

Summer 6-1-1952

Plenoaste Crystals from an Olivian Basalt, Caballo Mountains, New Mexico

Charles Maxwell

Follow this and additional works at: https://digitalrepository.unm.edu/eps_etds



Part of the [Geology Commons](#)

Recommended Citation

Maxwell, Charles. "Plenoaste Crystals from an Olivian Basalt, Caballo Mountains, New Mexico." (1952).
https://digitalrepository.unm.edu/eps_etds/184

This Thesis is brought to you for free and open access by the Electronic Theses and Dissertations at UNM Digital Repository. It has been accepted for inclusion in Earth and Planetary Sciences ETDs by an authorized administrator of UNM Digital Repository. For more information, please contact disc@unm.edu.

378.789

Un 3 Omax

1952

cop. 2

THE UNIVERSITY OF CHICAGO
PRESS

THE LIBRARY
UNIVERSITY OF NEW MEXICO



Call No.

378.789

Un30max

1952

cop.2

Accession
Number

175635

A14410 157747

DATE DUE

MAY 21 1978

10.51 NON ANTILUS

REC'D FROM MAY-478

MAY 21 2003

REC'D FROM MAY-778

MAY 14 2003

DEC 14 02

FROM: ION TO:

Txu

ILL #

252870

PATRON:

Haffer

2 WEEKS USE

SHIPPED:

2/16/84

FROM ION TO:

NMS-Silver City

ILL #:

4806355

PATRON:

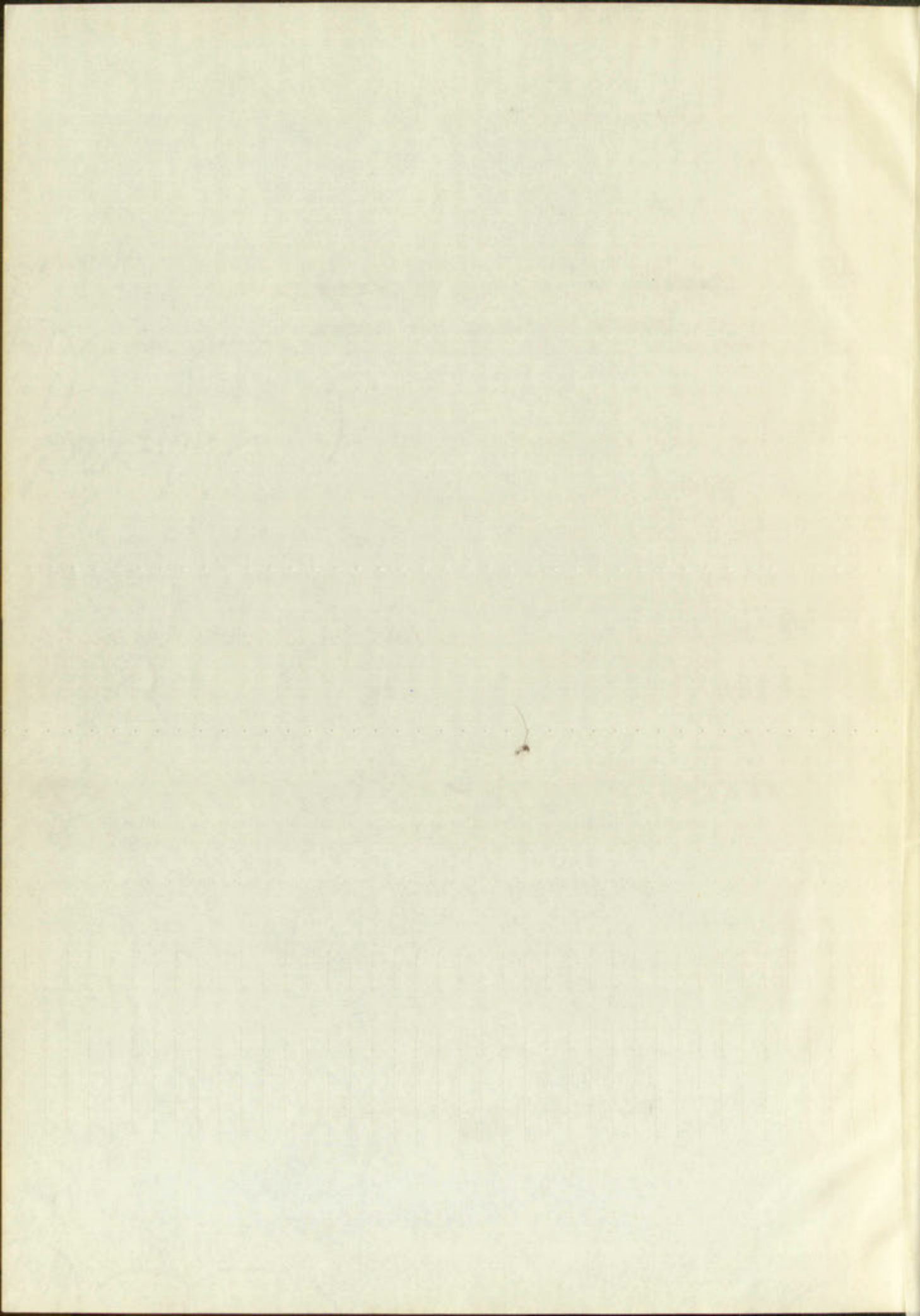
RON

WEEKS USE:

2+

SHIPPED:

10/29



UNIVERSITY OF NEW MEXICO LIBRARY

MANUSCRIPT THESES

Unpublished theses submitted for the Master's and Doctor's degrees and deposited in the University of New Mexico Library are open for inspection, but are to be used only with due regard to the rights of the authors. Bibliographical references may be noted, but passages may be copied only with the permission of the authors, and proper credit must be given in subsequent written or published work. Extensive copying or publication of the thesis in whole or in part requires also the consent of the Dean of the Graduate School of the University of New Mexico.

This thesis by Charles Maxwell
has been used by the following persons, whose signatures attest their acceptance of the above restrictions.

A Library which borrows this thesis for use by its patrons is expected to secure the signature of each user.

| <u>NAME AND ADDRESS</u> | <u>DATE</u> |
|-------------------------|-----------------|
| <i>Peter F. ...</i> | <i>11/4/68</i> |
| <i>...</i> | <i>4/24/78</i> |
| <i>Anita Keller</i> | <i>11/20/82</i> |

MANUSCRIPT LABEL

Unpublished manuscripts of the author, and those of his
associates, deposited in the University of New Mexico Library, are
open for inspection, but not to be loaned out, and the right to the
right of the author, his heirs, assigns, or executor, or to the
publisher, may be copied only with the permission of the author, and
proper credit must be given in any reproduction. No part of this
document may be reproduced in any form or by any means, electronic or
mechanical, including photocopying, recording, or by any information
storage and retrieval system, without the permission in writing of the
University of New Mexico.

Manuscript No. _____

This book by _____
has been used by the following persons whose names are attached
in recognition of the above mentioned

A library which borrows this book for use in its
expected to return the signature of the user

NAME AND ADDRESS _____ DATE _____

[Faint, illegible handwritten signatures and text in the lower half of the page.]

Pleonaste Crystals from an Olivine Basalt,
Caballo Mountains, New Mexico.

by Charles Maxwell

A thesis
in partial fulfillment
of the requirements
for the Degree of
Master of Science
in Geology

The University of New Mexico
1952

Plasmids Synthesized from an *Escherichia coli* Plasmid
Labeled with ³²P-Phosphate



by Charles S. G. Owen

A thesis
in partial fulfillment
of the requirements
for the degree of
Master of Science
in Biology

The University of New Mexico
1962

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

E. Wastetter

DEAN

6/2/52

DATE

Thesis committee

Carl W. Beck

CHAIRMAN

V. G. Kelly

J. Paul Fitzsimmons

This report should be approved by the committee's chair
and has been prepared by the committee members of the
Committee on New York in regard to the situation of the
state for the year.

LETTER OF REPLY

[Faint handwritten signature]

[Faint handwritten signature]

The committee

[Faint handwritten signature]
[Faint handwritten signature]
[Faint handwritten signature]

FOR THE BOARD

378.789
Un30max
1952
cop. 2

CONTENTS

| | Page |
|-------------------------------|------|
| TABLES | 11 |
| PLATES | 111 |
| INTRODUCTION | 1 |
| Location and Accessibility | 1 |
| Physiography | 1 |
| Discovery and Utilization | 2 |
| Methods of Study | 3 |
| Acknowledgments | 3 |
| GENERAL GEOLOGY | 4 |
| PETROGRAPHY OF THE FLOW ROCKS | 9 |
| MINERALOGY OF PLEONASTE | 21 |
| Crystallography | 21 |
| Physical Properties | 21 |
| Structural Crystallography | 30 |
| X-ray Data | 30 |
| Composition and Cell Content | 33 |
| Optical Properties | 35 |
| THEORETICAL CONSIDERATIONS | 36 |
| CONCLUSIONS | 41 |
| REFERENCES | 42 |

175635

312184
1952
copy

CONTENTS

1
1
1
2
3
3
4
5
5
21
21
23
23
25
25
26
26
27

| | |
|--|-------------------------------|
| | INTRODUCTION |
| | Location and Accessibility |
| | Physiography |
| | Discovery and Utilization |
| | Methods of Study |
| | Acknowledgments |
| | GENERAL GEOLOGY |
| | PETROGRAPHY OF THE FLOW ROCKS |
| | MINERALOGY OF TROUSERS |
| | Crystallography |
| | Physical Properties |
| | Structural Crystallography |
| | X-ray Data |
| | Composition and Cell Content |
| | Optical Properties |
| | THEORETICAL CONSIDERATIONS |
| | CONCLUSIONS |
| | REFERENCES |

175025

TABLES

| Table | Page |
|--|------|
| 1 Mode and Classification of the Flow Rocks | 13 |
| 2 Specific Gravities of Several Pleonaste Crystals | 22 |
| 3 X-ray Powder Pattern | 31 |
| 4 Chemical Analysis of Pleonaste | 33 |

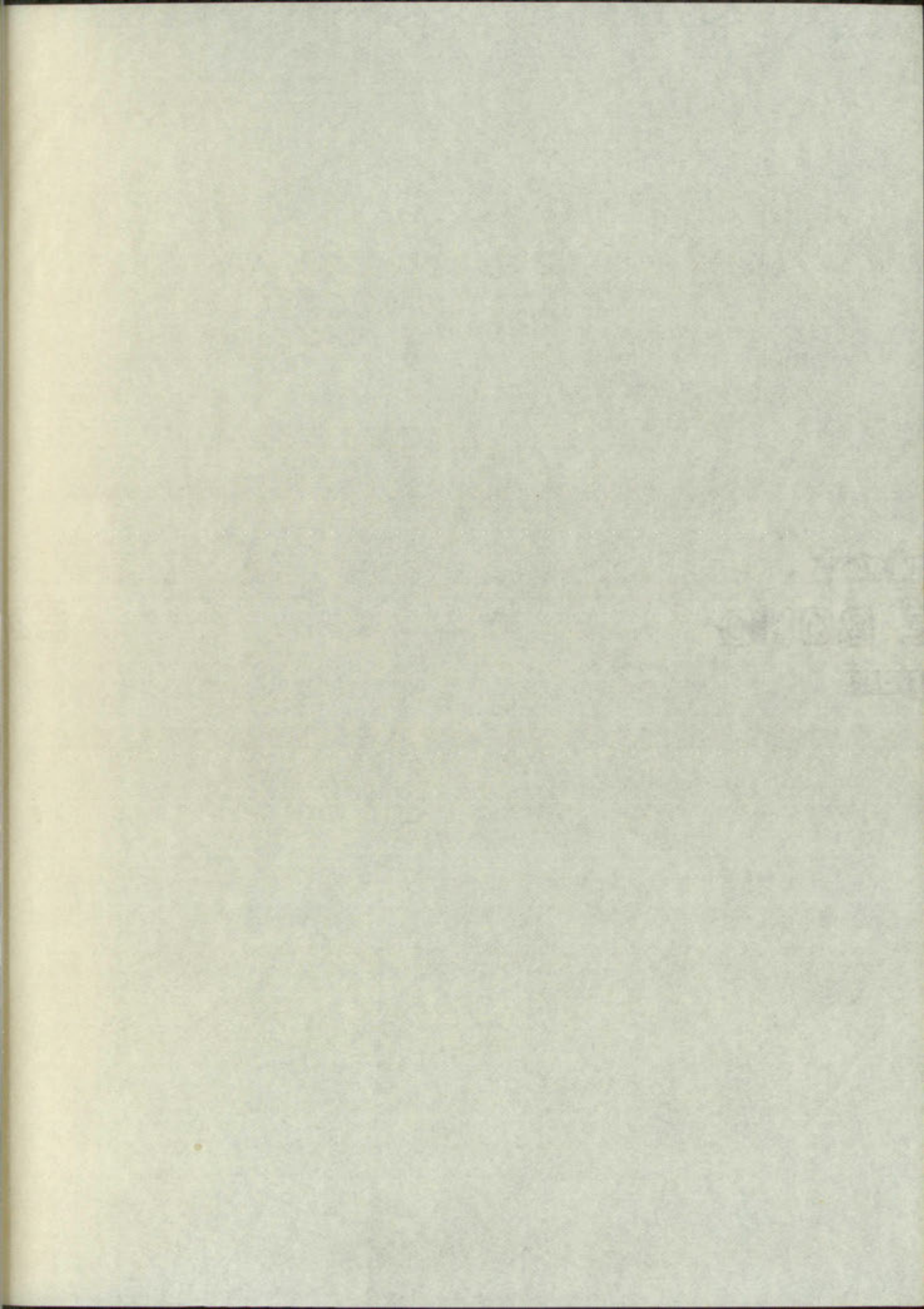
| Page | Table |
|------|--|
| 13 | 1 Mode and Classification of the Flow Rock |
| 25 | 2 Specific Gravities of Several Fissure Crystals |
| 31 | 3 X-ray Powder Pattern |
| 33 | 4 Chemical Analysis of Fissure |

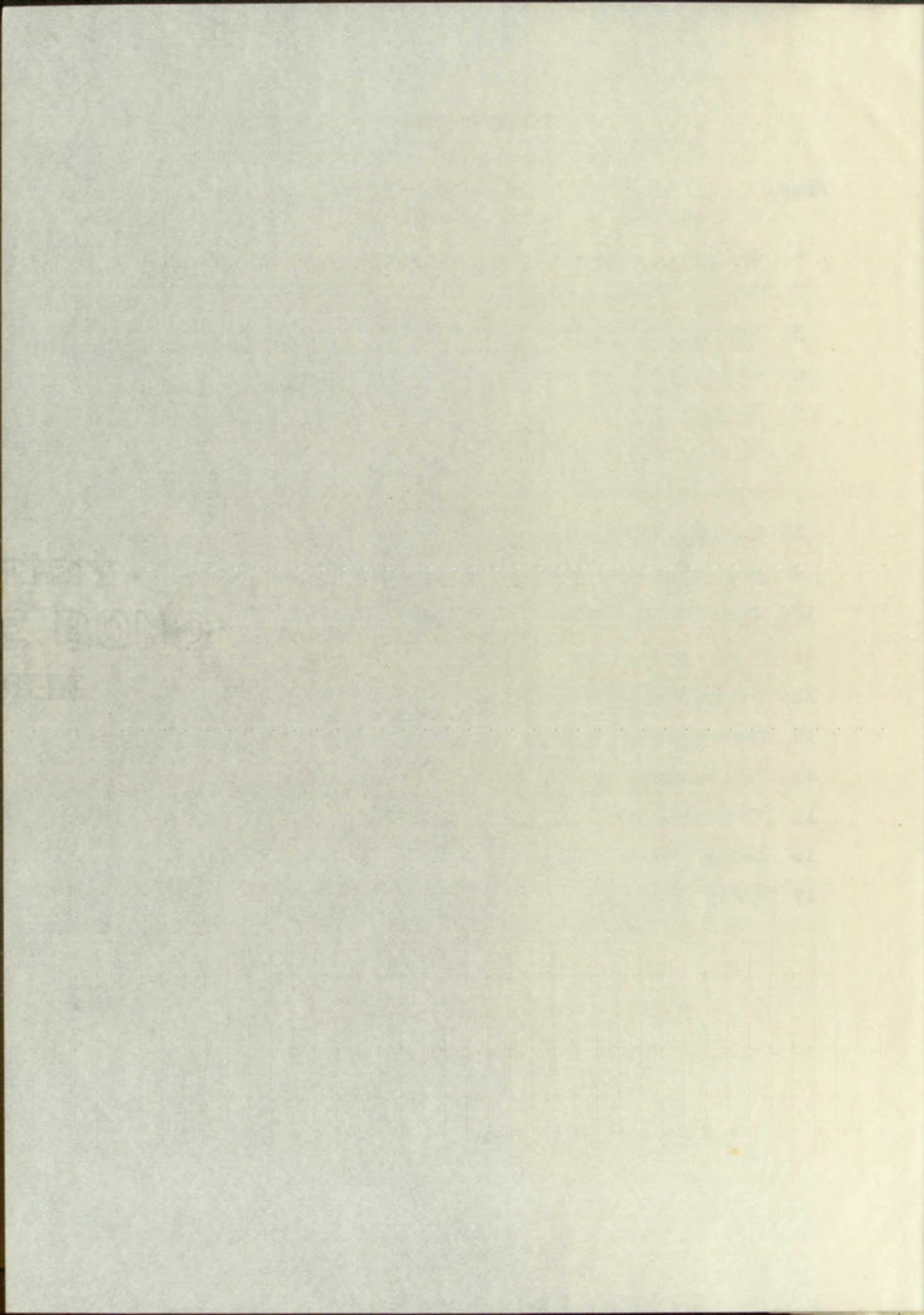
PLATES

| Plate | Following Page |
|--------------------------------------|-------------------|
| 1 Index Map of New Mexico | 6 |
| 2 Geologic Map of Thesis Area | 7 |
| 3 Photographs of Basalt Samples | 14 |
| 4 Photographs of Basalt Samples | 15 |
| 5 Photographs of Basalt Samples | 16 |
| 6 Photographs of Basalt Samples | 17 |
| 7 Photomicrographs of Thin Sections | 18 |
| 8 Photomicrographs of Thin Sections | 19 |
| 9 Photomicrographs of Thin Sections | 20 |
| 10 Drawings of Ideal Crystals | 23 |
| 11 Drawings of Ideal Crystals | 24 |
| 12 Photographs of Pleonaste Crystals | 25 |
| 13 Photographs of Pleonaste Crystals | 26 |
| 14 Photographs of Pleonaste Crystals | 27 |
| 15 Photographs of Pleonaste Crystals | 28 |
| 16 X-ray Powder Photographs | 32 |
| 17 Phase Diagram | 38 |

PLATES

| Plate | Following Page |
|-------|-------------------|
| 1 | 6 |
| 2 | 7 |
| 3 | 14 |
| 4 | 15 |
| 5 | 16 |
| 6 | 17 |
| 7 | 18 |
| 8 | 19 |
| 9 | 20 |
| 10 | 23 |
| 11 | 24 |
| 12 | 25 |
| 13 | 26 |
| 14 | 27 |
| 15 | 28 |
| 16 | 32 |
| 17 | 38 |





INTRODUCTION

Location and Accessibility

The area included in this report comprises about 5 square miles, including parts of Sections 1, 2, 11, 12, 13, 14, 23, and 24, T. 14 S., R. 4 W.; and parts of Sections 6, 7, 18, and 19, T. 14 S., R. 3 W. This area is about $2\frac{1}{2}$ miles southeast of U. S. Highway 85 at the town of Truth or Consequences (Hot Springs), Sierra County, New Mexico, and about 2 miles south of State Highway 52 at the Elephant Butte Dam. A road which leads to Mescal Canyon turns off State Highway 52 at the bridge across the Rio Grande. By following the bed of Mescal Canyon and Salt Canyon (Pl. 2), a point within a mile of the flows can be reached. Mescal Canyon can be followed further to within half a mile of the eastern edge of the flows (Pls. 1, 2).

Physiography

The thesis area lies along the eastern base of North Ridge which forms the northern part of the Caballo Mountains. This ridge rises abruptly, about 1,500 feet, above the considerably dissected lowland on which the area is located. The lowland lies near the head of Mescal Canyon and is dissected into ridges and valleys with a relief of as much as 300 feet. The drainage is east and north into Mescal Canyon (Pl. 2) which joins the Rio Grande just below the Elephant Butte Dam.

INTRODUCTION

Location and Accessibility

The area included in this report comprises about 2 square miles, including parts of Sections 1, 2, 11, 12, 13, 14, 23, and 24, T. 14 S., R. 4 W.; and parts of Sections 6, 7, 18, and 19, T. 14 S., R. 3 W. This area is about 2 1/2 miles southeast of U. S. Highway 82 at the town of Truth or Consequences (Hot Springs), Sierra County, New Mexico, and about 2 miles south of State Highway 25 at the Elephant Butte Dam. A road which leads to Mesas Canyon turns off State Highway 25 at the bridge across the Rio Grande. By following the bed of Mesas Canyon and Salt Canyon (Fig. 1), a point within a mile of the flows can be reached. Mesas Canyon can be followed further to within half a mile of the eastern edge of the flows (Fig. 1, S).

Physiography

The thesis area lies along the eastern base of North Ridge which forms the northern part of the Gallego Mountains. This ridge rises abruptly about 1,500 feet above the considerably dissected lowland on which the area is located. The lowland lies near the head of Mesas Canyon and is dissected into ridges and valleys with a relief of as much as 300 feet. The drainage is east and north into Mesas Canyon (Fig. 1) which joins the Rio Grande just below the Elephant Butte Dam.

Discovery and Utilization

In 1928, two prospectors found some very hard black crystals weathering out of basaltic igneous rocks at the north end of the Caballo Mountains. These crystals caused considerable excitement among the people who saw them; they were certain that the crystals were "black diamonds." Subsequent investigation proved they were not diamonds but a spinel which, with sufficient supply, might replace diamonds in some commercial uses. The financial returns would be small from such a venture and therefore the prospectors abandoned the project. The spinel crystals are scattered through a tough, fine-grained basaltic rock. Mining operations would be difficult, and the number of usable crystals would be small. The good specimens which were recovered were found on the surface of the ground on and near the flows. Even by extensive placer operations no great number of usable crystals could be recovered. At the present time, synthetic spinels with varying physical properties can be manufactured very cheaply. This, of course, makes any attempt at recovery of the natural crystals unfeasible today.

In 1946 the crystals came to the writer's attention, and were collected and identified as pleonaste. The crystals occur in a series of basic lava flows, and several probable dikes. Large crystals of spinel in a flow seemed to be incongruous so a study of the mineral and the flows was undertaken in 1951.

Discovery and Utilization

In 1928, two prospectors found some very hard black crystals weathering out of basaltic igneous rocks at the north end of the Tabala Mountains. These crystals caused considerable excitement among the people who saw them; they were certain that the crystals were "black diamonds." Subsequent investigation proved they were not diamonds but a spinel which, with sufficient supply, might replace diamonds in some commercial uses. The financial returns would be small from such a venture and therefore the prospectors abandoned the project. The spinel crystals are scattered through a tough, fine-grained basaltic rock. Mining operations would be difficult, and the number of usable crystals would be small. The good specimens which were recovered were found on the surface of the ground on and near the river. Even by extensive search operations no great number of usable crystals could be recovered. At the present time, synthetic crystals with varying physical properties can be manufactured very cheaply. This, of course, makes any attempt at recovery of the natural crystals unfeasible today.

In 1946 the crystals came to the writer's attention, and were collected and identified as diamonds. The crystals occur in a series of basaltic flows, and several probable diamonds, large crystals of spinel in a flow seemed to be inconspicuous as a study of the mineral and the flow was undertaken in 1951.

Methods of Study

The mineral was identified by chemical analysis and optical and X-ray properties as pleonaste. The lava flows were studied in thin section with a petrographic microscope.

Subsequent to the beginning of this study similar occurrences of pleonaste were observed in several other localities, two of them a few miles to the north and north-east of the thesis area, and another in the Gabazon Peak area in north-central New Mexico. These localities are marked by stars on the index map (Pl. 1).

Acknowledgments

The writer wishes to gratefully acknowledge the help of the thesis committee, Dr. Carl W. Beck, Dr. J. Paul Fitzsimmons, and Dr. Vincent C. Kelley; especial thanks are due Dr. Beck, under whose direction this thesis was written. The writer acknowledges the assistance of George Brunton in some of the field and laboratory work.

Methods of Study

The mineral was identified by chemical analysis and optical and X-ray properties as diopside. The layers were studied in thin section with a petrographic microscope. Subsequent to the beginning of this study similar occurrences of diopside were observed in several other localities, two of them a few miles to the north and northeast of the thesis area, and another in the Gabon forest area in north-central New Mexico. These localities are marked by stars on the index map (Pl. I).

Acknowledgments

The writer wishes to gratefully acknowledge the help of the thesis committee, Dr. Carl W. Beck, Dr. Paul P. Bickelmann, and Dr. Vincent G. Kelley; special thanks are due Dr. Beck, under whose direction this thesis was written. The writer acknowledges the assistance of George Byrston in some of the field and laboratory work.

GENERAL GEOLOGY

The oldest rock in the mapped area is that of the Magdalena group of Pennsylvanian age. The Magdalena group makes up most of North Ridge immediately to the west of the area. The Magdalena group is about 1,200 feet thick, and consists dominantly of limestone with lesser amounts of shale and sandstone. The Magdalena is overlain by the Manzano group of Permian age, consisting of the Abo formation (550 feet thick), the Yeso formation (750 feet thick), and the San Andres formation (760 feet thick). The Abo is a red-brown formation consisting of shale and sandstone of continental origin. The Yeso consists of tannish-brown siltstone and sandstone, gypsum, and some limestone of both marine and continental origin. The San Andres formation is dominantly a gray marine limestone, but with lesser amounts of shale and sandstone. Disconformably overlying the Manzano group is the Dakota sandstone (250 feet thick), Mancos shale (400 feet thick), and the Mesaverde formation (2,500 feet thick), all of late Cretaceous age. The Dakota sandstone is composed of tan and buff sandstone with a small amount of shale. The Mancos is a greenish shale. The Mesaverde formation consists mostly of alternating sandstone and shale units with local beds of coal.*

The above Paleozoic and Mesozoic formations are generally tilted eastwardly in the mapped area at steep to

*Kelley, V. C., oral communication.

The oldest rock in the region is that of the Madisonian group of Pennsylvanian age. The Madisonian group makes up most of North Ridge immediately to the west of the area. The Madisonian group is about 1,500 feet thick and consists dominantly of limestones with lesser amounts of shale and sandstone. The Madisonian is overlain by the Seneca group of Devonian age, consisting of the two formations (250 feet thick), the York formation (75 feet thick) and the San Antonio formation (700 feet thick). The latter is a red-brown formation consisting of shale and sandstone of continental origin. The York consists of sandstone, shales and sandstone, gypsum, and some limestone of both marine and continental origin. The San Antonio formation is dominantly a gray shaly limestone, with occasional amounts of shale and sandstone. Disturbances overlying the Seneca group is the York shales (250 feet thick), Seneca shales (400 feet thick), and the lower Devonian (2,500 feet thick) all of late Devonian age. The latter sandstone is composed of tan and buff sandstone with a small amount of shale. The latter is a granitic shale. The Niagara formation consists mostly of alternating sandstone and shale with thin local beds of coal.

The above Paleozoic and Mesozoic formations are generally tilted easterly in the region west of them to

moderate angles. In late Pliocene or early Pleistocene time the upturned edges of the older rocks were widely beveled by a pediment which encroached upon the range from the Jornada del Muerto Valley. The basaltic flows containing the pleonaste lie upon this erosion surface near its junction with the mountains (Pl. 2).

The northernmost flows all dip very gently to the east, and the contact between them and the underlying moderately dipping strata is remarkably level and uniform. The several large bodies of lava in this section are fairly uniform in thickness and attitude. They are composed of four separate flows, with a total thickness of about twenty feet--the first flow is three feet thick; the second, six feet; the third, seven feet; and the fourth, about four feet. The top flow is eroded from most of the area, and much of the third flow is gone. The two bottom flows seem to be present in all of the northern outcrops.

In the southern section of the mapped area, in the smaller patches of lava, the contact with the underlying sediments is very irregular and the flows themselves range greatly in thickness and attitude. A number of gentle folds in the lava were apparently caused by a post-flow folding.

An old pediment covers the northernmost flow and a similar remnant covers part of the sediments in the southern part of the area. The present stream gradient is considerably lower and steeper than these old remnants of dep-

moderate angles. In late Eocene or early Miocene
 the the upturned edges of the older rocks were widely
 leveled by a pediment which encroached upon the range from
 the Jornada del Muerto Valley. The basaltic flows contain-
 ing the pinnacles lie upon this erosion surface near the
 junction with the mountains (Pl. 2).

The northernmost flow all dip very gently to
 the east, and the contact between them and the underlying
 moderately dipping strata is remarkably level and uniform.
 The several large bodies of lava in this section are fairly
 uniform in thickness and attitude. They are composed of
 four separate flows, with a total thickness of about twenty
 feet--the first flow is three feet thick; the second, six
 feet; the third, seven feet; and the fourth, about four
 feet. The top flow is eroded from west of the area, and
 much of the third flow is gone. The two bottom flows seem
 to be present in all of the northern outcrops.

In the southern section of the range area, in
 the smaller patches of lava, the contact with the underly-
 ing sediments is very irregular and the flows themselves
 range greatly in thickness and attitude. A number of gen-
 eral folds in the lava were apparently caused by a post-flow
 folding.

An old pediment covers the northernmost flow and
 a similar remnant covers part of the sediments in the south-
 ern part of the area. The present stream gradient is con-
 siderably lower and steeper than these old remnants of dep-

osition which were largely removed and deeply eroded by the rejuvenated streams (Pl. 2).

PLATE 1

Index Map of New Mexico

Stars represent known pleonaste localities outside of
thesis area.

6

condition which were largely removed and finally eroded by the

rejuvenated stream (Pl. 2).

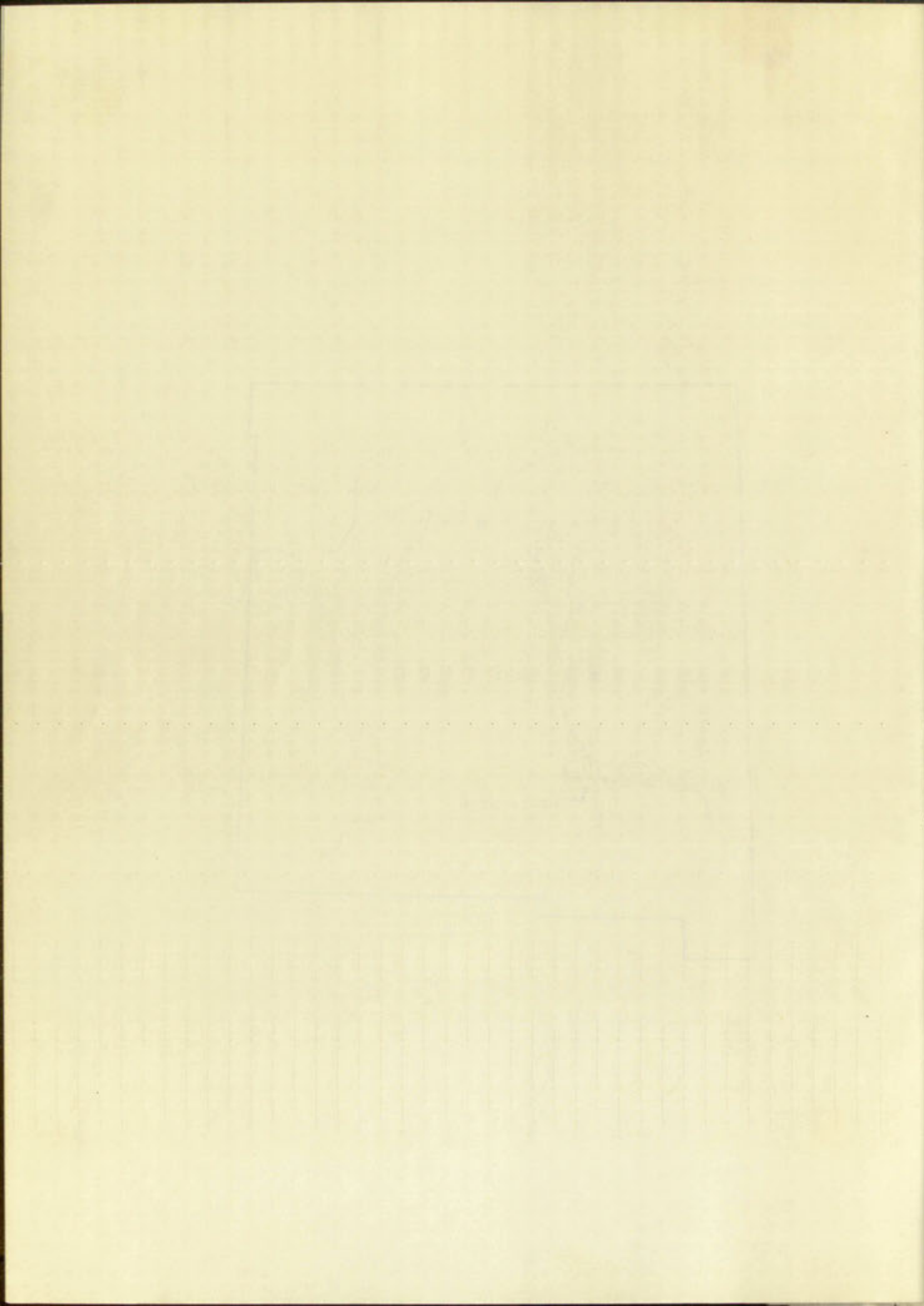
PLATE 1

Index Map of New Mexico

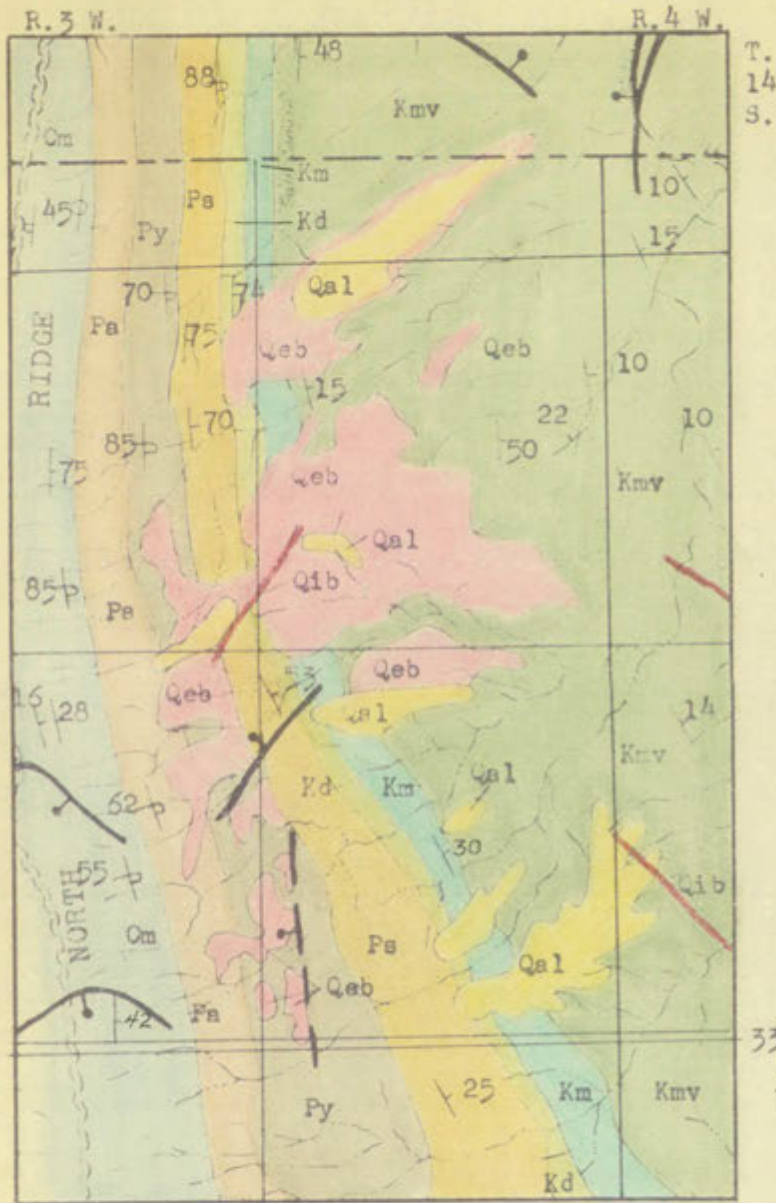
Stars represent known pinnacled locations outside of

Chaco area.



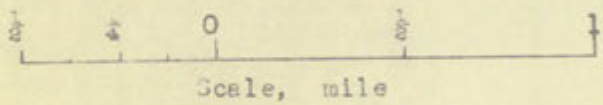


GEOLOGIC MAP OF THESIS AREA



LEGEND

- Horizontal beds
- Strike and dip symbol
- Overturned beds strike and dip symbol
- Contacts
- Covered contacts
- Fault downthrown side
- Fault downthrown side
- Ridge
- Intermittent stream
- Land Grant boundary
- Section lines



33°05'

N

After Kelley, V. C., and Silver, C. (1952)

| | | | | | |
|----|-----------------|----|----------------------|---------|--|
| Cm | Magdalens group | Pa | San Andres formation | Kmv | Mesaverde formation |
| Pa | Abo formation | Kd | Dekota group | Qeb Qib | Quaternary basalt dikes Quaternary basalt flows |
| Py | Yeso formation | Km | Mancos shale | Qal | Quaternary alluvium |

PETROGRAPHY OF THE FLOW ROCKS

Samples of the flow rocks were taken at chosen intervals throughout the thesis area. No attempt was made to delineate and correlate the various flow layers in one part of the area with the flow layers in other parts. A great number of samples were taken; studied under magnifications of 6 to 40 diameters; and divided into five groups on the basis of the appearance of the weathered surface, fresh surface, texture, and those minerals large enough to be seen. Thin sections were made from representative samples of each of the five types, and studied with a petrographic microscope. The modes, or percentages of the mineral components, were calculated by use of a Wentworth stage on the microscope. The linear traverses on a Wentworth stage are proportional to the surface areas, which in turn are proportional to the volumes of the constituent minerals. Following are macroscopic and microscopic descriptions of each sample:

Sample 1 (Pl. 3, Fig. 1).

This rock is dense, dark gray, porphyritic, with phenocrysts composed of yellowish olivine, a black amphibole, and spinel. The groundmass ranges from very fine grained to aphanitic. The phenocrysts range in size from less than 1 mm to as large as 20 mm. in diameter. The surface weathers to a gray-buff color with an earthy appearance.

MINERALOGY OF THE ...

Samples of the ... intervals throughout the ... to delineate and correlate the ... part of the area with the ... great number of samples were taken ... sections of 6 to 10 diameter and divided into ... on the basis of the appearance of the ... fresh surface, texture, and those ... be seen. Thin sections were made ... pins of each of the five types, and ... graphic microscope. The ... areal components, were calculated by use of a ... stage on the microscope. The linear ... worth stage are proportional to the ... in turn are proportional to the ... minerals. Following are ... tions of each sample:

Sample 1 (Pl. 3, Fig. 1)

This rock is ... phenocrysts composed of ... hole, and spiral. The ... ground to spherulitic. The ... less than 1 mm to as large as 10 mm in diameter. The ... face weather to a grey-buff color with an ...

Thin-section studies showed a groundmass of glass and unidentifiable crystallites around randomly oriented, twinned plagioclase laths, giving the rock a felty or hyalophitic texture. Many small grains of augite and hornblende occur in the groundmass, and some of the larger grains show a core of olivine. Many small grains of an opaque mineral, probably magnetite, are usually associated with the olivine, augite and hornblende grains. Large euhedral and subhedral olivine phenocrysts have a corona of serpentine, and most of the cracks contain serpentine (Pl. 7, Fig. 1). Small grains, usually single crystals, of anhedral nepheline occur near the rims of the olivine phenocrysts, and occasionally scattered through the groundmass. The occasional phenocrysts of augite are dark greenish-brown with a darker brown pleochroic halo of hornblende. The spinel occurs as large euhedral and subhedral grains with sharp boundaries, dark emerald green in the center and lighter green around the edges. They exhibit two prominent directions of parting at angles of 90 degrees (Pl. 7, Fig. 2). The mode of this rock is given in table 1.

In Johannsen's classification, sample would be 3316E, which is unnamed. The hypabyssal equivalent (3316H) is madeirite (Johannsen, Vol. IV, pp. 69, 73-74).

Sample 2 (Pl. 3, Fig. 2; Pl. 4, Figs. 1a, 2).

This rock is fine grained, porphyritic, vesicular, dark gray-brown, with phenocrysts of black pyroxene, spinel

This section shows a number of grains

and unidentifiable crystallites brownish, rounded, twinned diagenetic form, giving the rock a fairly regular optical texture. Many small grains of quartz and feldspar occur in the groundmass, and some of the larger grains show a core of olivine. Many small grains of quartz, probably magnesian, are usually associated with the olivine, and nepheline grains. Large subhedral and euhedral olivine phenocrysts have a nucleus of quartz, and some

of the cracks contain serpentine (Fig. 1, p. 10). Small grains, usually single crystals, of subhedral nepheline occur near the rims of the olivine phenocrysts, and occasionally

scattered through the groundmass. The occasional phenocrysts of quartz are dark greenish-brown with a slightly brown pleochroic halo of nepheline. The optical texture is large euhedral and subhedral grains with sharp outlines, dark emerald green in the center and lighter green toward the edges. They exhibit two prominent directions of twinning at angles of 90 degrees (Fig. 1, p. 10). The mode of this rock is given in Table 1.

In Johnson's classification, nepheline is a nepheline (Johnson, Vol. 1, p. 13-14).

Sample 2 (Fig. 2, p. 11, A, Fig. 1, p. 10). This rock is fine grained, porphyritic, vesicular, dark gray-brown, with phenocrysts of black quartz, which

and yellow-brown olivine. The phenocrysts range in size from less than 1 mm to 20 mm in diameter. The vesicles are small, irregular, and elongate in one direction. This rock weathers to a buff-colored, earthy, porous mass.

Thin section studies showed a groundmass of crystallites and microlites of plagioclase around randomly oriented, twinned plagioclase laths, similar to sample 1. Many small grains of augite and hornblende occur in the groundmass, some with cores of olivine. Nepheline is common, and there are minor amounts of riebeckite, clinoenstatite, aegirine, analcime and biotite. The nepheline is found in large aggregates, usually adjoining the olivine phenocrysts, and is composed of small anhedral grains with a random orientation. A small percentage is in single grains in the groundmass (Pl. 9, Figs. 1, 2). The minor accessories are in small grains scattered through the groundmass. The mode of this rock is given in table 1.

In Johannsen's classification, sample 2 would be the effusive equivalent of kyllite (3320P) (Johannsen, Vol. IV, p. 226), which would be similar to Lehman's atlantite (3320E) (Johannsen, Vol. IV, p. 240).

Sample 3 (Pl. 4, Figs. 1b, 1c; Pl. 5, Figs. 1, 2).

This rock is medium to dark brown, porphyritic, vesicular, fine grained to aphanitic, with small phenocrysts of olivine and spinel and an occasional phenocryst of pyroxene. There are a few large, euhedral crystals of spinel in

and yellow-brown olivine. The olivine grains are
from less than 1 to 10 microns in diameter. The olivines
are small, irregular, and elongate in one direction. This
rock weathers to a buff-colored, earthy, porous mass.

This section shows a groundmass of
crystallites and aggregates of plagioclase which are
oriented, curved plagioclase forms, similar to sample 1.
Many small grains of quartz and orthopyroxene occur in the
groundmass, some with cores of olivine. Pyroxene is com-
mon, and there are small amounts of clinopyroxene, albite,
actinolite, epidote, anorthite and biotite. The epidote is
found in large aggregates, usually replacing olivine
phenocrysts, and is composed of small angular grains with
a random orientation. A small amount of zircon is also
found in the groundmass (cf. 9, 10, 11, 12). The olivine
phenocrysts are in small grains scattered through the ground-
mass. The mode of this rock is given in table 1.

In Johnson's classification, sample 2 would be
the olivine equivalent of basalt (35502) (Johnson, 1951,
IV, p. 256), which would be similar to Lewis's androite
(33202) (Johnson, Vol. IV, p. 256).

Sample 3 (Fig. 1, Plate 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100)

This rock is similar to dark brown, vesicular,
vesicular, fine grained andesite, with small phenocrysts
of olivine and clinopyroxene and occasional phenocrysts of pyrox-
ene. There are a few large, subhedral crystals of olivine in

this rock (Pl. 13, Figs. 1, 3b; Pl. 14, Figs. 1b, 1c; Pl. 15, Figs. 1, 2).

Thin sections of this rock show textures and minerals similar to those of sample 1. The augite and hornblende are more prominent and more widely scattered through the groundmass; the phenocrysts are, in general, smaller and the olivine shows a greater amount of alteration to serpentine and hornblende on the larger phenocrysts, and to hornblende and augite on the smaller grains. There is a greater percentage of larger grains of opaque minerals. There is also a higher percentage of glass. The mode of this rock is given in table 1.

Johannsen's classification of this rock would be 3316E, the same as sample 1.

Samples 4 and 5 are of this same rock at different orientations. The descriptions and modes are the same.

Sample 6 (Pl. 4, Fig. 1d; Pl. 6, Fig. 1).

This sample is a gray and light brown rock which weathers to a mottled rich brown and light gray; otherwise it is the same as sample 3.

The thin sections are identical with those of samples 3, 4, and 5.

Sample 7 (Pl. 6, Fig. 2).

This sample is a dark brown, vesicular, aphanitic to fine grained rock which grades into scoria in places. The scoria weathers to a medium brown, and the vesicular

This rock (Pl. 1, Fig. 1, Pl. 12, Misc. 1, 2)

Pl. 1, Fig. 2

Thin sections of this rock show textures and minerals similar to those of sample 1. The amphibole and hornblende are more prominent and more widely scattered through the groundmass; the plagioclase are, in general, smaller and the olivine about a greater amount of alteration in serpentine and hornblende on the larger grains, and to hornblende and mica on the smaller grains. There is a greater percentage of angular grains of opaque minerals. There is also a higher percentage of glass.

The mode of this rock is given in table 1.

Johannsen's classification of this rock would be

3335, the same as sample 1.

Samples 4 and 5 are of this same rock as follows and orientations. The description and notes are the same.

Sample 6 (Pl. 4, Fig. 1; Pl. 6, Fig. 1)

This sample is a gray and light brown rock which weathers to a mottled rich brown and light gray, otherwise it is the same as sample 3.

The thin sections are identical with those of

samples 3, 4, and 5.

Sample 7 (Pl. 6, Fig. 2)

This sample is a dark brown, weathering, somewhat to fine grained rock which grades into sample 1 in places. The rock weathers to a medium brown, and the vesicular

rock weathers to a medium and light earthy brown.

Thin sections show a groundmass composed largely of very small laths and microlites of labradorite, crystallites of plagioclase (?), and glass. Augite and hornblende occur as dark brown, shadow-like masses, altering to serpentine. Olivine occurs in the largest grains, most of which are altered to serpentine and hornblende-augite, with only small residual cores of olivine. A few very small irregular grains of brownish-green spinel, and many small opaque grains are scattered through the groundmass. The mode and classification of this rock is given in table 1.

TABLE 1

Mode and Classification of the Flow Rocks

| Minerals | Samples | | | |
|----------------|---------|------|-------|------|
| | 1 | 2 | 3 | 7 |
| Labradorite | 30.8 | 23.3 | 19.7 | 24.3 |
| Nepheline | 1.2 | 7.3 | 3.3 | 2.1 |
| Augite | 12.4 | 5.7 | 18.2 | 19.3 |
| Hornblende | 6.2 | 4.3 | 7.0 | 10.8 |
| Olivine | 32.0 | 30.8 | 21.4 | 15.3 |
| Opacites | 1.0 | 2.1 | 2.6 | 10.8 |
| Spinel | 1.0 | 1.1 | 1.3 | 0.3 |
| Serpentine | 7.1 | 6.4 | 13.0 | 9.0 |
| Accessories | 6.4 | 16.0 | 10.5 | 3.0 |
| Glass | 1.8 | 2.0 | 3.0 | 4.0 |
| Total | 99.9 | 99.0 | 100.0 | 98.9 |
| Classification | 3316 | 3320 | 3316 | 3316 |

rock weathers to a medium and light gray color. Thin sections show a groundmass composed largely of very small grains and aggregates of leucophaea, crystals of plagioclase (?), and glass. Agites and hornblende occur as dark brown, water-like masses, similar to serpentines. Olivine occurs in the largest grains, most of which are altered to serpentines and amphibole-agites, with only small residual cores of olivine. A few very small irregular grains of brownish-green spinel, and many small opaque grains are scattered through the groundmass. The mode and classification of this rock is given in table 1.

TABLE 1
Mode and Classification of the Flow Rocks

| Minerals | Samples | | | |
|----------------|---------|------|-------|------|
| | 1 | 2 | 3 | 4 |
| Leucophaea | 30.8 | 27.3 | 10.7 | 26.7 |
| Rephelins | 1.2 | 1.7 | 2.3 | 2.1 |
| Agite | 12.4 | 2.7 | 18.3 | 10.7 |
| Hornblende | 6.2 | 4.7 | 7.0 | 10.0 |
| Olivine | 22.0 | 30.8 | 21.4 | 12.7 |
| Quartz | 1.0 | 2.1 | 2.6 | 10.8 |
| Spinel | 1.0 | 1.1 | 1.3 | 0.9 |
| Serpentine | 7.1 | 6.4 | 12.0 | 2.0 |
| Accessory | 8.4 | 12.0 | 12.5 | 2.4 |
| Glass | 1.8 | 2.8 | 3.0 | 4.0 |
| Total | 92.9 | 92.9 | 100.0 | 92.9 |
| Classification | 316 | 320 | 316 | 316 |

PLATE 3

Photographs of Basalt Samples

Figure 1. Photograph of specimen of
basalt, sample 1. :X₁.
S = spinel crystal.

Figure 2. Photograph of specimen of
basalt, sample 2. :X₂.
S = spinel crystal.

PLATE 3

Photographs of Basalt Samples

Figure 1. Photograph of specimen of
basalt, sample I. XI.
S = spinel crystal.

Figure 2. Photograph of specimen of
basalt, sample S. IX.
S = spinel crystal.



Figure 1



Figure 2



PLATE 4

Photographs of Basalt Samples

Figure 1. Photograph of specimens of basalt. a = sample 2, b and c = sample 3, d = sample 6. :X $\frac{1}{2}$.

Figure 2. Photograph of specimen of basalt, sample 2. :X1.
S = spinel crystal.
P = pyroxene phenocryst.

PLATE I

Photographs of Basalt Samples

Figure 1. Photograph of specimens of
 basalt, sample S. 1 and
 S. 2 = sample 1, S. 3 = sample 2.
 X₂.

Figure 2. Photograph of specimen of
 basalt, sample S. 1X1.
 S = spinel crystal.
 P = pyroxene phenocryst.



Figure 1



Figure 2



PLATE 5

Photographs of Basalt Samples

Figure 1. Photograph of specimen of
basalt, sample 3. :Xl.
S = spinel crystal.

Figure 2. Photograph of specimen of
basalt, sample 3. :Xl.

PLATE 2

Photographs of Basalt Samples

Figure 1. Photograph of specimen of
basalt, sample J. XI.
S = spinel crystal.

Figure 2. Photograph of specimen of
basalt, sample J. XI.

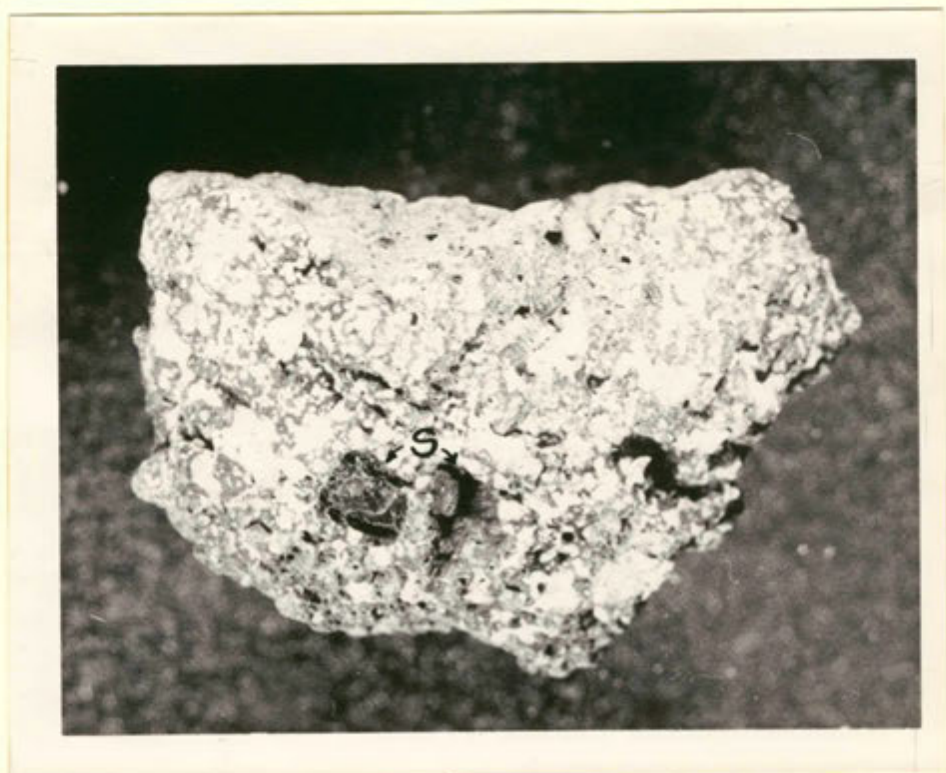


Figure 1



Figure 2



PLATE 6

Photographs of Basalt Samples

Figure 1. Photograph of specimen of
basalt, sample 6. :Xl.
S = spinel crystal.

Figure 2. Photograph of specimen of
basalt, sample 7. :Xl.

PLATE 6

Photographs of Basalt Samples

Figure 1. Photograph of specimen of
basalt, sample 6. XI.
S = spinel crystal.

Figure 2. Photograph of specimen of
basalt, sample 7. XI.



Figure 1



Figure 2

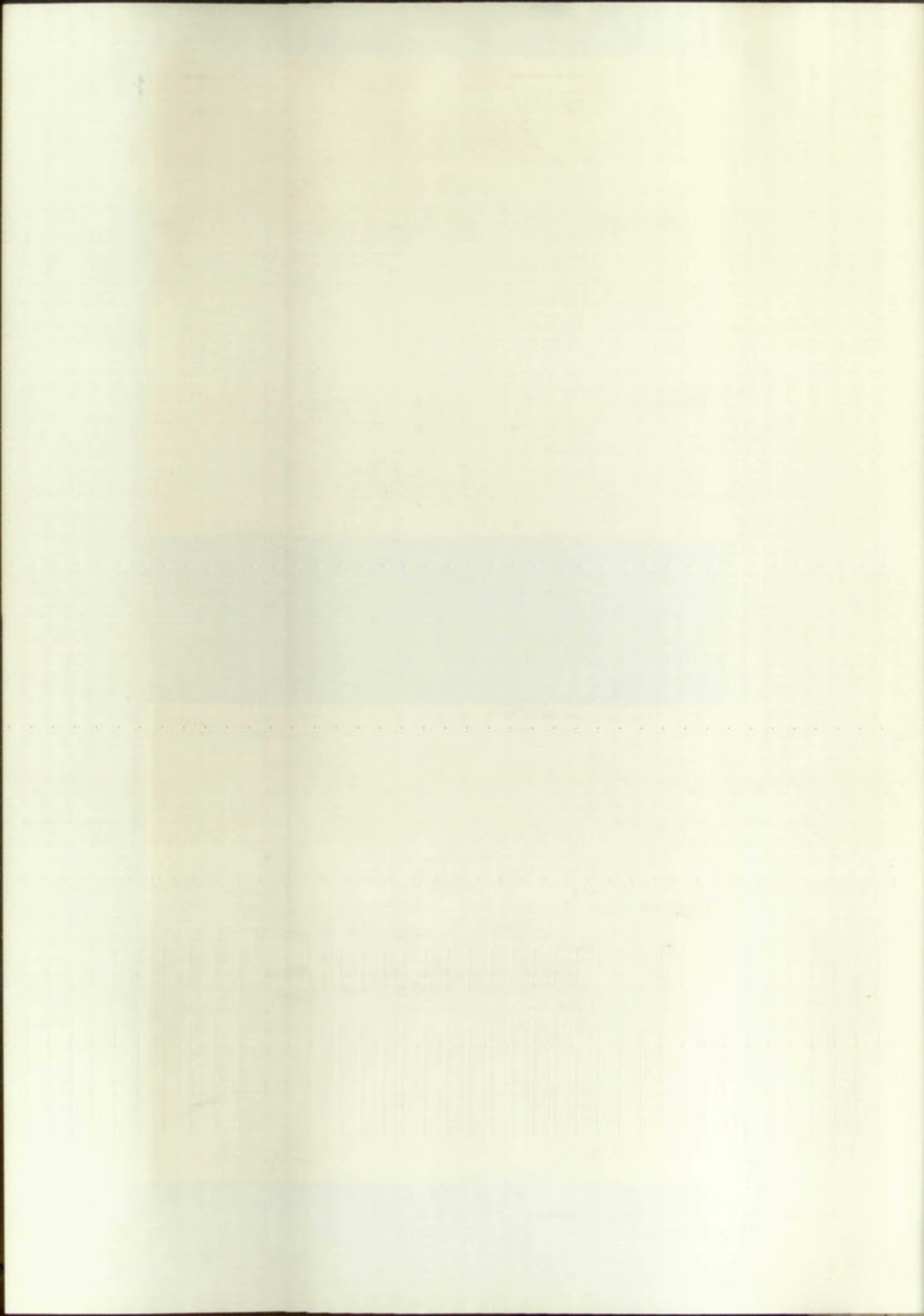


PLATE 7

Photomicrographs of Thin Sections

Figure 1. Photomicrograph of thin section
from sample 1. Plane light.
:X100.
O = olivine crystal showing
serpentinization.

Figure 2. Photomicrograph of thin section
from sample 2. Plane light.
:X35.
Spinel crystal showing two
colors and cubic parting.

PLATE 7

Photomicrographs of Thin Sections

Figure 1. Photomicrograph of thin section
 from sample 1. Plane light.
 X100.
 O = olivine crystal showing
 serpentinization.

Figure 2. Photomicrograph of thin section
 from sample 2. Plane light.
 X35.
 Spinel crystal showing two
 colors and cubic parting.

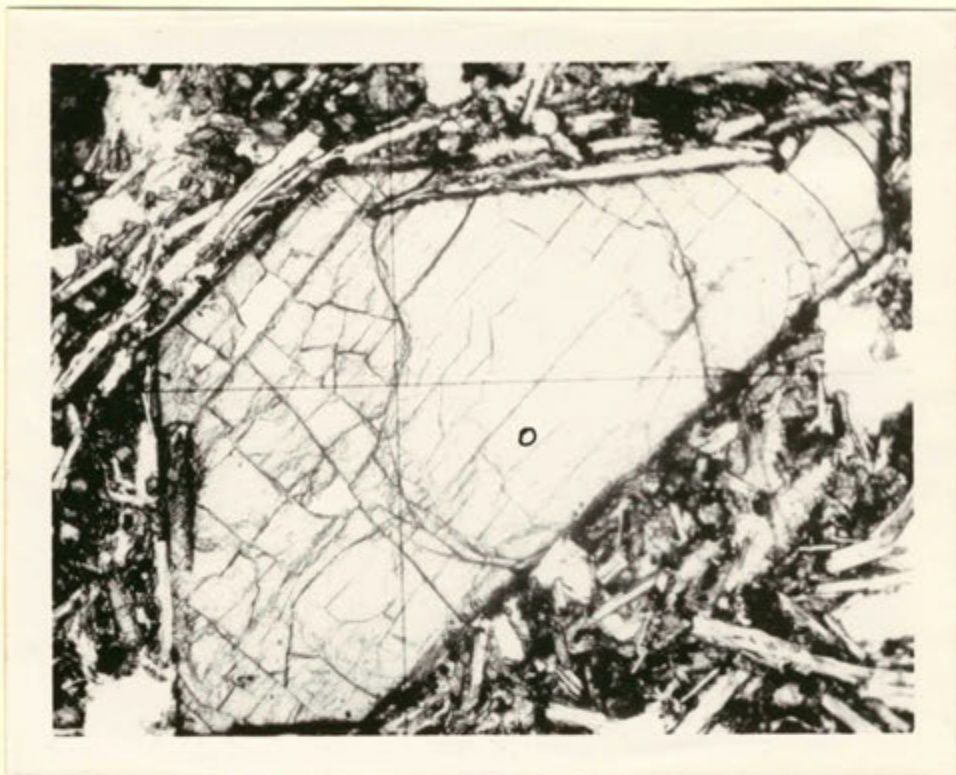


Figure 1

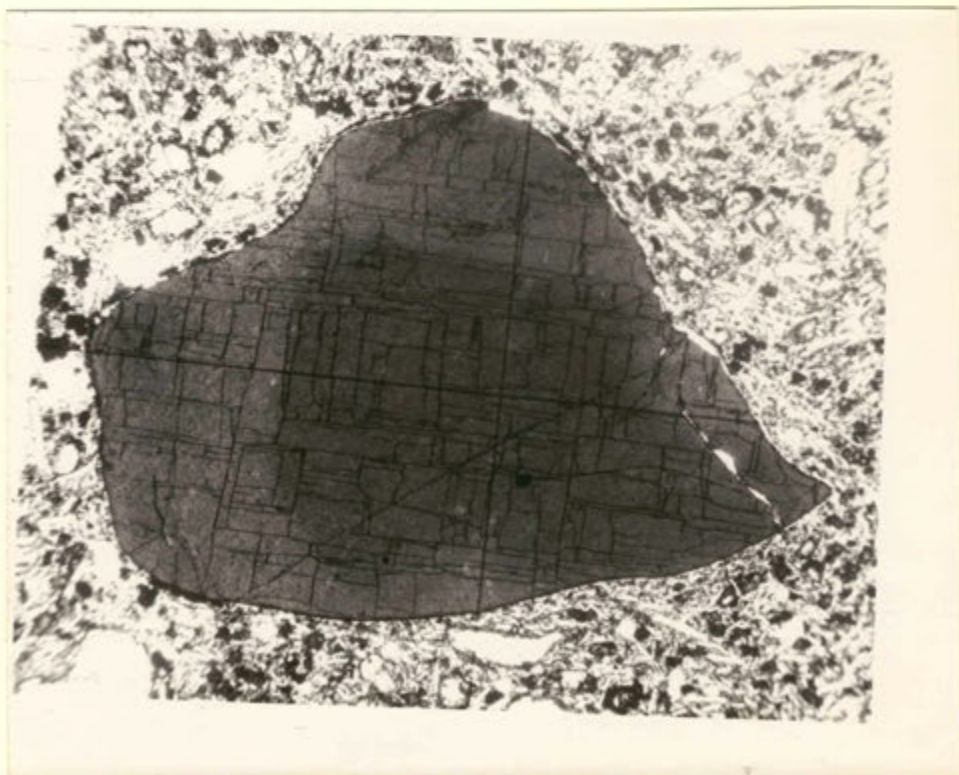


Figure 2



PLATE 8

Photomicrographs of Thin Sections

Figure 1. Photomicrograph of thin section of basalt sample showing typical arrangement of minerals. Plane light. :X200.
O = olivine.
P = plagioclase lath.

Figure 2. Same as figure 1, crossed nicols.

PLATE 8

Photomicrographs of Thin Sections

Figure 1. Photomicrograph of thin section
of basalt sample showing typical
arrangement of minerals. Plane
light. X200.
O = olivine.
P = plagioclase feldspars.

Figure 2. Same as figure 1, crossed nicols.



Figure 1

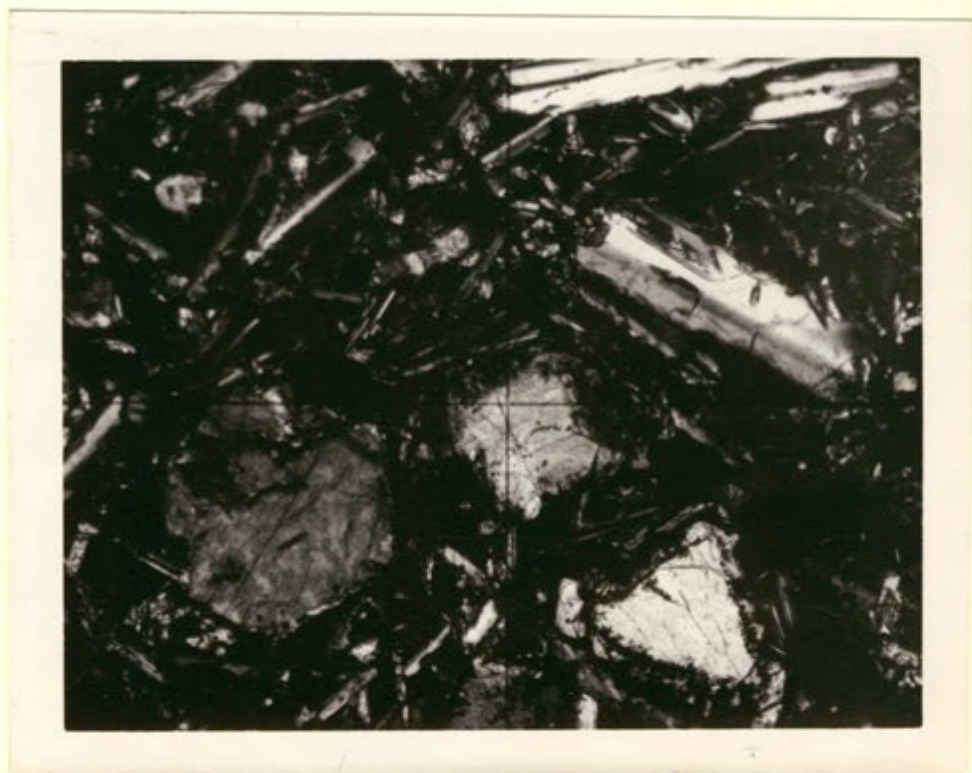


Figure 2



PLATE 9

Photomicrographs of Thin Sections

Figure 1. Photomicrograph of thin section
from sample 2. Plane light.
x100.
S = spinel.
O = olivine.
N = nepheline.
Se = serpentine.

Figure 2. Same as figure 1, crossed nicols.

PLATE 9

Photomicrographs of Thin Sections

Figure 1. Photomicrograph of thin section
 from sample S. Plane light.
 X100.
 S = spinel.
 O = olivine.
 N = nepheline.
 Se = serpentine.

Figure 2. Same as figure 1, crossed nicols.

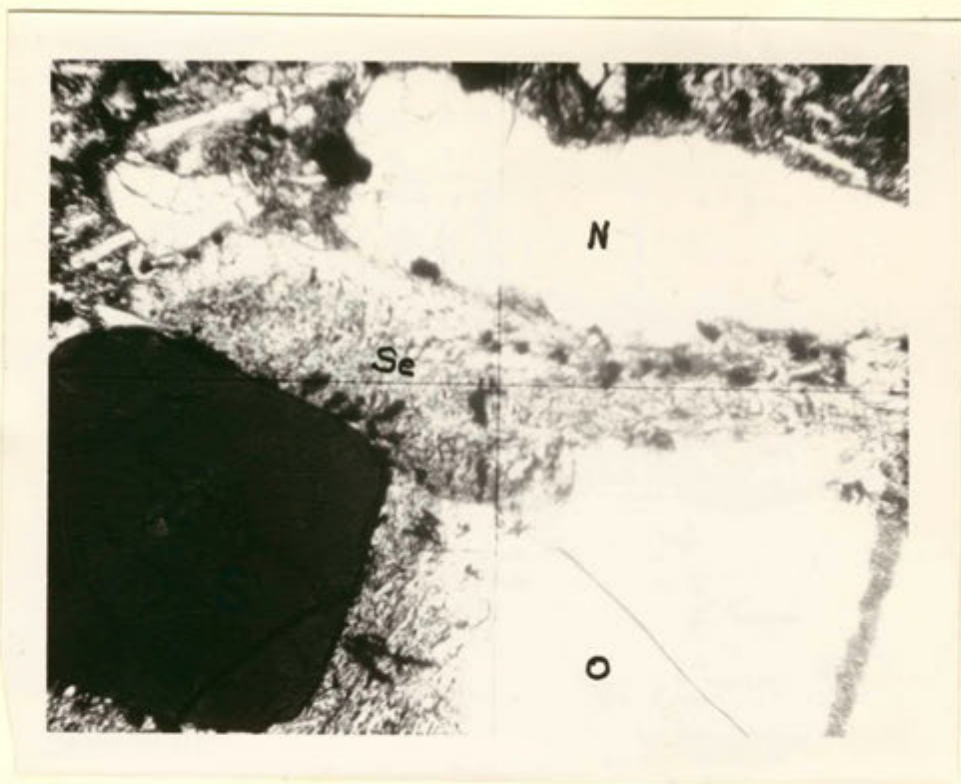


Figure 1

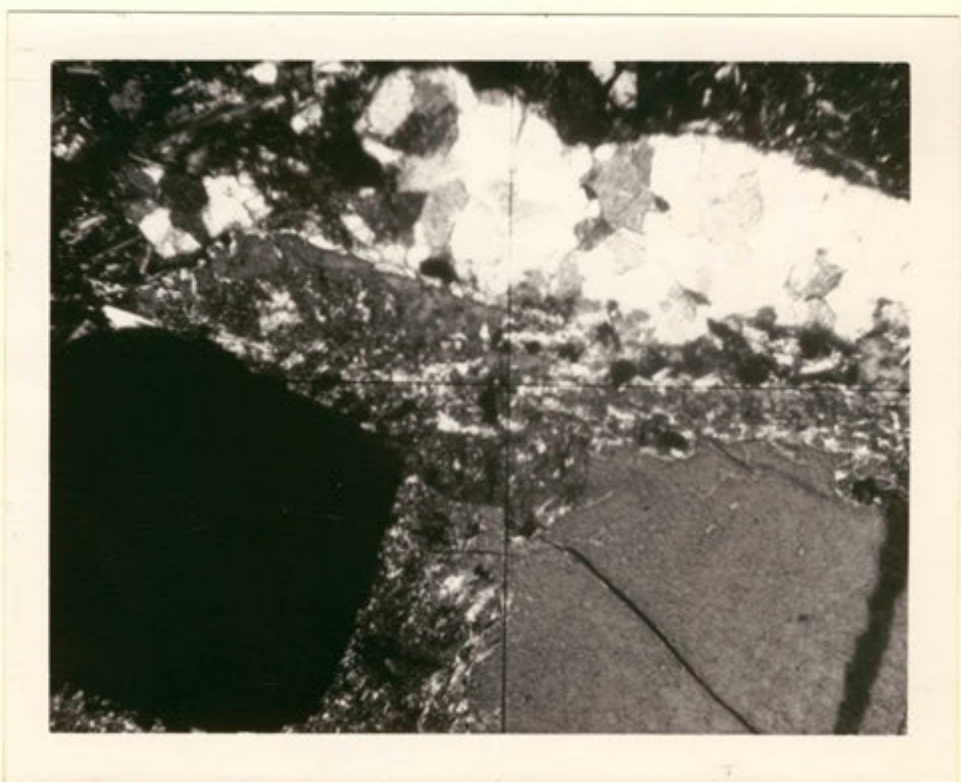


Figure 2



MINERALOGY OF PLEONASTE

Crystallography

Isometric, hexoctahedral. It is found usually in octahedrons, sometimes with dodecahedral truncations, rarely with cubic truncations (Pls. 10, 11, 12, 13, 14). Most specimens are malformed, with rounded edges (Pl. 12, Fig. 2); some have pitted surfaces (Pl. 13, Fig. 1); most of them are incomplete crystals. Twins are rare, but when found are spinel twins; that is, the twin axis is the axis of three-fold symmetry.

Physical Properties

The color is dark green and brown; diaphaneity, nearly opaque; fracture, conchoidal; tenacity, brittle; luster, dull on external surface, vitreous to splendid on fractures; streak, white; hardness, 8.

The specific gravity of the mineral was determined with a Jolly balance, which measures the relative weight of the mineral in air and in water. The equation used is:

$$\text{Specific Gravity} = \frac{\text{Weight in Air}}{\text{Weight in Air} - \text{Weight in Water}}$$

The specific gravity for this pleonaste ranges from 3.8280 to 3.8839 and averages 3.8563 (Table 2).

The theoretical specific gravity of a crystal may be calculated from the equation:

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}}$$

Crystallography

laminar, hexagonal. In thin sections, they are
 octahedral, sometimes with hexagonal prisms, some-
 times with cubic prisms (Fig. 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100).
 Some have pitted surfaces (Fig. 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100).
 Some are incomplete crystals. Some are twins. Some are found as single twins; but the twin axis is the axis of three-fold symmetry.

Physical Properties

The color is dark green and brown; translucent, nearly opaque; fracture, subconchoidal; tenacity, brittle; luster, dull to exceptional luster, almost to adamantine on fresh surfaces; white, translucent, transparent. The specific gravity of the mineral was determined with a Jolly balance, which measures the relative weight of the mineral in air and in water. The specific gravity used is:

$$\text{Specific Gravity} = \frac{\text{Weight in Air}}{\text{Weight in Air} - \text{Weight in Water}}$$

The specific gravity for this mineral ranges from 3.880 to 3.889 and average 3.885 (Table 5).

The theoretical specific gravity of a crystal

may be calculated from the equation:

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}}$$

TABLE 2

Specific Gravities of Several Pleonaste Crystals

| Crystal No. | Measurements | | | |
|----------------|--------------|--------|--------|---------|
| | 1st | 2nd | 3rd | Average |
| 1 | 3.8491 | 3.8508 | 3.8390 | 3.8463 |
| 2 | 3.8849 | 3.8757 | 3.8647 | 3.8751 |
| 3 | 3.8250 | 3.8190 | 3.8400 | 3.8280 |
| 4 | 3.8566 | 3.8579 | --- | 3.8572 |
| 5 | 3.8774 | 3.8905 | --- | 3.8839 |
| 6 | 3.8384 | 3.8308 | --- | 3.8346 |
| 7 | 3.8417 | --- | --- | 3.8417 |
| 8 | 3.8737 | --- | --- | 3.8737 |
| 9 | 3.8656 | --- | --- | 3.8656 |
| Average = | | | | 3.8563 |

TABLE 2

Specific Gravities of Several Minerals, Dry Basis

| Mineral | Specific Gravity | | | Crystal No. |
|-------------|------------------|-------|-------|-------------|
| | 20°C | 25°C | 30°C | |
| Quartz | 2.650 | 2.648 | 2.646 | 1 |
| Orthoclase | 2.550 | 2.548 | 2.546 | 2 |
| Albite | 2.620 | 2.618 | 2.616 | 3 |
| Microcline | 2.560 | 2.558 | 2.556 | 4 |
| Plagioclase | 2.600 | 2.598 | 2.596 | 5 |
| Calcite | 2.710 | 2.708 | 2.706 | 6 |
| Dolomite | 2.850 | 2.848 | 2.846 | 7 |
| Fluorite | 3.180 | 3.178 | 3.176 | 8 |
| Barite | 4.500 | 4.498 | 4.496 | 9 |

Source: U.S. Geological Survey

U.S. GEOLOGICAL SURVEY
BULLETIN 1000

PLATE 10

Drawings of Ideal Crystals

Figure 1. Drawing of an ideal octahedron.
Clinographic projection.

Figure 2. Drawing of an ideal octahedron
with dodecahedral truncations.
Clinographic projection.

PLATE 10

Drawings of Ideal Crystals

Figure 1. Drawing of an ideal octahedron.
Cathodographic projection.

Figure 2. Drawing of an ideal octahedron
with dodecahedral truncations.
Cathodographic projection.

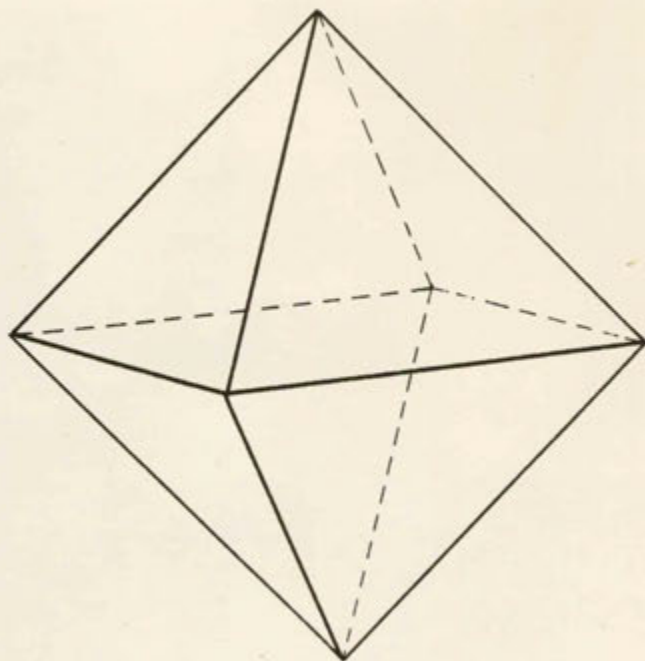


Figure 1.

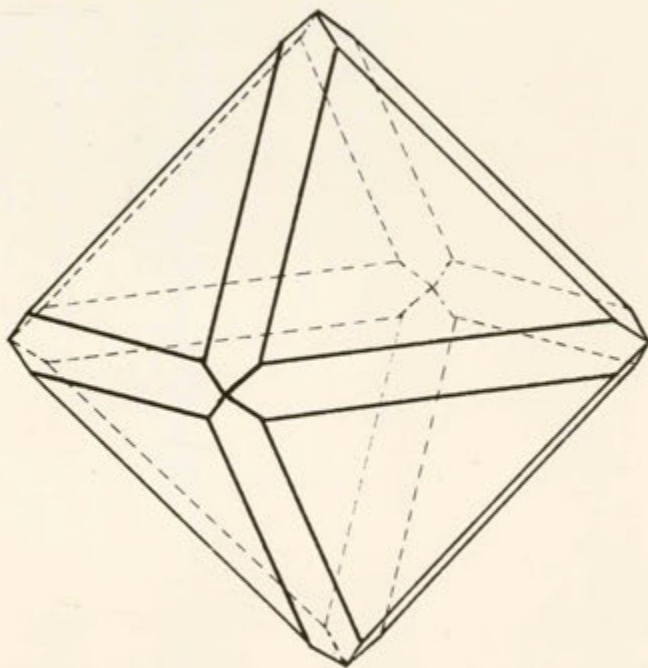


Figure 2.

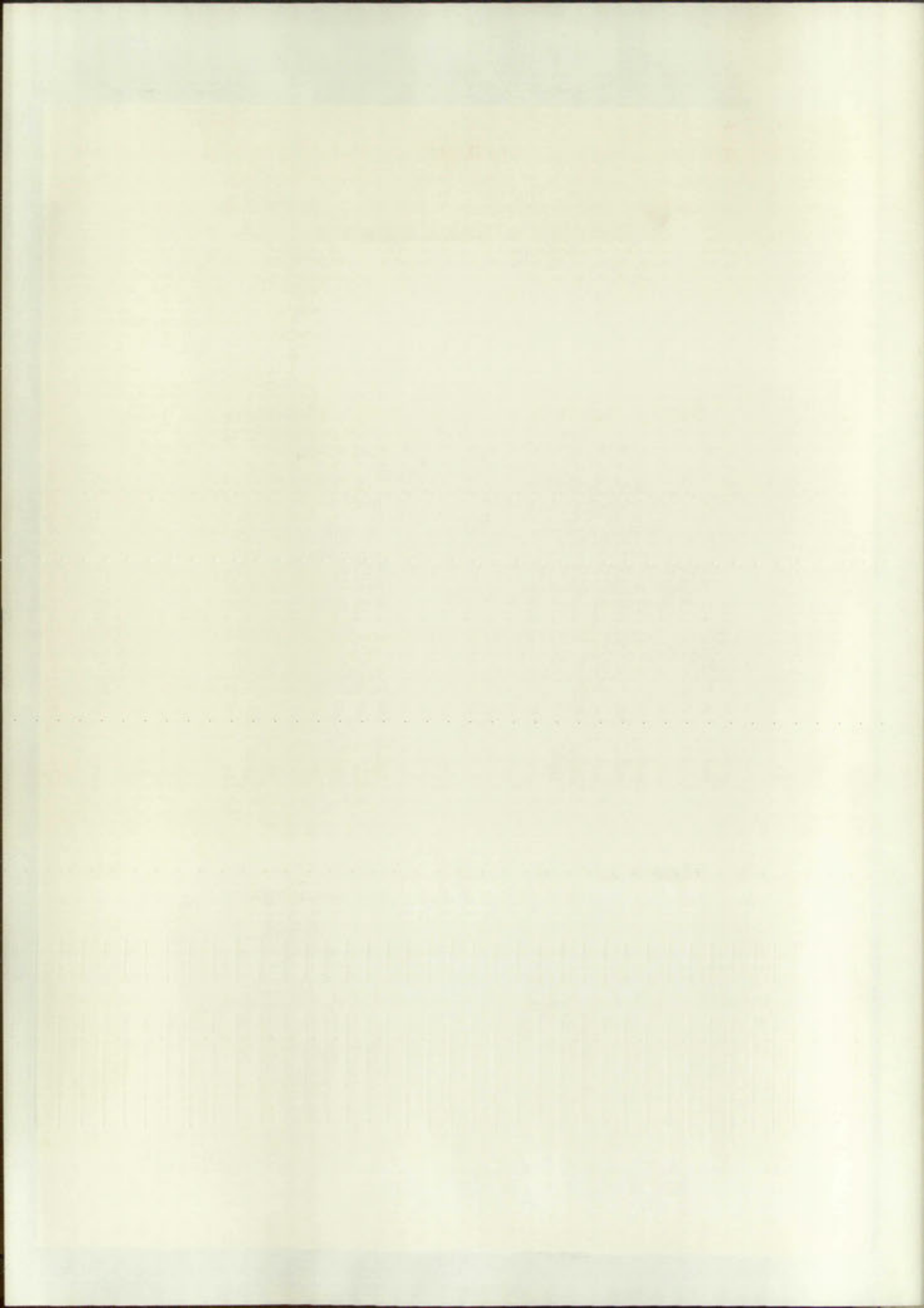


PLATE 11

Drawings of Ideal Crystals

Figure 1. Drawing of an ideal octahedron
with dodecahedral truncations.
Clinographic projection.

Figure 2. Portrait of an actual spinel
crystal in an ideal drawing.

PLATE II

Drawings of Ideal Crystals

Figure 1. Drawing of an ideal octahedron
with hexahedral terminations.
Clinographic projection.

Figure 2. Portrait of an actual spinel
crystal in an ideal drawing.

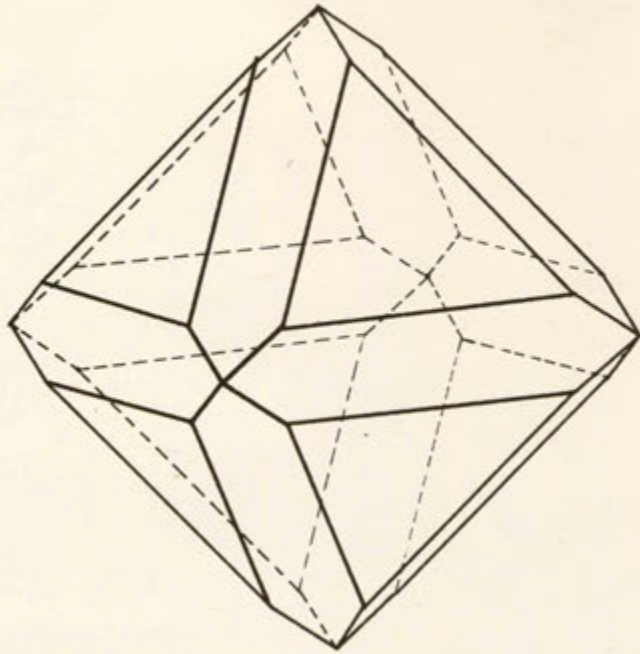


Figure 1.

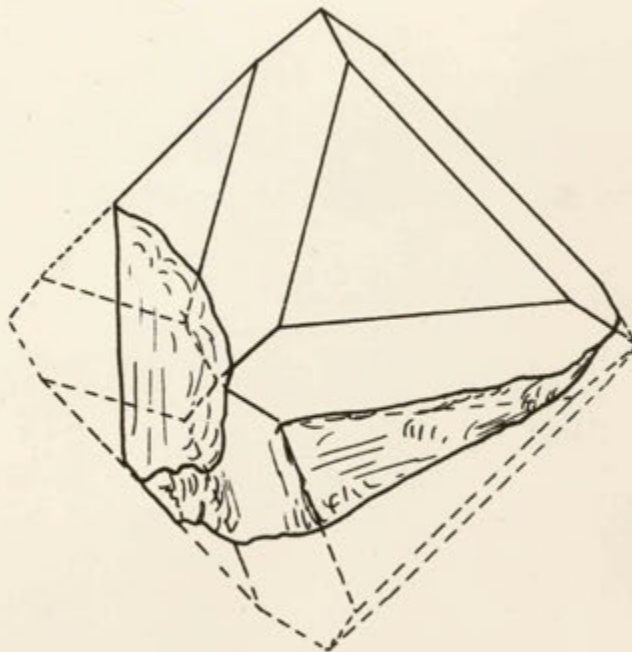


Figure 2.



PLATE 12

Photographs of Pleonaste Crystals

Figure 1. Photograph of pleonaste crystals from basalt. Scale in inches on photograph.

Figure 2. Photograph of pleonaste crystals from basalt. $\times 14$

PLATE 12

Photographs of Pleonaste Crystals

Figure 1. Photograph of pleonaste crystals
from basalt. Scale in inches on
photograph.

Figure 2. Photograph of pleonaste crystals
from basalt. X14

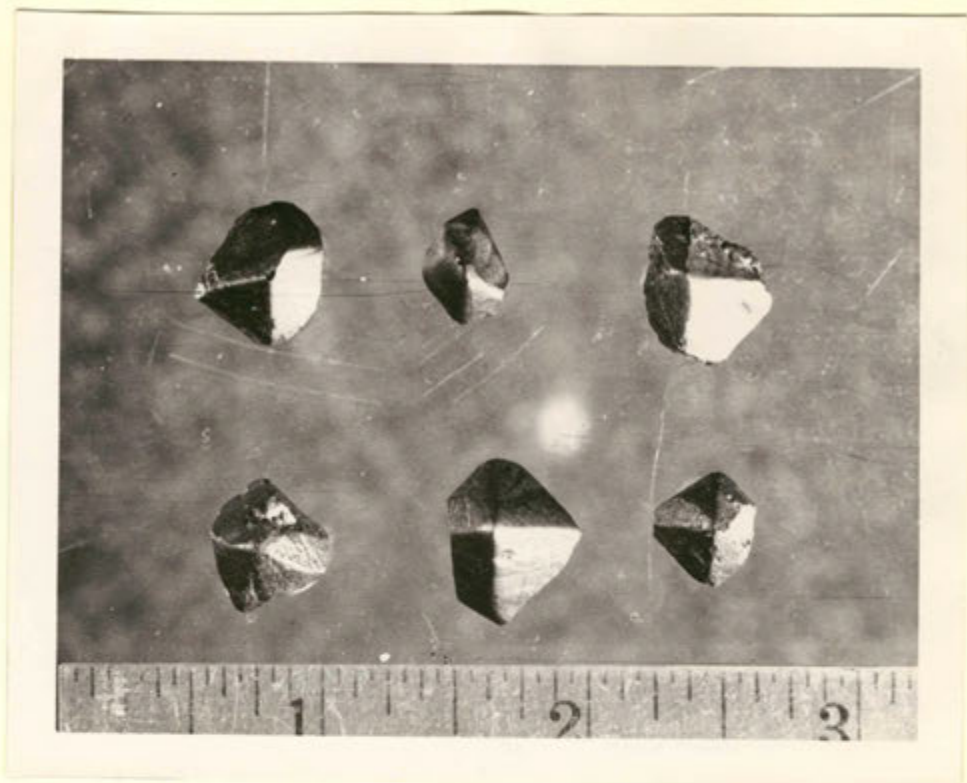


Figure 1

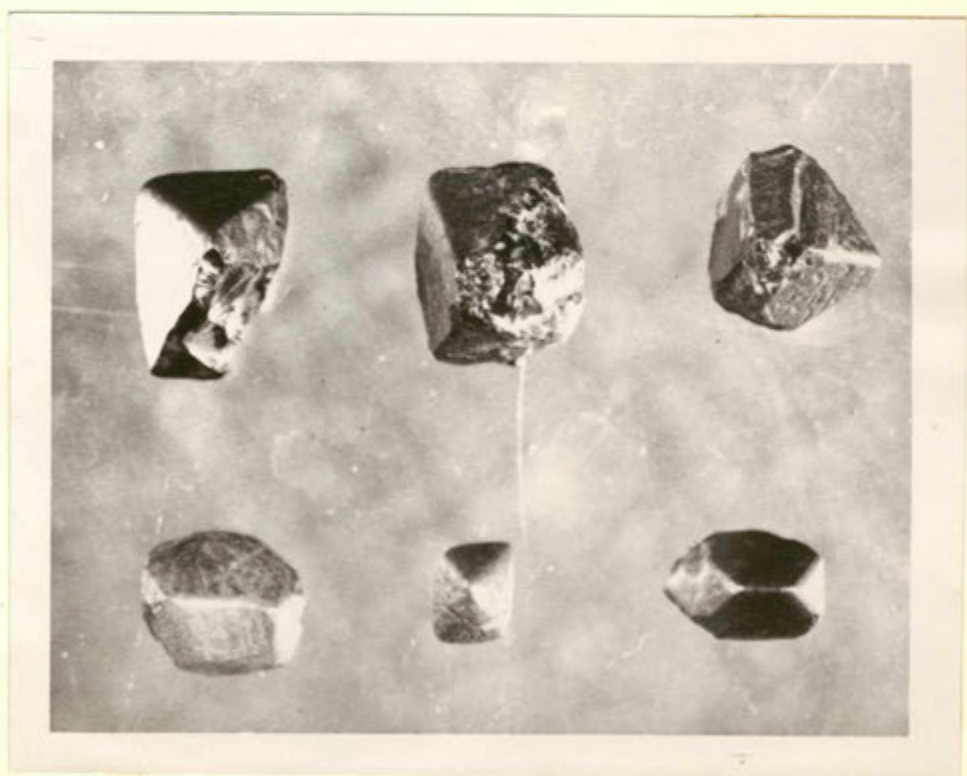


Figure 2



PLATE 13

Photographs of Pleonaste Crystals

Figure 1. Photograph of pleonaste crystal showing pitted surface. :X2.

Figure 2. Photograph of pleonaste crystal from basalt. :X3.

Figure 3. Photograph of four pleonaste crystals (a, b, c, and d) from basalt. :X2.

PLATE 13

Photographs of Pleonaste Crystals

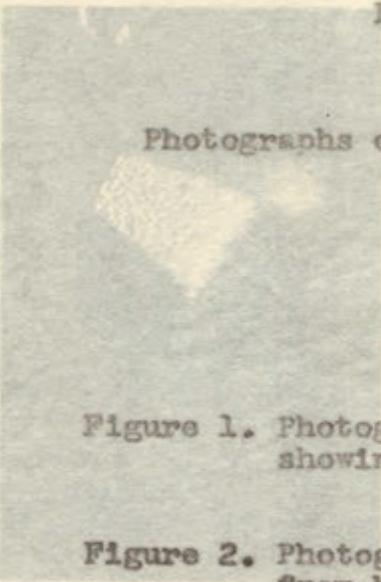


Figure 1. Photograph of pleonaste crystal showing pitted surface. :X2.

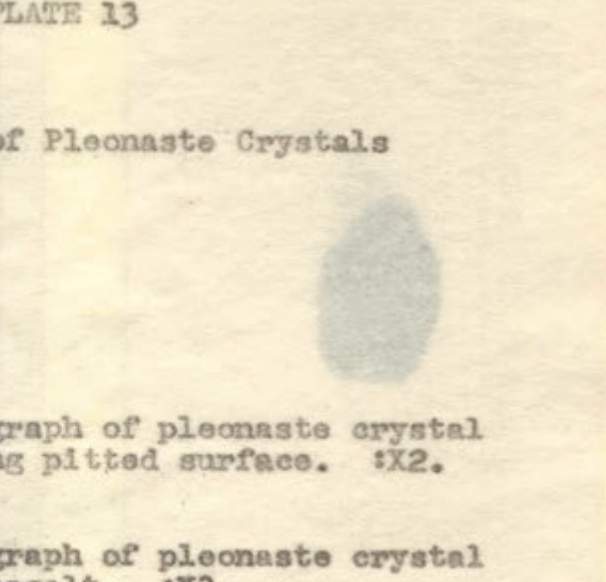


Figure 2. Photograph of pleonaste crystal from basalt. :X3.

Figure 1

Figure 2

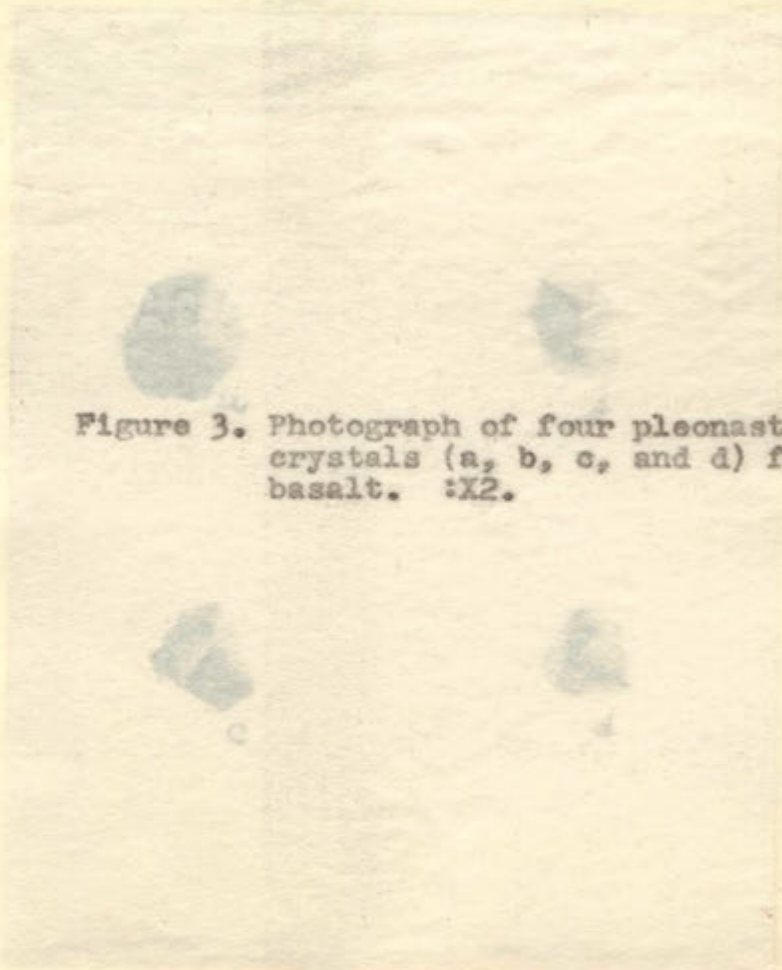


Figure 3. Photograph of four pleonaste crystals (a, b, c, and d) from basalt. :X2.

Figure 3

PLATE 13

Photographs of Pleonaste Crystals

Figure 1. Photograph of pleonaste crystal showing pitted surface. X2.

Figure 2. Photograph of pleonaste crystal from basalt. X2.

Figure 3. Photograph of four pleonaste crystals (a, b, c, and d) from basalt. X2.



Figure 1



Figure 2



Figure 3

PLATE 14

Photographs of Pleonaste Crystals

Figure 1. Photograph, enlargement of fig. 3a, Pl. 13. :X4.

Figure 1

Figure 2

Figure 2. Photograph, enlargement of fig. 3c, Pl. 13. :X4.

Figure 3. Photograph of three pleonaste crystals from basalt (a, b, and c). :X1.

Figure 3

Figure 4. Photograph, enlargement of fig. 3a above. :X4.

Figure 4

PLATE II

Photographs of Pleonaste Crystals

Figure 1. Photograph, enlargement of fig.
 3a, pl. 13. X1.

Figure 2. Photograph, enlargement of fig.
 3a, pl. 13. X1.

Figure 3. Photograph of three pleonaste
 crystals from basalt (a, b,
 and c). X1.

Figure 4. Photograph, enlargement of fig.
 3a above. X1.



Figure 1



Figure 2



Figure 3



Figure 4

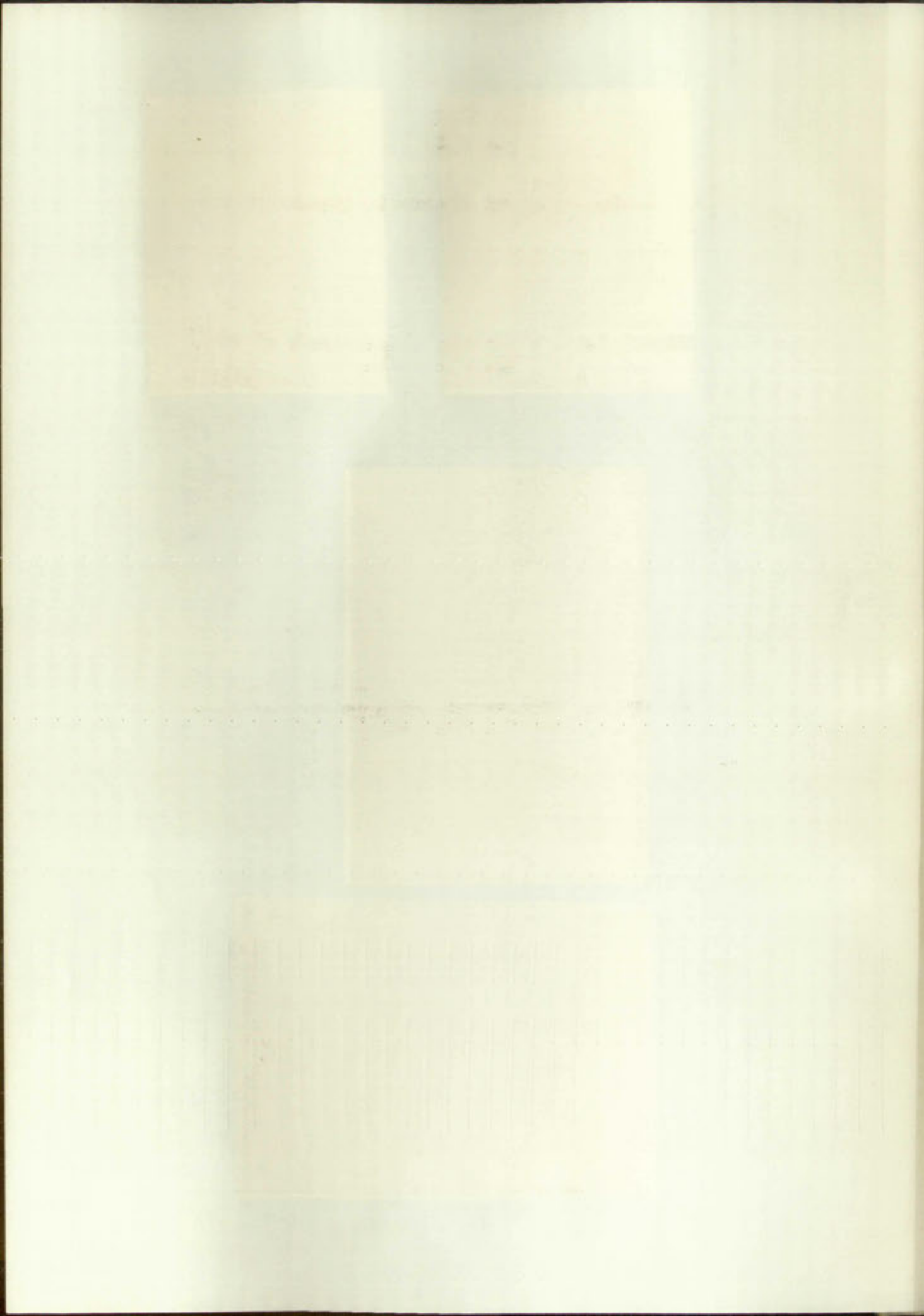


PLATE 15

Photographs of Pleonaste Crystals

Figure 1. Photograph, enlargement of fig.
3b, Pl. 14. :X4.

Figure 2. Photograph, enlargement of fig.
3c, Pl. 14. :X4.

PLATE 12

Photographs of Pinnate Crystals

Figure 1. Photograph, enlargement of fig.
30, Pl. 11. X14.

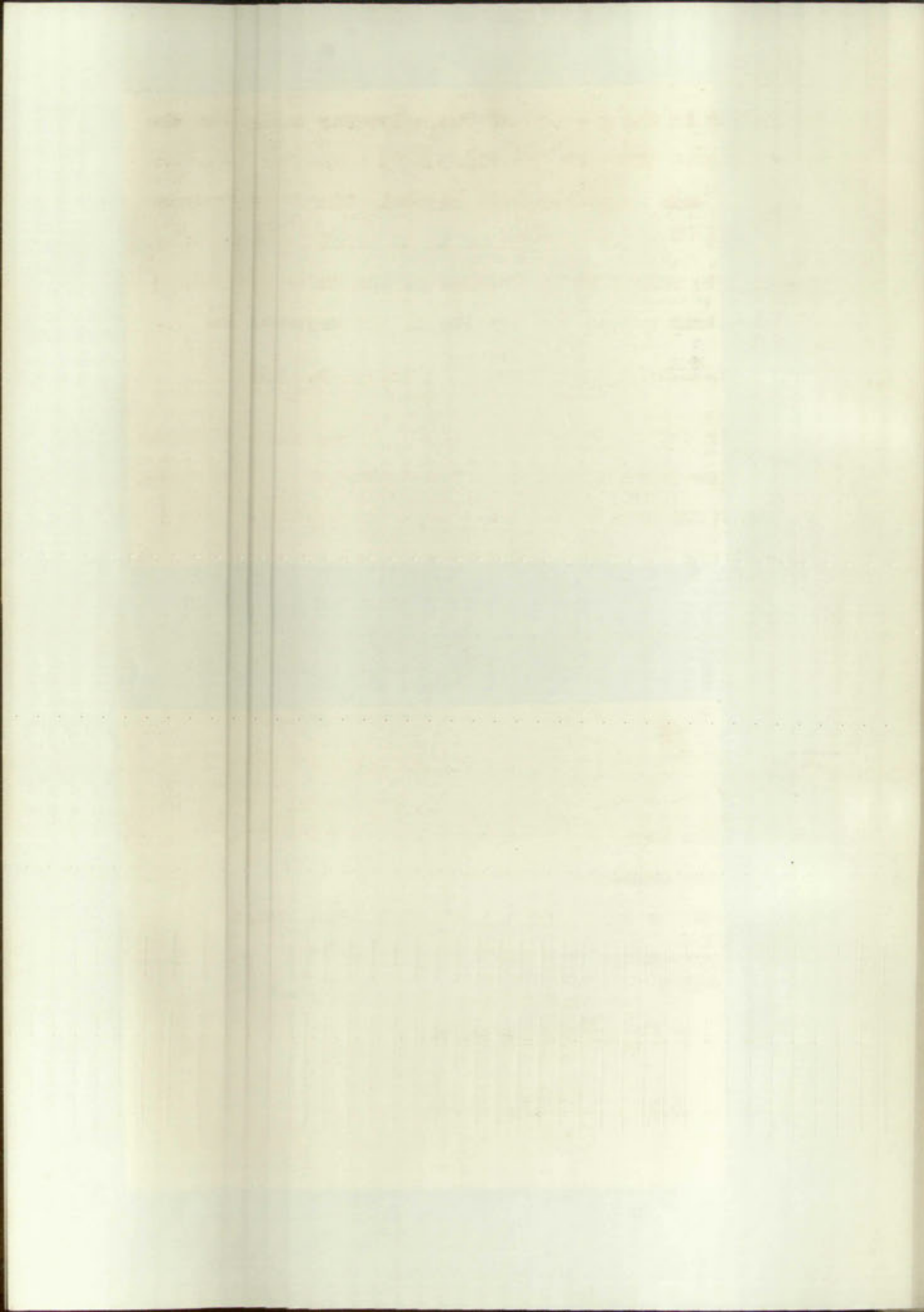
Figure 2. Photograph, enlargement of fig.
30, Pl. 11. X14.



Figure 1



Figure 2



The weight is the product of the molecular weight of the chemical unit of which the crystal is composed times the number of such units per unit crystal, times the factor 1.649×10^{-24} which changes units of atomic weight into grams. The volume is the volume of the unit crystal. In the isometric system the density of the crystal is:

$$\rho = n \frac{M \times 1.649 \times 10^{-24}}{a_0^3} \quad (\text{Davey, p. 35})$$

where M is the molecular weight, a_0 is the edge of the unit cube in centimeters, and n is the number of points associated with the unit cube in the crystal lattice. n is 1 for a simple cube, 2 for a body-centered cube, 4 for a face-centered cube, and 8 for a diamond cube.

a_0 was determined from X-ray powder photographs of the mineral by the equation:

$$n\lambda = 2d \sin \theta \quad (\text{Buerger, p. 98})$$

where n is the order of the reflection, λ is the wavelength of the X-ray beam, d is the atomic spacing (a_0), and θ is the angle the reflected X-ray beam makes with the plane of the crystal.

M was determined in the following way:

$$M = \text{percentage molecular weights of FeO} + \text{MgO} + \text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$$

$$\text{FeO} = 71.85 \times \frac{16.07}{33.23} = 34.74$$

$$\text{MgO} = 40.32 \times \frac{17.16}{33.23} = 20.82$$

The weight of the crystal is the product of the molecular weight of the chemical unit of which the crystal is composed and the number of such units per unit crystal, since the latter is 1.69×10^{-23} when expressed in terms of atomic weight units. The volume is the volume of the unit crystal. In the following equation the density of the crystal is

$$\rho = \frac{M \times 1.69 \times 10^{-23}}{V}$$

(Density, g. cc.)

where M is the molecular weight, v is the volume of the unit crystal in cubic centimeters, and n is the number of polymer units per unit volume in the crystal. For a face-centered cube, v is $a^3/4$ for a simple cube, $2/3$ for a body-centered cube, $1/2$ for a face-centered cube, and $1/8$ for a diamond cube.

ρ was determined from X-ray powder measurements of the material by the equation:

$$\rho = \frac{M}{V} \times \frac{1}{\sin^2 \theta} \times \frac{1}{d^2}$$

where n is the number of the reflection, λ is the wavelength of the X-ray used, d is the distance between the end of the angle the reflection lines make with the plane of the crystal.

M was determined in the following way:

$M = \text{percentage molecular weight of } \text{C}_2\text{H}_4 + \text{O}_2$
 Also

$$\text{Pct} = \frac{18.07}{17.23} \times 100 = 104.9$$

$$\text{MgO} = \frac{14.34}{32.03} \times 100 = 44.77$$

$$\text{Fe}_2\text{O}_3 = 159.7 \frac{1.60}{66.67} = 3.83$$

$$\text{Al}_2\text{O}_3 = 101.94 \frac{65.07}{66.67} = 99.49$$

$$M = 158.88$$

Substituting figures in the equation on page 29,
we get:

$$\rho = 8 \frac{158.88 \times 1.649 \times 10^{-24}}{(8.12)^3 \times 10^{-24}} = 8 \frac{262.0}{535.4} = 3.9144$$

The calculated specific gravity, 3.9144, compares favorably with the average measured specific gravity, 3.8563.

Structural Crystallography

The mineral spinel is the type mineral for the spinel group, all of which have the same isometric atomic structures. For spinel the structure may be described as having the O atoms arranged on a face-centered cubic lattice with the Mg atoms lying in the center of tetrahedral groups of four atoms, while the Al atoms are each surrounded by a group of six O atoms. Space group, $Fd\bar{3}m$; a_0 , 8.12 Å; unit cell content, 8 (Winchell, Part II, p. 81).

X-ray Data

Because the mineral is isometric, with equal axes at 90 degrees to each other, the only X-ray photographs taken were powder pictures. The pleonaste was mixed with a small amount of halite so a check could be made on the

$$1000 \times \frac{1.00}{66.51} = 150.7 \times 1.03$$

$$1000 \times \frac{1.00}{66.51} = 150.7 \times 1.03$$

$$n = 1.58.58$$

Substituting these in the equation on page 20

we get

$$1000 \times \frac{1.00}{66.51} = 150.7 \times 1.03$$

The calculated specific gravity, 2.011, compares

favorably with the average measured specific gravity, 1.985.

Structural Crystallography

The crystal structure is the same as that of the

orthorhombic form, all of which have the same structural elements

arranged. The only difference between the two is that the

spacing of the atoms is different in the two forms, the

spacing being larger in the orthorhombic form.

Groups of four atoms, with the ab axis and c axis

of a group of six atoms. These groups, taken as a whole, are

not well defined, but they are well defined.

References

See also the mineral in the literature, with special reference

to the orthorhombic form, the only form known.

The present work was done by the author and his

colleagues at the University of California, Berkeley.

measurements taken from the X-ray films. Photographs were taken with both $\text{CuK}\alpha$ and $\text{FeK}\alpha$ radiation (Pl. 16). Tabulated results of these photographs are shown in table 3 below.

TABLE 3

X-ray Powder Pattern

| Isometric, Pd_3m ; $a_0 = 8.12 \text{ \AA}$ | | | | | |
|---|-----------|-------|------------------------------|-----------|-------|
| $\text{FeK}\alpha$ Radiation | | | $\text{CuK}\alpha$ Radiation | | |
| I | 2θ | d | I | 2θ | d |
| 1 | 23.75 | 4.710 | 2 | 18.85 | 4.700 |
| | 36.15 | 3.120 | 4 | 30.95 | 2.890 |
| 2 | 39.35 | 2.877 | 10 | 36.55 | 2.450 |
| | 42.05 | 2.700 | 5 | 44.45 | 2.030 |
| 10 | 46.45 | 2.456 | 1 | 55.15 | 1.660 |
| | 47.15 | 2.420 | 5 | 58.85 | 1.560 |
| 4 | 56.80 | 2.036 | 6 | 64.65 | 1.440 |
| | 58.95 | 1.970 | 1 | 76.65 | 1.240 |
| 1 | 71.25 | 1.663 | 2 | 83.85 | 1.150 |
| 3 | 76.25 | 1.569 | 1 | 90.15 | 1.080 |
| | 77.15 | 1.553 | 1 | 93.75 | 1.050 |
| 6 | 84.55 | 1.440 | 1 | 98.95 | 1.010 |
| | 89.45 | 1.376 | 1 | 101.35 | 0.996 |
| 2 | 100.70 | 1.258 | 1 | 110.75 | 0.938 |
| 1 | 111.15 | 1.170 | 1 | 110.35 | 0.938 |
| 2 | 114.70 | 1.149 | 1 | 119.75 | 0.890 |
| | 115.05 | 1.150 | 1 | 129.45 | 0.851 |
| 1 | 116.70 | 1.137 | 1 | 130.15 | 0.851 |
| 1 | 126.10 | 1.086 | 1 | 146.55 | 0.804 |
| | 126.60 | 1.086 | 1 | 147.15 | 0.804 |
| 2 | 132.45 | 1.058 | 1 | 157.05 | 0.786 |
| | 133.00 | 1.057 | | 158.45 | 0.786 |
| 1 | 139.65 | 1.031 | | | |
| | 140.50 | 1.030 | | | |
| 1 | 152.30 | 0.997 | | | |

measurements taken from the 1st T.D. (approximately same

fauna with both sea- and land-water collected in 1904)

Tabulated results of these measurements are given in table

below.

TABLE I

Water quality station

Station No. 10 - 11, 12

Temperature, etc. (see page 10)

| Station | Date | Temperature | | |
|---------|------------|-------------|------|------|
| | | Surface | 1 m | 2 m |
| 1 | 1904.12.10 | 27.1 | 24.1 | 23.1 |
| | 1904.12.11 | 25.1 | 22.1 | 21.1 |
| | 1904.12.12 | 24.1 | 21.1 | 20.1 |
| | 1904.12.13 | 23.1 | 20.1 | 19.1 |
| | 1904.12.14 | 22.1 | 19.1 | 18.1 |
| | 1904.12.15 | 21.1 | 18.1 | 17.1 |
| | 1904.12.16 | 20.1 | 17.1 | 16.1 |
| | 1904.12.17 | 19.1 | 16.1 | 15.1 |
| | 1904.12.18 | 18.1 | 15.1 | 14.1 |
| | 1904.12.19 | 17.1 | 14.1 | 13.1 |
| | 1904.12.20 | 16.1 | 13.1 | 12.1 |
| | 1904.12.21 | 15.1 | 12.1 | 11.1 |
| | 1904.12.22 | 14.1 | 11.1 | 10.1 |
| | 1904.12.23 | 13.1 | 10.1 | 9.1 |
| | 1904.12.24 | 12.1 | 9.1 | 8.1 |

PLATE 16

X-ray Powder Photographs

Figure 1. X-ray powder photograph of pleonaste from the Caballo Mountains. FeK α radiation.

Figure 2. X-ray powder photograph of pleonaste from the Caballo Mountains. CuK α radiation.

PLATE 16

X-ray Powder Photographs

Figure 1. X-ray powder photograph of glass-
waste from the Gashio Mountains.
CuK α radiation.

Figure 2. X-ray powder photograph of glass-
waste from the Gashio Mountains.
CuK α radiation.

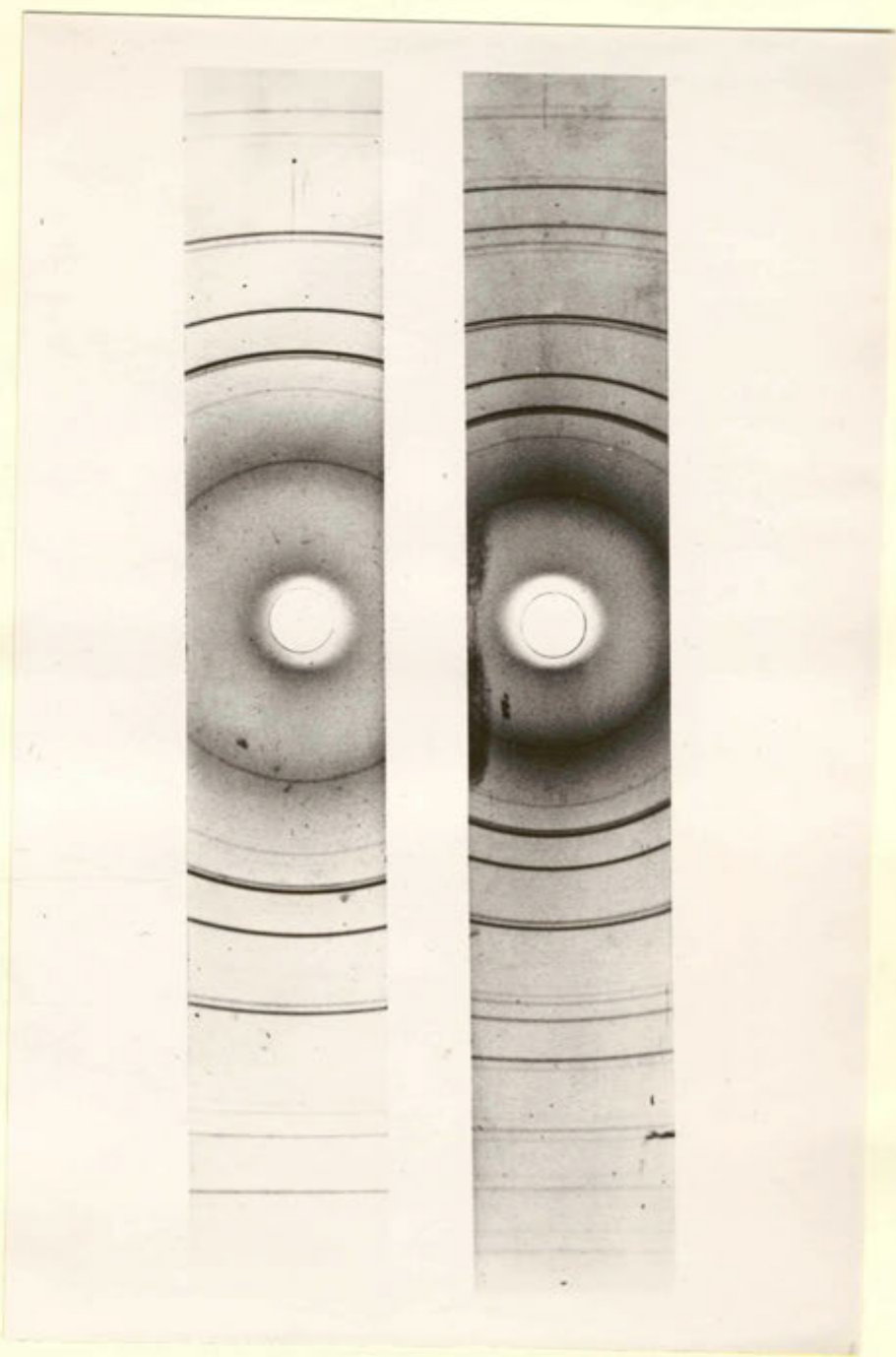
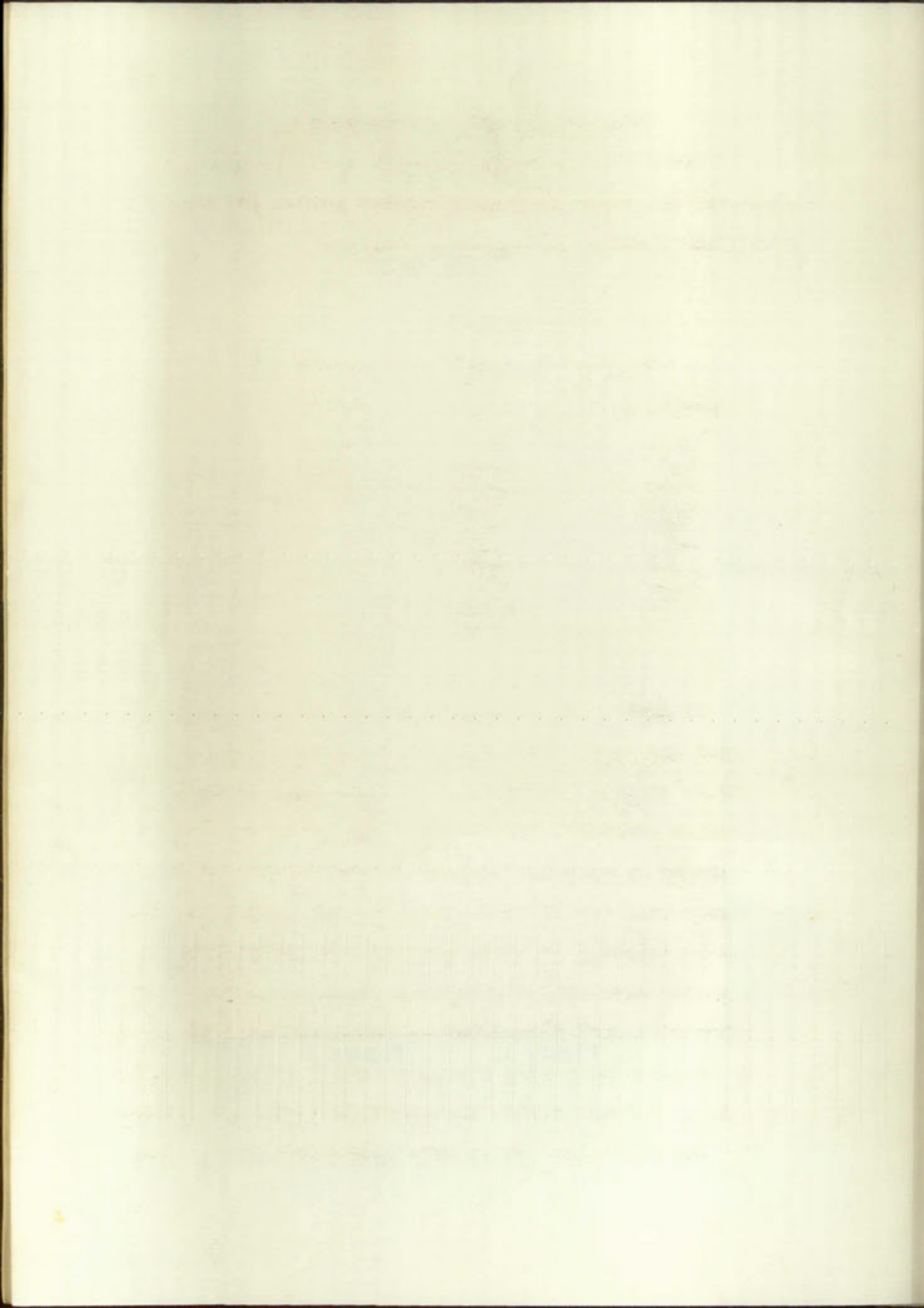


Figure 1

Figure 2



Composition and Cell Content

Table 4 below shows a quantitative chemical analysis of pleonaste and the molecular ratios of the constituents (Matthew E. Carlisle, analyst).

TABLE 4

Chemical Analysis of Pleonaste

| Constituent | Percent | Ratio |
|--------------------------------|---------|--------|
| Al ₂ O ₃ | 65.07 | 0.638 |
| MgO | 17.16 | 0.425 |
| FeO | 17.51 | 0.243 |
| Cr ₂ O ₃ | 0.05 | 0.0003 |
| MnO | nil | --- |
| SnO ₂ | nil | --- |
| TiO ₂ | nil | --- |
| ZnO | trace | --- |
| SiO ₂ | trace | --- |
| Total | 99.79 | |

In making the chemical analysis, 4.025 grams of the mineral was used. The highly refractory nature of pleonaste is attested to by the fact that when fused in molten sodium carbonate for 20 days, the material lost less than 1 percent by weight. Similarly, when treated with hydrofluoric acid for 20 days, the material lost less than 1 percent by weight. Solution was finally attained by fusing the pleonaste with molten potassium bisulfate for 20 days. The pleonaste was not ground before chemical analysis because the high hardness presented the possibility of contamination by grinding. The analytical procedure of Scott was followed.

The molecular ratios were determined by dividing

Composition and Cell Contents

Table I below shows a quantitative analysis of the mineral and the molecular ratios of the constituents (Nashua, N. Carolina, analysis).

TABLE I

Chemical Analysis of Minerals

| Constituent | Percent | Ratio |
|--------------------------------|---------|--------|
| Al ₂ O ₃ | 17.07 | 0.038 |
| SiO ₂ | 17.10 | 0.038 |
| FeO | 17.81 | 0.041 |
| Cr ₂ O ₃ | 0.02 | 0.0003 |
| MnO | nil | --- |
| CaO | nil | --- |
| MgO | nil | --- |
| ZnO | Trace | --- |
| PbO | Trace | --- |
| Total | 67.02 | --- |

In making the chemical analysis (A. O. Nashua, N. C.) the mineral was used. The highly refractory nature of the mineral is attested to by the fact that when fused in molten sodium carbonate for 20 days, the material lost less than 1 percent by weight. Similarly, when fused with hydrofluoric acid for 20 days, the material lost less than 1 percent by weight. Solution was likewise obtained by fusing the mineral with water possessing dilute HCl for 20 days. The mineral was not ground before chemical analysis because the high hardness prevented the possibility of some loss by grinding. The analytical procedure of Nashua was followed. The molecular ratios were determined by dividing

the percentage of each elemental oxide by its molecular weight. In recasting the chemical formula, the molecular ratios (Table 4) were placed in the general pleonaste formula. From the general formula for pleonaste, $(\text{Fe,Mg})\text{O} \cdot \text{Al}_2\text{O}_3$, the molecular ratio between the Al_2O_3 and the sum of the FeO and the MgO would have to be equal. The amount of Cr_2O_3 is negligible. The sum of the FeO and MgO is higher by 0.30 ratio units than the Al_2O_3 . All of the iron would be oxidized to the Fe_2O_3 state when fused in potassium bisulfate so that in the analysis there would be no test for FeO . The results in table 4 are based on the assumption that all the iron was in the plus 2 oxidation state. However, the above unbalance demands some Fe_2O_3 and requires the general formula for the pleonaste to be $(\text{Fe,Mg})\text{O} \cdot (\text{Fe,Al})_2\text{O}_3$. Recasting the chemical formula on this basis produced the following results:

| Constituent | Percent | Ratio |
|-------------------------|---------|-------|
| Al_2O_3 | 65.07 | 0.638 |
| FeO | 16.07 | 0.224 |
| MgO | 17.16 | 0.425 |
| Cr_2O_3 | 0.05 | --- |
| Fe_2O_3 | 1.60 | 0.010 |
| Total | 99.95 | |

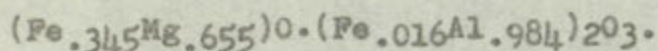
Changing some of the FeO to Fe_2O_3 gives a larger total amount, closer to the 100 percent total, for the analysis percentages, and gives a difference of only 0.001 ratio units between the FeO-MgO and the $\text{Fe}_2\text{O}_3\text{-Al}_2\text{O}_3$ totals.

the percentage of each elemental oxide in the molecular weight. In rounding the chemical formula, the molecular ratios (Table I) were listed in the general formulae from the general formula for pyroxene, $(\text{Fe}, \text{Mg})_2\text{Si}_2\text{O}_6$. Also, the molecular ratio between the FeO and the MgO of the FeO and the MgO would have to be equal. The amount of Cr_2O_3 is negligible. The sum of the FeO and MgO is higher by 0.30 ratio units than the Al_2O_3 . All of the iron would be oxidized to the Fe^{3+} state when used in pyroxene formulae so that in the analysis there would be no iron present. The results in Table I are based on the assumption that all the iron was in the Fe^{3+} oxidation state. However, the actual balance between iron Fe^{2+} and Fe^{3+} requires the general formula for the silicate to be $(\text{Fe}, \text{Mg})_2\text{O} \cdot (\text{Fe}, \text{Al})_2\text{Si}_2\text{O}_6$. Recasting the chemical formula on this basis produced the following results:

| Ratio | Percent | Constituent |
|-------|---------|-------------------------|
| 0.538 | 52.07 | Al_2O_3 |
| 1.234 | 16.07 | FeO |
| 0.452 | 1.18 | MgO |
| --- | 0.08 | Cr_2O_3 |
| 0.010 | 1.60 | Fe_2O_3 |
| | 100.00 | Total |

Changing some of the FeO to Fe_2O_3 gives a larger total amount, closer to the 100 percent total, for the analysis percentages, and gives a difference of only 0.001 ratio units between the FeO - MgO and the Fe_2O_3 - Al_2O_3 ratios.

The formula taken from the above data would be:



Optical Properties

The optical properties of the pleonaste, determined by immersion oils and the petrographic microscope, are: isotropic, high refringence, $n = 1.788$ to 1.789 . Grains and fragments, even when as small as 8 to 10 microns in size, are a dark green, almost opaque; fragments 2 to 4 microns in size are transparent and a dull green; fragments over 50 microns appear opaque.

The formula is given from the above data and is

$$(\rho \cdot \mu_{\text{eff}}) = 0.001 \cdot \mu_{\text{eff}}$$

Optical Properties

The optical properties of the plastic, when

mixed by immersion oils and the microscopic

are: isotropic, high refractive index, $n = 1.70$ to 1.75 .

Grains and fragments, even when as small as 5 to 10 microns

in size, are a dark green, almost opaque; fragments $\leq 5 \mu$

microns in size are transparent and a dull green; fragments

over 50 microns appear opaque.

THEORETICAL CONSIDERATIONS

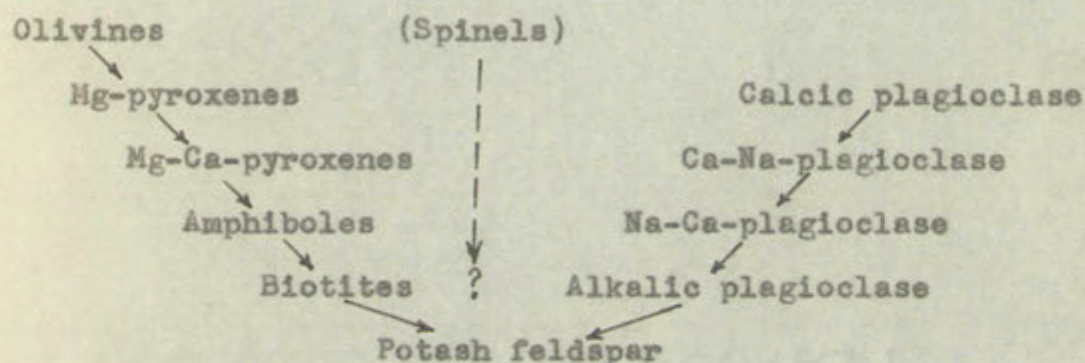
The rocks in the thesis area come under the general heading of basalt. There is a wide variation in the composition of basalt or basaltic rocks. In relation to the amount of silica they may be oversaturated, saturated, or undersaturated. The ratio of alumina to soda, potash and lime gives additional peraluminous, metaluminous, subaluminous and peralkaline types (Shand, 1947, pp. 225-245). These are but two of the numerous variations which may change the mode and naming of the rock. Basalt is generally defined as a rock which has as its essential mineral, calcic plagioclase feldspar, and as varietal, minor, or accessory minerals: olivine, augite, hornblende, feldspathoids, biotite, iron oxides, alkali feldspars, sodic plagioclase, soda-bearing pyroxenes and amphiboles, and quartz. The mafic minerals and the calcic plagioclase and other light minerals occur in approximately equal amounts (Tyrrell, p. 128; Wahlstrom, p. 294).

The order of crystallization probably depends not only on the original composition but also on the rate of cooling, which, in turn, is a function of the injection or ejection history. The exact nature of the formation of the many types of basaltic rocks from the original melt or magma is not definitely known, but a theoretical order of crystallization of the components can be formulated. The following is a theoretical history of the rocks from the

The rocks in the tholeiitic series consist of
 general basaltic rocks. There is a wide variation in
 the composition of basaltic or basaltic rocks, in relation
 to the amount of silica they may be overrepresented, alkali
 rich, or underrepresented. The ratio of elements is varied,
 potash and lime gives additional peraluminous, magnesian,
 and peralkaline types (Table I, pp. 22-23).
 These are but two of the numerous variations which
 may change the mode and nature of the rocks. Some are
 generally defined as a rock which has as its essential
 mineral, calcic plagioclase, feldspar, and quartz,
 minor, or accessory minerals: olivine, apatite, hornblende,
 feldspathoids, biotite, iron oxides, alkali chlorides,
 sodic plagioclase, soda-bearing pyroxenes and amphiboles,
 and quartz. The ratio of elements and the nature of the
 and other light minerals occur in the rocks (Table I, p. 22).

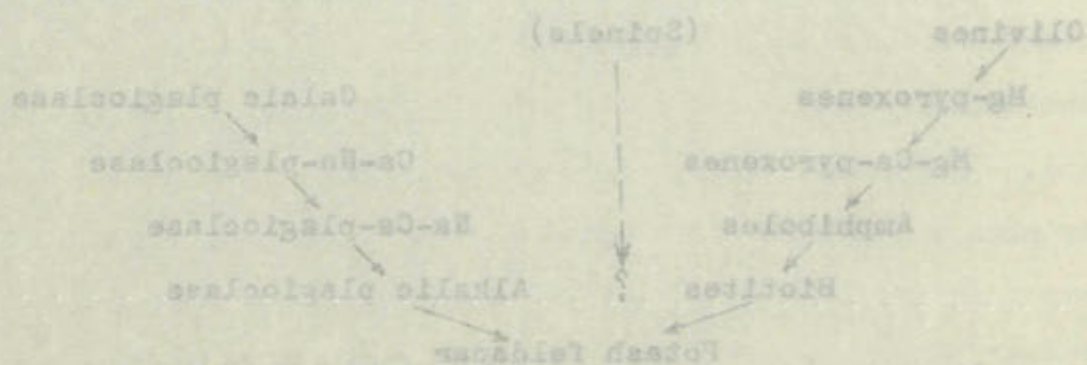
The order of crystallization probably depends
 not only on the original composition but also on the rate
 of cooling, which, in turn, is a function of the thickness
 or ejection history. The exact nature of the formation of
 the many types of basaltic rocks from the original melt or
 magma is not definitely known, but a theoretical order of
 crystallization of the components can be formulated. The
 following is a theoretical history of the rocks from the

thesis area with the theoretical and experimental data outlined in Barth (1952), Turner and Verhoogen (1951), Tyrrell (1926), Shand (1947), and Wahlstrom (1947, 1950), as a basis. A generalized idea of the order in which the common minerals crystallize from a magma is given by Bowen's (1922) reaction series:



Olivine is one of the earliest minerals to crystallize in rocks, but in the presence of sufficient silica, it is converted to pyroxene (Brunton, 1952). Calcic plagioclase is also early in crystallization, slightly later than the olivine. Consider a mineral system embracing olivine (forsterite), calcic plagioclase (anorthite), and silica in a phase equilibrium diagram (Pl. 17): it is divided into five fields corresponding to the primary crystallization of silica, clinoenstatite, forsterite, anorthite and spinel. If a melt of composition a begins to crystallize, the composition of the remaining melt will change as the forsterite crystallizes, as indicated by the straight line to b where spinel would begin to crystallize. The composition would continue to change along line b-c. When

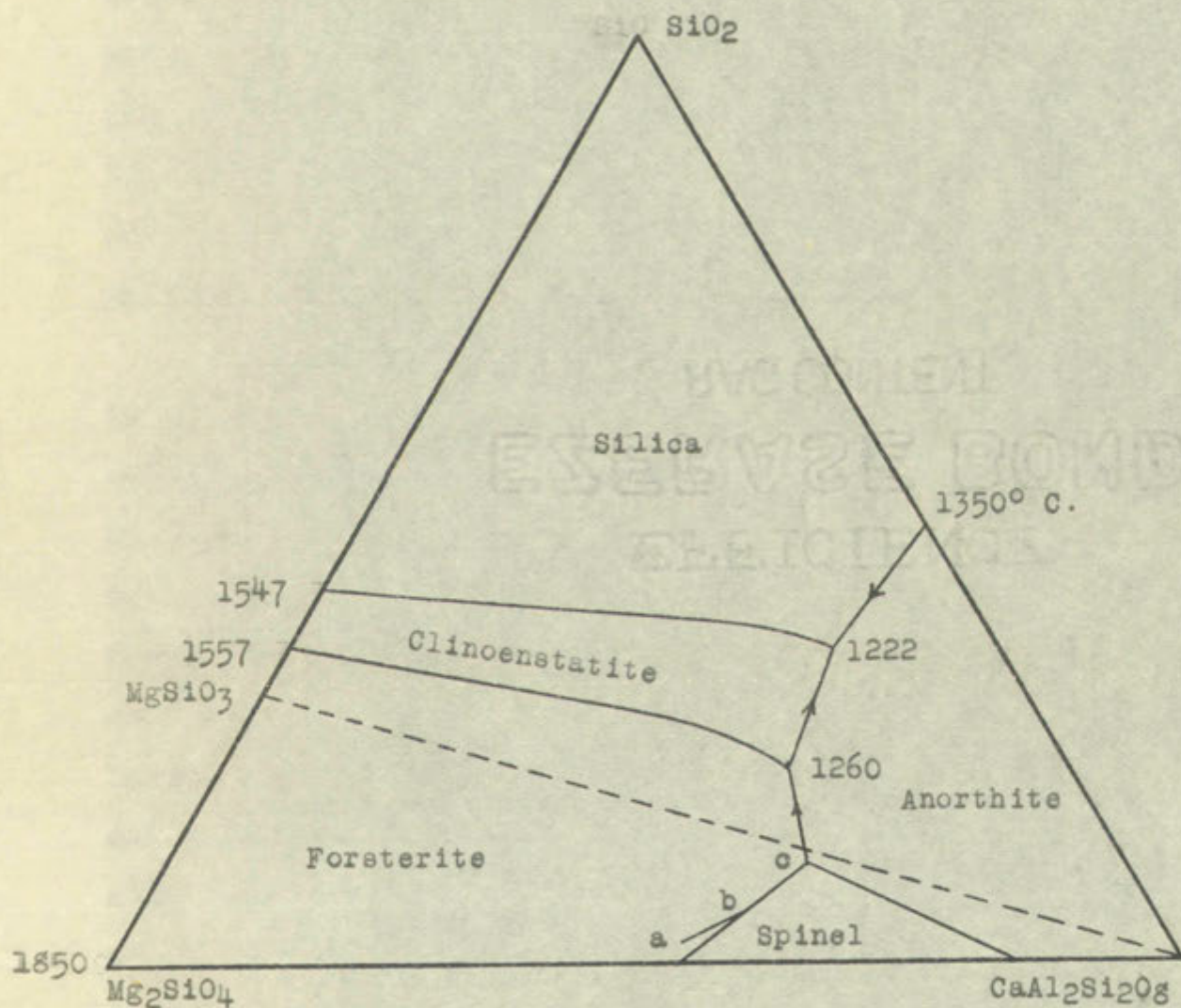
these areas with the theoretical and experimental data outlined in Barth (1952), Turner and Verbeek (1951), Tyrrell (1956), Shand (1957), and Walker (1957, 1959), as a basis. A generalized idea of the order in which the common minerals crystallize from a magma is given by Bowen's (1927) reaction series:



Olivine is one of the earliest minerals to crystallize in rocks, but in the presence of sufficient silica, it is converted to pyroxene (Barton, 1952). Calcic plagioclase is also early in crystallization, slightly later than the olivine. Consider a mineral system consisting of olivine (forsterite), calcic plagioclase (anorthite), and silica in a phase equilibrium diagram (Fig. 17); it is divided into five fields corresponding to the primary crystallization of olivine, clinopyroxene, forsterite, anorthite, and spinel. If a melt of composition a begins to crystallize, the composition of the remaining melt will change as the forsterite crystallizes, as indicated by the straight line to b where spinel would begin to crystallize. The composition would continue to change along line b-c. When

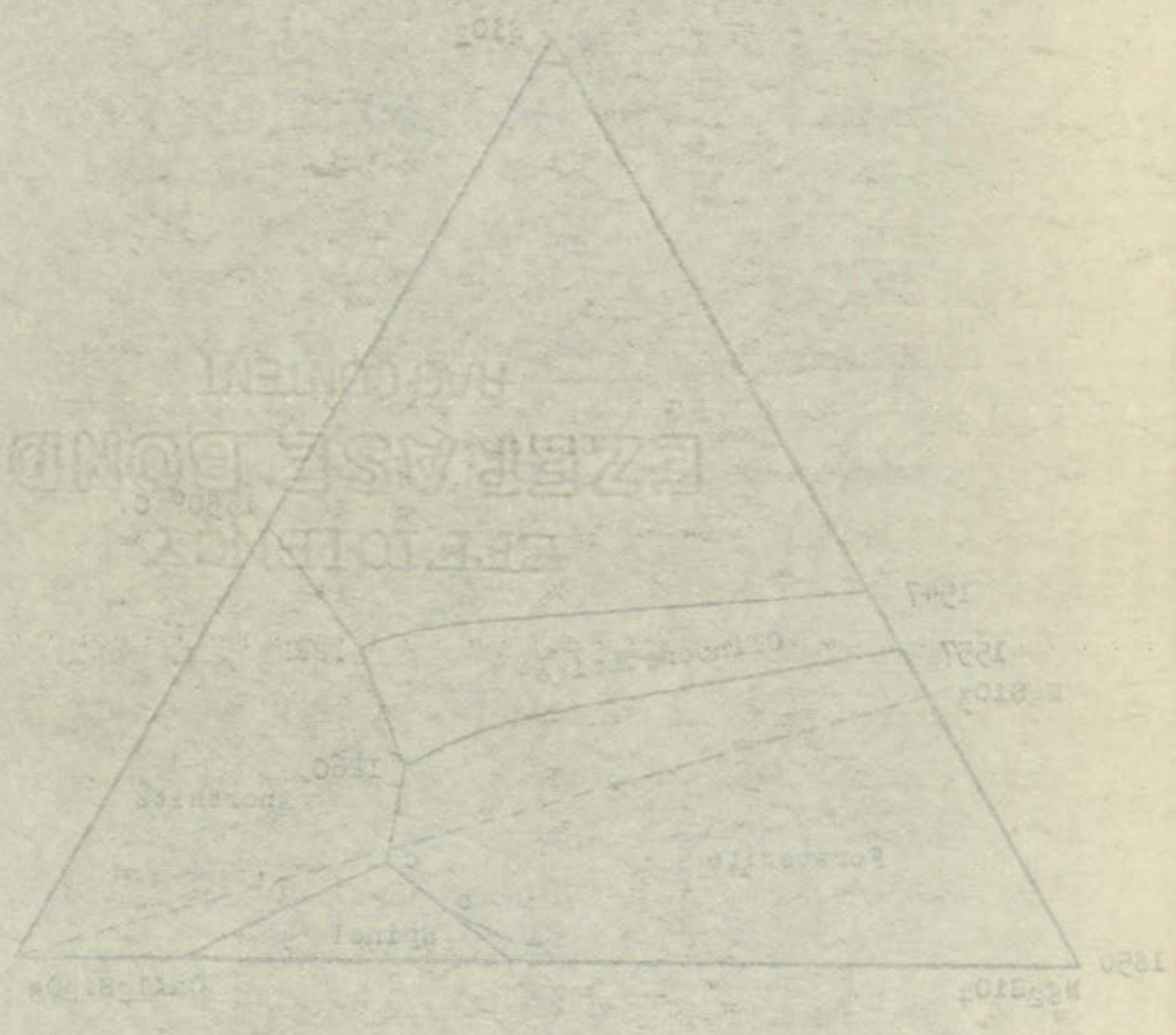
PLATE 17

Phase Equilibrium Diagram



Phase diagram for the system anorthite-forsterite-silica
(Turner and Verhoogen, p. 104).

Phase Equilibrium Diagram



Phase diagram for the system... (W. R. Scott, J. Chem. Phys., 1937, 5, 271)

point c is reached, the spinel would no longer crystallize. From point c the composition would follow along line c-1260°, with the crystallization of anorthite and forsterite. At point 1260° the forsterite would react with the liquid to form clinocostatite. As progressive cooling takes place, the composition of the remaining liquid would follow the path of the arrows until all of the melt has crystallized. Iron in the plus 2 and plus 3 oxidation states could replace the magnesium and the aluminum to form other minerals or variations in the ones shown.

By projecting the modal composition of the rocks in the Caballo Mountains area into this diagram, a line of crystallization similar to the one outlined above would fit. Olivine and spinel could crystallize from the melt and, if the melt were high enough in the oxides of magnesium, iron, and aluminum and low enough in silica, a considerable amount of spinel and olivine could precipitate and produce large crystals. Then, with continued cooling, the olivine and spinel would be reacted upon by the liquid to produce augite and clinocostatite. If there were still an excess of alumina and sodium and a deficiency of silica, nepheline would crystallize in the 1404°-1490° range; if an excess of silica were present, plagioclase would form. Clinocostatite alters readily to serpentine and would not be preserved in the rock.

The foregoing outline of events is made on the basis of continued equilibrium of the melt, but in nature

point of its reaction. The original would no longer crystallize.
From point of the composition would follow along line of
1250°, with the crystallization of anorthite and feldspar.
At point 1250° the feldspar would react with the liquid
to form clinopyroxene. As progressive cooling takes
place, the composition of the remaining liquid would follow
the path of the arrows until all of the melt has crystallized.
Iron in the pyroxene and feldspar would be retained in the
minerals or variations in the case shown.

By projecting the total composition of the rock
in the Calsio Mountains area into this diagram, a line of
crystallization starts to the left and reaches point 1250°.
Olivine and spinel would crystallize first, but as
all the melt were high enough in the ratio of calcium
iron, and aluminum and 1/2 calcium to silica, a considerable
amount of spinel and olivine could crystallize and produce
large crystals. Then, with continued cooling, the olivine
and spinel would be reacted upon by the liquid to produce
augite and clinopyroxene. If there were a little excess
of alumina and sodium and a deficiency of silica, reaction
would crystallize in the 1200°-1100° range. If an excess
of silica were present, clinopyroxene would form. Clinopyroxene
stable silica readily to assemblage and would not be
preserved in the rock.

The foregoing outline of events is made on the
basis of continued equilibrium of the melt, but in nature

There are many disturbing elements in the order of crystallization which would preclude any possibility of the melt behaving as it theoretically should. However, an equilibrium diagram such as Plate 17 does give a good basis for the explanation of the occurrence of the various minerals in a given rock, and any inequilibrium would favor the preservation of the early-formed spinel and olivine.

There are many interesting elements in the study of crystals
which would provide any possibility of the
behaving as is theoretically stated. However, an
this diagram such as that if does give a good basis for
the explanation of the occurrence of the various elements
in a given rock, and any irregularities would favor the
preservation of the early-formed crystals and olivine.

1940
1941
1942

CONCLUSIONS

From this study of the occurrence of large spinel crystals in a flow rock, the writer has concluded that the melt, high in the basic oxides and low in silica, was intruded in a vent or fissure, or was in the top of a magma chamber, where it remained under fairly stable conditions of temperature and pressure. This would allow the formation of large crystals of spinel and olivine, euhedral in outline, provided the conditions and composition were correct for their crystallization. The writer assumes this was true, and that the magma was then ejected and cooled rapidly enough so that very little reaction took place between the spinel and olivine crystals and the magma.

This is the first recorded occurrence of primary pleonaste in New Mexico and the first occurrence of pleonaste of such unusually large size in the Southwest. Northrop (1942) records the occurrence of "a green magnesian spinel", or pleonaste" mentioned by Dunham (1935) as occurring in metamorphosed chert nodules in dolomite xenoliths near Goat Ranch, in a gully southeast of the Merrimac Mine, Dona Ana County, Organ district, New Mexico.

CONCLUSIONS

From this study of the occurrence of large spinel crystals in a flow rock, the writer has concluded that the spinel, like in the basic oxides and in siliceous, was formed in a vein of lithium, or was in the top of a magma chamber, where it remained under fairly stable conditions of temperature and pressure. This would allow the formation of large crystals of spinel and olivine, especially in outline, provided the conditions and composition were not too far from their crystallization. The writer assumes this was true, and that the magma was too elevated and cooled rapidly enough so that very little re-equilibration could be between the spinel and olivine crystals in the magma. This is the first recorded occurrence of spinel in the province in New Mexico and the first occurrence of spinel of such unusually large size in the Southwest. The spinel (1912) records the occurrence of "a green magnesian spinel", or "pleonaste" mentioned by Turner (1912) as occurring in metamorphosed chert nodules in dolomite localities near Gust Ranch, in a gully southeast of the station Mine, Dona Ana County, Organ district, New Mexico.

REFERENCES

- Barth, Tom. F. W., 1952, Theoretical petrology: John Wiley & Sons, Inc., New York, 387 pp.
- Bowen, N. L., 1922, The reaction principle in petrogenesis: Jour. Geol., vol. 30, pp. 177-198.
- Brunton, G., 1952, The study of an unusual augite near Cabezon Peak, Sandoval County, New Mexico: Masters thesis, Univ. of New Mexico, 40 pp.
- Buerger, M. J., 1942, X-ray crystallography: John Wiley & Sons, Inc., New York, 531 pp.
- Bunn, C. W., 1949, Chemical crystallography: Clarendon Press, Oxford, 422 pp.
- Clark, G. C., 1932, Applied X-rays: McGraw-Hill Book Co., Inc., New York, 470 pp.
- Dana, E. S., (Revised by Wm. E. Ford) 1932, A textbook of mineralogy: John Wiley & Sons, Inc., New York, 851 pp.
- Davey, W. P., 1934, A study of crystal structure and its application: McGraw-Hill Book Co., Inc., New York, 695 pp.
- Dunham, K. C., 1935, The geology of the Organ Mountains, with an account of the geology and mineral resources of Dona Ana County, New Mexico: New Mexico Sch. Mines, State Bur. Mines & Min. Res., Bull. 11, 272 pp.
- Kelley, V. C., and Silver, C., 1952, Geology of the Caballo Mountains: Unpublished report.
- Northrop, S. A., 1942, Minerals of New Mexico: The Univ. of New Mexico Bulletin, Geol. Series, vol. 6, no. 1, 387 pp.
- Phillips, F. C., 1946, An introduction to crystallography: Longmans, Green and Co., New York, 302 pp.
- Scott, W. W., (Furman, N. H., Ed.) 1939, Standard methods of chemical analysis: D. van Nostrand Co., Inc., New York, 5th ed., vol. 1, 1234 pp.
- Shand, S. James, 1947, Eruptive rocks: John Wiley & Sons, Inc., New York, 488 pp.

REFERENCES

Barth, Tom P. W., 1952, *Investigative techniques in geophysics*, John Wiley & Sons, Inc., New York, 257 pp.

Bower, H. L., 1955, *The essential principles in geophysics*, John Wiley & Sons, Inc., New York, 301 pp.

Burton, G., 1952, *The study of an unusual granite near Capatzen Peak, Baflovat County, New Mexico*, *Journal of the Geological Society of New Mexico*, 10 pp.

Burger, H. J., 1952, *X-ray crystallography*, John Wiley & Sons, Inc., New York, 233 pp.

Bunn, C. W., 1949, *Chemical crystallography*, Clarendon Press, Oxford, 412 pp.

Clark, G. G., 1945, *Applied X-rays*, McGraw-Hill Book Co., Inc., New York, 10 pp.

Dana, E. S., (revised by W. M. Foshag, 1935), *A text-book of mineralogy*, John Wiley & Sons, Inc., New York, 651 pp.

Davey, W. F., 1938, *A study of oriented minerals and its application to X-ray diffraction*, *Journal of Applied Crystallography*, 1, 1-10.

Dunbar, K. W., 1935, *The geology of the State of New Mexico with an account of the geology and mineral resources of Dona Ana County, New Mexico*, *The Texas Geological Survey Bulletin*, 1, 1-375 pp.

Kelly, V. C., and Silver, C., 1932, *Geology of the Cobalt Mountains*, unpublished report.

Kortrop, E. A., 1943, *Minerals of New Mexico: The Geology of New Mexico Bulletin*, *Geological Survey*, vol. 10, no. 1, 387 pp.

Phillips, F. C., 1941, *An introduction to X-ray crystallography*, John Wiley & Sons, Inc., New York, 202 pp.

Reed, W. W., (revised by H. E. Merrett, 1939), *Standard methods of chemical analysis*, G. Van Nostrand Co., Inc., New York, 5th ed., vol. 1, 1-123 pp.

Shand, S. James, 1911, *Mineralogy*, John Wiley & Sons, Inc., New York, 100 pp.

- Turner, Francis J., and Verhoogen, Jean, 1951, Igneous and metamorphic petrology: McGraw-Hill Book Co., Inc., New York, 602 pp.
- Tyrrell, G. W., 1926, Principles of petrology: Dutton and Co., London, 349 pp.
- Wahlstrom, Ernest E., 1947, Igneous minerals and rocks: John Wiley & Sons, Inc., New York, 367 pp.
- Wahlstrom, Ernest E., 1950, An introduction to theoretical igneous petrology: John Wiley & Sons, Inc., New York, 365 pp.
- Winchell, Alexander N., 1951, Elements of optical mineralogy; an introduction to microscopic petrography: John Wiley & Sons, Inc., New York, 3 parts.

Turner, Francis G., and J. H. Turner, 1951. *Journal of
metamorphic petrology*. McGraw-Hill Book Co., Inc., New
York, 402 pp.

Tyrell, G. W., 1956. *Principles of petrology*. Boston and
Co., London, 369 pp.

Wahlstrom, Ernest E., 1947. *Essays in metamorphic
John Wiley & Sons, Inc., New York, 367 pp.*

Wahlstrom, Ernest E., 1950. An introduction to metamorphic
petrology. John Wiley & Sons, Inc., New York,
362 pp.

Winchell, Alexander S., 1951. *Principles of optical mineralogy
an introduction to microscopic petrology*. John Wiley
& Sons, Inc., New York, 3 vols.

Wahlstrom
Principles of
Petrology

EFFICIENCY
ERASE BOARD
RAG CONTENT

