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GEOLOGY OF THE HIDDEN MOUNTAINS
VALENCIA COUNTY, NEW MEXICO

By

Patrick J. F. Gratton

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Geology

The University of New Mexico

1958

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. F. Castetter
DEAN

June 3, 1958
DATE

Thesis committee

J. Paul Fitzsimmons
CHAIRMAN

Abraham Rosenzweig

Sherman A. Wengerd

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

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ABSTRACT

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The Hidden Mountains are a group of hills covering a few square miles and standing up to 500 feet above the flood plain of the Rio Puerco. The hills are formed by relatively resistant igneous sills in the Santa Fe formation of late Tertiary age.

The trough-filling Santa Fe formation is at least 14,000 feet thick in the vicinity of the Hidden Mountains. Late Tertiary, basic igneous rocks have intruded the Santa Fe formation at several levels in the Albuquerque-Belen basin.

The Hidden Mountains expose two hypabyssal bodies in the upper half of the Santa Fe formation. The older of these units, the olivine basalt upper sill, caps the Hidden Mountains in most places. This rock was probably derived from a parent magma at a depth greater than 10,000 feet. This magma was in the early stages of crystal sorting at the time it was tapped to form the olivine basalt upper sill. The younger unit, the augite diabase lower sill, intrudes the olivine basalt upper sill as well as the Santa Fe formation. The augite diabase lower sill is probably a slightly later expression of the same parent magma from which the olivine basalt upper sill was derived. The Santa Fe formation in contact

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with these sills is indurated by low-grade, thermal metamorphism. At least one occurrence of magmatic-hydrothermal alteration of the Santa Fe may have been effected by fluids escaping from these sills.

Near the end of the Tertiary, the Santa Fe formation and both sills were gently folded by compressional forces probably caused by the cross-sectional diminution of the sinking Albuquerque-Belen basin.

Normal faulting followed the folding and was effected by gravity adjustment of the folded structures.

During the late Tertiary or Quaternary, small- to medium-sized, vesicular basalt plugs forcibly intruded or "punched through" the older rocks in the north end of the Hidden Mountains. Apparently, this local feature was produced and controlled by faults penetrating a shallow basalt reservoir. Local low-grade, hypothermal, hematite mineralization may have been associated with these plugs.

During Quaternary time, the area was exposed and reduced by erosion.

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INTRODUCTION

Purpose and Extent of Work

This thesis, Geology of the Hidden Mountains, Valencia County, New Mexico, was undertaken in order to fulfill the requirements for the Master of Science degree in Geology at the University of New Mexico.

This study was initiated in the spring of 1956 and completed in the spring of 1958. Detailed mapping was accomplished in the field with the aid of enlarged, slightly modified, U. S. Geological Survey topographic maps, plane table and alidade, Brunton compass, and hand level. Thin sections of ten igneous rock samples were examined under the petrographic microscope. Library research was carried on contemporaneously. Including the preparation of the manuscript, a total of about 400 man-hours of labor were spent in the development of this thesis.

Previous Work

Short comments on the geology of the Hidden Mountains had been made previous to the writer's investigation, by Darton (1916); Kelley and Wood (1946); Wright(1946); and Kelley, Wood, Silver, and Smith (1951). Wright's paper contains the most information; however the treatment is not detailed.

Acknowledgments

The writer is indebted to Professor J. Paul Fitzsimmons, who has guided this thesis. Professor Sherman A. Wengerd read the manuscript and made helpful suggestions. My sincere thanks are extended to Patrick H. Gratton and Brian Gratton who accompanied me into the field on numerous occasions and substantially reduced the physical difficulties associated with the mapping stage of the investigation. F. D. Huning allowed the writer to go into his ranch, which includes most of the Hidden Mountains. The writer was ably assisted in the field in the spring of 1956 by Richard A. Ullrich. The writer wishes to acknowledge the very valuable aid of his wife, Jean M. Gratton, in preparing the manuscript. Thanks are also due Robert L. Fay for making certain facilities of Shell Oil Company available. Paul Dollahon drafted Figure 3. I thank Mark L. Robinson, Duff Kerr, Phillip Fickman, Sam Thompson, and Vernon Heath for their assistance.

The writer is indebted to Professor J. Paul Wittenberg, who has guided this thesis. Professor Andrew A. Meigs read the manuscript and made helpful suggestions. Appreciation is also extended to Patrick F. Costa and Stephen Curtis who accompanied me into the field on numerous occasions and patiently endured the physical difficulties associated with the mapping aspects of the investigation. H. D. Hunting allowed the writer to go into his land, which includes most of the Hidden Mountains. The writer was ably assisted in the field in the spring of 1956 by Richard A. Vulliet. The writer wishes to acknowledge the very valuable aid of his wife, Jean M. Gratton, in preparing the manuscript. Thanks are also due Robert L. Fay for making certain facilities of Shell Oil Company available. Paul Dollahan, Lindsey Pierce, Jack Moore, Hoyt E. Hutchinson, Duff Kerr, Robbin Pickman, Sam Inveigen, and Vernon Smith, for their assistance.

GEOGRAPHY

Location and Access

The Hidden Mountains (sometimes called Cerros Mohinos) are located in Valencia County in the northwest part of Central New Mexico. The mapped area includes all or part of sec. 31, T. 7 N., R. 1 W.; secs. 6, 7, and 18, T. 6 N., R. 1 W.; secs. 35 and 36, T. 7 N., R. 2 W.; and secs. 1, 2, 11, 12, 13, and 14, T. 6 N., R. 2 W., New Mexico Principal Meridian (Fig. 1).

This area is easily accessible in an automobile by 21 miles of paved U. S. Highway 85 south of Albuquerque, New Mexico, to Los Lunas, New Mexico, then by 15 miles of paved New Mexico State Highway 6 west of Los Lunas and across the Rio Puerco Bridge. Twelve hundred feet west of the Rio Puerco Bridge on New Mexico State Highway 6, a dirt road leads about 3000 feet directly south and west across the Santa Fe Railroad tracks and Arroyo Garcia into the northern end of the mapped area (Fig. 1). Interior accessibility is facilitated by several dirt roads. Difficulty in travel is usually confined to short periods during thunderstorms and flash floods which render the arroyos and flood plains impassable except by foot.

The northern edge of the mapped area may also be reached by riding the Santa Fe Railway from Albuquerque, New Mexico, 35 miles southwest to the Rio Puerco siding and then walking about 2000 feet south.

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The northern edge of the mapped area may also be reached by riding the Santa Fe Railway from Albuquerque, New Mexico, 38 miles southwest to the Rio Puerco siding and then walking about 4000 feet south.

Descriptive Geomorphology

The Hidden Mountains are a group of hills standing up to 500 feet above the floor (average elevation of the floor is about 5020 feet) of the broad valley of the Rio Puerco (Fig. 2). The hills are formed from the poorly consolidated Santa Fe formation where it has been capped by hypabyssal olivine basalt intrusives. The Santa Fe material which originally lay above the highest intrusive has been almost completely stripped off. Thus the highest surface is determined by the structural attitude of the intrusives.

Steep slopes and cliffs descend the hills. In many places talus slopes of basalt and diabase are present. In the north edge of sec. 13, T. 6 N., R. 2 W., percolating vadose waters have formed youthful, hummocky, karst-like topography on the locally gypsiferous beds of the Santa Fe formation, which forms a rather steep slope. Local base level for these waters is the bottom of the steep slope where relatively impervious ribs of Santa Fe siltstone prevent further immediate downward movement of the vadose water through the formation.

Alluvial fans and cones, individually up to 30 acres in areal extent and in places over 40 feet deep on the thick edge of the wedge, spread out from the bases of the hills onto valley alluvium where they are interstratified with flood-plain and other alluvial deposits as well as with sand dunes.

The red clay and silt flood plain of the Rio Puerco dominates the lower topography on the east half of the area while reworked Santa Fe clastics in the form of small stream deposits, sand dunes

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Figure 2. Hidden Mountains from New Mexico State Highway 6, 14.3 miles west of Los Lunas, New Mexico.

and Santa Fe bedrock are prominent in the lower elevations in the west half of the area. Sand dunes have migrated into all areas.

Steep-walled arroyos, 30-50 feet deep, have been cut into the old Rio Puerco flood plain and the Santa Fe formation. The two major examples of this feature are Arroyo Garcia and the arroyo of the Rio Puerco.

Drainage

Drainage is easterly toward the through-flowing Rio Puerco. The Rio Puerco flows southeast and south for about 30 miles from the bridge on State Highway 6 and joins the Rio Grande at a point about half way between Socorro, New Mexico, and Belen, New Mexico.

Climate

Climatological data are lacking for the area proper; however, records from Albuquerque, New Mexico, are fairly applicable to the Hidden Mountains because of proximity and similarity of climate.

At Albuquerque the maximum and minimum recorded temperatures and rainfall are 109 and -17 degrees F., 16 and 3 inches per year, respectively. At Albuquerque the annual mean temperature is 56.6 degrees F. and the annual mean precipitation is 8.68 inches.

In the Hidden Mountains most of the rain falls from thunderclouds during the months of July and August. Frequently these and Santa Fe bedrock are prominent in the lower elevations in the west half of the area. Sand dunes have migrated into all areas.

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In the Hidden Mountains most of the rain falls from thunderclouds during the months of July and August. Frequently these ephemeral showers are torrential. Days are rarely calm and usually the wind rises to at least 10 miles per hour by early afternoon. Often the wind blows much harder. In addition to these features, the climate is characteristically dry and sunny.

Vegetation

The Hidden Mountains lie entirely within the Upper Sonoran life zone. At the lower elevations on the east side of the area salt cedars grow along the banks of Arroyo Garcia and the Rio Puerco, prairie grasses and tumbleweeds on the plains. The generally higher elevations of the west half of the area contain prairie grasses, tumbleweeds, and juniper trees, which become abundant along the southwest edge of the Hidden Mountains. Cacti grow throughout the area.

PREHISTORY AND HISTORY

Numerous ruins (see Fig. 1 and Fig. 3 for location), fragments of pottery (Fig. 4), and petroglyphs (Fig. 5) give mute testimony to habitation of the area by Pueblo Indians before the arrival of the Spanish.

Some potsherds from ruins exposed in the roadcut in the center of the west half of sec. 36, T. 7 N., R. 2 W., have been identified as Pueblo II(?) (second half of the Developmental-Pueblo period) and/or Pueblo III (Classic Pueblo or Great-Pueblo period). This indicates residence in the area by these Indians possibly as early as 700 to 900 A. D., and almost certainly as early as 1050 A. D.

The rich site of Pottery Mound (Fig. 1) immediately southeast of the area was a Pueblo IV (Regressive-Pueblo period) structure chiefly. Beautifully painted kiva walls at this site attest to a highly developed, esthetic people, who were probably raising corn, beans, and cotton on the Rio Puerco flood plain for several centuries before the advent of the Spanish in New Mexico (1539-40 A. D.). Large, unexcavated ruins on top of Hidden Mountain proper near the north line of sec. 1, T. 6 N., R. 2 W., were probably used by these Indians as a fortress against marauding nomads. Possibly the climate in the 14th and 15th centuries was moister than now. The Rio Puerco may have had a heavier and more persistent flow at that time, which would have allowed irrigation of the crops.

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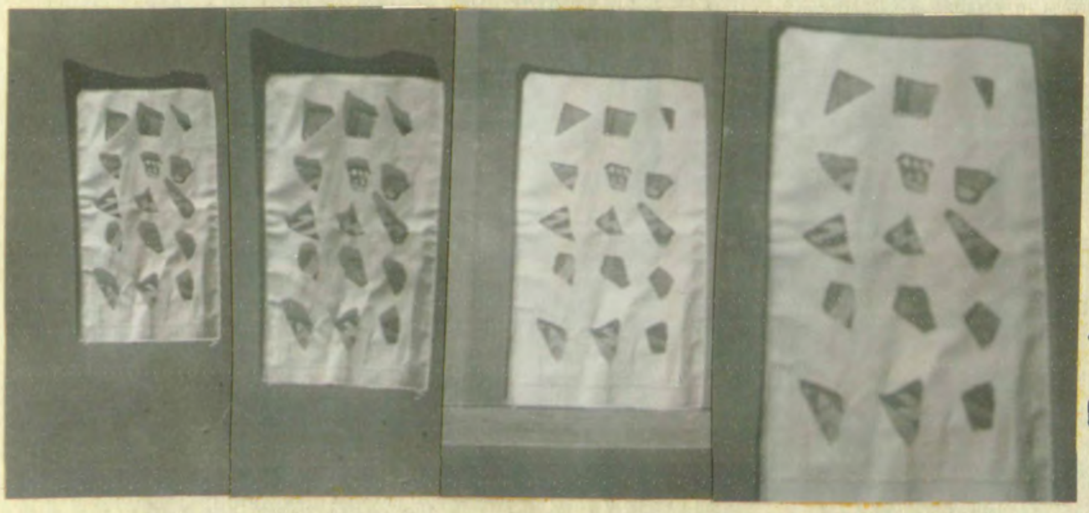

Figure 4. Potsherds from the Hidden Mountains.

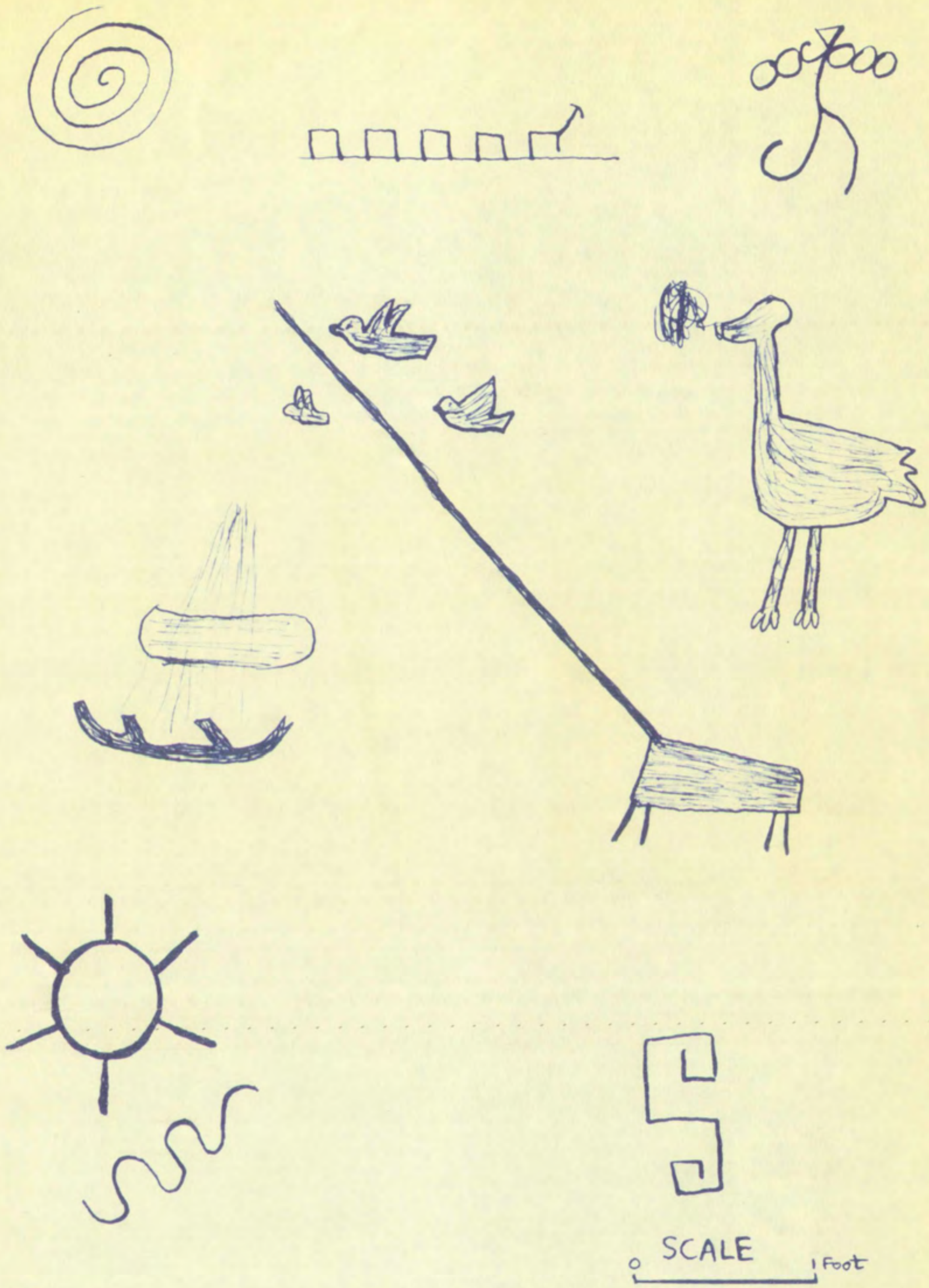

Figure 5. Petroglyphs from the Hidden Mountains.

assumed that Pottery Mound was the site of an abandoned pueblo by the middle of the 16th century.

The Spanish concentrated their colonizing efforts in the Rio Grande Valley, and as a consequence the Rio Puerco Valley was more or less uninhabited until the 19th century.

About the middle of the 19th century, shortly after Mexico had ceded the New Mexico Territory to the United States, large ranches were established in this part of the Rio Puerco Valley. In 1880-81 the Santa Fe Railroad laid the main line track just north of the area (Fig. 1) on the route from Kansas City to Los Angeles.

During the early part of the 20th century, New Mexico State Highway 6 (in its early days part of the U. S. Highway 66 system) was built through the general area (Fig. 1).

Current population of this part of the Rio Puerco Valley is very low. Only a few ranchers continue to live here, and in many ways the valley is probably much as it was when the Pueblo Indians disappeared.

GEOLOGY

Regional Setting

The Hidden Mountains are located near the center of the west half of the Albuquerque-Belen basin in the structural and geomorphic Rio Grande depression (Fig. 1). The Rio Grande depression is an axial series of north-trending grabens arranged in echelon north-northeasterly along the course of the Rio Grande (Kelley, 1952, p. 93). Fenneman (1931, p. 328) placed that part of the Rio Grande depression which lies south of Espanola, New Mexico, in the Mexican Highlands Section of the Basin and Range Province. As such it forms a narrow separating arm between the Sacramento Section of the Basin and Range and the Datil Section of the Colorado Plateau.

Kelley's (1952, p. 93) interpretation of the Rio Grande depression as a narrow, linear feature stretching from near Saguache, Colorado, 450 miles south to near El Paso, Texas, seems a more natural one, because it gives continuity to the lands on either side of the Rio Grande.

Continental, clastic, trough-filling sediments, principally of the Mio-Pliocene Santa Fe formation, occupy the Albuquerque-Belen Basin. Late Tertiary and Quaternary volcanic extrusives and hypabyssal bodies occur at several levels in this thick section.

The development of the depression, the sediments which filled the depression, and the vulcanism that followed shortly thereafter (e. g., in the Hidden Mountains) seem to be closely related and interdependent.

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Sedimentary Rocks

Although older sedimentary units are exposed on Mesa Lucero several miles west of the area, only the Tertiary Santa Fe formation and Quaternary sediments are on the surface in the Hidden Mountains.

Tertiary Santa Fe Formation

The Santa Fe formation is exposed on the steep slopes and on top of the Hidden Mountains. In the lower elevations it is covered by a veneer of Quaternary alluvium.

The typical development of the Santa Fe formation is an alluvial fan deposit of a characteristic pinkish or light tan color (Kelley, 1952, p. 101), which filled the sinking troughs of the Rio Grande depression during late Miocene and Pliocene time. In the vicinity of the Hidden Mountains the Santa Fe formation is at least 14,000 feet thick (Fig. 6). The bottom of the Santa Fe (top of the Cretaceous) is 4,846 feet below mean sea level in the Humble, Santa Fe Pacific No. 1 (Figs. 1, 6) dry hole immediately south of the area mapped. With allowances for erosion, the Santa Fe formation may have been originally several thousand feet thicker than the minimum figure cited above. These figures for thickness of the Santa Fe formation are considerably greater than those usually cited.

The Santa Fe formation in the surface and subsurface near the Hidden Mountains may be divided into six generalized lithologic zones (Fig. 6). Zones 1, 2, 3, 4, and 6 probably represent alluvial fan environments with varying degrees of flood-plain influence. Zone 5 represents a playa environment (Wright, 1946, Sedimentary Rocks

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The Santa Fe Formation in the eastern and southern portions of the Hidden Mountains may be divided into six generalized lithologic zones (Fig. 6). Zones 1, 2, 3, 4, and 6 probably represent alluvial fan environments with varying degrees of flood-plain influence. Zone 5 represents a playa environment (Wright, 1946,

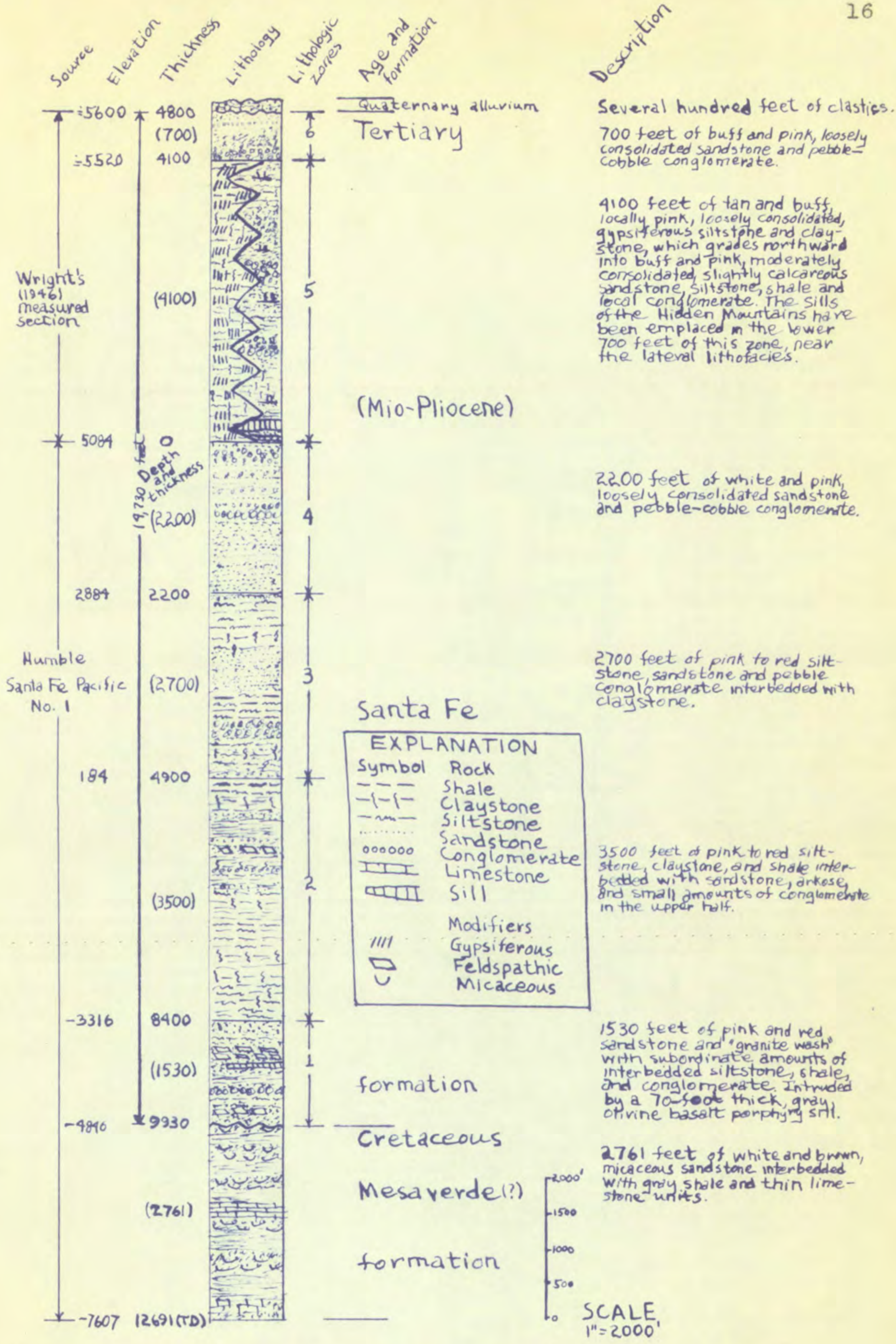

Figure 6. Composite, generalized, lithologic section of the Santa Fe formation in T. 6 N., R. 1 and 2 W., N. M. P. M.

p. 407-412). The provenances for all of these Santa Fe deposits must have been bordering highlands to the west and north during the late Miocene and Pliocene.

Sills of diabase and basalt invaded the Santa Fe (e. g., the sills of the Hidden Mountains) at several levels. Volcanic plugs "punched through" the Santa Fe. Some rounded fine grains incorporated in altered Santa Fe deposits at locality Datatron in sec. 7, T. 6 N., R. 1 W., are rhyodacite and are dissimilar to the igneous rocks of the Hidden Mountains. Perhaps these pebbles were derived from Mt. Taylor or the Jemez area.

The Santa Fe formation exposed on the surface in the Hidden Mountains is brown to light pink, interbedded, only locally well cemented, slightly calcareous, sandstone, siltstone, mudstone, shale, and conglomerate. Along the southwest edge of the area, the Santa Fe is gypsiferous (the playa facies of Wright, my lithologic zone 5). The Santa Fe is indurated immediately above and below each sill.

Quaternary Sediments

Quaternary sediments cover the Santa Fe formation in a large part of the thesis area. Chiefly, they are in the form of sand dunes, stream alluvium, flood plains, and alluvial fans.

Sand dunes are made of translucent to transparent, fine- to medium-grained, rounded, frosted quartz sand. Stream alluvium (exclusive of the Rio Puerco flood plain) is composed of eroded Santa Fe, olivine basalt, augite diabase, and vesicular basalt material. The flood plain of the Rio Puerco consists of red to pink silt, mud, and clay derived from provenances of older rocks (mostly

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The Santa Fe formation exposed on the outliers in the Hidden Mountains is brown to light pink, interbedded, only locally well cemented, slightly calcareous, sandstone, siltstone, mudstone, shale, and conglomerate. Along the southwest edge of the area, the Santa Fe is gypsiferous (the playa facies of Wright, op. lithologic zone 5). The Santa Fe is indurated immediately above and below each sill.

Quaternary Sediments

Quaternary sediments cover the Santa Fe formation in a large part of the thesis area. Chiefly, they are in the form of sand dunes, stream alluvium, flood plains, and alluvial fans.

Sand dunes are made of translucent to transparent, fine- to medium-grained, rounded, frosted quartz sand. Stream alluvium (exclusive of the Rio Puerco flood plain) is composed of eroded Santa Fe, olivine basalt, augite diabase, and Magdalena basalt material. The flood plain of the Rio Puerco consists of red to pink silt, mud, and clay derived from provenances of older rocks (mostly

Mesozoic and late Paleozoic) exposed on the Colorado Plateau northwest of the Hidden Mountains. Alluvial fans are composed of trap and Santa Fe material derived from the Hidden Mountains proper.

Igneous Rocks

The exposed Tertiary and/or Quaternary igneous rocks of the Hidden Mountains are chiefly local, basic, hypabyssal intrusives into the middle and/or upper members of the Santa Fe formation. These bodies are expressed most commonly in the general form of slightly discordant sills; however dikes and plugs are also represented.

Three distinct igneous rock units can be identified. The earliest of these units is the olivine basalt upper sill. This rock has been intruded by the augite diabase lower sill in the northern end of the area. Finally, both of these units have been forcibly intruded by vesicular basalt plugs.

Olivine Basalt Upper Sill

The olivine basalt upper sill (Fig. 7) has a total exposed area of about one square mile scattered over several sections. The total area originally covered by this rock, including the subsurface and that which has been eroded, was probably 4 or 5 square miles. Thickness ranges from 0 to 350 feet. Slight post-emplacement deformation is represented by folds and faults.

Mesozoic and late Paleozoic, exposed on the Colorado Plateau north-west of the Hidden Mountains. Alluvium, then, is composed of trap and Santa Fe material derived from the Hidden Mountains uplift.

Igneous Rocks

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Olivine Basalt Upper Sill

The olivine basalt upper sill (Fig. 7) has a total exposed area of about one square mile scattered over several portions. The total area originally covered by this rock, including the subsurface and that which has been eroded, was probably about 3 square miles. Thickness ranges from 0 to 350 feet. Slight post-emplacement deformation is represented by folds and faults.

Figure 7. Olivine basalt upper sill (Tob) and augite diabase lower sill (Tad) in the Santa Fe formation (Tsf) in the Hidden Mountains.

This sill is slightly discordant (dips are greater and less than the enclosing Santa Fe in different places). Locally, e. g., in the NW$\frac{1}{4}$ sec. 1, T. 6 N., R. 2 W., it assumes the attitude of a dike.

Although erosion has stripped most of the Santa Fe formation from this sill, embayed, thermally indurated Santa Fe can be observed above the sill in the south half of the Hidden Mountains (structure section B-B', Fig. 3).

Since the upper contact is usually eroded and the bottom contact is often not visible, dip and strike readings on this sill are sparse. The dip and strike of a peculiar platy fracture was found to roughly approximate the dip and strike of the sill. This parameter was measured frequently where the orientation of the sill itself was not observable.

Generally the olivine basalt upper sill appears homogeneous in texture and composition; so only two samples (rock numbers 11-9-3 and 11-9-4) were taken for microscopic examination.

Megascopically this rock is a dark gray, fine- to medium-grained, locally "limonite"-stained, surficially weathered, impermeable basalt, which exhibits a peculiar platy fracture in many localities. Plagioclase laths, augite(?), and olivine(?) can be recognized with a fair degree of reliability in the hand sample. However, the fine granularity makes positive identification and estimates of percentages impossible.

Under the microscope the rock is seen to be an olivine basalt or an olivine-bearing basalt, which is holocrystalline and generally

fine grained although a number of the plagioclase laths approach two millimeters in length. Hypidiomorphic, microporphyritic, subophitic, intergranular, and intersertal textures are evident in that order of importance in this suite of rocks. About three quarters of the rock is labradorite. Olivine (occasionally as fractured microphenocrysts) and augite are present in moderate quantities. Small amounts of magnetite and volcanic glass are present. Magnetite, hematite, iddingsite(?), and "limonite" are fairly common alteration products of ferromagnesian and iron minerals. Small quantities of epidote(?) and kaolin are moderately developed on plagioclase.

Augite Diabase Lower Sill

The augite diabase lower sill (Fig. 7) crops out in several sections and has a total exposed area of about one half square mile. The total area originally covered by this rock, including the subsurface and that which has been eroded, was probably very roughly coincident with the earlier but structurally higher olivine basalt sill. Two centers of concentration appear in the present distribution of this sill, one in sec. 36, T. 7 N., R. 2 W. and another in sec. 12, T. 6 N., R. 2 W. The thickness ranges from 0 to about 100 feet.

Moderate post-emplacement folding and faulting has been effected.

This sill is slightly discordant. Although dips are locally steeper than the enclosing Santa Fe formation, they are usually one to five degrees less. In the east half of sec. 36, T. 7 N., fine grained although a number of the plagioclase laths approach two millimeters in length. Hyalidomorphic, microporphyritic, subophitic, intergranular, and intersertal textures are evident in that order of importance in this suite of rocks. About three liters of the rock is labradorite. Olivine (pseudomorphs as scattered microphenocrysts) and augite are present in moderate quantities. Small amounts of magnetite and volcanic glass are present. Magnetite, hematite, iddingsite(?), and "bowlingite" are fairly common alteration products of ferromagnesian and iron minerals. Small quantities of epidote(?) and kaolin are moderately developed in plagioclase.

Augite Diabase Lower Sill

The augite diabase lower sill (Fig. 7) crops out in several sections and has a total exposed area of about one half square mile. The total area originally covered by this rock, including the subsurface and that which has been eroded, was probably very roughly coincident with the earlier but structurally higher olivine basalt sill. Two centers of concentration appear in the present distribution of this sill, one in sec. 36, T. 7 N., R. 2 E. and another in sec. 12, T. 6 N., R. 2 E. The thickness ranges from 5 to about 100 feet.

Moderate post-emplacement folding and faulting has been effective. This sill is slightly discordant. Although dips are locally steeper than the enclosing Santa Fe formation, they are usually one to five degrees less. In the west half of sec. 36, T. 7 N.,

R. 2 W., this sill intrudes the olivine basalt upper sill (Fig. 8). At locality Dextrose a finer-grained equivalent of the rock of the lower sill has formed a small dike.

The Santa Fe formation can be observed usually in contact with the top and bottom of this sill. In these places the Santa Fe is indurated in zones ranging from 1 to 20 feet in thickness. No Santa Fe was found above this sill in the northern end of the area. This fact suggests the possibility that this rock may represent a surface flow in sec. 36, T. 7 N., R. 2 W. However, no flow structures were found. More probably this occurrence is that of a sill with the upper contact removed by erosion.

This rock is slightly heterogeneous but displays enough similarity to be recognized as one mappable unit throughout the area. In sec. 36, T. 7 N., R. 2 W. some small, irregular, vesicular basalt bodies are mapped as part of the augite diabase unit. Dissimilarities are in the form of granularity and texture. In the north part of the Hidden Mountains it occasionally displays a diktytaxitic texture which is not present in the south half. Usually a coarser granularity is apparent in the north half of the area. In order to study these variations more closely, six samples (rock numbers 11-2-1, 11-9-1, 11-9-2a, 11-9-2c, 11-10-1, 12-7-1) were taken for microscopic examination.

Megascopically this rock is a dark gray to yellow-green-brown, medium-grained, often altered (permeable, friable, and "limonitic") augite diabase. Occasional fractures, up to three inches wide, are filled with a hard, yellow-brown felsite (rock number 11-9-2b) of probable magmatic-hydrothermal origin.

R. 2 W., this sill intrudes the olivine basalt upper sill (Fig. 2). At locality Dextrose a finer-grained selvage of the rock of the lower sill has formed a small dike.

The Santa Fe formation can be observed usually in contact with the top and bottom of this sill. In these places the Santa Fe is indurated in zones ranging from 1 to 30 feet in thickness. No Santa Fe was found above this sill in the northern end of the area. This fact suggests the possibility that this rock may represent a surface flow in sec. 36, T. 7 N., R. 2 W. However, no flow structures were found. More probably this occurrence is that of a sill with the upper contact removed by erosion.

This rock is slightly heterogeneous but displays enough similarity to be recognized as one mappable unit throughout the area. In sec. 36, T. 7 N., R. 2 W. some small, irregular, vesicular basalt bodies are mapped as part of the augite diabase unit. Dissimilarities are in the form of granularity and texture. In the north part of the Hidden Mountains it occasionally displays a diktytaxitic texture which is not present in the south half. Usually a coarser granularity is apparent in the north half of the area. In order to study these variations more closely, six samples (rock numbers 11-2-1, 11-9-1, 11-9-2a, 11-9-2c, 11-10-2, 12-7-1) were taken for microscopic examination.

Megascopically this rock is a dark grey to yellow-green-brown, medium-grained, often altered (permeable, friable), and "ironstained" augite diabase. Occasional fractures, up to three inches wide, are filled with a hard, yellow-brown calcite (rock number 11-9-2b) of probable magmatic-hydrothermal origin.

Figure 8. Augite diabase lower sill (Tad) intruding the olivine basalt upper sill (Tob) in the Hidden Mountains.

Under the microscope the rock is seen to be an augite diabase (or in one case, a basalt), which is usually holocrystalline and generally medium grained. Hypidiomorphic, subophitic (only one example of true ophitic texture was observed), intergranular, dikty-taxitic, allotriomorphic, intersertal, microporphyritic, vesicular, amygdaloidal, and axiolitic textures occur in that order of importance in this suite of rocks. About two thirds of the rock's volume is labradorite. Augite is important enough to be varietal. Magnetite and hematite are next in importance. Finally, glass, the alteration products, and olivine are present in small amounts.

Vesicular Basalt Plugs

In sec. 36, T. 7 N., R. 2 W., 28 vesicular basalt plugs forcibly intrude the Santa Fe formation, the augite diabase lower sill, and the olivine basalt upper sill (Fig. 9). These plugs range from less than 10 feet to over 200 feet in diameter. The dip of the country rock immediately surrounding the plugs has been steepened considerably (Figs. 9, 10). This field evidence of "punching through" action is extremely striking. All of the plugs seem to have been truncated by erosion.

Certain plugs display linear alignments which parallel or coincide with known faults. This strongly suggests that these plugs were intruded after initial deformation along zones of weakness. Perhaps these volcanic features are late Pliocene or Quaternary.

Megascopically these rocks are dark gray, vesicular and amygdaloidal basalt. Occasionally the vesicular texture grades to a scoriaceous one. The amygdules are composed of zeolites(?) and calcite.

Figure 9. Vesicular basalt plug (TQb) intruding and "punching through" the Santa Fe formation (Tsf), the augite diabase lower sill (Tad), and the olivine basalt upper sill (Tob) in the Hidden Mountains.

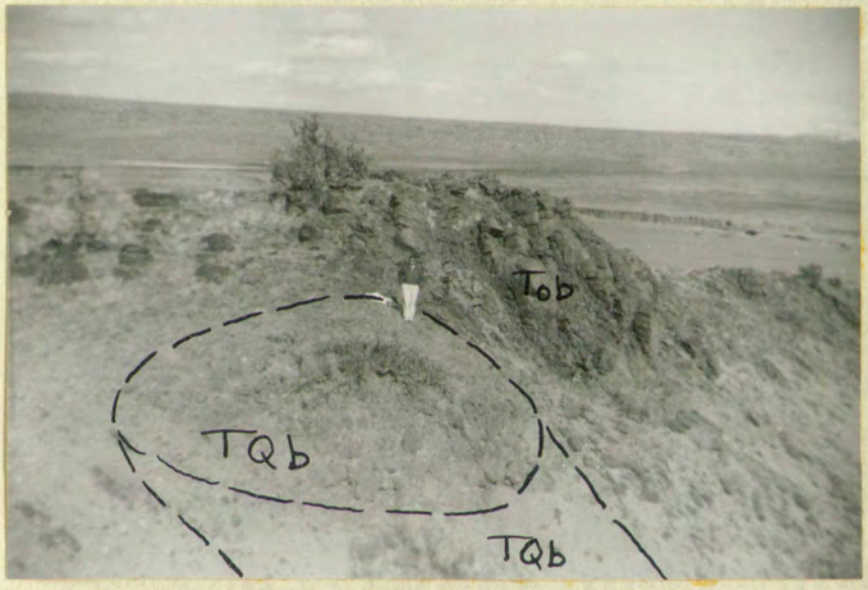

Figure 10. Vesicular basalt plug (TQb) intruding and steepening dip of the olivine basalt upper sill (Tob) in the Hidden Mountains.

Metamorphic Rocks

Thermal Alterations

The Santa Fe formation, above and below each sill, is thermally metamorphosed. This alteration is of low intensity and usually confined to zones ranging from 1 to 20 feet thick above and below the sills. In the west half of sec. 7, T. 6 N., R. 1 W., however, an irregular, embayed body of the Santa Fe is thermally altered to a depth exceeding 100 feet.

Megascopically, the alteration is chiefly one of induration. The Santa Fe in these alteration zones is typically well cemented and "hard," and consequently more resistant to weathering and erosion than unaltered Santa Fe. No thermal metamorphic minerals were in evidence.

Magmatic-Hydrothermal Alterations

In the center of the west half of sec. 7, T. 6 N., R. 1 W., the Santa Fe formation displays intense magmatic-hydrothermal alteration. At this locality, a dike-like body measuring 350 feet by 100 feet stands out prominently because of resistance to erosion and weathering (Fig. 11). A sample (rock number 12-7-2) of this rock was examined microscopically.

Megascopically this rock is mottled light tan to buff and red-brown, very fine to medium grained, slightly calcareous, well cemented, and permeable. Pebble-sized clay(?) particles of altered Santa Fe material are cemented together by hematite and "limonite." The rock has an unusually low gross density.

Metamorphic Rocks

Thermal Alterations

The Santa Fe formation, above and below each sill, is thermally metamorphosed. This alteration is of low intensity and usually confined to zones ranging from a few to 20 feet thick above and below the sills. In the west half of sec. 7, T. 5 N., R. 7 W., however, an irregular, elongated body of the Santa Fe is thermally altered to a depth exceeding 100 feet.

Megascopically, the alteration is entirely one of induration. The Santa Fe in these alteration zones is typically well cemented and "hard," and consequently more resistant to weathering and erosion than unaltered Santa Fe. No thermal metamorphic minerals were in evidence.

Magmatic-Hydrothermal Alterations

In the center of the west half of sec. 7, T. 5 N., R. 7 W., the Santa Fe formation displays intense magmatic-hydrothermal alteration. At this locality, a dike-like body measuring 300 feet by 100 feet stands out prominently because of resistance to erosion and weathering (Fig. 11). A sample (rock number 12-7-2) of this rock was examined microscopically.

Megascopically this rock is mottled light tan to gray(?) and red-brown, very fine to medium grained, slightly calcareous, well cemented, and permeable. Pebble-sized clay(?) particles of altered Santa Fe material are cemented together by hematite and "limonite." The rock has an unusually low gross density.

Figure 11. Resistant metaclaystone of the altered Santa Fe formation in the Hidden Mountains.

Under the microscope the rock is seen to be a metaclaystone of the altered Santa Fe formation. The detrital part of the rock is made of fine and very fine grains which form pebble-sized aggregates.

The cement was formed by hydrothermal-magmatic solutions which have deposited andesine-labradorite, volcanic glass, hematite, and magnetite in and around the pebble aggregates. The same or later solutions have altered (to clay ?) much of the Santa Fe material. Some of the clay may be "primary" or due to weathering.

Rounded grains of plagioclase in the altered Santa Fe are oligoclase. Constituent minerals indicate that many of the rounded volcanic aphanitic pebbles in the Santa Fe formation are rhyodacite and thus dissimilar to the basic igneous rocks of the Hidden Mountains.

Mineralization

Mineralized zones exclusive of those described above occur in the igneous rocks of the Hidden Mountains (Fig. 3). These zones are small areas of low-grade hematite mineralization probably associated with nearby faults and vesicular basalt plugs. Some of these zones have been trenched by prospectors. All known mineralization is sub-economic.

Structure

Folds and faults deform most of the rocks in the Hidden Mountains. Only those structures which appear on the surface in the immediate vicinity of the Hidden Mountains are described.

Under the microscope the rock [illegible] the altered Santa Fe formation. The detrital part of the rock is made of fine and very fine grains [illegible] matrix.

The cement was formed by [illegible] have deposited adularia [illegible] magnetite in and around the pebbles [illegible] solutions have altered [illegible] the Santa Fe material. Some of the clay may be [illegible] Santa Fe material.

Rounded grains of plagioclase in the altered Santa Fe [illegible] plagioclase. Constituent minerals indicate that many of the pebbles of volcanic aphanitic pebbles in the Santa Fe formation are [illegible] and thus dissimilar to the basic igneous rocks of the Hidden Mountains.

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Structure

Folds and faults deform most of the rocks in the Hidden Mountains. Only those structures which appear on the surface in the immediate vicinity of the Hidden Mountains are described.

Folding

The trace of the axial plane of the Gabaldon anticline strikes N. 30° W. through the southwest edge of the mapped area and plunges gently northward in sec. 11, T. 6 N., R. 2 W. This anticline is one of the few large folds found in the Santa Fe formation (Wright, 1946, p. 425). Most of the Hidden Mountains lie on the east limb of this structure, where the Santa Fe formation and the lower and upper sills dip at various angles to the northeast. The Humble, Santa Fe Pacific No. 1 is located just south of the mapped area near the surface trace of the axial plane.

In the northwest quarter of sec. 12, T. 6 N., R. 2 W., the trace of the axial plane of a smaller anticline trends northerly. Resultant dips in the Santa Fe formation and the igneous rocks are low.

Near the center of E½E½ sec. 12, T. 6 N., R. 2 W., the trace of the axial plane of a very small anticline strikes north. The strata dip about 20 degrees on either side of the axial plane in this tightly compressed structure. These features and an adjacent fault indicate that this is a drag fold. Many other drag folds probably exist in the area. This interpretation is shown in the cross sections of Figure 3.

Faulting

Faulting is conspicuous in the Hidden Mountains. Most, if not all, of these faults are normals with throws ranging from 10-15 feet to over 300 feet.

In the south half of the Hidden Mountains most of these faults trend in a northwesterly direction, more or less parallel to the Gabaldon anticline. By tilting of blocks, these faults have increased and decreased the dips of the strata created by the Gabaldon anticline.

In the north half of the Hidden Mountains faulting is multidirectional. Some of the faulting in sec. 1, T. 6 N., R. 2 W., appears to be part of a slumping action. In sec. 36, T. 7 N., R. 2 W., the largest fault in the area, the Fence-line fault (Fig. 12), and subordinate faults have localized many vesicular basalt plugs.

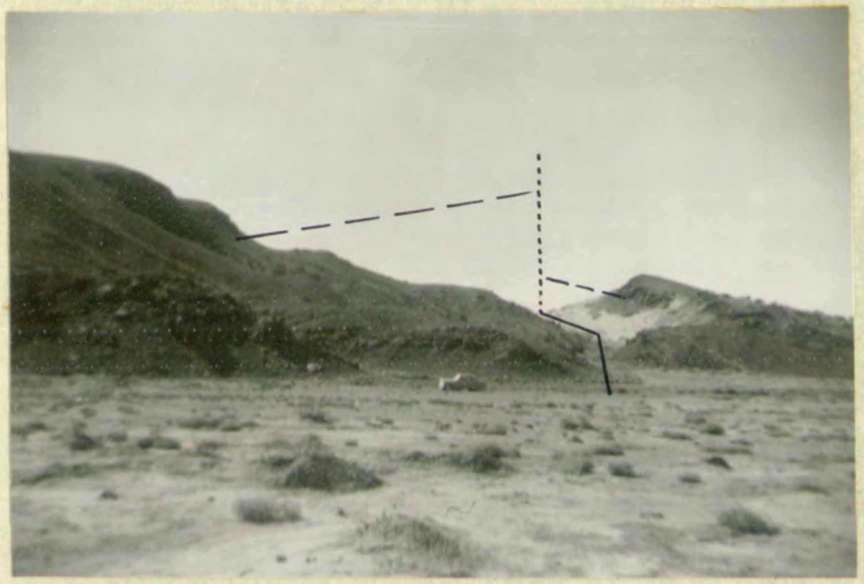

Figure 12. Fence-line fault in the Hidden Mountains showing surface trace of the fault plane (solid line), vertical line in the projected fault plane (dotted line), and projected bottom contact of the displaced and rotated olivine basalt upper sill (dashed lines).

GEOLOGIC HISTORY

Late Tertiary deep-seated rifting probably caused the in echelon basins and uplifts which constitute the Rio Grande depression (Kelley, 1952, p. 103). Detritus derived from the bordering highlands filled the basins during late Miocene and Pliocene time. This material is known as the Santa Fe formation.

Within the Albuquerque-Belen basin of the Rio Grande depression, down-faulting of the Santa Fe probably continued during deposition of the Santa Fe.

In the Hidden Mountains area of this basin, this tectonism allowed the accumulation of at least 14,000 feet of Santa Fe material. Most of this sedimentation was of the alluvial fan type with some flood-plain influence; however at least one important playa environment existed (Wright, 1946, p. 407).

Near the end of Santa Fe deposition, slightly discordant olivine basalt sills were emplaced at different levels in the Santa Fe formation and produced low-grade thermal metamorphism of the sedimentary rock. Shortly after this, discordant augite diabase sills intruded the Santa Fe and the olivine basalt sills. Again, slight metamorphism of the Santa Fe took place.

Continued sinking of the Albuquerque-Belen graben in the vicinity of the Hidden Mountains produced localized compression as a result of the diminution in the cross-sectional area of the graben (Wright, 1946, p. 426). The compression was dissipated in the formation of the Gabaldon anticline and the small anticline in

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Continued sinking of the Albuquerque-Belen graben in the vicin-ity of the Hidden Mountains produced localized compression as a result of the diminution in the cross-sectional area of the graben (Wright, 1946, p. 425). The compression was dissipated in the formation of the Gabaldon anticline and the small anticline in sec. 12, T. 6 N., R. 2 W. The Gabaldon anticline may have been localized by the differential competence and the lower structural strength of the thick gypsiferous playa deposits within the Santa Fe formation.

Faulting, mostly of the gravity (normal) type, followed folding as a natural readjustment phenomenon after relaxation and dissipation of the compressional forces. This moderate faulting displaced the Santa Fe formation, the upper olivine basalt sill, and the lower augite diabase sill.

Immediately following and perhaps during the faulting, small- to medium-sized vesicular basalt plugs intruded and "punched through" the Santa Fe formation and both sills in sec. 36, T. 7 N., R. 2 W. Apparently the faults served as loci for this vulcanism. The localization of all these plugs in section 36 suggests that a local basalt reservoir existed at shallow depth in this section during late Pliocene or Quaternary. Hematite mineralization of a hypothermal and magmatic nature followed, or was contemporaneous with faulting and vesicular basalt plug intrusion.

During late Pliocene or in the Pleistocene, a pediment (the Ortiz-Mesa Lucero surface) was cut on the Santa Fe formation in the Rio Grande depression. The elevation of this surface in the Hidden Mountains area was probably about 100 feet above the present maximum elevation.

Probably during early Quaternary, the Albuquerque-Belen basin became integrated by the Rio Grande, and the Rio Puerco began to develop by headward erosion. Sometime in the Quaternary the Rio Puerco effected the capture of easterly-flowing streams in the sec. 12, T. 6 N., R. 2 W. The Galisteo structure may have been localized by the differential competence and the lower structural strength of the thick gypsiferous playa deposits within the Santa Fe formation.

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During late Pliocene or in the Pleistocene, a pediment (the Ortiz-Mesa Lucero surface) was cut on the Santa Fe formation in the Rio Grande depression. The elevation of this surface in the Hidden Mountains area was probably about 200 feet above the present maximum elevation.

Probably during early Quaternary, the Albuquerque-Belen basin became integrated by the Rio Grande, and the Rio Puerco began to develop by headward erosion. Sometime in the Quaternary the Rio Puerco effected the capture of westerly-flowing streams in the general area. Down-cutting by the Rio Puerco formed the Rio Puerco Valley and exposed the igneous rocks which form the Hidden Mountains.

Temporary aggradation of the Rio Puerco formed alluvial deposits which covered part of the igneous rocks exposed earlier by the Rio Puerco.

The present arroyo-cutting cycle has developed on the alluvium of the Rio Puerco Valley and has re-exhumed some of the igneous rocks of the Hidden Mountains.

CONCLUSIONS

The igneous rocks of the Hidden Mountains are apparently consanguineous. The earlier, olivine basalt upper sill is probably a normal hypabyssal intrusion from a basic, moderate-sized, magma chamber at a depth greater than 10,000 feet. The presence of a moderate amount of fractured olivine phenocrysts in the olivine basalt upper sill indicates that the parent magma had differentiated itself crudely by the time it was tapped to form the olivine basalt intrusion. The olivine basalt is finer grained than the augite diabase because the olivine basalt, as the first representative of igneous activity in the Hidden Mountains, had the task of driving off the residual water in the intruded Santa Fe formation; and this caused a great and immediate loss of heat from the sill. This desiccation of the Santa Fe clastics effected better cementation of the Santa Fe in the immediate vicinity of the sill.

From the same magma chamber, another tap allowed the emplacement of the thinner, augite diabase lower sill. By this time, however, the differentiation of the parent magma had progressed to a point where the fluids which formed this lower but later sill crystallized augite and intermediate plagioclase at the same time and thus produced the subophitic texture so common in this rock. Although thinner, the augite diabase lower sill is coarser grained than the olivine basalt upper sill because the "dried out" Santa Fe formation and the overlying olivine basalt sill served as fairly effective insulators and allowed slow crystallization of the augite diabase.

CONCLUSIONS

The igneous rocks of the Hidden Mountains are apparently consanguineous. The earlier, olivine basalt upper sill is probably a normal hypabyssal intrusion from a basic, moderate-sized magma chamber at a depth greater than 10,000 feet. The presence of a moderate amount of fractured olivine phenocrysts in the olivine basalt upper sill indicates that the parent magma had differentiated itself crudely by the time it was tapped to form the olivine basalt intrusion. The olivine basalt is listed ahead of the augite diabase because the olivine basalt, as the first representative of igneous activity in the Hidden Mountains, had the job of driving off the residual water in the [illegible] Santa Fe formation and this caused a great and immediate loss of heat from the sill. This desiccation of the Santa Fe [illegible] of the Santa Fe in the immediate vicinity of the sill.

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These igneous bodies developed as sills because the "lines of least resistance" at this level in the Santa Fe formation were bedding planes. In places the sills show discordance which was due to local variations in the resistance of the Santa Fe formation. These local variations were probably in the form of facies changes or fracture zones.

As shown above, the differences in texture and composition of the two rocks is essentially a reflection of difference in relative time of intrusion and not necessarily one of different sources. Although these rocks may have been derived from separate magmas, this assumption is not necessary.

The volcanic plugs in the north end of the Hidden Mountains may have been derived from a local, shallow magma chamber in this area, which may or may not have been an expression of the deeper magma chamber from which the sills were derived. These plugs have risen along zones of weakness probably caused by the intersection of faults (post-sills in age) of two systems, one striking westerly, the other, northwesterly.

The small size of some of these plugs and the strong deformation of the country rock are striking testimony of the dynamic character of these small features.

Other known igneous rocks of similar age (late Tertiary) in this part of the Rio Grande depression are expressed chiefly as basaltic flows and plugs. The difference between these rocks and those of the Hidden Mountains is due to mode of occurrence. They are similar in composition. Both types of occurrence were probably

controlled by linear zones of weakness or faults. It is probable that the ascending magmas which were responsible for the flows and plugs in this part of the Rio Grande depression also formed sills. This is not known definitely because the flows have retarded erosion of the Santa Fe formation below themselves and where erosion has cut deep enough to expose sills the surface expression of the vulcanism has probably been removed also.

Perhaps this is the situation in the Hidden Mountains. The maximum elevation of the Hidden Mountains is several hundred feet below the projected Mesa Lucero-Ortiz erosion surface. The vulcanism in the Hidden Mountains may have been expressed also as a flow on or near this surface. Perhaps the proximity of the Rio Puerco has facilitated the more rapid denudation of the adjacent terrain and thus removed this part of the geologic record.

controlled by linear [illegible] It is probable
that the ascending magma which [illegible]
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maximum elevation of the Hidden Mountains is several hundred feet
below the projected Mesa Lucero-Ortiz erosion surfaces. The vol-
canism in the Hidden Mountains may have been expressed also as a
flow on or near this surface. Perhaps the proximity of the Rio
Puerco has facilitated the more rapid denudation of the adjacent
terrain and thus removed this part of the geologic record.

APPENDIX

Introduction to Thin-section Analyses

The remarks below refer, in general, to the thin-section analyses which follow this section.

Ten thin sections were studied. Two samples (rock numbers 11-9-3 and 11-9-4) were taken from the olivine basalt upper sill. Six samples (rock numbers 11-2-1, 11-9-1, 11-9-2a, 11-9-2c, 11-10-1, and 12-7-1) were taken from the augite diabase lower sill. One sample (rock number 11-9-2b) was taken from a felsite filling fractures in the augite diabase. One sample (rock number 12-7-2) was taken from highly altered Santa Fe formation. All of these sample localities are shown on Figure 3.

The igneous rocks are classified on the bases of quantity of quartz present, character and quantity of the feldspars, quantity of olivine, quantity of augite, textures, and observed mode of occurrence. The quantity ten percent was used to distinguish whether or not an essential mineral was common enough to exercise control upon the classification. Similarly, 20 percent was used as the quantity necessary for an accessory mineral, e. g., augite, to assume the varietal role. Where olivine was present in quantities greater than four percent, but less than ten percent, the prefix, olivine-bearing, was attached to the rock name.

Textures and minerals are listed in relative order of importance on the following pages. Very fine grains are less than 0.02 mm in maximum dimension. Fine grains are greater than 0.02 mm and

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The igneous rocks are classified on the basis of quantity of quartz present, character and quantity of the feldspars, quantity of olivine, quantity of augite, textures, and observed mode of occurrence. The quantity ten percent was used to distinguish whether or not an essential mineral was abundant enough to exercise control upon the classification. Similarly, [illegible] percent was used as the quantity necessary for an accessory mineral, e.g., augite, to assume the varietal role. Where olivine was present in quantities greater than four percent, but less than ten percent, the prefix, olivine-bearing, was attached to the rock name.

Textures and minerals are listed in relative order of importance on the following pages. Very fine grains are less than .02 mm in maximum dimension. Fine grains are greater than .02 mm and less than 1.00 mm in maximum dimension. Medium grains are greater than 1.00 mm and less than 5.00 mm in maximum dimension. Coarse grains are greater than 5.00 mm and less than 30.00 mm in maximum dimension.

Under the textural subdivision of crystallinity the term holocrystalline was used where the glass content was less than five percent. Hypocrystalline was used where glass was more abundant.

The following is a list of the more important "primary" minerals recognized and their classification with respect to the development of crystal faces and outlines:

Euhedral	Subhedral	Anhedral
plagioclase (occasional)	plagioclase (common)	plagioclase (occasional)
olivine (phenocrysts)	olivine	magnetite
augite	augite	hematite

The theoretical considerations which are noted in the thin-section analyses have been summarized and included in earlier parts of this paper.

Thin-section Analyses

Olivine Basalt Upper Sill

(Rock Suite 11-9-3, 11-9-4)

Rock number and location: 11-9-3; center, NE¼SE¼ sec. 36, T. 7 N., R. 2 W., N. M. P. M.

Rock name: Olivine-bearing basalt

Megascopic description:
Dark gray, fine- to medium-grain, impermeable, augite basalt (or diabase) from outcrop of sill(?) about 40 feet above base of sill. Plagioclase, 50 percent; augite, 40 percent; pitchstone-obsidian(?), 5 percent; hematite(?) and alteration products, 5 percent. Prominent fractures produce plates 1 to 5 cm in thickness.

Microscopic description:

Texture: Hypidiomorphic, subophitic, slightly intersertal, slightly intergranular
Crystallinity: Holocrystalline
Granularity: Fine grain, medium grain

Essential minerals:
75% Ab_{34-47} (occasional penetration twin)
8% Olivine (highly altered along crystal periphery and fractures)

Accessory minerals and alteration products:
7% Augite
3% Magnetite (mostly primary, some altered from olivine)
2% Volcanic glass (fills interstices, especially between plagioclase laths)
2% Epidote(?) (altered from plagioclase)
1% "Limonite" (altered from magnetite and hematite)
1% Iddingsite(?) (altered from olivine)
1% Hematite (altered from magnetite and olivine)

Theoretical considerations:
After olivine, then augite and labradorite, then finally magnetite had crystallized; deuteric action followed by sudden cooling produced the alteration products and the volcanic glass, respectively, in this sill. This rock is a member of a suite, the other member of which is 11-9-4, characteristic of the upper sill.

Rock number and location: 11-9-4; Brian site, center, SE¼SW¼ sec. 12, T. 6 N., R. 2 W., N. M. P. M.

Rock name: Olivine basalt porphyry

Megascopic description:
Dark gray, fine- to medium-grain, impermeable, olivine-bearing basalt (or diabase) from outcrop of sill(?) about 30 feet above base of sill. Plagioclase, 75 percent; augite, 15 percent; olivine(?), 9 percent; "limonite" and other alteration products, 1 percent. Prominent fractures produce plates 3 to 9 cm in thickness. Heavy alteration characteristically extends just 2 to 3 mm below the surfaces of the platy fractures. Alteration is probably due to weathering. Scale-like fillings of fractures are principally calcium sulfate and calcium carbonate.

Microscopic description:

Texture: Hypidiomorphic, microporphyritic, intergranular, very slightly intersertal
Crystallinity: Holocrystalline
Granularity: Fine grain, medium grain (phenocrysts)

Essential minerals:
70% Ab_{37} (moderately altered)
10% Olivine (5% phenocrysts, 5% grains in groundmass; both occurrences show appreciable alteration)

Accessory minerals and alteration products:
10% Augite
5% Magnetite (primary and altered from olivine)
2% "Limonite" (altered from magnetite)
2% Kaolin (developed on plagioclase)
1% Volcanic glass

Theoretical considerations:
Although this rock is megascopically similar to 11-9-3 and both were mapped as the same kind, this rock is finer grained and otherwise different in texture. However, the two rocks are closely related. Apparently, at the time of emplacement the magma contained olivine crystals. This indicates that the parent magma had already undergone the first stages of differentiation by crystal sorting. Order of development: olivine, plagioclase, augite, magnetite, kaolin, and "limonite." This rock is a member of a suite, the other member of which is 11-9-3, characteristic of the upper sill.

Augite Diabase Lower Sill

(Rock Suite 11-2-1, 11-9-1, 11-9-2a, 11-9-2c, 11-10-1, 12-7-1)

Rock number and location: 11-2-1; Dixie site, center, SE¼ sec. 12, T. 6 N., R. 2 W., N. M. P. M.

Rock name: Diabase

Megascopic description:
Light gray-brown, fine- to medium-grain, highly altered, permeable, friable, "limonitic" diabase from two feet above the bottom contact of a 15-foot thick sill with the Santa Fe formation. Plagioclase, 50 percent; augite(?), 10 percent; "limonite" and other alteration products, 40 percent. Structural and petrographic characteristics suggest that this rock is probably closely related to 11-9-1, 11-9-2a, 11-9-2c, and 12-7-1.

Microscopic description:

Texture: Hypidiomorphic, intergranular to subophitic, intersertal, slightly microporphyritic
Crystallinity: Holocrystalline
Granularity: Fine grain, medium grain

Essential mineral:
72% Ab_{35-42} (altered, larger crystals are more calcic, one large plagioclase xenocryst, a contamination product, has volcanic glass filling many fractures)

Accessory minerals and alteration products:
10% Augite
4% Magnetite
4% Hematite (mostly altered from magnetite, fills some fractures)
4% "Limonite" (mostly altered from hematite)
3% Sericite and kaolin (moderately intense mottled development on plagioclase)
3% Volcanic glass
trace Epidote (altered from plagioclase)

Theoretical considerations:
In addition to petrogenesis similar to others of the lower sill, this rock has been altered by late hydrothermal activity (hematite filling fractures and sericite) and weathering ("limonite" and kaolin). Some assimilation in the history of this rock is indicated by the glass-filled plagioclase xenocryst which was probably derived from an older igneous body at some point above the parent magma chamber and below this sill. This rock is one member of the suite, 11-9-1, 11-9-2a, 11-9-2c, 11-10-1, 12-7-1, characteristic of the lower sill.

Rock number and location: 11-9-1; Campsite No. 1, center, NE¼SE¼ sec. 36, T. 7 N., R. 2 W., N. M. P. M.

Rock name: Diabase

Megascopic description:
Red to yellow-brown, fine- to medium grain, altered, permeable, "limonitic," diktytaxitic, augite diabase from outlier (probably part of sill) in which structural relations with other rocks are not definitely determinable. Plagioclase, 55 percent; augite, 20 percent; "limonite" and other alteration products, 25 percent.

Microscopic description:

Texture: Allotriomorphic, diktytaxitic, subophitic
Crystallinity: Holocrystalline
Granularity: Medium grain, fine grain

Essential mineral:
72% Ab_{46}

Accessory minerals and alteration products:
13% Augite
7% Hematite (altered from magnetite, some may be primary)
4% Magnetite
2% "Limonite" (altered from hematite)
1% Sericite and kaolin
1% Volcanic glass(?)

Theoretical considerations:
This rock is one member of the suite, 11-2-1, 11-9-2a, 11-9-2c, 11-10-1, 12-7-1, characteristic of the lower sill.

Rock number and location: 11-9-2a; center, $E\frac{1}{2}SW\frac{1}{4}NE\frac{1}{4}$ sec. 36, T. 7 N., R. 2 W., N. M. P. M.

Rock name: Augite diabase

Megascopic description:
Mottled red-yellow and dark gray, medium-grain, altered, permeable, "limonitic," slightly calcareous, slightly diktytaxitic, augite diabase from bottom of outcrop of discordant sill intruding dense basalt and Santa Fe formation. Plagioclase(?), 65 percent; augite, 20 percent; "limonite," calcite, and other alteration products, 15 percent. This rock is apparently closely related to 11-9-1.

Microscopic description:

Texture: Hypidiomorphic, ophitic to subophitic, slightly intergranular
Crystallinity: Holocrystalline
Granularity: Medium grain, fine grain, coarse grain

Essential mineral:
63% Ab_{50} (slightly altered, some of the larger crystals are fractured)

Varietal mineral:
20% Augite

Accessory minerals and alteration products:
7% Magnetite
6% Hematite (altered from magnetite, some primary filling fractures in plagioclase)
4% "Limonite" (altered from hematite)
trace Epidote (altered from plagioclase)

Theoretical considerations:
This rock is extremely similar to 11-9-1. Part of the hematite in both rocks was probably emplaced hydrothermally. (A zone of hematite mineralization lies about halfway between the two sample sites.) This rock is one member of the suite, 11-2-1, 11-9-1, 11-9-2c, 11-10-1, 12-7-1, characteristic of the lower sill.

Rock number and location: 11-9-2c; center, $E\frac{1}{2}SW\frac{1}{4}NE\frac{1}{4}$ sec. 36, T. 7 N., R. 2 N., N. M. P. M.

Rock name: Augite diabase

Megascopic description:
This augite diabase has about the same megascopic description as 11-9-2a, but was taken from the same outcrop about 7 feet higher in the sill. A minor difference in mineral composition between these two rocks is effected by an apparent increase (5 to 10 percent) in augite at the expense of plagioclase.

Microscopic description:

Texture: Subophitic, hypidiomorphic, slightly intergranular, slightly diktytaxitic
Crystallinity: Holocrystalline
Granularity: Medium grain, fine grain

Essential mineral:
62% Ab_{48-50} (medium-grain crystals may be more calcic)

Varietal mineral:
25% Augite (some primary, some altered from magnetite and hematite)

Accessory minerals and alteration products:
8% Magnetite (some has invaded fractures on Albite twin planes, some has filled voids created by diktytaxitic texture)
3% Hematite (some primary, some altered from magnetite)
1% "Limonite" (altered from hematite and magnetite)
1% Epidote (altered from plagioclase)

Theoretical considerations:
Although this rock is a little finer grained and contains less primary hematite than 11-9-2a, the rocks are closely related to each other and 11-9-1. This rock is one member of the suite, 11-2-1, 11-9-1, 11-9-2a, 11-10-1, 12-7-1, characteristic of the lower sill.

Rock number and location: 11-10-1; Danger site, center, SE¼SE¼ sec. 11, T. 6 N., R. 2 W., N. M. P. M.

Rock name: Augite diabase

Megascopic description:
Dark gray, fine- to medium-grain, impermeable, augite diabase from center (in vertical plane) of sill. Plagioclase, 65 percent; augite, 25 percent; olivine(?), 5 percent; "limonite" and other alteration products, 5 percent. Weathering produces peculiar angular to subangular, spheroidal aggregates of plagioclase and augite measuring 5 to 10 mm in diameter.

Microscopic description:

Texture: Hypidiomorphic, intergranular, slightly intersertal, slightly microporphyritic
Crystallinity: Holocrystalline
Granularity: Fine grain, medium grain

Essential minerals:
70% Ab_{41-49} (larger crystals are more calcic, moderate alteration due to weathering is developed on part of the plagioclase crystals)
3% Olivine (moderately altered, especially along periphery)

Varietal mineral:
20% Augite

Accessory minerals and alteration products:
5% Magnetite (3% primary, 2% altered from olivine)
1% "Limonite" (altered from magnetite)
1% Volcanic glass

Theoretical considerations:
This rock is related to 11-2-1, but has developed somewhat differently. This is probably due to its location on the periphery of the intrusion. This rock is one member of the suite, 11-2-1, 11-9-1, 11-9-2a, 11-9-2c, 12-7-1, characteristic of the lower sill.

Rock number and location: 12-7-1; Dextrose site, center, $E\frac{1}{2}W\frac{1}{2}$ sec. 7, T. 6 N., R. 1 W., N. M. P. M.

Rock name: Basalt

Megascopic description:
Dark gray-green, fine-grain (many grains approach 1 mm in diameter, however), vesicular (2 to 30 mm in diameter, about 7 percent of volume), amygdaloidal (calcite as many radiating crystals or as large mass is often present inside cavity lined with "limonite" and a small number of spherulites of unknown composition), relatively impermeable, slightly altered, olivine basalt from outcrop of narrow dike. Plagioclase, 70 percent; olivine, 10 percent; augite, 10 percent; hematite, 1 percent; "limonite," iddingsite, and other alteration products, 9 percent. Fine granularity is probably due to the narrowness of the body, which would have allowed quick cooling.

Microscopic description:

Texture: Hypidiomorphic, vesicular, amygdaloidal, intergranular, intersertal, identifiable plagioclase laths are disposed in a subparallel manner (probably as a result of flow), axiolitic (microlites as amygdaloidal filling in vesicles)
Crystallinity: Hypocrystalline
Granularity: Fine grain

Essential minerals:
59% Ab_{46} (with mottled alteration)
1% Olivine

Accessory minerals and alteration products:
10% Augite(?)
10% Altered (clay ?), devitrified volcanic glass (lining vesicle walls and containing inclusions of calcite lined with hematite)
8% Sericite and kaolin (altered from plagioclase)
6% Volcanic glass
3% Hematite (primary inclusions in glass)
3% Magnetite
trace Calcite

Theoretical considerations:
Although large amounts of volcanic glass, fine granularity, "flow structure," and amygdules give this rock a character not duplicated in the other thin sections which were studied, these features are probably explained by the form and structural attitude of the body from which the sample was taken. In the field and under the microscope, a definite mineral kinship between this rock and 11-2-1 can be recognized. This rock is one member of the suite, 11-2-1, 11-9-1, 11-9-2a, 11-9-2c, 11-10-1, characteristic of the lower sill.

Felsite Fracture Filling

Rock number and location: 11-9-2b, center, E½SW¼NE¼ sec. 36, T. 7 N., R. 2 W., N. M. P. M.

Rock name: Felsite

Megascopic description:
Yellow-brown, impermeable felsite from outcrop described under rock number 11-9-2a, where it occurs as fracture fillings (up to 3 inches thick) in the augite diabase.

Microscopic description:

Texture: Allotriomorphic-granular, occasional kelyphitic rims of fine-grain quartz(?) surround vesicle which may have contained gas
Crystallinity: Holocrystalline
Granularity: Very fine grain (cryptocrystalline), fine grain

Esential minerals:
85%(?) Quartz(?) and feldspar(?) (microlites, locally fine grains)

Accessory minerals and alteration products:
15%(?) Hematite and "limonite" (finely disseminated, occasional primary fine grain of hematite)

Note: Because of the extremely fine granularity, exact identification of minerals and estimates of percentages are impossible. Because of these conditions the name felsite is assigned.

Theoretical considerations:
This fracture filling probably represents late stage silicic and alkalic, hematitic hydrothermal activity.

Altered Santa Fe Formation

Rock number and location: 12-7-2; Datatron site, center, $E\frac{1}{2}W\frac{1}{2}$ sec. 7, T. 6 N., R. 1 W., N. M. P. M.

Rock name: Metaclaystone

Megascopic description:
Mottled light tan to buff and red-brown, very fine- to medium-grain, slightly calcareous, well cemented, permeable metaclaystone of the altered Santa Fe formation. Migrating fluids (probably from adjacent basalt dike) have invaded the Santa Fe formation and produced an alteration product characterized by pebbles (mostly altered to clay, if not originally quartz) individually surrounded and cemented by iron oxides and silicates. The saturated mass appears to have moved vertically (probably a short distance, however) and is expressed geomorphically by resistance to erosion and weathering (due to better cementation than adjacent Santa Fe formation).

Microscopic description:

Texture: Magmatic-hydrothermal: Hyaloophitic, microvesicular
Sedimentary: Hydroclastic
Crystallinity: Magmatic-hydrothermal: Hypocrystalline
Granularity: Magmatic-hydrothermal and sedimentary: fine grain, very fine grain (detrital grains of this size form aggregates of medium-grain and coarse-grain size)

Essential minerals:
Magmatic-hydrothermal:
50% Ab_{50} (fine-grain crystals and microlites)
Sedimentary:
20% Ab_{76-84}
10% Quartz
3% Orthoclase
(all as subangular to well rounded fine grains of rhyodacitic composition)

Accessory minerals and alteration products:
Magmatic-hydrothermal:
37% Volcanic glass (partly devitrified, usually altered)
8% Hematite (mostly primary, some altered from magnetite)
3% Magnetite
2% "Limonite" (altered from hematite)
Sedimentary:
67% Alteration products (probably mostly clay)

Theoretical considerations:
Santa Fe claystones and siltstones have been altered by permeating magmatic-hydrothermal solutions which have deposited plagioclase, glass, hematite, etc. in conduits surrounding particles of Santa Fe material and in the particles which were permeable.

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