THE PETROLOGY AND PETROGRAPHY OF THE IGNEOUS

ROCKS OF RILEY COUNTY, KANSAS

by

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of Agriculture and Applied Science, 1950

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A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology

KANSAS STATE COLLEGE

OF AGRICULTURE AND APPLIED SCIENCE

1953

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INTRODUCTION

There are five igneous intrusions outcropping in Riley County, Kansas. Each consists of a fine grained serpentine groundmass with many inclusions of sedimentary, metamorphic and igneous rocks from microscopic size up to several inches in diameter. The inclusions give the intrusive a brecciated appearance. Shattered masses of wine colored garnet, rounded masses of magnetite and ilmenite and large crystals of phlogopite are also abundant.

The intrusions bear the names of small towns near which they are found. The exact locations of the intrusions are:

Bala, N.W.¼ N.W.¼ sec. 6 T. 9 S. R. 5 E.

Stockdale, N.W.¼ S.E.¼ Sec. 23 T. 8 S. R. 6 E.

Leonardville, S.E.¼ N.W.¼ Sec. 22 T. 8 S. R. 5 E.

Randolph No. 1, N.W.¼ N.W.¼ Sec. 35 T. 6 S. R. 6 E.

Randolph No. 2, S. W.¼ S.E.¼ Sec. 27 T. 6 S. R. 6 E.

The location of the Bala, Stockdale, and Leonardville intrusions were the only ones reported until Kenneth L. Parish and Carl F. Crumpton of the U.S.G.S. discovered two others near Randolph, Kansas, in 1950.

Moore and Haynes (1920) credited T. S. Harrison of Denver, Colorado, for the discovery of the Bala intrusion. Jewett (1941) credited Professor G. H. Failyer of Manhattan, Kansas, with the discovery of the Stockdale intrusive. No record was found by the author concerning the discovery of the Leonardville intrusive.

PURPOSE

The purpose of this thesis is to determine the relationship
between sedimentary, metamorphic and igneous inclusions, found
in the serpentine plugs exposed in Riley County, and the ground-
mass, in order to help in determining the history of the in-
trusion, the reaction sequence and original composition.

SAMPLING PROCEDURE

Most of the samples were taken from the Stockdale intrusion
because it was exposed in a small stream bed where the water had
removed the soil and highly weathered material which gave a
relatively fresh surface with which to work.

A count was made of the inclusions, ranging from one inch
to three inches in diameter, shown in an exposed area of the
intrusive and listed according to their composition. One hund-
red inclusions were counted of which 32 were limestone, 10 shale,
8 gneiss, 5 schist, 15 gabbro, and 30 pyroxenite. Only 5 of the
pyroxenite inclusions still had unaltered pyroxene in the center,
but all of the other inclusions listed as pyroxenite had the
yellow-orange colored serpentine which was characteristic of the
reaction rims around the other pyroxenite inclusions that still
had unaltered pyroxene in the center. The crystal outline of
the pyroxene was still present in the altered areas of the in-
clusions. In some cases the yellow-orange antigorite replacing
the pyroxene contained some green chlorite or antigorite as

was described in sample B 10 where the augite seemed to contain more iron than in some of the other samples.

The sedimentary inclusions examined showed no reaction rims, but were of the same general composition throughout. A description of these was given in samples B 1 and B 7.

The metamorphic inclusions showed two to three definite color zones of reaction. The general order of color zone arrangement was dark brown or black to yellowish white, but in one sample, B 3, there seemed to be a bleached zone around the central unaltered core in which no apparent alteration could be seen with the microscope. The usual dark zone surrounded this bleached zone in B 3 and a yellowish white zone was present around the dark zone. The composition of these rims is described on page 35.

The igneous inclusions had two to three reaction rims. The pyroxenite inclusions had a dark zone around the unaltered center. This dark zone was composed chiefly of bastite. The yellow-orange colored rim around the dark zone was composed chiefly of antigorite and crystal outlines and cleavage traces were still present. B 2, B 11, and B 12 are descriptions of the pyroxenite.

The gabbro inclusions were of two kinds: those containing pyroxene and those containing both pyroxene and amphibole. The feldspar had altered to antigorite and the pyroxene and amphibole had altered to chlorite first, then to antigorite. Samples B 5, B 6, B 8 and B 10 are descriptions of the gabbro inclusions.

The plagioclase altered to serpentine much more rapidly
then the pyroxene where it occurred in the same inclusion. The
reaction rim around the pyroxenite inclusions were as thick or
thicker in some cases as they were around the gabbro inclusions
and all of the igneous inclusions showed thicker reaction rims
than the metamorphic inclusions (Plate IV) although the gabbro
and gabbro gneiss were of similar composition.

Twelve inclusions were selected for a thin section analysis.
Of the twelve samples examined there were two sedimentary, three
metamorphic and seven igneous rocks.

X-ray diffraction patterns were made of the two color rings
around sample B 12 in search of an explanation for the difference
in color. X-ray diffraction patterns were taken of samples from
the Stockdale and Randolph groundmass and compared with diffraction
patterns made from Kentucky, Hoboken, and verde antique ser-
pentines and with inclusions from the plug.

Selfridge (1936) used Hoboken serpentine in some of his
x-ray studies of serpentine.

Kentucky serpentine was labeled kimberlite from Elliot
County, Kentucky.

The presence of chromium was indicated in a test made on one
of the opaques from the Stockdale plug. An x-ray was taken and
it was determined to be ilmenite. Later it was found that Dr.
Chelikowsky, (personal communication) of the Kansas State
College Geology Department had obtained a chemical analysis of
the same material some time before and the chromium content was
determined to be around 4%. Dr. Dragsdorf, (personal communi-

cation) of the Kansas State College Physics Department indicated that a small amount of chromium could fit into the space lattice of ilmenite without disrupting the crystal structure.

In addition to the micro veinlets and clusters of calcite crystals found in thin sections of inclusions and the groundmass, there were larger veins of calcite that ranged up to three inches in thickness, cutting across the intrusive in various directions. These veins of calcite also contained dendrites of magnetite.

Magnetite and ilmenite occurred in the groundmass of serpentine as rounded masses ranging from microscopic size up to an inch in diameter. Some ilmenite was found as a graphic intergrowth in an inclusion that was formerly a pyroxene or amphibole, but which had been altered to serpentine.

Ilmenite made up the greatest percentage of the opaque material in the serpentine groundmass. Most of the magnetite occurred in inclusions and in micro veinlets in the groundmass and inclusions.

A magnet was used to separate the magnetite from the ilmenite. An x-ray defraction pattern was used to determine more definitely the mineral species.

HISTORY

Moore and Haynes (1920) had Tomlinson of Swartmore, Pennsylvania, make thin section analysis of the Bala plug from two samples sent him. Wallace Pratt gave the following report on Tomlinson's findings:

Sample 1

Minerals present	Original minerals
Serpentine 75%	Olivine
Calcite 15%	Augite
Chlorite	Biotite
Chromite	Chromite
Apatite	Apatite

Sample 2

Serpentine 60%	Olivine
Calcite 30%	Augite
Chlorite	
Chromite	Chromite
Brucite	
Magnetite	Magnetite

The phenocrysts which form about half the rock are rounded and consist of serpentine and calcite replacing olivine. A few have the forms of augite but as the angles have been rounded in alteration, it is impossible to say what proportion.

Professor Arthur B. Sperry (1929) of the Kansas State College Geology Department gave a paper before a meeting of the Kansas Acadamy of Science entitled "The Intrusive Rocks of Riley County, Kansas." In this paper he had a comparison of the chemical analysis of several mica peridotites in the United States as well as some of the kimberlites of South Africa, with a chemical analysis of the Leonardville plug of Riley County.

Professor Sperry's Comparative Chemical Analysis

	1	2	3	4	5	6	7	8	9
SiO_2	24.15	14.48	26.16	37.77	34.65	31.38	32.56	33.84	38.78
Al_2O_3	2.03	5.44	3.79	3.00	13.83	8.50	2.82	5.88	6.85
Fe_2O_3	6.51	7.23	7.88	6.75	1.76	14.52	9.28	7.04	8.83
FeO	1.85	3.13	2.63	2.73	3.60		3.17	5.16	1.99
MgO	24.45	22.53	23.40	30.53	22.40	23.76	27.00	22.96	26.34
CaO	15.87	18.21	14.70	3.00	12.26	4.90	8.82	9.46	3.88
Na_2O									
K_2O	.30	.98	.78	1.60	1.14		.62	2.37	3.34
H_2O+	8.50	8.46	6.75	8.83	8.60		8.97	7.50	7.86
H_2O-	.84	.38	.16	2.07	.10		.88	.68	1.95
TiO_2	1.50	1.56	2.50	1.54	.16		2.40	3.78	.89
CO_2	12.04	17.51	9.94	1.30	.37		2.90	.43	.14
P_2O_5	.62	.30	.86	.88	.51		.68	.89	
SO_3	.20								
						Loss			
Others		.65	.71		.61	17.14	.30	.55	
	98.86	100.86	100.14	100.00	99.97	100.15	100.40	100.54	100.84
Sp.gv.	2.66	2.78	2.51				2.69		

[1] Sperry, 1929. Stockdale, Riley County, Kansas.

[2] Honess and Graeber, 1924. Mica Peridotite, Dixonville, Pennsylvania.

[3] Williams, 1932. Kimberlite, Jaegersfountein, South Africa.

[4] Daly, 1933. Kimberlite, Average of Six Ordinary Kimberlites.

[5] Singewald and Milton, 1930. Alnoite, Avon, Missouri.

[6] Gordon, 1927. Mica Peridotite, Union County, Tenn.

[7] Williams, 1932. Kimberlite Dike, Koffyfountain Mine, South Africa.

[8] Diller, 1892. Mica Peridotite, Crittenden County, Kentucky.

[9] Miser and Ross, 1923. Peridotite, Prairie Creek, Arkansas.

The wine-colored mineral found in the Stockdale plug was called ruby spinel after Mudge (1879) reported finding ruby spinel in a shale in northern Riley County. Bagrowski (1941) had a chemical analysis made which proved it to be pyrope garnet.

$$SiO_2 \ldots \ldots \ldots \ldots 40.42\%$$
$$Al_2O_3 \ldots \ldots \ldots \ldots 21.12\%$$
$$Cr_2O_3 \ldots \ldots \ldots \ldots 7.90\%$$
$$Fe_2O_3 \ldots \ldots \ldots \ldots 10.50\%$$
$$MgO \ldots \ldots \ldots \ldots 14.42\%$$
$$Ca O \ldots \ldots \ldots \ldots 4.71\%$$

Dreyer's (1947) magnetic survey of the Bala intrusive with a vertical magnetometer indicated that the intrusive was an eastwardly-plunging vertical dike. Taylor (1950) attributed the dikes to a magma welling up through a gash fracture developed from a strike slip fault located in the vicinity of the Abilene arch.

REVIEW OF LITERATURE

In William's (1932, p.195) commentary on the temperature of the kimberlite of South Africa at the time of its implacement, he indicated the temperature must have been relatively low because the shale and limestone inclusions would have been affected had it been very high. He further stated that:

> It is most difficult to explain why the kimberlite magma was of such a low temperature, but it is suggested that water and carbon dioxide have been responsible for delaying the crystalization point to an astoundingly low figure.

He also stated (p.159) that serpentinization took place after implacement and in course of time altered the whole rock.

The kimberlite of South Africa contained many inclusions
of rock through which it passed. (p. 84)

He gave the following listing of minerals, (p. 251)

Primary	Transported Minerals of Primary Origin (in Conclusions)	Secondary
Olivine	Olivine	Serpentine
Phlogopite	Enstatite	Talc
Ilmenite	Garnet	Chlorite
Perovskite	Zircon	Calcite
Magnetite	Diopside	Siderite
Apatite	Chrome diopside	Magnetite
Nickel	Phlogopite	Limonite
	Spinel	Perovskite
	Chromite	Phlogopite
	Ilmenite	Amphibole
	Rutile	Hematite
	Augite	Pyrite
	Magnetite	Leucoxene
	Hornblende	

In Miser's and Ross' (1923) report on diamond bearing
peridotites of Pike County, Arkansas, they described three
general types of rocks occurring in the same general area.
They were (1) the tuffs and fine grained breccia, (2) volcanic
breccia, and (3) hypabyssal intrusive peridotite. All three of
the rocks have about the same composition.

They state that the hypabyssal peridotite was the first in-
trusion which was followed by volcanic explosions that broke up
much of the hypabyssal peridotite and some of the surrounding
shale and sandstone of Carboniferous age.

In the area of peridotite near Prairie Creek the
fragments were apparently ejected into the air and
then deposited in inclined layers which, in hardening,
have formed a breccia. . . .

A second group of explosions probably formed the
tuffs and closely associated fine-grained breccias of
the area near Prairie Creek.

The breccias were alleged to be upper Cretacious in age.
Goodspeed (1953) wrote:

> Breccias formed during metamorphism and exhibiting
> crystallablastic features and flow structures cannot be
> adequately explained as orthomagmatic, but support the
> interpretation of movement of metamorphosed material. .
> . . . . It is suggested that breccias formed under such
> conditions be termed rhemorphic breccias.

Singewald and Milton (1930) described an intrusion near
Avon, Missouri, as a peridotite pipe which consisted of olivine
(altered to serpentine), phlogopite, melilite and accessory
apatite, magnetite, chromite, and perovskite. The groundmass
consisted of spherules of serpentine or olivine that were sur-
rounded by a carbonate matrix. They attributed the breaking
up of the original magma into spherules to explosions caused
by the release of CO_2 when the dolmite inclusions were dis-
solved. The explosions caused a shattering of the wall rock
and thus gave rise to a brecciated appearence of the pipe.

According to Daly (1933, p. 553) Gisolf, in a paper on
some New Guinea rocks, postulated that serpentinization was a
late magmatic stage that occurred when the gaseous components
could not escape, thus causing olivine and pyroxene to absorb
the gaseous constituents and this in turn would cause the ser-
pentinization of the rock at a later stage.

Daly appeared to favor the idea of serpentine crystalizing
directly as a late magmatic stage and questioned that the
greater part of the serpentine in the kimberlite of South Africa
was a direct replacement of the olivine.

In Diller's (1892) description of the Flanary dike, Crittended County, Kentucky, he proposed the name "mica peridotite" because of the abundance of primary mica in the groundmass.

Honess and Graeber (1924) attributed the serpentinization of the Dixonville dike to hydrothermal alteration and subsequently carbonation as the groundmass cooled and became more highly charged with carbonic acid. They also mentioned ilmenite carrying a little chromium and red garnets not over a few mm. in diameter in connection with the Dixonville dike.

Benson's (1918) conclusions indicated that serpentine was produced from peridotite intrusion more or less pyroxenic. The hydration was brought about by the agency of water emitted from the magma that produced the peridotite.

Hess (1933) attributed serpentinization to an auto-metamorphic reaction and pointed out that if this were true, the peridotite would have to have the magmatic residium that produced the alteration within the volume of the original ultrabasic. Calculations made on this basis would show a slight volume decrease whereas if calculations were made on the basis of a dry unserpentinized peridotite, there would be a tremendous increase in volume. He further pointed out that the serpentinized peridotites did show the presence of small fissures which are filled with chrysotile. He also stated:

> Serpentinization in most cases is either evenly distributed throughout the ultrabasic or in a haphazard distribution unrelated to the borders of the ultrabasic, but in a few cases serpentinization increases outward from the core of the ultrabasic.

Chawner (1934) in referring to Hess' article indicated his observations in Cuba disclosed the possibility that expansion due to serpentinization was very evident.

Dresser (1934) referred to Hess' observation concerning chrysotile veins forming due to decrease in volume and points out that conclusions of Keith and Bain were drawn essentially from a study of the "slip-fiber" or deformed deposit of Lowell Mountain, Vermont, and were applicable only to deposits of that class.

Bain (1934) replied to Dresser that there were no deposits of asbestos or ultrabasic rocks in Lowell Mountain, he was referring to Belvedere Mountain, Vermont.

In a 1936 article he described three types of serpentinizations in Vermont--automorphic or red weathering type, tectonic or verde antique, and meteoric serpentinization. The verde antique formed along the borders of fracture zones and showed schistose effect.

In Bowen's analysis (1928 p.147), of the peridotites of Skye, he indicated the strong evidence that the peridotite was at least crystalline in part when it was injected, because the contact zones indicated no chilling and the olivine crystals showed strain shadows and crushing effects near the contact.

He also pointed out that in one specimen obtained near the contact which contained both feldspar and augite, the feldspar had completely changed to serpentine or talc whereas the augite was unaltered.

Sharp boundaries on inclusions probably indicate rapid cooling and insufficient time for changing them.

Turner and Verhoogen (1951 p. 248), state that:

> On the whole the relations of serpentine to peridotite in space seems equally compatible with alternative mechanisms of serpentinization involving internally (i.e., magmatically) or externally derived waters respectively.

Bain (1932) said that Keith's studies indicated that chrysotile veins occur as a filling of open fractures in peridotite, dunite, and serpentine, and that the amount of filling derived by direct recrystallization of the wall rock was insignificant.

Chrysotile bearing solutions were not in equilibrium with feldspars and so far as determined were in equilibrium only with serpentine, olivine and rarely pryoxene, reactions with feldspars gave chlorite veins and streaks.

"Chrysotile occurs in the least altered parts of lens." . . . "Serpentine (H_4 Si O_4 Mg$_2$ Si O_4 2H$_2$O) must be removed in large amounts from the most altered parts of any talc-serpentine-dunite mass."

Chrysotile deposits seem to require a fracture cleavage system in conjunction with a serpentine or talc deposit.

Wells (1929) did not succeed in producing serpentine from olivine at temperatures under:

620°C,	301 atms,	24 hrs.
520°C,	267 atms,	9 hrs.
420°C,	232 atms,	48 hrs.

by using the following reagents in the presence of water.
Na HCO$_3$ and Na$_2$ CO$_3$. He concluded that there must be other
materials present and that serpentine formed as a late magmatic
hydrothermal alteration at temperatures exceeding 520°C.

He did find that serpentine could be formed from magnesium
carbonate rocks or from magnesium solutions by the action of
silicifying solutions at temperatures as low as 375°C and
pressures as low as 219 atms.

Bowen and Tuttle (1949) by experiments placed the limits
of serpentinization of forsterite in the presence of water vapor
between 400°(Ca) and 500°(Ca) using pressures up to 50,000
pounds per square inch. From 500°(Ca) to 625°(Ca) talc was
formed.

Winchell (1927, pp.373-386), listed the serpentine minerals
under the chlorite group as end members of them. Rodgers and
Kerr (1942, pp. 361-363), listed the serpentine minerals as
antigorite, serpophite, and chrysotile.

Grout (1932, p. 109), wrote:

> Chrysotile is characterized by a fiberous structure;
> antigorite by a "mesh" structure; bastite has a structure
> suggesting origin from a pyroxene. The serpentine may be
> deuteric or hydrothermal.

Selfridge (1936) published his results on an x-ray study
in which the different serpentine minerals were examined. He
concluded the varieties of serpentine could very well be com-
bined under the headings serpentine and antigorite. Chrysotile,
a flexible fiber form of serpentine, and other names were used
as textural terms more than as mineral varieties.

He included bastite with serpentine in his analysis, but the x-ray studies made on samples of bastite from the intrusions studied by this author matched the defraction patterns of Selfridge's "Picrolite" or antigorite better than his serpentine. Therefore his conclusion that they stood for textures more than definite mineral varieties of serpentine was verified in this case.

Bates and Mink (1950) stated that:

Studies with the electron microscope supported by x-ray and DTA data show that natural and synthetic chrysotile are composed of tube-like fibers, whereas antigorite consists of plates and laths. In both instances the morphological characteristics of the artificial materials are better defined than those of the natural minerals. The units of chrysotile always show curvature of the (001) plane parallel to the a of b axis. In antigorite this curvature is less marked or absent.

Interpretation of the data suggests that antigorite and chrysotile differ morphologically only in the degree of lateral curvature affecting their component units. Evidence indicates that this curvature is most pronounced where the ideal serpentine composition is obtained, such as in synthetic chrysotile, and decreases with the amount of trivalent ions replacing magnesium in the structure. It is believed that the degree of curvature depends upon (1) the discrepancy in dimensions of the "sheets" which make up the unit of structure, and (2) the strength of the bonds between the units. This is in accord with the theory previously proposed to account for tubular crystals of endellite.

Nagy and Bates (1952) state that:

Chrysotile asbestos is less stable than antigorite as shown by treatment with HCl and analysis of the results by x-ray and differential thermal patterns, electron micrographs, and solubility data. Since nitrogen absorption measurements reveal no signigicant difference in surface area of the test samples, the difference in solubility may be the result of greater strain in the outer layers of chrysotile tubes than is present in the

flat antigorite plates. Hydrothermal treatment of finely
ground chrysotile fibers produces a flaky substance re-
sembling antigorite.

X-RAY ANALYSIS

Plate I is a comparison between diffraction patterns of
serpentines from the general groundmass of Stockdale, Kentucky,
Randolph, and Hoboken intrusives. The Stockdale, Kentucky, and
Randolph serpentines give almost identical patterns. The
Hoboken serpentine has a similar pattern but some of the lines
are missing and the background is lighter on the negative.
The Hoboken serpentine seems to be very similar to the ser-
pentine verde antique.

Plate II is a comparison between diffraction patterns of
serpentine from: (1) a dark inclusion showing foliation
(sample B 9), (2) a white serpentine with pearley luster
(sample B 8), (3) black reaction rim around an augite center
(sample B 12), (4) verde antique, (5) yellow-orange reaction rim
around the black reaction rim (film 3) in a pyroxene inclusion
(sample B 12). All of the samples came from the Stockdale
intrusion except the verde antique which came from Belvedere
Mountain, Vermont.

Plate III is a study of the effect of grinding upon samples
taken from the reaction rims around a pyroxene inclusion (sample
B 12). B 12 W 4 hr. is a sample of the yellow-orange reaction
rim ground fine enough to pass a 220 mesh screen and exposed
for four hours to produce an x-ray diffraction pattern. B 12 W

$5\frac{1}{2}$ hr. is a sample of the same yellow-orange reaction rim which was ground for $43\frac{1}{2}$ hours and exposed $5\frac{1}{4}$ hours to obtain an x-ray diffraction pattern. B 12 B 4 hr. is a sample of the black bastite reaction rim around the central augite core which was ground fine enough to pass a 220 mesh screen and exposed for four hours to obtain an x-ray diffraction pattern.

Bastite (sample B 12 B) does not show the lines on the diffraction pattern as distinct as antigorite (sample B 12 W), although the same lines are present. After B 12 W was ground for $43\frac{1}{2}$ hours, the lines were less distinct and were more nearly like B 12 B lines than the original B 12 W. Dr. Dragsdorf of the Kansas State College Physics Department explained that the grinding caused a stacking disorder of the crystal lattice, thus bringing about a change in line intensity.

The difference in color between B 12 W and B 12 B might be explained on the basis of more abundant iron in B 12 B, causing a difference in electronic levels, or stains set up inside the crystal lattice due to stresses brought about by alteration.

d (A°) Spacings for B 12 B 4 hr. and B 12 W 4 hr.

B 12 B			B 12 W		
7.26 vs	1.77 m		7.47 vs	1.40 w	
4.54 m	1.72 w		4.54 m	1.32 vw	
4.16 vw	1.59 vw		3.84 w	1.30 m	
3.84 vw	1.53 vw		3.62 s	1.28 m	
3.59 s	1.49 s		3.32 vw	1.24 vw	
3.30 vw	1.40 m		2.82 vw	1.21 vw	
3.11 vw	1.32 vw		2.56 w	1.16 m	
2.98 w	1.30 m		2.49 s	1.10 vw	
2.81 vw	1.27 w		2.42 vw	1.07 w	
2.63 w	1.20 vw		2.28 m	1.05 w	
2.48 s	1.16 vw		2.13 s	.99 m	
2.37 vw	1.05 vw		1.94 w	.98 vw	
2.28 vw	.99 w		1.78 m	.96 w	
2.13 m	.97 w		1.72 vw	.95 vw	
1.94 vw	.95 vw		1.55 vw	.92 m	
1.89 vvw	.94 vw		1.52 s	.88 m	
1.85 vw			1.49 s	.87 vw	
			1.45 vw	.86 vw	
				.82 vw	

s= strong
m= medium
w= weak
vw= very weak

Film Data for Plates I and II

Sample	Camera	Exposure time	Radiation
B 12 B	2	$3\frac{1}{2}$ hours	Cu Ka
B 12 W	1	$4\frac{1}{4}$ hours	Cu Ka
B 8 W	2	$3\frac{1}{2}$ hours	Cu Ka
B 9 B	1	$3\frac{1}{2}$ hours	Cu Ka
Stockdale groundmass	2	$3\frac{1}{2}$ hours	Cu Ka
Hoboken	2	$4\frac{1}{4}$ hours	Cu Ka
Kentucky	2	$3\frac{1}{2}$ hours	Cu Ka
Randolph groundmass	1	$3\frac{1}{2}$ hours	Cu Ka
Verde antique	2	$3\frac{1}{2}$ hours	Cu Ka

Film Data for Plate III

Sample	Ground	Exposure time	Radiation
B 12 W	$43\frac{1}{2}$ hours	$5\frac{1}{2}$ hours	Cu Ka
B 12 W	to pass 220 mesh screen	4 hours	Cu Ka
B 12 B	to pass 220 mesh screen	4 hours	Cu Ka

EXPLANATION OF PLATE I

X-ray diffraction patterns of the

1. Stockdale groundmass

2. Kentucky serpentine

3. Randolph serpentine

4. Hoboken serpentine

PLATE I
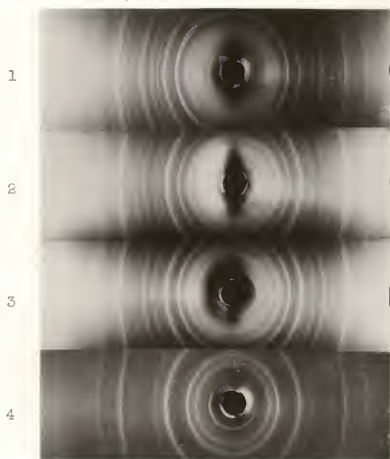
EXPLANATION OF PLATE II

X-ray Diffraction Patterns

1. Foliated inclusion from the Stockdale
   intrusion (Sample B 9).

2. A white serpentine inclusion from the
   Stockdale intrusion (Sample B 8).

3. A black rim around an augite center
   (Sample B 12).

4. Serpentine verde antique from Belvedere
   Mountain, Vermont.

5. Yellow-orange antigorite from around
   the black rim in Sample B 12.

PLATE II

1

2

3

4

5
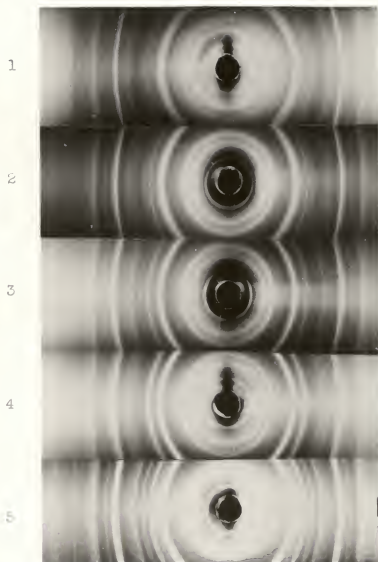
EXPLANATION OF PLATE III

X-ray diffraction patterns of the reaction rims around
            Sample B 12.

B 12 W 4 hr. -- yellow-orange antigorite ground to pass
            a 220 mesh screen.

B 12 W 5½ hr. -- yellow-orange antigorite ground for
            43½ hours.

B 12 B 4 hr. -- black lastite ground to pass a 220
            mesh screen.

PLATE III
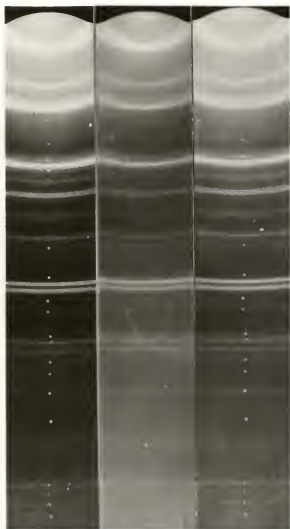
B 12 W   B 12 W   B 12 S
4 hr.   5½ hr.   4 hr.

EXPLANATION OF PLATE IV

Cross sections of igneous, metamorphic, and sedi-
mentary inclusions.

PLATE IV

1. Gabbro inclusion--sample 6.

2. Pyroxenite inclusion--sample 12.

3. Gneiss inclusion--sample 3.

4. Limestone inclusion--sample 7.

SUMMARY OF X-RAY ANALYSIS

The lines on an x-ray diffraction pattern have shown the
serpentines of the general groundmass of Randolph, Leonardville,
and Kentucky to be almost identical. Hoboken serpentine is
similar but some of the lines are weak or absent and the back-
ground is much lighter on the film which indicates the scarcity
of some element or elements between 22 and 29 on the periodic
table that is present in the other three serpentines. The
elements are probably iron or titanium. The presence of a
greater number of lines probably means the presence of some
material other than serpentine.

X-ray diffraction patterns taken of the serpentinization
sequence in a pyroxenite inclusive have shown an increase
in line intensity from bastite to antigorite. The bastite
rim was shown to have more iron present than the antigorite
rim.

Upon grinding a sample from the antigorite rim for
$43\frac{1}{2}$ hours, the line intensity decreased to a similar intensity
to that of bastite.

Upon making further comparisons between antigorite and ser-
pentines that showed schistosity or some other evidence of stress,
it was found that there was a decrease in line intensity and line
number in those samples which showed evidence of stress.

In comparisons made between antigorite and chrysotile, it
was noted that there was a decrease in line number as well
as line intensities in chrysotile.

Nagy and Bates (1952) have suggested that the increased solubility of chrysotile over antigorite might be due to strain in the chrysotile.

Bates and Mink (1950) have shown by studies with the electron microscope the relationship between the presence of trivalent ions and the curvature of the serpentine plates with an increase in curvature with a decrease in trivalent ions.

Dragsdorf (1951) in studies on the effects of grinding on clay minerals found that decreases in line intensities were brought about by stacking disorders caused by grinding. His results with grinding experiments on the antigorite of sample B 12 were similar to the results obtained with clay samples.

In comparing the results of Nagy and Bates, Bates and Mink, and Dragsdorf, there seem to be a relationship between the number of lines and line intensities, and strains or stacking disorders in a crystal lattice.

Since the bastite rim shows more iron than the antigorite rim, the author suggests the possibility that a relatively large amount of iron along with magnesium and aluminum in the crystal structure could produce stress just as the absence of iron does.

This correlates very well with Winchell's (1927, p. 375), description of antigorite in which he gave the composition of antigorite as: 80 per cent or more antigorite (H_4 Mg_3 Si_2O_9) and 20 per cent or less ferroantigorite (H_4 Fe_3 Si_2O_9), amesite (H_4 Mg_2 Al_2 Si O_9) and or daphnite (H_4 Fe_2 Al_2 Si O_9).

The x-ray defraction patterns of serpentine minerals
having schistos and "slip fiber" structure show a decrease in
line number and intensity comparable to x-ray defraction
patterns showing stacking disorders brought about by effects of
grinding.

THIN SECTION ANALYSIS

Sample B 1--Shale Inclusion.

I Megascopic.

    A. Overall description.

        1. Color--gray.

        2. Texture--fine even grained.

        3. Mica is the only mineral recognizable.

    B. General description of individual minerals.

        1. Mica.

            a. Light yellow-brown.

            b. Size 1 mm.

II Microscopic.

    A. Essential minerals.

        1. Serpentine 50%

        2. Phlogopite 25%

        3. Calcite 15%

        4. Rutile 10%

    B. Accessory minerals.

        1. Ilmenite.

    C. Texture.

        1. Porphyritic.

     a. Large crystals of mica imbedded in a
      groundmass of serpentine.

D. Structure.

  1. Calcite masses surrounding the phlogopite crystals
   and calcite micro veinlets, that were roughly
   parallel, extending from one phlogophite crystal
   to the other.

  2. Rutile occurred at random throughout the rock and
   as metacrysts in the mica.

E. Individual minerals.

  1. Serpentine.

    a. Optical properties.

      1. Colorless.

      2. Aggregate form.

      3. Relief--low.

      4. Birefringence weak (.007).

  2. Phlogopite.

    a. Optical properties.

      1. Color--light yellow-brown--pleochroic.

      2. Form--tabular crystals.

      3. Birefringence--strong.

      4. Extinction--wavy, parallel to cleavage.

      5. 2v very small.

      6. Opt (-).

      7. Contains inclusions of rutile.

  3. Calcite.

    a. Colorless.

     b. Form--fine aggregates in micro veinlets and
      course aggregates around mica.

     c. Birefringence--extreme.

   4. Rutile.

     a. Color--red center; opaque borders.

     b. Form--small prismatic crystals.

     c. Relief--very high.

     d. Birefringence--extreme.

     e. Extinction--parallel.

   Under plain light outlines of irregular grains that have
been replaced by serpentine were seen. The spaces between
the grains were filled in many places by rutile.

   A hydrogen peroxide test made on the sample showed the
presence of titanium. Hurlbut (1946, p. 126).

Sample B 2--Pyroxenite.

I Megascopic.

  A. Overall description.

    1. Dark colored rock with streaks of green and
     yellowish-brown through it.

    2. Three distinct color bands; black center with a
     dark green rim around it and a light yellow-brown
     outer zone.

    3. Cleavage faces were seen in all three zones.

    4. Prismatic crystals of augite were about 1/8 inch
     in size.

II Microscopic.

    A. Center zone essential minerals.

        1. Augite 85%

        2. Antigorite 15%

        3. Accessory minerals.

            a. Limonite.

            b. Ilmenite.

    B. The zone surrounding the center.

        1. Bastite. 70%

        2. Augite 15%

        3. Antigorite 10%

        4. Accessory minerals.

            a. Limonite.

            b. Chrysotile?

    C. Outer zone.

        1. Antigorite 95%

        2. Ilmenite.

    D. The augite alters to bastite and antigorite. Magnetite dust was seen along cleavage planes.

    E. Individual mineral optical properties.

        1. Leucaugite.

            a. Color--light green to colorless.

            b. Cleavage two directions at about right angles.

            c. Birefringence--moderate.

            d. Extinction angle 46°.

            e. 2v large.

   f. op ($\not=$).

   g. Altered to antigorite and bastite with
     magnetite dust in cleavage planes.

  2. Bastite.

   a. Colorless.

   b. Birefringence--low.

   c. Pseudomorph after augite.

   d. opt. (-).

  3. Antigorite.

   a. Colorless.

   b. Form--aggregate.

   c. Birefringence--low.

   d. Pseudomorph after bastite and augite.

  The sample shows different colors for antigorite depending
upon the size of the antigorite crystals. The larger the
crystals were, the darker the color was in the hand specimen.

  The finest variety of antigorite gave a transparent
appearance in the hand specimen.

  All of the antigorite showed the original structure of the
augite except the antigorite filling cracks and voids in the
rock.

  There were also micro veinlets of a fibrous mineral with a
higher birefringence than antigorite with parallel extinction
that was possibly chrysotile. The mineral was yellow colored
in plain light.

Sample B 3--Gabbro gneiss.

I Megascopic.

    A. Light colored with dark streaks roughly parallel.

    B. Medium grained.

    C. Gneissoid structure.

    D. Three distinct color zones.

        1. Center gray with black streaks.

        2. Rim around center white with black streaks.

        3. Outer rim black.

II Microscopic.

    A. Essential minerals.

        1. Center.

            a. Labradorite 75%

            b. Augite 25%

            c. Accessory minerals.

                1. Magnetite.

        2. Black rim.

            a. Antigorite. 95%

            b. Unaltered augite 5%

    B. Alterations.

        1. Center unaltered.

        2. Rim next to center partially altered to serpentine.

        3. Outer all plagioclase altered to serpentine and
            most of the augite had been altered to serpentine.

    C. Optical properties of individual minerals.

        1. Maximum extinction angle of albite twins cut normal

to 010--30°.

    2. Extinction angle--50°.

    3. Bent crystals.

Sample B 4--Gabbro Gneiss.

I Megascopic.

    A. Center--light gray colored rock with redish-black
        streaks that were roughly parallel running through it.

    B. Rim around center--brownish rim about 1/16 inch thick
        around center.

    C. Outer rim--white to yellowish-green.

II Microscopic.

    A. Center.

        1. Bytownite 70%

        2. Augite. 15%

        3. Perovskite. 10%

        4. Magnetite 5%

        5. Zircon.

    B. Outer rim.

        1. Serpentine (antigorite) . 80%

        2. Augite. 10%

        3. Perovskite. 10%

        4. Magnetite.

The augite and perovskite formed bands through the plagio-
clase. The perovskite was clustered in crystaline masses around
the augite. The augite contained a lot of inclusions which may
be remnants of the original mineral from which the augite formed.

The outer alteration rim showed the bytownite completely changed to antigorite and the augite only partly changed.

The perovskite was apparently unaffected.

The feldspar was called bytownite because of a high extinction angle (36°) of albite twins cut normal to 010 and a opt-sign.

Sample B 5--Normal Gabbro.

I Megascopic.

    A. Three color zones.

        1. Center: color--gray; texture--grandular.

        2. Rim around center: color--black; texture--granular but less granular than center.

        3. Outer rim: color--white; texture--not evident. At one end in the outer rim, the color was yellowish-green and was translucient.

II Microscopic.

    A. Three color zones.

        1. Center--Bytownite 60%

                  Augite 35%

                  Magnetite.

        2. Rim around center.

                  Chlorite clinochlore . . 25%

                  Serpentine 70%

        3. Outer rim.

                  Serpentine.

                  Calcite--extreme outer edge.

The transparent yellowish-green mentioned in the outer rim was not shown in the thin section.

The crystals of feldspar and pyroxene did not show strain shadows for any evidence of crushing.

The pyroxene showed no apparent allignment.

The augite had altered to chlorite and the feldspar had altered to antigorite.

The feldspar had altered much more rapidly than the augite.

Sample B 6--Normal Gabbro.

I Megascopic.

    A. Color--three color bands around center.

        1. Center--a dark colored mineral intermixed with a light colored mineral.

        2. Rim around center (Rim 1).
        Same as center except for the appearance of a red mineral replacing the dark mineral.

        3. (Rim 2)
        Yellowish-green mineral replacing most of the dark and light colored minerals.

        4. The outer rim is dark blue in color.

II Microspic.

    A. Essential minerals.

        1. Bytownite 60%

        2. Hornblende. 40%

        3. Augite.

    B. Accessory minerals.

        1. Ilmenite or magnetite.

        2. Biotite.

    C. Even textured.

    D. Nothing but the center is present in this section.

    E. Labradorite.

        1. Extinction angle of allite twin cut normal to
           the 101= 42°.

    F. Hornblende.

        1. Color--brown.

        2. Strong pleochrism.

        3. Strong birefringence (0.019).

        4. Symetrical extinction in cross sections.

        5. Cleavage parallel to 110 at about 56° and 124°.

The three rings were not evident in the thin section.

    G. Biotite.

        1. Color--greenish-brown.

        2. Strong pleochroism.

        3. Strong birefringence (0.036).

        4. Parallel extinction.

Sample B 7--Limestone.

I Megascopic.

    A. Color--light yellow.

    B. Stratified.

    C. Magnetite formed along stratification plains.

    D. No apparent reaction rim around hand specimen.

II Microscopic.

    A. Inclusion.

        1. Calcite 90%

        2. Antigorite 10%

        3. Magnetite.

    B. Groundmass round inclusion.

        1. Antigorite 50%

        2. Calcite 35%

        3. Garnet.

        4. Phlogopite.

The calcite in the inclusion apparently has not been re-
crystallized except in micro veinlets running through the in-
clusion and in isolated masses throughout the inclusion.

The antigorite and magnetite occurred mostly along strati-
fication plains although traces can be found throughout the
inclusion.

The groundmass contained many outlines of minerals that
have been replaced by antigorite as well as crystals of garnet,
ilmenite, and magnetite that have not been altered or only
slightly altered as was the case with some of the garnet.

The material filling the spaces between the crystal out-
lines of minerals was composed of antigorite, phlogopite,
magnetite and large crystals of calcite and those from the
groundmass were ilmenite.

The calcite from the inclusion appears to have been re-
crystallizing into the groundmass around it.

Sample B 8--Normal Gabbro.

I Megascopic.

    A. Color--white with black specks.

    B. Greasy luster.

II Microscopic.

    A. Antigorite 80%

    B. Bastite 10%

    C. Magnetite.

    D. Apatite.

    E. Zircon.

    F. Limonite stain.

The antigorite occurred in a fine crystalline mass filling in spaces between outlines of crystals that were formerly pyroxene but that have been altered to bastite. In some cases cleavage traces at nearly right angles were seen. Other crystal outlines showed cleavage traces in only one direction. No unaltered pyroxene or feldspar remained in the sample, but on the basis of the mineral content of other inclusions and their process of alteration, the assumption that the original material was a normal gabbro seems logical.

In other samples that showed the original plagioclase and pyroxene, the antigorite that replaced the pyroxene retained some of the crystal structure whereas the antigorite replacing the plagioclase did not retain much of the crystal structure. The plagioclase altered much more rapidly than the pyroxene.

The apatite occurred in small elongated prismatic crystals that have the following optical properties:

1. Colorless.
2. Parallel extinction.
3. Weak birefringence--first order gray.
4. Fracture parallel to basal section.
5. Moderate relief.

The apatite occurred at random throughout the section without any apparent alignment.

The zircon had the following optical properties:

1. Colorless.
2. High relief.
3. Extreme birefringence.
4. Microscopic--sized crystals.

Both primary and secondary magnetite were present. The primary magnetite occurred in anhedral masses and the secondary magnetite occurred in fine grains within the serpentine replaced crystals of pyroxene.

Sample B 9--Schist.

I Megascopic.

A. Dark brown rock with light brown, gray and white streaks through it.

B. Planes of stratification or foliation were present. Possibly a limestone shale, or schist inclusion that had been altered to serpentine.

II Microscopic.

    A. Antigorite.

    B. Calcite in veins.

The antigorite is very fine crystalline except for small veinlets of courser antigorite. The light gray streaks seen in the hand specimen are the course antigorite.

The white streaks that were seen in the hand specimen are calcite.

A thin section made at right angles to the foliation plains showed the antigorite crystals oriented parallel with the foliation planes.

A thin section made parallel to the foliation plane showed no such arrangement.

Sample B 10--Normal Gabbro.

I Megascopic.

    A. Three color zones.

        1. From center out.

            a. Gray with dark brown crystals scattered throughout the gray.

            b. Black with brown and yellow-orange crystals scattered through the black. The yellow-orange crystals appeared to be an alteration of the brown crystals. The brown crystals were more numerous than the yellow-orange.

            c. The black zone gradually graded out to a green color zone where the brown crystals

have mostly altered to yellow-orange.

II Microscopic.

  A. From center out.

    1. Center.

      a. Primary minerals.

        1. Anorthite 57° 75%

          (Partially altered to antigorite)

        2. Augite 20%

          (Partially altered to antigorite

          and magnetite).

        3. Magnetite.

      b. Secondary minerals.

        1. Serpentine.

        2. Magnetite.

    2. Black rim.

      a. Primary minerals.

        1. Augite 5%

        2. Magnetite 5%

      b. Secondary minerals.

        1. Antigorite 70%

        2. Chlorite (pennine). 15%

        3. Magnetite 15%

        4. Limonite stain.

        5. Hematite.

    3. Outer green rim.

      a. Primary minerals.

        1. Magnetite.

b. Secondary minerals.

    1. Antigorite 85%

    2. Magnetite 10%

    3. Calcite 5%

    4. Limonite stain.

    5. Hematite.

The plagioclase altered more rapidly than the pyroxene. The pyroxene was appearently very high in iron.

Two stages of alteration seemed to be present in the plagioclase. The plagioclase in the core was shot through with serpentine and there was also a reaction rim around the inclusion that had completely altered the plagioclase to serpentine.

The pyroxene crystals were partially replaced by magnetite, and limonite stain covered a large part of the remaining crystal outline in many cases.

The plagioclase altered directly to antigorite but the pyroxene altered to pennine first then from pennine to antigorite.

Calcite occurred in the outer green rim as clusters of crystals in and around crystal outlines of augite.

Penninite had the following optical properties.

    1. Color--pale green.

    2. Low birefringence-- first order gray.

    3. Relief higher than antigorite around it.

    4. Interference figure biaxial negatavial with a very small 2v.

Sample B 11--Pyroxenite.

I Megascopic.

    A. Color black with green filing in the spaces between
        the black minerals.

    B. No color rims were apparent.

II Microscopic.

    A. Primary minerals.

        1. Augite 5%

    B. Secondary minerals.

        1. Antigorite 75%

        2. Jenkinsite 20%

        3. Magnetite.

        4. Hematite.

        5. Limonite stain.

        6. Calcite.

The augite had almost completely altered first to chlorite
then to serpentine. There was very little secondary magnetite
associated with the altered augite in comparison with the
altered augite in sample B 10. Hematite was seen around the
borders of the unaltered augite. The magnetite occurred as
fine specks in the chlorite and antigorite.

Augite cleavage lines were preserved in some of the anti-
gorite replaced crystals.

Sample B 12--Pyroxenite.

I Megascopic.

    A. Three distinct color zones.

    1. Center.

        a. Color--green.

        b. Crystalline.

    2. Zone around center.

        a. Color--mostly black with some light green
           crystals intermixed with the black.

    3. Zone around black zone.

        a. Color--yellow-orange with green filling in
           around the yellow-orange.

  B. The color zones do not grade into each other but have
    a sharp dividing line.

II Microscopic.

  A. Center.

    1. Primary minerals.

        a. Augite 95%

    2. Secondary minerals.

        a. Antigorite 5%

        b. Calcite

  B. Black zone.

    1. Primary minerals.

        a. Augite 5%

    2. Secondary minerals.

        a. Bastite 80%

        b. Antigorite 15%

        c. Calcite.

  C. Yellow-orange zone.

1. Secondary minerals.

    a. Antigorite 95%

    b. Limonite stain.

    c. Calcite.

The augite did not show the alteration from augite to chlorite to antigorite that samples B 2, B 10, and B 11 show, but altered first to bastite and then to antigorite. Very little iron was present in the augite unless it was removed as soon as the augite altered to bastite.

The calcite occurred in micro veinlets in all three zones.

X-rays were taken of the black zone and the yellow-orange zone. The films showed the same lines but the film from the yellow-orange zone showed some of the lines very plain that were very weak on the film from the black zone.

SUMMARY OF MINERAL ANALYSIS

List of Minerals

Primary Minerals of Matrix	Transported Minerals of Primary Origin	Secondary in Inclusions and Matrix
Augite (Crystal Outlines in Groundmass)	Augite (in Pyroxenite and Gabbro)	Serpentine (in Both)
Phlogopite (Crystal Plates)	Hornblende (in Gabbro)	Chlorite (in Both)
Ilmenite (An-hedral Masses)	Rutile (in Shale)	Magnetite (in In-clusions and Veins)
Garnet (Anhedral Masses)	Plagioclase (in Gabbro)	Calcite (in In-clusions and Veins)
Calcite?	Magnetite (in Gabbro and Veins)	Limonite (on Mag-netite)
Serpentine?	Garnet (in Gneiss)	Hematite (around Augite in Gabbro)
	Zircon (in Gabbro)	Phlogopite (in Shale Inclusion only)
	Biotite (in Gabbro)	
	Apatite (in Gabbro)	
	Calcite (in Lime-stone)	
	Perovskite (in Gabbro)	
	Serpentine?	

CONCLUSIONS

Many theories have been presented in the literature as to
the genesis of kimberlites and mica peridotites. According to
the data gathered and observations made in relation to the
Riley County plugs, the most plausible explanation from the
author's point of view is that a release in pressure due to
gash fractures, as was suggested by Taylor (1950), caused a

relatively cool pyroxenite or pyroxenite differentiation of a gabbroic magma which had undergone partial serpentinization to well up through the fractures carrying with it fragments of the wall rock through which it passed. Water and serpentine formed a kind of mush which acted as a lubricant.

Sosman (1938) in his discussion of the intrusion-temperature of peridotites states that:

> . . . . . The ceramist is familiar with the artificial intrusion of clay mixes containing relatively little water, especially when certain organic chemicals are added that have a specific plasticizing effect. What is needed is, first, crystals of the right shape, and second, thin films of lubricating liquid separating these crystals, films sometimes only one or two molecular diameters in thickness.

Partial or total serpentinization of the included fragments, depending upon their composition occurred as they were incorporated in the magma. Bowen (1928, p. 197), stated: "Any magma will tend to make inclusions over into the phase or phases with which it is saturated, in so far as the composition of the inclusions will permit." Evidence for the validity of this statement of Bowen's is exemplified by the conversion of shale to serpentine whereas inclusions of limestone are unaffected except for solution effects and for scattered serpentine crystals along bedding plains which probably represent the conversion of the clay impurities in the limestone to serpentine.

Other evidence that gave support to Daly's (1933) contention that serpentinization is a late magmatic stage, lies in the reaction rims around the inclusions found in the plug. The pyroxene inclusions show thicker alteration rims than the gabbro inclusions and the gabbro inclusions show thicker

alteration rims than the gabbro gneiss. In inclusions con-
taining both feldspar and augite, the feldspar has altered more
than the augite. This same phenomenon was pointed out by
Bowen (1928, p. 197), in his analysis of the peridotite of
Skye. Therefore in order for the pyroxene inclusions to
have a thicker alteration rim, it seems logical they must
have undergone more alteration or alteration for a longer
time.

The Bala and Randolph plugs have a finer grained appearance .
than the Leonardville and Stockdale plugs. The Bala and Ran-
dolph have large angular inclusions of limestone while the
Stockdale and Leonardville plugs have small rounded inclusions
that were far more abundant. The inclusions of metamorphic
and igneous rock were rare in the Bala and Randolph plugs.
It seemed reasonable to assume that the Bala and Randolph in-
trusives were exposed nearer the top of the intrusive mass,
whereas the Stockdale and Leonardville represent a lower level
of the same intrusive material.

X-ray studies made on the different zones of alteration of
inclusions, and x-ray studies conducted by others on serpentine
minerals, pointed out the possibility that the different ser-
pentine minerals were very similar except for disorders caused
by strains set up in the crystal structure due to the number of
trivalent ions replacing magnesium (Bates and Mink 1950), or
strains brought about by external physical forces. Nagy and
Bates (1950) by experiment showed antigorite to be more stable

than chrysotile. Therefore the presence of trivalent ions seems to decrease the structural strain. Verde antique, bastite, antigorite after it had been ground for $43\frac{1}{2}$ hours, and an inclusion showing schistose structure gave the same general defraction pattern (Plate II). This seemed to indicate that physical force from the outside can create stresses within the crystal to produce the same effect as the presence or absence of trivalent ions.

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THE PETROLOGY AND PETROGRAPHY OF THE IGNEOUS

ROCKS OF RILEY COUNTY, KANSAS

by

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A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology

KANSAS STATE COLLEGE

OF AGRICULTURE AND APPLIED SCIENCE

1953

ABSTRACT

There are five serpentinized igneous intrusions in Riley County, Kansas. In the groundmass of the serpentine are many inclusions of sedimentary, metamorphic and igneous rocks that have been carried up by the magma from formations through which it has passed. The inclusions give the rock a brecciated appearance.

A thin section analysis shows the following minerals:

Primary Minerals of Matrix	Transported Minerals of Primary Origin	Secondary in Inclusions and Matrix
Augite (Crystal Outlines in Groundmass)	Augite (in Pyroxenite and Gabbro)	Serpentine (in Both)
	Hornblende (in Gabbro)	Chlorite (in Both)
Phlogopite (Crystal Plates)	Rutile (in Shale)	Magnetite (in Inclusions and Veins)
Ilmenite (Anhedral Masses)	Plagioclase (in Gabbro)	Calcite (in Inclusions and Veins)
Garnet (Anhedral Masses)	Magnetite (in Gabbro and Veins)	Limonite (on Magnetite)
Calcite?	Garnet (in Gneiss)	Hematite (around Augite in Gabbro)
Serpentine?	Zircon (in Gabbro)	Phlogopite (in Shale Inclusion only)
	Biotite (in Gabbro)	
	Apatite (in Gabbro)	
	Calcite (in Limestone)	
	Perovskite (in Gabbro)	
	Serpentine?	

Serpentinization can occur from either internally or externally derived waters. The serpentinization of the Riley County intrusive was attributed to internally derived water which acted as a lubricating mechanism at a late magmatic stage.

The magma was believed to have been intruded at low temperatures and serpentinization was believed to have already begun before intrusion. The original material was probably a pyroxenite or a pyroxenite differentiation of a gabbroic magma.

The different serpentine minerals are probably textural varieties of the same mineral. The texture is determined by the strain set up in the crystal structure by the presence or absence of trivalent ions replacing magnesium, or stresses caused by external physical forces.