XENOLITHS IN THE ORGAN BATHOLITH, NEW MEXICO

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With a Morphological Description of Diopside Crystals

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CONTENTS

INTRODUCTION

The Organ Mountains lie on the east side of the Rio Grande in Southern New Mexico, east of the town of Las Cruces. During 1933–1935 they were the object of a field study, the results of which will shortly appear.[1] In the course of mapping the Tertiary batholith from which the most spectacular part of the range has been carved, several groups of large accidental xenoliths were discovered, among which the most interesting proved to be those situated near South Canyon on the east side of the mountains, 15 miles by desert road south of San Agustin Pass. The present note is concerned mainly with the geology and mineralogy of these xenoliths, which are of special interest to mineralogists because of the presence in some of them of well-crystallized green diopside, associated with the chrome-garnet uvarovite.

Dr. M. A. Peacock has kindly undertaken a morphological study of the diopside crystals, and a summary of his results is included in this paper. The writer wishes to express his gratitude to him, and also to Professors Palache and Larsen for laboratory facilities at Harvard University, where the petrographic examination of the material was carried out.

GENERAL GEOLOGY

The following is a brief outline of the geology of the Organ Mountains:

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[1] Dunham, K. C., The geology of the Organ Mountains, *N. Mex. Sch. Mines, State Bur. Mines Min. Res.*, Bull. **11**, 1936.

On the east side of the range are exposed Pre-Cambrian granites containing masses of schist, gneiss and quartzite. The granites are cut by epidiorite dikes, also of Pre-Cambrian age, which were probably intruded as diabases, but which have suffered metamorphism to oligoclase-amphibolites. Resting on the crystalline basement there is a succession of sedimentary rocks including the Bliss sandstone (Cambrian), the El Paso and Montoya formations (Ordovician), the Fusselman formation (Silurian), the Percha shale (Devonian), the Lake Valley limestone (Mississippian) and the Magdalena limestone series (Pennsylvanian). The Ordovician and Silurian rocks consist almost wholly of "formational" dolomites, while the post-Devonian calcareous rocks are calcitic limestones. Late Cretaceous or Tertiary lavas overlie an eroded surface of Pennsylvanian rocks; they include rhyolite-tuffs, rhyolites and andesites. Following the outpouring of the lavas came the intrusion of a composite batholith in which there were three major intrusive phases: (1) dark monzonite, (2) quartz monzonite, (3) quartz-bearing monzonite. The batholith visibly cuts across all earlier formations from the Pre-Cambrian rocks to the lavas. It is considered to have been emplaced by stoping, a conclusion which is supported by the presence in it of large masses of the country rock. There appears to have been a progressive concentration of volatile fluxes and hyperfusibles during the intrusive cycle, for while phase (2) was able to bring about metamorphic effects involving only limited metasomatic changes in the rocks engulfed in and adjacent to it, phase (3) gave rise to intense metasomatism in the rocks bordering on it, during which silicates and metallic sulphides and tellurides were introduced. The effects to be described in this note are related only to phase (2); a more complete account of the Tertiary metamorphism will be found in the publication mentioned above.

The South Canyon Xenoliths

Accidental inclusions. On the south side of South Canyon, xenoliths of granite, epidiorite, shale, dolomite and limestone are found enclosed in the quartz monzonite (intrusive phase 2). Their lithology, as seen in the field, is so little modified that no hesitation is felt in assigning their origin to the formations into which the batholith was intruded. The accompanying map (Fig. 1) shows the distribution and character of the xenoliths. They vary in length from about 50 feet to over 2000 feet; there is a remarkable lack of smaller accidental inclusions, though small cognate xenoliths, derived from the dark monzonite (intrusive phase 1) are found in the quartz monzonite. The former character of the sedimentary inclusions is evident from their texture and from the minerals which have been developed in them by metamorphism.

The granite inclusions on the southeast side of the ridge have suffered no alteration; evidently the minerals were stable in the thermal and chemical environment of the quartz monzonite magma. Epidiorite dikes cutting through the granite inclusions, however, have been profoundly

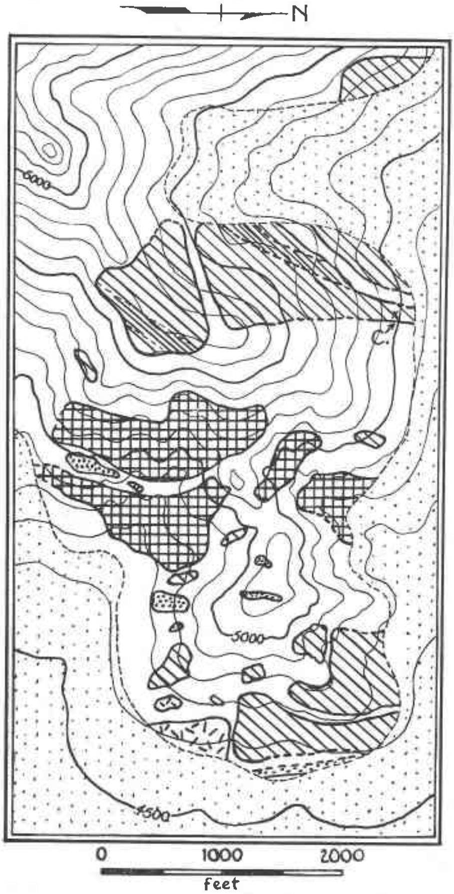

FIG. 1. Geologic Map of the ridge south of South Canyon, Organ Mountains.
Unshaded areas, quartz monzonite.
Diagonal shading, limestone xenoliths, possibly containing some magnesian beds at the east end of the ridge.
Closed-spaced diagonal shading, shale-limestone xenoliths.
Cross shading, dolomite xenoliths.
Irregular shading, Pre-Cambrian granite and epidiorite.
Heavy stipple, quartzite xenoliths.
Light stipple, alluvium.
Contour interval, 100 feet.

changed. In areas remote from the metamorphosing influence of the Tertiary batholith, the epidiorites consist of oligoclase in lath-shaped crystals which were formerly more calcic (as shown by remnants of feldspar ranging from labradorite to andesine, and by their shape), with secondary hornblende and actinolite. The metamorphism of these dikes, from diabase to epidiorite, is believed to have taken place prior to the Tertiary intrusive cycle, and to bear no relation to this cycle. After further metamorphism of the epidiorite in the xenoliths by the quartz monzonite there were developed irregular masses of andesine, $Ab_{68}An_{32}$, and streaks of colorless pyroxene with the following optical properties: Biaxial positive; $2V=60°$; $\alpha=1.680$, $\beta=1.689$, $\gamma=1.708$; maximum extinction against the (110) cleavage, 43°. In one specimen examined microscopically, pleochroic blue apatites up to 3 mm. long were noted. Clinozoisite is locally present in these rocks, and magnetite grains are abundant.

The quartzites show little alteration in the South Canyon area, but further north, in Rucca Canyon, quartzite xenoliths containing blue lazulite, andalusite, rutile and muscovite were found.

The dolomite xenoliths have been uniformly converted into brucite-marble and brucite-serpentine marble. Three stages in the metamorphism of these inclusions may be recognized. In pure dolomites, the first stage was the production of periclase, which is still fairly abundant in the large brucite marble masses south of the crest of the ridge shown in Fig. 1. It occurs in small idiomorphic crystals ($n=1.740$) which stand out in bold relief against the carbonate matrix. In siliceous dolomite beds, the magnesia and silica combined during the first stage to give rise to forsterite, which occurs in colorless crystals with the following optical properties: Biaxial, $2V=90°$, $\alpha=1.637$, $\beta=1.665$, $\gamma=1.672$; no cleavage. The El Paso formation contains siliceous streaks, possibly the remains of sea weed. Streaks identical in appearance with these are found in the xenoliths, but they consist not of silica but of forsterite, with some associated ferruginous material. The conversion of the $MgCO_3$ in the dolomite to periclase and forsterite seems to have been remarkably complete, since the carbonate matrix now consists of calcite ($\gamma=1.660$).

The second stage of metamorphism brought about the partial hydration of the periclase to brucite, which in rosette-like aggregates is now the most abundant new mineral of the xenoliths. Forsterite was partly converted into serpentine. Later than these changes, the third stage of metamorphism led to the production locally of lenticular bodies of magnesite from the brucite-serpentine marble.

The shale specimens examined exhibit only slight evidence of alteration. The clay material has apparently been converted into white mica, which occurs in bands of different grain size. There is no evidence of directional orientation of the mica.

The limestone inclusions, probably derived from the Carboniferous series, present more variety in composition than the dolomites. New minerals therefore tend to be restricted to certain beds in the xenoliths, while other beds contain only recrystallized calcite. The diopside and uvarovite occur in one such bed, in the large inclusion at the west end of the ridge shown on Fig. 1. An excavation at the point marked "C" on the map has exposed the bed, which is about 2 feet thick, and which dips 70° west and strikes N.15°E. In material from this pit, wollastonite, white mica and green diopside were found in thin sections. The diopside has grown partly in coarse white calcite, and partly in narrow open cavities; it has developed excellent crystals, which are described in the next section. Further south, apparently in the same bed, small emerald green crystals of uvarovite are abundant. This mineral has a refractive index exceeding 1.85; in thin section its green color is very noticeable, and in crossed polarized light it is found to be feebly birefringent, giving a gray interference color. One specimen shows its relation to grossularite and diopside, with which it is associated. The grossularite crystals ($n=1.731$) are about 2 mm. in diameter and are nearly free from inclusions. They have not developed crystal faces, but are surrounded by a fine-grained intergrowth of uvarovite and diopside. Veinlets of colorless apophyllite traverse this rock.

Other beds in the limestone xenoliths contain grossularite, wollastonite, diopside and tremolite.

Contamination of the intrusive rock. Specimens of the quartz monzonite taken near its contact with the dolomite xenoliths failed to show any abnormal features; the normal minerals of the rock, oligoclase, orthoclase-perthite, biotite and quartz were present in their usual proportions. It appears then, that there was no tendency for the magnesia to combine with the magma to produce new minerals. At many points near the limestone xenoliths, no change could be detected, but between the limestone and granite xenoliths at the east end of the ridge, an area of contaminated monzonite was found. Here the minerals consist of oligoclase and orthoclase-perthite, both apparently crystallized earlier than the exotic minerals. A zonal intergrowth of quartz and a birefringent garnet ($n=1.800$) followed; this intergrowth is believed to have developed at the time when quartz would normally have been crystallizing in the igneous rock. Fibrous actinolite also occurs.

Theoretical considerations. The results of the metamorphism of the xenoliths are summarized in the accompanying table:

	Before Metamorphism	After Metamorphism
Granite	Orthoclase Quartz Biotite	No change
Epidiorite	Hornblende Actinolite Oligoclase or Andesine Magnetite	Augite, Apatite, Andesine, Clinozoisite, Magnetite
Quartzite	Quartz Glauconite Clay material	Quartz, Lazulite, Andalusite, Rutile, White mica
Dolomite	Pure dolomite Siliceous dolomite	Periclase, Brucite (Magnesite), Forsterite, Serpentine, Periclase, Brucite (Magnesite)
Limestone	Calcite, Silica	Wollastonite, Grossularite, Diopside, Uvarovite, Apophyllite
Shale	Clay material	White mica

This table shows that the constituents necessary for making most of these minerals are already available in the rocks undergoing metamorphism. In a general way the changes may be classed as due to "thermal metamorphism" in the sense of Harker;[2] however, the evidence indicates clearly that water has played its part in the process, and while it is not necessary to postulate wholesale introduction of silica, there may well have been some migration of this substance. This process, with the elimination of carbon dioxide and the addition of water, has undoubtedly brought about substantial changes in composition, and it is clearly impossible to draw a rigid distinction here between thermal metamorphism and metasomatism.

In the case of the chromium, there can be little doubt that it was introduced from the magma; uvarovite must be classed as metasomatic. As far as the writer is aware, the only other example of chromium minerals developed from solutions arising from a granitic (rather than a gabbroic) magma, is that recently described by Eskola from Outokumpu, Finland.[3] The occurrence lends confirmation to Sampson's view that chromium may appear as a constituent of hydrothermal solutions.[4]

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[2] Harker, A., *Metamorphism*, London, **1932**, pp. 7, 14–18.

[3] Eskola, P., On the Chrome minerals of Outokumpu: *Bull. Comm. Géol. Finlande*, **103,** pp. 26–44, 1933.

[4] Sampson, E., Varieties of chromite deposits: *Econ. Geol.*, vol. **26**, pp. 833–839, 1931.

At the level in the earth's crust at which the magma consolidated, probably a shallow one, there was no quantitatively important assimilation of the limestone and other included rocks. The local development of garnet in the quartz monzonite is evidence of only feeble contamination. The evidence here described provides no solution to the riddle of the fate of the vast quantity of sedimentary and igneous material which was removed by stoping to make room for the batholith.

GREEN DIOPSIDE

Morphology. The diopside from the limestone inclusions occurs in drusy crusts of close-set olive-green crystals 1–3 mm. in diameter and in single yellow-green crystals, up to 12 mm. across, emplanted on the calcite matrix. The smallest crystals are suitable for exact measurement on the goniometer. The following forms were determined on three crystals which are representative of the occurrence: *c*(001), *b*(010), *a*(100), *m*(110), *z*(021), *p*($\bar{1}$01), *u*(111), *s*($\bar{1}$11), *o*($\bar{2}$21), λ($\bar{3}$31), *I*($\bar{2}$11), γ($\bar{1}$51). The followlowing two-circle angles measured on one twin crystal are in very close agreement with Goldschmidt's[5] calculated angles for diopside:

Forms	No. of faces	Measured		Calculated	
		φ	ρ	φ	ρ
b 010	2	0°00′	90°00′	0°00′	90°00′
a 100	2	89 59	90 00	90 00	90 00
m 110	4	43 34	90 00	43 33	90 00
z 021	4	13 32	50 34	13 32½	50 29
s $\bar{1}$11	2	−25 14	33 05½	−25 07½	33 04
o $\bar{2}$21	1	--35 07	55 21	−35 22	55 19½
γ $\bar{1}$51	2	−5 18	71 25	− 5 21½	71 20

The twelve forms observed are all among the well-known forms of monoclinic pyroxene and, except for *I*($\bar{2}$11), they are among the commoner forms of this form-rich species. Figures 2 and 3 illustrate typical crystals which closely approach the ideal symmetry of the drawings. Single crystals (Fig. 2) are few; most of the crystals are contact twins (Fig. 3) after the common pyroxene law: twinning by reflection in (100) with composition on this plane. The crystals do not vary greatly in habit. In the prism zone *m* is large, *a* and *b* narrower; on the terminations *c z u s o* γ are commonly present; *p I* λ are rare. Figure 4 is a gnomonic projection of the observed forms; it shows that the common form γ($\bar{1}$51), with its complex symbol and small reticular density, is in simple zonal relation to the principal forms.

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[5] *Winkeltabellen*, Berlin, **1897.**