J.V.
and Hunter, C.E.

Fig. 1

Fig. 2 Cross sections of Webster-Addie ring along lines A-A', B-B', Fig.1

Fɪɢ. 2

selves. If the magma had been intruded up the flanks of a dome which even approached the steepness of the Webster-Addie dome, it is suggested that the outline of the ultramafic ring might have been highly irregular. Such extreme doming would be likely to cause fractures in the country rock which would have been zones of weakness. Since the ultramafic rocks are concordant with the gneiss and essentially regular in outline, it is thought that no such fractures existed at the time of intrusion. However, it is not possible to say that the mass was intruded horizontally. The thickening at the ends of the long diameter certainly suggests a phacolithic type of intrusion. The most important point is that the Webster-Addie ultramafic rocks were intruded as a sheet-like mass (the term "sheet," as opposed to "sill," has been used advisedly), and that their present elliptical outcrop and steep dip is the result of post-emplacement doming of the gneiss into which they were intruded.

No contact metamorphism is at present observable in the gneiss either inside or outside of the Webster-Addie ring. However, the gneiss itself, since it contains garnets, indicates a moderately high temperature environment. At every locality where the dunite-gneiss contact is exposed, a six inch to three foot zone of vermiculite is present in the gneiss. This zone has been caused by later hydrothermal solutions which came up along the contacts and obliterated any narrow contact metamorphosed zone which may have existed.

Dunite

The ultramafic rocks of the Webster-Addie ring fall into three groups; dunite, websterite, and enstatite pyroxenite. Dunite is far more abundant than the other two. In this paper dunite is defined as containing ninety per cent or more of olivine. Under this classification there is no harzburgite in the Webster-Addie ring, although in almost all hand specimens occasional grains of enstatite can be seen.

The least altered dunite of the Webster-Addie ring consists of medium to coarse, allotriomorphic olivine together with very minor amounts of accessory minerals. It is worthy of note that none of the four and six inch giant olivine crystals found at Balsam Gap, $3\frac{1}{2}$ air miles east of Addie, have been found in the dunites of the Webster-Addie ring. Under the microscope the olivine is colorless, transparent and has the typical optical properties of high index of refraction, high birefringence, and an optic angle approaching 90 degrees. The grains are often transected by uneven fractures and/or imperfect cleavage parallel to [010]. Most grains are free of inclusions, but occasionally "dusty" brown chromite is present along cleavage traces.

The maximum amount of replacement of olivine by serpentine noted

by this writer in any of the Webster-Addie dunites is in the neighborhood of forty per cent. Serpentinization begins first along grain boundaries, cleavage traces, and fractures in the olivine grains. Where serpentinization has progressed to a considerable extent, the olivine grains become rounded and there is noticeable development of iron oxides concentrated along their peripheries. No iron oxides form where only small amounts of serpentine are present.

The beta index of refraction was measured on oriented grains of olivine from nine dunite specimens from the Webster-Addie ring. Seven of these were samples taken across the large outcrop near Webster; the other two were from the quarry at Addie. Their indices and corresponding content of the Fe_2SiO_4 molecule are given in Table 1. The figures for the molecular Fe_2SiO_4 content were taken from Poldervaart's chart (1950, p. 1073). It will be noted from Table 1 that the maximum variation in the Fe_2SiO_4 content for the specimens tested is $1\frac{1}{4}$ per cent for all the samples. Furthermore, the seven Webster olivines show no "trend" in composition across twelve hundred feet or about three quarters of the thickness of the mass.

TABLE 1. THE BETA INDEX OF REFRACTION AND MOLECULAR PER CENT Fe_2SiO_4 OF NINE OLIVINE SAMPLES FROM THE WEBSTER-ADDIE DUNITES

Specimen	Beta	Distance from footwall contact (feet)	Molecular Fe_2SiO_4 (%)
W-39	1.6669	90	7.5
W-41	1.6657	210	6.75
W-43	1.6670	430	7.5
W-45	1.6671	730	7.75
W-46	1.6681	770	8.0
W-47	1.6660	860	7.0
W-51	1.6671	1175	7.75
A-13	1.6660		7.0
A-5	1.6651		6.5

WEBSTERITE

The type locality of websterite lies in the large dunite mass southeast of the town of Webster. It lies wholly within the dunite in a zone with a maximum exposed width of about 260 feet on the north bank of the Tuckasegee River, and from this locality extends about one half mile to the north and one half mile to the south, parallel to the general strike of the dunite mass. Its position within the dunite is slightly below the center of the body, being about 900 feet from the hanging wall contact

and only 430 feet from the footwall contact. Under the microscope web-sterite is an allotriomorphic aggregate of enstatite and diopside. These minerals have a tendency to form bands and "nests," and crystals of both many times larger than the average are common. The websterite has been considerably less altered than the surrounding dunite, there being almost no serpentine visible in thin section. A few small chromite grains are scattered through the rock, and tiny irregular magnetite (?) specks are common. The latter occur either interstitially or along cleav-age traces in the pyroxenes. Small, rounded, translucent, greenish brown picotite grains commonly occur in the larger plates of pyroxene. They are usually arranged parallel to the cleavage.

Hess has given a chemical analysis and the optical properties of the fine grained diopside from this rock (Hess, 1949, p. 645). The maximum index of refraction and the optic angle were measured by this writer on one of the large diopside crystals in the websterite. The optic angle was essentially the same as that given by Hess for the fine-grained type. The average beta index, however, was determined to be 1.6880 with a range of plus or minus .0003, or .0098 higher than that given by Hess. Using his chart (Hess, 1949, p. 634) this difference indicates about a three per cent increase in iron and a very small increase in calcium in the coarse-grained over the fine-grained diopside.

The enstatite from the websterite was also analysed by Hess and Phillips (Hess and Phillips, 1940, p. 276). Their sample had a molecular $MgSiO_3$ content of 89.60 per cent. (Hess and Phillips, 1940, plate 1). In the present investigation the gamma index of refraction was measured for two samples of enstatite from websterite, one fine grained and one coarse. These indices were 1.6780 and 1.6755 (average), respectively, with a range in each case of plus or minus .0004. Using Hess' chart (Hess, 1952, Figure 2), these indices indicate a molecular $MgSiO_3$ content of $89\frac{1}{2}$ per cent for the fine-grained variety and $90\frac{1}{2}$ per cent for the coarse-grained variety.

ENSTATITE PYROXENITE

Two types of this rock are found on the north bank of the Tuckasegee River southeast of Webster. A bright green coarsely crystalline rock made up almost entirely of interlocking grains of enstatite occurs as a lense or pod within the websterite zone. This lens or pod is roughly twenty feet wide and probably not more than one hundred feet long. In thin section the prevalence of strain banding, wavy extinction, and inter-stitial small grains of grass green amphibole suggest crushing and some later hydrothermal action. A brown variety of enstatite pyroxenite oc-curs as boulders at the same locality. This rock shows less strain banding,

wavy extinction, and green amphibole than the green variety, suggesting a greater resistance to granulation.

Diopsidic lamellae occur in both the green and brown enstatite, but are very much more common in the latter. They are best seen under crossed nicols in sections containing Y and Z. The lamellae are parallel to the optic plane. Individual lamellae vary in width from too narrow to be measured under the ordinary petrographic microscope up to 0.003 mm. There is also a great variation in the number of lamellae per millimeter. Generally, the larger grains contain many more lamellae per millimeter than the small ones. Counts show about ten lamellae per millimeter as the maximum concentration, but in adjacent grains of the same size one may have this concentration and the other be completely free of lamellae. There is no apparent relationship between the width and the spacing of the lamellae.

In addition to the lamellae there are occasionally irregular grains or blebs of the same material associated with the lamellae. These have their long axis parallel to the long axis of the lamellae, and are apparently oriented the same way as they extinguish simultaneously. They are generally tabular in form; up to 0.01 mm. in width; and have straight, parallel sides and highly irregular ends. A lamellae-free area is common at the

TABLE 2. ANALYSES OF ENSTATITE

	1	2
SiO_2	56.59	57.73
Al_2O_3	1.42	0.95
Fe_2O_3	0.71	0.42
FeO	7.14	3.57
MgO	33.22	36.13
CaO	0.57	0.23
H_2O+	0.28	0.52
H_2O-	0.04	0.04
TiO_2	0.05	0.04
Cr_2O_3	0.42	0.46
MnO	0.18	0.08
NiO	0.07	0.35
Total	100.69	100.52
Density	3.303	3.249
$MgSiO_3$ (Molecular)	87.50	94.50
Gamma Index	1.6702	1.6776

1. Brown enstatite from enstatite-pyroxenite, Webster, N. C., Analyst L. C. Peck.
2. Green enstatite from enstatite-pyroxenite, Webster, N. C., Analyst L. C. Peck.

ends of the blebs, but no such impoverishment is present along their sides (i.e. parallel to their long axis), lamellae often almost touching them. There is no "gradational" form between the lamellae and the blebs, even where they occur in the same grain. Both lamellae and blebs only rarely reach the periphery of the host grain, but tend to be concentrated near the center. A very pronounced concentration of lamellae is often present at the junction of two strain bands in an enstatite grain. Tiny grains of picotite are also arranged along some of these planes but seem to occur wholly within the enstatite rather than in the lamellae. Where individual lamellae transect these strain planes they are either bent at a slight angle or offset. The amount of offset is difficult to measure because of the previously mentioned concentration of lamellae along the planes, but it was never measured with certainty to be more than one or two hundredths of a millimeter.

The presence and concentration of the lamellae and blebs are reflected by the CaO content of the analyzed specimens in Table 2. No lamellae were noted in the enstatites in any of the dunites, even when they were properly oriented on a universal stage.

CHROMITE

Chromite occurs in the ultramafic rocks of the Webster-Addie ring as sparsely scattered grains or more rarely as bands made up of small to medium size grains. The concentration of chromite grains in these bands varies from being almost imperceptible to almost solid chromite. Likewise the width of the bands varies from merely a series of closely spaced small grains to bands an inch or more in width. Under the microscope these chromite bands show alternating coarse uncrushed layers and finer grained highly sheared layers identical in appearance with the layering in the dunites. Thus any grain-size sorting which may have existed in the chromite has been obscured by post-emplacement shearing. However, similar bands of chromite have been described from areas where shearing has been less pronounced, and E. Sampson says that: "They (the bands) appear to represent crystal settling, the banding in many cases probably being accentuated by flowage during consolidation" (Sampson, 1942, p. 110). There is no available evidence in the Webster-Addie area to support an opinion as to when (i.e., pre- or post-intrusion) the chromite was concentrated in these bands. This question can only be answered by a fuller understanding of the temperature and physical characteristics of ultramafic masses during intrusion.

Ross (1929) has presented evidence that at least some of the chromite in the Webster-Addie ring is later than the surrounding silicates; the relation of the chromite to shear planes in dunite and its occurrence as
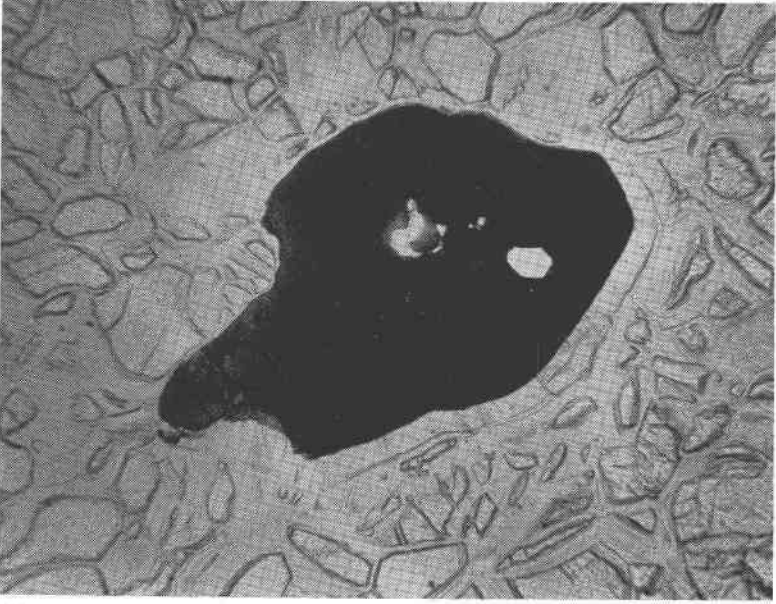
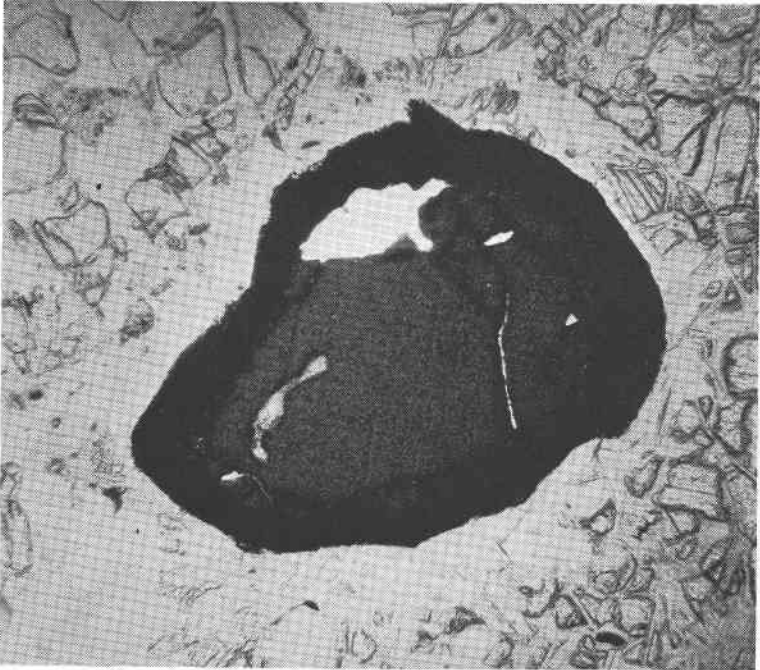FIG. 3. Unaltered chromite grain surrounded by serpentine. ×70.

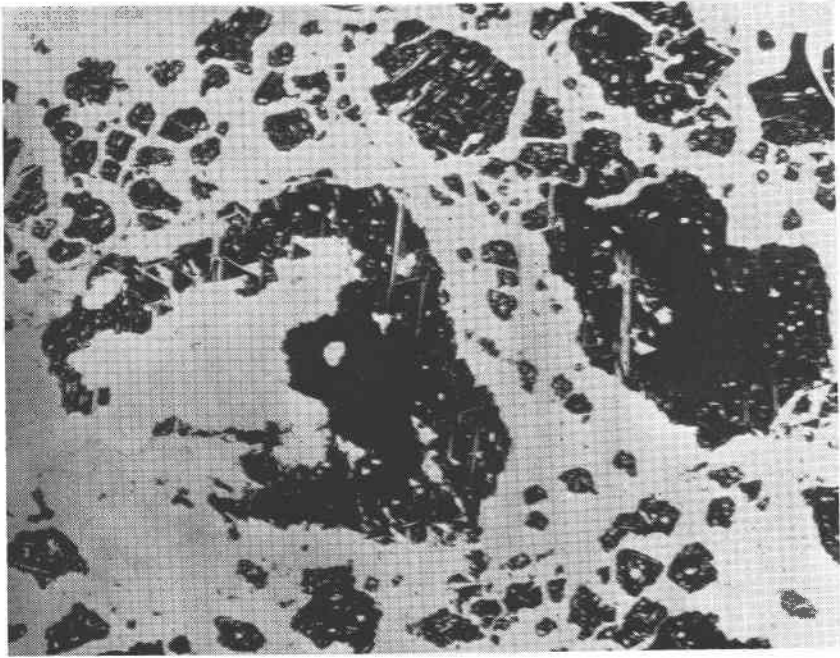FIG. 4. Chromite grain surrounded by chlorite and partially altered
to black opaque material. ×60

Fig. 5. Chromite grains with primary cores and alteration zones of opaque chromite (black) and kammererite (white). ×25

"vein-like" masses where it is associated with chrome-bearing hydro-thermal minerals. The occurrence has been noted of small unaltered olivine grains in chromite grains in highly serpentinized (for the Webster area) dunite. It is unlikely that these olivine grains are merely irregularities in the chromite grains which on slicing appear as inclusions, because in the Webster dunites serpentinization always starts along contacts between grains. Such inclusions are considered evidence that some of the chromite is later than the olivine. A further line of evidence is supplied by the distinct interstitial relationship which some of the fine-grained chromite bears to the olivine.

During serpentinization chromite develops chlorite aureoles and a rim of black opaque material forms around the periphery of the chromite grain (Fig. 4). As this reaction progresses, parting develops in the opaque material allowing the chlorite to "eat" into the center of the grain until none of the typical brown non-opaque chromite is left. Figures 5, and 6 show this reaction. In some cases the chromite grain becomes a mass of tiny, rounded globules of the opaque material (Fig. 7). These are gradually replaced by the chlorite until almost no trace of the original chromite grain is left (Fig. 8). It is believed that knots of chlorite that show no
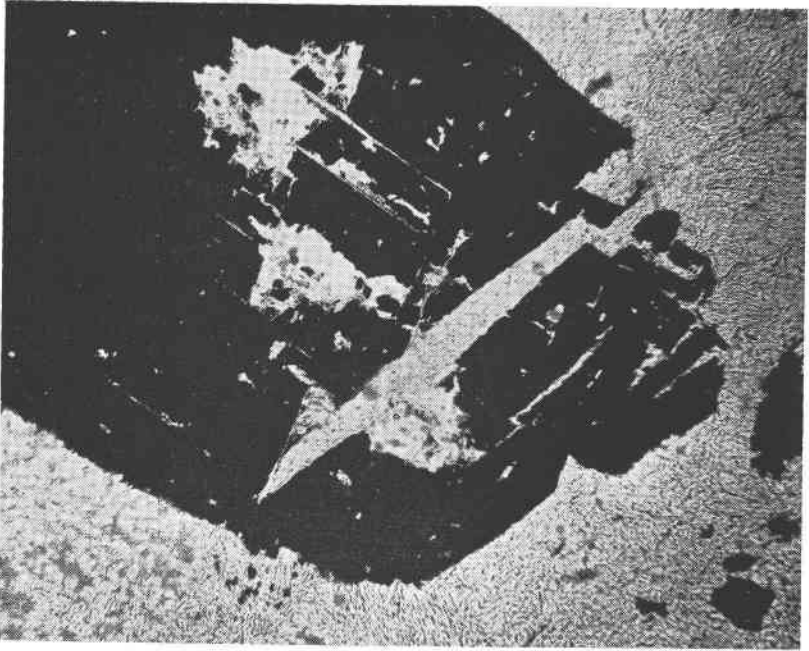
Fig. 6. Same as Fig. 5. ×75

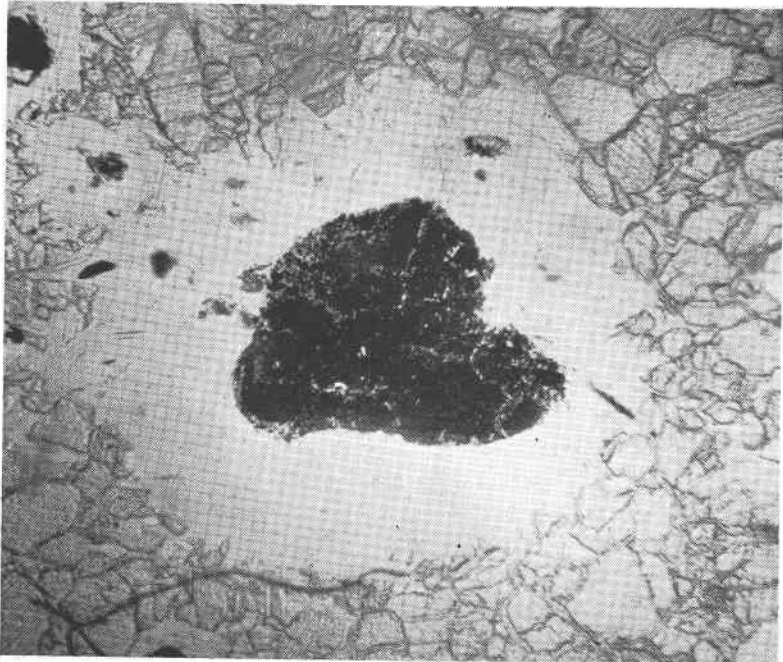Fig. 7. Altered chromite grain in kammererite "knot." In this case the black opaque
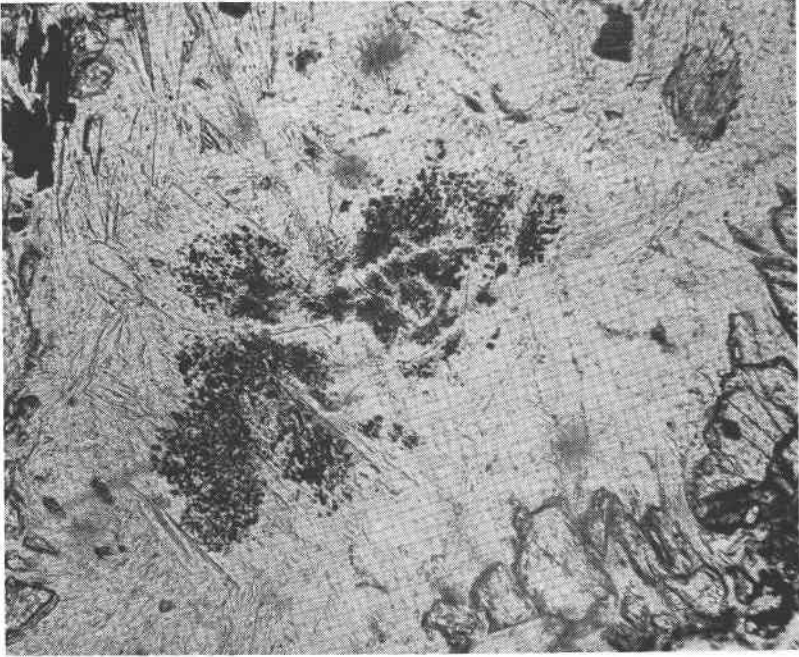chromite is in the form of tiny rounded grains. ×37

Fɪɢ. 8. Partial replacement of black opaque grains by kammererite. ×144

remnants of chromite are places where the reaction has progressed to the point where all of the chromite has been replaced. The chlorite is a kammererite as shown in Table 4.

An effort was made to separate the black opaque material from unaltered chromite for chemical analysis. This was not entirely successful as the two apparently have almost the same magnetic susceptibility and specific gravity. Two samples were analyzed, one of which showed about 80 per cent of black opaque material and the other in which the chromite was unaltered. These samples were from the same locality (Table 3, columns 1 and 2).

The specimen of altered chromite which was analyzed was known to contain some kammererite which was impossible to separate even by fine crushing. The analysis shows this impurity in the figure for SiO_2 and water. Assuming that the SiO_2 content is all in the form of kammererite, 6.31% of this mineral was subtracted from the altered chromite analysis. In this calculation the analysis of kammererite given in Table 4 was used. The resulting material was further estimated to contain about 20% of unaltered chromite in the cores of the grains. Using column 1 of Table 3

TABLE 3. ANALYSES OF UNALTERED AND ALTERED CHROMITE

	1	2	3
SiO_2	0.82	2.06	0.00
Al_2O_3	10.97	4.59	2.41
Fe_2O_3	3.62	10.92	13.62
FeO	19.68	20.58	21.74
MgO	9.52	7.65	5.87
CaO	0.31	0.34	0.35
H_2O (tot.)	0.21	1.12	0.34
TiO_2	0.26	0.32	0.30
Cr_2O_3	54.49	52.06	54.84
MnO	0.29	0.38	0.44
NiO	0.05	0.11	0.09
Total	100.22	100.13	100.00

1. Unaltered chromite. Analyst L. C. Peck.

2. Altered chromite. Analyst L. C. Peck.

3. Altered chromite recalculated after removal of 6.31% kammererite and 20% unaltered chromite.

Using Thayer's method (1946) the ratio $RO/R_2O_3 = 1.03/1$, and the composition of the unaltered chromite in molecular percentages of RO and R_2O_3 is $Cr_{73}Al_{22}(Mg_{46})$. The necessary R'' ions were subtracted to balance the small amount of silica assumed to be an impurity.

TABLE 4. ANALYSIS OF KAMMERERITE

Analyst, L. C. Peck

Specimen W-31 Kammererite	Weight Per cent	Molec- ular Ratios	Atomic Ratios		Cations to 18 $O \cdot (OH)$		Theo- retical
SiO_2	31.95	532	Si	532 ⎱167			4.00
Al_2O_3	13.94	139	Al	278	Z	3.99	4.00
Cr_2O_3	3.90	26	Cr	52 ⎰111			
Fe_2O_3	0.22	1	Fe'''	3	X	6.04	6.00
FeO	1.83	25	Fe''	25			
MnO	0.01	—	Mg	865	(OH)	7.97	8.00
MgO	34.87	865	Ni	3			
NiO	0.21	3	Ca	3			
CaO	0.18	3					
H_2O+	12.61	700	OH	1400			
H_2O-	0.13	7			$2V = 20°$		
Na_2O	0.00	—			optic sign $(+)$		
K_2O	0.04	1			$\beta = 1.5855$ (range $= \pm .0005$)		
TiO_2	0.02	—			dispersion v > r weak		
P_2O_5	0.00	—					
	99.91						

this was also removed and the results are given in column 3 of Table 3. This material, the calculated black opaque, has a ratio $RO/R_2O_3 = 1/1.01$. Using Thayer's method (1946) the composition in molecular percentages of RO and R_2O_3 is $Cr_{77}Al_5(Mg_{34})$. The foregoing calculations indicate that as the reaction progresses there is a tendency toward the abstraction $MgO \cdot Al_2O_3$ and an increase of $FeO \cdot Fe_2O_3$. In addition some Cr_2O_3 is being lost to the kammererite. The end product of the reaction theoretically would be an ideal chromite ($FeCr_2O_4$)—magnetite solid solution.

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