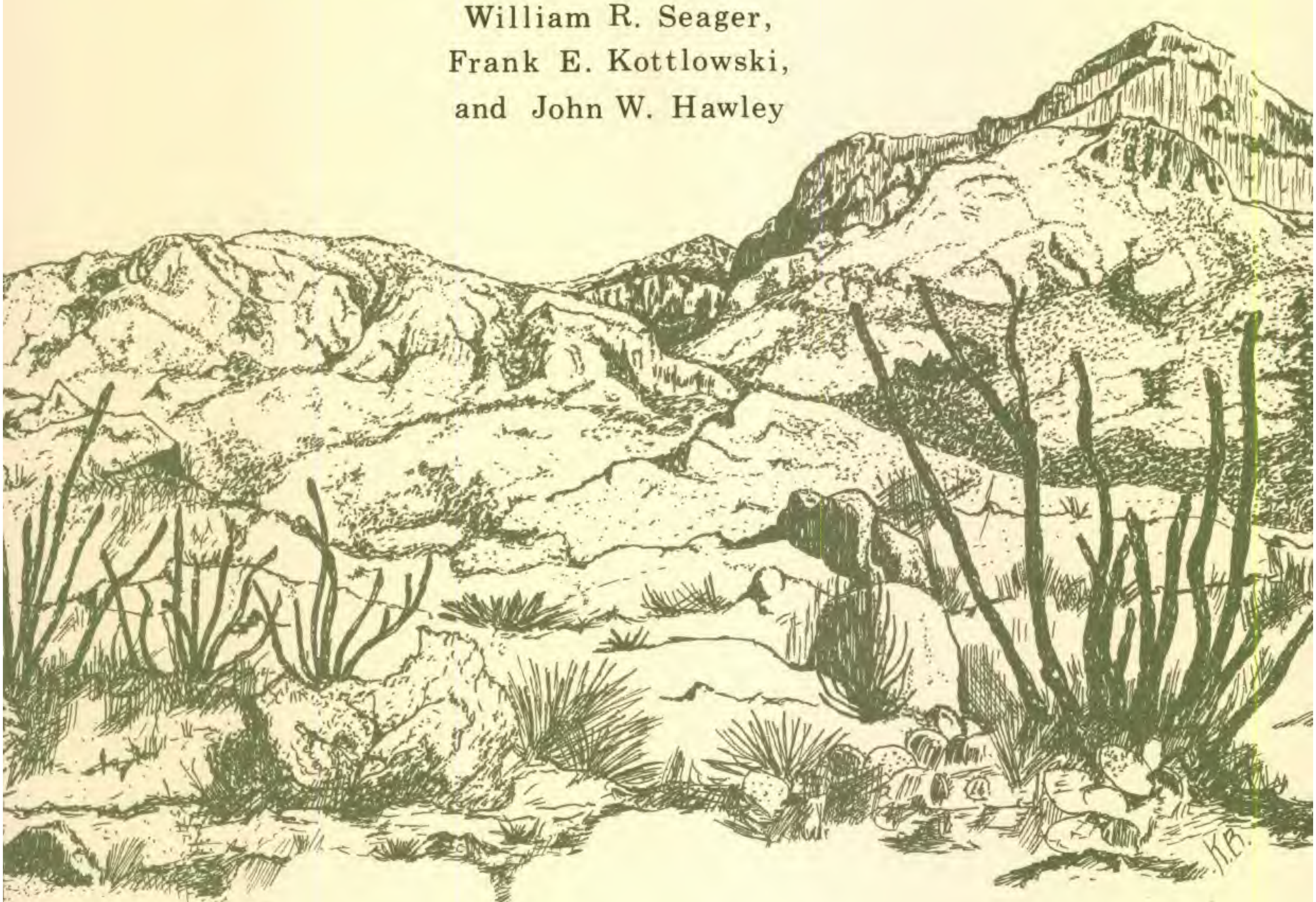
CIRCULAR 147 1976

Geology of Doña Ana Mountains, New Mexico

by

William R. Seager,
Frank E. Kottlowski,
and John W. Hawley



New Mexico Bureau of Mines & Mineral Resources

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

Circular 147

New Mexico Bureau of Mines & Mineral Resources

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

Geology of Doña Ana Mountains, New Mexico

by William R. Seager, Frank E. Kottlowski, and John W. Hawley

SOCORRO 1976

NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY
Kenneth W. Ford, *President*

NEW MEXICO BUREAU OF MINES & MINERAL RESOURCES
Frank E. Kottlowski, *Director*

BOARD OF REGENTS
Ex Officio
Jerry Apodaca, *Governor of New Mexico*
Leonard DeLayo, *Superintendent of Public Instruction*

Appointed
William G. Abbott, President, 1961-1979, *Hobbs*
John M. Kelly, 1975-1981, *Roswell*
Dave Rice, 1972-1977, *Carlsbad*
Steve Torres, 1967-1979, *Socorro*
James R. Woods, 1971-1977, *Socorro*

BUREAU STAFF

Full Time

William E. Arnold, *Scientific Illustrator*
George S. Austin, *Indust. Minerals Geologist*
Robert A. Bieberman, *Senior Petrol. Geologist*
Lynn A. Brandvold, *Chemist*
Corale Brierley, *Chemical Microbiologist*
Judy Burlbaw, *Assistant to Editor*
Patricia E. Candelaria, *Secretary*
Charles E. Chapin, *Senior Geologist*
Richard R. Chavez, *Technician*
Ruben A. Crespin, *Technician*
Thea Ann Davidson, *Geological Technician*
Lois M. Devlin, *Office Manager*
Jo Drake, *Administrative Ass't. & Sec'y.*
Rousseau H. Flower, *Senior Paleontologist*
Roy W. Foster, *Senior Petrol. Geologist*
Stephen C. Hook, *Paleontologist*
Robert W. Kelley, *Editor & Geologist*
Arthur J. Mansure, *Geophysicist*
Norma J. Meeks, *Clerk-Typist*
Candace H. Merillat, *Editorial Assistant*
Neila M. Pearson, *Scientific Illustrator*
Judy Peralta, *Secretary*
Christopher Rautman, *Economic Geologist*
Marshall A. Reiter, *Geophysicist*
Jacques R. Renault, *Geologist*
James M. Robertson, *Mining Geologist*
Ronald J. Roman, *Chief Research Metallurgist*
Robert Shantz, *Metallurgist*
Jackie H. Smith, *Laboratory Assistant*
William J. Stone, *Hydrogeologist*
David E. Tabet, *Geologist*
Joseph E. Taggart, Jr., *Mineralogist*
Samuel Thompson III, *Petroleum Geologist*
Robert H. Weber, *Senior Geologist*
Michael R. Whyte, *Field Geologist*
Shirley Whyte, *Secretary I*
Michael W. Wooldridge, *Scientific Illustrator*

Part Time

Christina L. Balk, *Geologist*
Charles O. Grigsby, *Laboratory Technician*
Charles B. Hunt, *Environmental Geologist*
Charles A. Mardirosian, *Geologist*
Jack B. Pearce, *Director, Information Services*
John Reiche, *Instrument Manager*
Allan R. Sanford, *Geophysicist*
Thomas E. Zimmerman, *Chief Security Officer*

Graduate Students

Richard Chamberlin
Joseph Dauchy
Jeffrey A. Fischer
Henry L. Fleischhauer
Joseph Iovinitti
Glenn R. Osburn
Charles Shearer
Paul Shuleski
Terry Siemers

Plus more than 35 undergraduate assistants

First printing, 1976

Published by Authority of State of New Mexico, NMSA 1953 Sec. 63–1–4
Printed by University of New Mexico Printing Plant, July, 1976

Available from New Mexico Bureau of Mines & Mineral Resources, Socorro, NM 87801

Price $3.00

Preface

The geology of the Doña Ana Mountains is the latest result of a series of studies, started in 1967, of the Rio Grande rift and adjacent uplifts between Caballo and Las Cruces. Mapping of the Doña Ana Mountains was actually started in 1952-53 by Kottlowski but, except for a small scale map published in the 1953 New Mexico Geological Society 4th Annual Field Conference Guidebook, the results of his study were delayed by his assumption of other responsibilities with the New Mexico Bureau of Mines & Mineral Resources. Seager resumed work in the mountain range in 1973 and continued through the summer of 1974, supported by the New Mexico Bureau of Mines & Mineral Resources. Hawley mapped Quaternary rock units in the area intermittently from 1962 to 1975. Between the middle 1950's and 1963, studies of Quaternary rocks, soils, and geomorphic evolution of the area adjacent to the range were also made by R. V. Ruhe, L. Gile, and F. F. Peterson. Much of our mapping of Quaternary rock units is based upon models developed by these men and we are grateful to them for their help in interpreting and distinguishing these units.

We wish to thank D. V. LeMone, University of Texas at El Paso, for his help in describing and measuring sections of the Permian rocks, and for his advice regarding the fauna and depositional environments represented by those strata. We are grateful to C. E. Chapin, New Mexico Bureau of Mines & Mineral Resources, for helpful discussions concerning the volcanic geology of the range. Chapin first recognized that the Doña Ana Rhyolite demanded interpretation in terms of a cauldron model, and then was very helpful in relating structural and stratigraphic features to that model. Finally we thank R. E. Clemons, New Mexico State University, for his help in interpreting thin sections of the ash-flow tuff sequence and W. E. King, New Mexico State University, for his help in the identification of the fusulinids.

William R. Seager
New Mexico State University

Frank E. Kottlowski
New Mexico Bureau of Mines &
Mineral Resources

John W. Hawley
Soil Conservation Service

Las Cruces and Socorro, New Mexico
and Portland, Oregon
October, 1975

Contents

TABLES

FIGURES

IN POCKET

Abstract

The Doña Ana Mountains are a westward-tilted fault block exposing rocks ranging in age from Permian to Quaternary. Hueco Limestone and Abo red beds (both Permian) are exposed in the northern part of the range. Westernmost outcrops are shelf facies nearly identical to those in the Robledo Mountains, but these shelf facies intertongue eastward into thick basinal deposits that formed along the margin of the Orogrande basin. The Hueco-Abo strata have been folded, faulted, and thermally metamorphosed by intrusion of a large Eocene andesitic stock or sheet and by an Oligocene monzonitic laccolith. The southern part of the range comprises a deeply eroded, partially exposed ash-flow tuff cauldron of Oligocene age. Although the southern part of the cauldron is covered by Quaternary fan gravels, aeromagnetic data indicate the cauldron is about 6 to 8 miles in diameter. Eruption of at least 2,500 ft of ash-flow tuff (Doña Ana Rhyolite) initiated cauldron collapse; at least 1,000 ft of flow-banded rhyolite flows and domes, ash-flow tuffs, volcaniclastic rocks, and bedded tuffs and breccia comprise younger cauldron fill. Flow-banded rhyolite, monzonite, and ignimbrite dikes are related to 1) a ring fracture zone exposed along the northwestern margin of the cauldron and 2) a smaller nested cauldron and intracauldron graben within the major structure. Late Tertiary uplift, accompanied by westward tilting and erosion of the cauldron, has exposed the cauldron floor along the eastern side of the range, as well as revealed the internal fabric of the cauldron down to perhaps 1,000 to 3,000 ft beneath the Oligocene surface. Several generations of Quaternary fans cover broad pediments around the edges of the mountain block.

Introduction

The Doña Ana Mountains are located in central Doña Ana County a few miles north of Las Cruces (fig. 1). The area mapped includes parts of the Las Cruces and San Diego Mountain 15-minute quadrangles. Access to the mountain range is by jeep roads beginning at Doña Ana and Hill, and from the graded Jornada road that traverses the Jornada del Muerto just east of the map. One jeep road follows Wagner Canyon through the northern part of the range, while another follows Cleofas Canyon, and still another traverses the unnamed east-west canyon just south of Cleofas Canyon. The latter two roads join near Dagger Flat and continue eastward across Dagger Flat. Access to the southern front of the range is furnished by the jeep road from Doña Ana.

PHYSIOGRAPHY

Physiographically, the mountain range may be divided into three sections. North of Wagner Canyon low limestone ridges, hogbacks and cuestas are surmounted by a group of high monzonite peaks, named Summerford Mountain. The steep, narrow mountain, 1,300 ft high, rises abruptly above the desert and dominates the surrounding landscape. It and the adjacent pedimented monzonite are carved from a laccolith intrusive into the limestone ridges. The central part of the range between Wagner Canyon and the Red Hills-Dagger Flat area comprises a maze of low rounded hills containing entrenched arroyo systems. The hills are largely developed on an andesite stock and associated volcaniclastic strata of Eocene age. The southern one-third of the range is carved largely from Oligocene intrusive rocks and ash-flow tuffs that formed within a major cauldron complex, now only partly exposed and deeply eroded. Ash-flow tuffs that erupted in and filled the cauldron form low dissected hills as well as narrow, sharp, high ridges. Pyramidal peaks that surmount the lower hills and ridges are developed on monzonite porphyry and related dike rocks. The highest of these peaks, Doña Ana Peak, altitude 5,829 ft, rises about 1,500 ft above the surrounding bolson plains, and is about 2,000 ft above the flood plain of the Rio Grande (fig. 2). Cliffs or steep slopes hundreds of ft high have developed locally along joint sets in the monzonite. One group of monzonite peaks and ridges nearly surrounds a topographic and structural basin named Dagger Flat. The basin appears to be the modern physiographic expression of a small cauldron nested within the larger cauldron, and the surrounding monzonite may represent the deeply eroded roots of a ring dike or cone sheet system.

Footslopes that extend away from the base of the range, especially those in the southern section of the mountains, are largely pediments 1 to 2 miles wide dissected by entrenched arroyo systems tributary to the Rio Grande; on the eastern side of the range they are nearly undissected (fig. 3). Variable thicknesses of Quaternary fan gravels mantle the pediment, but locally extensive areas of bedrock are exposed, even along the eastern side of the range where Rio Grande tributary drainage has not yet established itself. Few hills rise above the level of the erosion surface. The extensive development of the pediment in the Doña Ana Mountains is in contrast to other nearby ranges which show little or no pediment development, especially the Robledo, Cedar Hills and Tonuco uplifts.

PREVIOUS WORK

Few geological investigations of the bedrock geology of the Doña Ana Mountains have been published. Dunham (1935) described the general structural features near Dagger Flat as well as the volcanic and intrusive sequence in the same area. He briefly described thin sections of monzonite porphyry, Cleofas Andesite and obsidian (vitrophyre) from the range, but reported the occurrences of gold and malachite in some

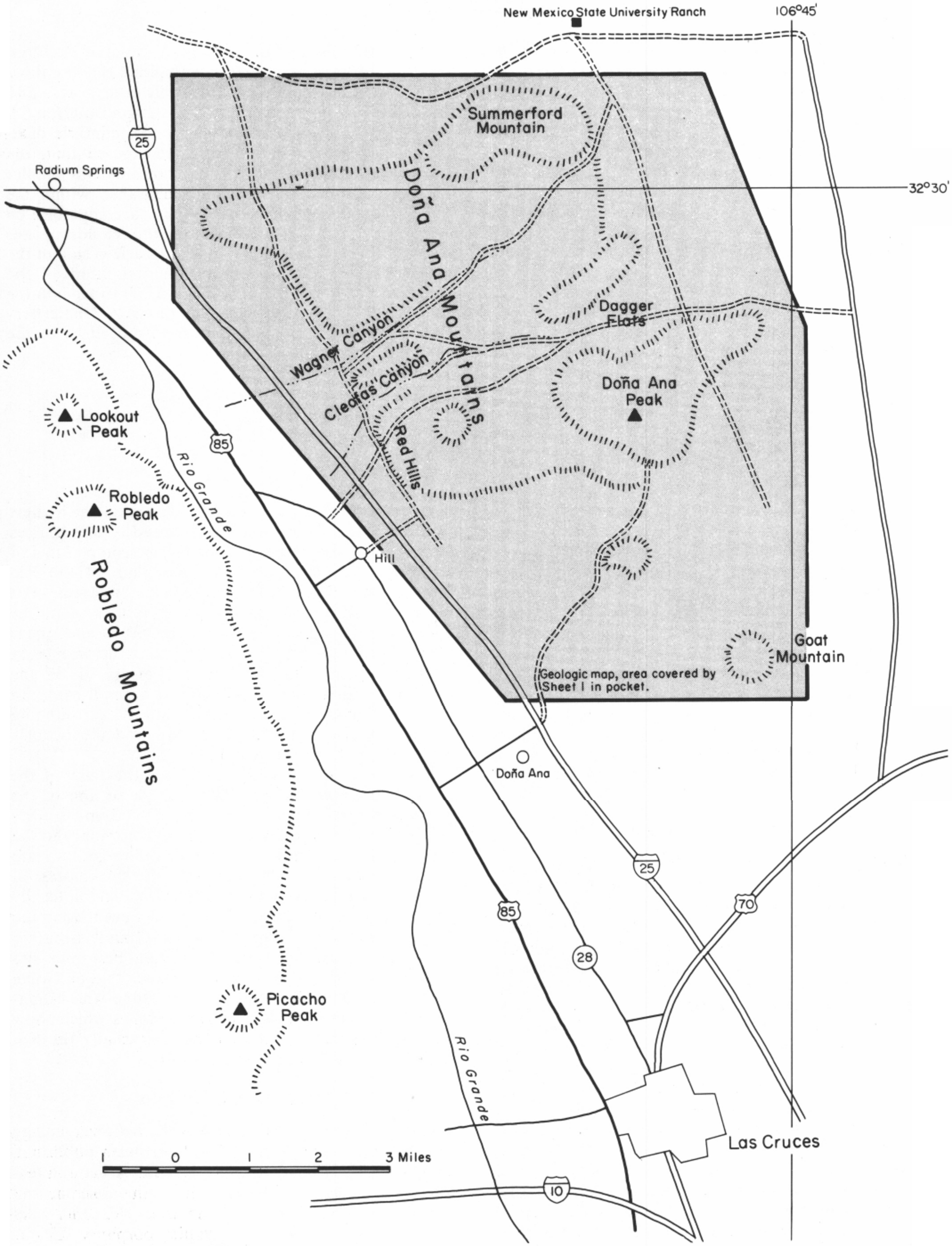


FIGURE 1—LOCATION MAP.

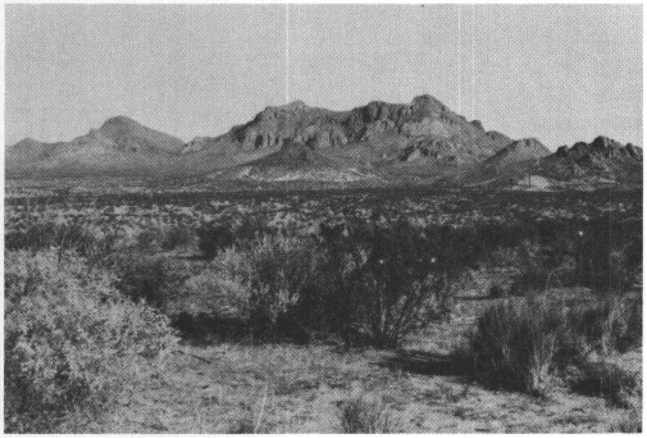


FIGURE 2—Doña Ana Rhyolite forms most of the Doña Ana Mountains. Highest peaks are monzonite porphyry; Doña Ana Peak is at the center of the skyline.

detail. Kottlowski's (1960a) geologic map of the Las Cruces 30-minute quadrangle included a generalized map of the Doña Ana Mountains. Fairly extensive soil and soil-geomorphic studies adjacent to the Doña Ana Mountains have been underway since about 1957 by Ruhe (1962; 1967) and by Leland Gile and John Hawley. Much of Gile and Hawley's work is currently being published. Already published studies include Gile (1967); Hawley and Gile (1966); Gile, Hawley, and Grossman (1971).

REGIONAL SETTING

The Doña Ana Mountains comprise one of many fault block uplifts within the Rio Grande rift of southern New Mexico (Kelley, 1952, 1955; Chapin, 1971; fig. 4). They form part of a structurally high block that extends from south of Las Cruces northwestward to the southern Caballo Mountains. The block borders the southwestern edge of the deep Jornada del Muerto basin; along its western edge the Rio Grande flows through a disconnected series of bordering grabens and half grabens and across several small fault blocks.

Middle Tertiary rocks within the Doña Ana Mountains and in the general Las Cruces area comprise the southeasternmost occurrence in New Mexico of the calc-alkalic volcanic and hypabyssal rock suite that is so well developed in the Mogollon-Datil field (Elston and others, 1973) and southward from there. Volcanic and hypabyssal rocks in the Doña Ana Mountains are primarily Eocene and Oligocene silicic to intermediate types related to a volcanic center in the Doña Ana Mountains. This center apparently was not a part of the Goodsight-Cedar Hills depression or Cedar Hills vent zone farther west (Seager, 1973; Seager and Clemons, 1975). Eruptive and intrusive rocks in the Organ Range are probably related to still another volcanic-intrusive center, although their petrologic similarity with Doña Ana rocks suggests a common source.

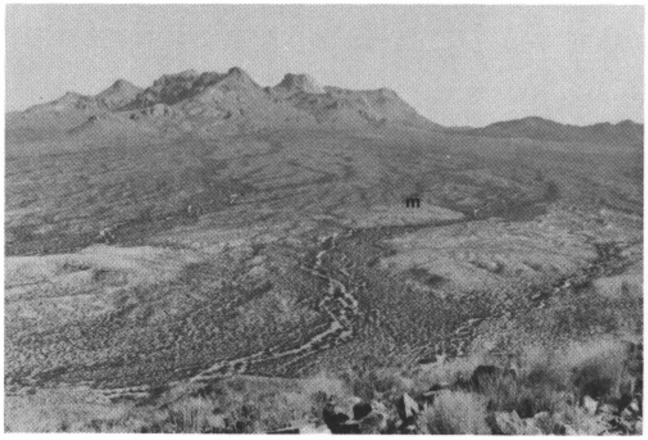


FIGURE 3—Broad pediment along southern side of Doña Ana Mountains seen from Goat Mountain. Erosional outlier of monzonite porphyry is marked by m. Light-colored patches in foreground are fluvial facies of the Camp Rice Formation.

STRATIGRAPHY

Permian, Tertiary, and Quaternary rocks are exposed in the Doña Ana Mountains (Sheet 1 in pocket) and are summarized in the composite stratigraphic column (fig. 5, Sheet 2 in pocket). A composite maximum thickness of more than 7,700 ft of stratified rocks is present. About one-third of these are marine and transitional sedimentary rocks of Wolfcampian age, and about two-thirds are volcanic and volcaniclastic rocks of Eocene and Oligccene age. Plutonic rocks in the form of dikes, sills, laccoliths, and stocks also are mostly of Eocene and Oligocene age, and most appear to be comagmatic with the volcanic rocks. Quaternary rocks are chiefly alluvial fan deposits and pediment veneers of several ages that form dissected aprons surrounding the mountains.

The map units that appear on the geologic map are discussed in the following sections. In some cases rocks will be described in groups of similar units rather than singly as, for example, mafic dike rocks, or felsic dike rocks.

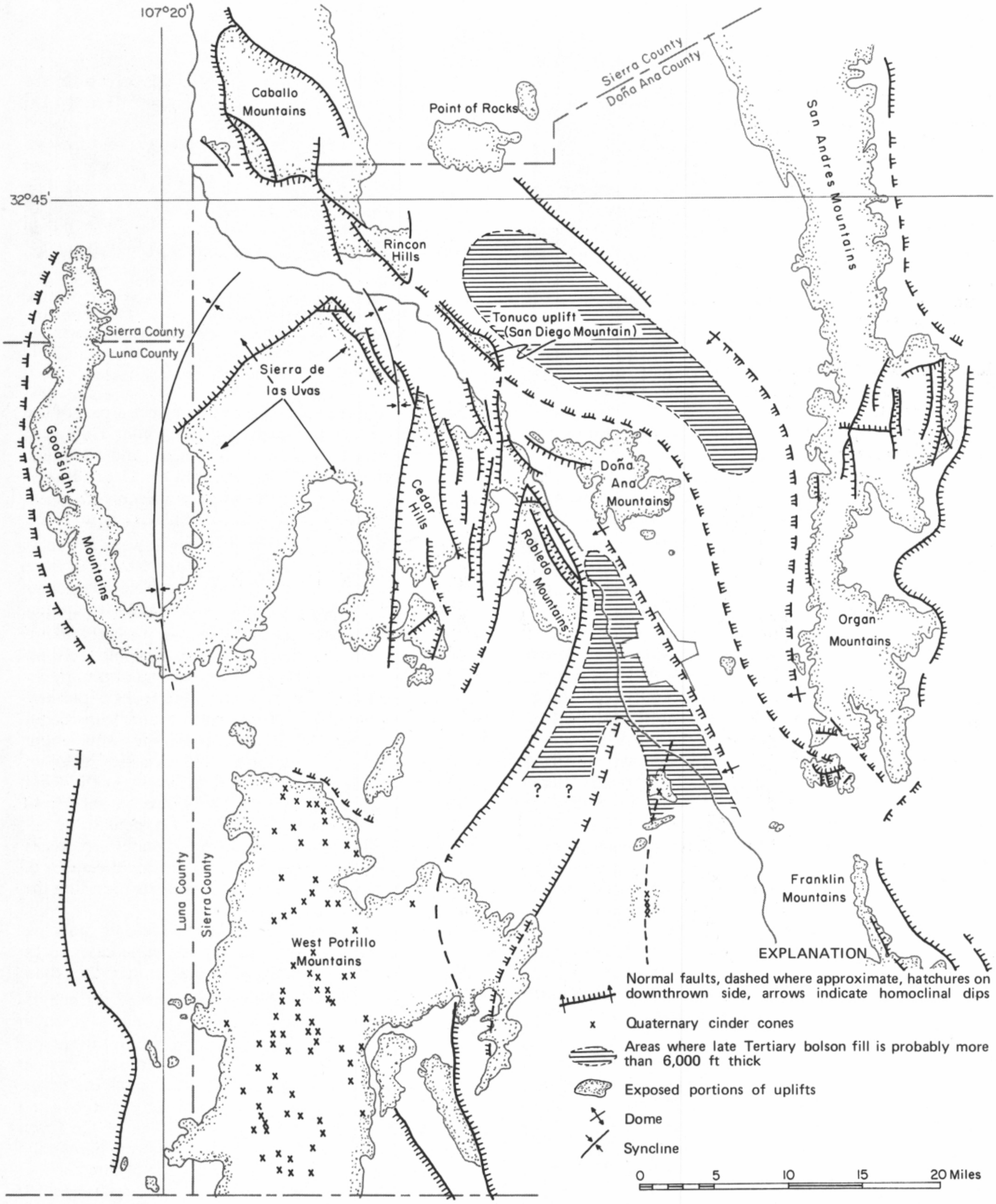


FIGURE 4—Late Tertiary faults.

Permian Stratigraphy

About 2,600 ft of Permian sedimentary rocks are exposed in the northern part of the range. Several middle Tertiary plutons have intruded the Permian strata resulting in local calc-silicate metamorphism and marbleization. Folding and faulting of the strata also apparently resulted from these intrusions and ranges from broad, open folds away from pluton contacts to nearly isoclinal, overturned folding adjacent to some intrusive masses. As a result, many sedimentary structures and fossil remains are obscure or obliterated, and locally, structural complications precluded piecing together a complete stratigraphic succession, or making reliable detailed correlations from one place to another along the outcrop belt. Clearly most of the Permian strata are assignable to the Hueco Limestone and Abo Formation of Wolfcampian age (Kottlowski, 1960a,b). Oldest exposed beds may be age equivalent of the Bursum Formation of the Oscura Mountain area (Wilpolt and others, 1946; Lloyd, 1949). In the Robledo Mountains the Abo Formation is a 475-ft-thick tongue of red beds and carbonate rocks in the upper part of the Hueco. The Abo presumably is similarly related to the Hueco in the Doña Ana Mountains, but upper Abo beds and overlying Hueco have been removed by pre-Eocene erosion.

Two facies of the Hueco Limestone were recognized in the Doña Ana Mountains: 1) a western facies comprising typical shelf limestones deposited on the Robledo shelf (Kottlowski, 1960b), grading upward into Abo red beds; and 2) an eastern facies, also grading upward into Abo, comprising porcellanite, black shale, sandstone, and sandy, non-fossiliferous limestone, probably related to deposition in the Orogrande basin (Pray, 1959). The north-northwest-trending boundary between the two facies is very abrupt, occurring over a distance of a mile or less. It is well displayed in Bursum? and lower to middle Hueco strata on the flanks of Grande dome (Sheet 1). Measured sections of both facies are presented in the appendix, and shown graphically on the stratigraphic cross sections. Current petrographic and faunal studies of these facies are in progress by D. V. LeMone, University of Texas at El Paso.

SHELF FACIES

The Hueco-Abo shelf facies crops out along the northwestern edge of the Doña Ana Mountains and is subdivided into 5 units, the upper of which is the Abo Formation. The lowest exposed unit may be correlative with strata in the Robledo Mountains identified by Thompson (1954) and mapped by Kottlowski (1953; 1960a) as Bursum. Hueco and Abo members above the Bursum are easily correlated with subdivisions of the Hueco and Abo described by Kottlowski (1960b) and Jordan (1971) in the Robledos. In fact, many of the same beds appear to be present in both areas. Correlation of Wolfcampian rocks between the Robledos, Doña Ana and San Andres Mountains are shown in fig. 6 and measured sections of the shelf sequence are presented in sections B and C, Appendix, and Sheet 3 (in pocket).

BURSUM? OR LOWER HUECO

About 200 ft of Bursum? or lowest Hueco beds are exposed in the center of Grande dome (section A, Appendix and Sheet 3). The top of the unit was placed at the base of a cliff-forming algal bioherm that forms a prominent semicircular ledge around the western side of the dome. The base of the unit is not exposed. The bioherm may be correlative with biohermal and biostromal units at the base of the Hueco in the Robledo Mountains and southern San Andres Mountains; if so, the underlying strata are probably of Bursum age. On the other hand, algal biohermal units also occur at several higher positions in the lower Hueco of the Robledos, so it is not altogether clear whether the strata beneath the bioherm in the Doña Ana Mountains are lower Hueco or Bursum. Fusulinids collected 195 ft above the algal bioherm are *Schwagerina andresensis* and *Pseudoschwagerina* (W. E. King, personal communication, 1975). *Schwagerina andresensis* also occurs in the basal 200 ft of lower Hueco strata in the Robledo Mountains.

The Bursum? or lower Hueco in the Doña Ana Mountains comprises mainly medium-gray micrite and biomicrite in thin to medium beds. Oolitic and intraclastic zones as well as algal biolithites are present in lesser amounts, and chert and limestone pebble conglomerates occur as thin lenses. Many of the beds are nodular and weather to crumbly slopes. Fossils are common and include petrified wood, phylloidal and stromatolitic algae, corals, gastropods and crinoids.

When traced eastward around the flanks of Grande dome, Bursum strata change facies abruptly. The normal marine shelf limestones grade and intertongue eastward into a thicker sandstone, porcellanite, and sandy or silty limestone section (section A, Appendix and Sheet 3). The predominantly clastic strata are interpreted to be lowest exposures of a basinal section; east of Grande dome, these strata comprise all of the Hueco Formation. This facies is described in a later section.

LOWER HUECO

Overlying the Bursum? or lowest Hueco strata are about 420 ft of shelf limestone clearly correlative with at least part of the lower Hueco member described by Kottlowski (1960b) in the Robledo Mountains. The unit is well exposed on the western flank of Grande dome (section B, Appendix and Sheet 3). Traced eastward around the northern and southern flanks of the dome, the lower Hueco changes facies into sandy, siliceous and shaly beds of the basin facies. The base of the lower Hueco is the prominent algal bioherm mentioned above. The top was placed at the highest of three or four rust- to orange-weathering micrite beds, each 1 to 3 ft thick. The same marker beds are present in the Robledo Mountains.

The lithology most characteristic of the lower Hueco of the Doña Ana Mountains is medium-gray, medium- to thick-bedded algal biomicrudite. This comprises much of the lower 240 ft of the unit, often occurring as lenticular beds, probably representing both bioherms and banks of transported algal filaments. The best developed bioherm marks the base of the lower Hueco map unit. It consists exclusively of algal filaments in a micrite matrix, has a maximum thickness of about 15 ft and can be traced laterally for about 1 mile before it pinches out in the basin facies. Other algal-rich units contain variable amounts of skeletal fragments of crinoids, gastropods, echinoids, brachiopods, bryozoans, corals, and locally fusulinids. Shaly limestone or thin-bedded nodular micrite occur as interbeds. The abundant oolite beds, so well developed in the Robledo Mountains, were not found in the Doña Anas.

The upper 180 ft of the lower Hueco is somewhat different. Micrite, typically weathering to shades of yellow, brown, tan or rust, is the predominant lithology, and biomicrudite, intramicrudite and algal beds occur only as occasional interbeds. Siliceous and calcareous blebs, streaks, laminae and aggregates are common.

MIDDLE HUECO

About 250 ft of middle Hueco limestone beds overlie the lower Hueco on the western flank of Grande dome (section B, Appendix and Sheet 3). The base of the unit is the highest orange- or rust-weathering micrite bed in the upper part of the lower Hueco. The upper contact is a fault at Grande dome, but the upper contact in an unfaulted section 1 mile to the north is marked by the first appearance of thick-bedded, dark-gray gastropod biomicrudite. Faulting at Grande dome probably has not removed more than a few tens of ft of middle Hueco strata. This is somewhat uncertain because strata equivalent to the middle Hueco in the unfaulted exposures in sections 8 and 9 are of a different facies (basin) and thickness, therefore not useful in evaluating the significance of faulting at Grande dome. Middle Hueco beds correlate closely with the lower two thirds of the unit mapped as middle Hueco in the Robledo Mountains (fig. 6).

Light-colored, thin- to medium-bedded biomicrite and micrite is typical of the middle Hueco. Light- to medium-gray, cream, yellow-gray, tan, and pale-yellow predominate. Siliceous and calcareous blebs, eyes, streaks, and laminae are common. Skeletal sand in biomicrite beds is generally fine grained, often bioturbated, and laminated. Pelletal and oolitic sand is present in at least two beds, and discontinuous intraclastic zones occur locally. Nodular to ropy chert is present in several beds. Ostracods are fairly common and occasional brachiopods, gastropods, crinoids, and foraminifera(?) were noted. The middle Hueco strata are interpreted to represent low energy, probably shallow shelf conditions, perhaps restricted in circulation from time to time.

GASTROPOD-BEARING MEMBER

Only a few ft of the gastropod-bearing member of the Hueco occurs above the middle Hueco at Grand dome, the remainder being removed by faulting. However in section 8 about 1 mile north of the dome, the entire member is present between the Abo Formation and basinal facies of the middle Hueco (section C, Appendix and Sheet 3). The unit is about 400 ft thick in this area. The base of the member was taken as the lowest occurrence of thick- to medium-bedded, gastropod-rich limestone; porcellanitic rocks and black shale predominate below this horizon. The top of the unit is transitional with overlying Abo, and was arbitrarily placed at the first thick crossbedded Abo-type sandstone. Occasional Abo siltstones are present beneath the contact, and thin gastropod limestones are fairly common above.

The gastropod-bearing member of the Hueco comprises mostly medium- to dark-gray fetid biomicrite in beds 1 to 3 ft thick. Many beds contain numerous unbroken planispiral gastropods 1 to 3 inches in diameter. Lesser amounts of nearly unbroken echinoid spines, brachiopod, pelecypod and scaphopod debris are common. Skeletal sand is subordinate and at least one 6-inch algal biolithite bed is interstratified. Soft, nodular, thin-bedded limestone, thin ripple-laminated siltstone units, and shale are also interbedded but not well exposed.

The gastropod member is not well developed in the Robledo Mountains. About 80 ft of dark-gray gastropod limestone in the upper part of the middle Hueco is probably correlative as shown in fig. 6. In the northern Organ Mountains at least 500 ft of dark-gray gastropod limestone comprises the entire middle Hueco member between an Abo tongue and the orange marker beds at the top of the lower Hueco. Similar beds about 400 ft thick also overlie the Abo in the Robledo Mountains.

The gastropod-bearing limestone member is thought to have formed on either a restricted shallow shelf or in local lagoons. This origin is indicated by the general dark color, the fetidness of the predominantly micritic rocks, and by the fauna, which appears to be restricted in the number of genera.

ABO FORMATION

About 265 ft of Abo Formation was measured in the broad outcrop belt 1 to 3 miles northwest of Grande dome (section C, Appendix and Sheet 3). This section represents only a partial thickness because uppermost beds were eroded in pre-late Eocene time. A complete section exposed in the Robledo Mountains is 475 ft thick and occurs as a tongue between middle and upper limestone members of the Hueco (Kottlowski, 1960b). Presumably the Abo occurs as a tongue in the Hueco in the Doña Ana Mountains also, but this cannot be demonstrated because of the pre-Eocene erosion. The base of the Abo in the Doña Ana Mountains was placed at the base of a 40-ft-thick, crossbedded, tan sandstone, locally containing plant remains. Although occasional Abo red beds occur below this marker, the sandstone marks the beginning of frequent Abo clastic units in the section.

Cyclical repetition of Abo red beds with Hueco marine shale and limestone characterize the Abo Formation in the Doña Ana-Robledo area. Abo beds are usually red, hematitic siltstone or gray to brown sandstone units 1 to 40 ft thick. Ripple crosslaminations are very common, and some of the thicker sandstone beds occupy broad channels and exhibit low-angle cross stratification in sets 1 to 3 ft thick. The beds are calcareous and locally

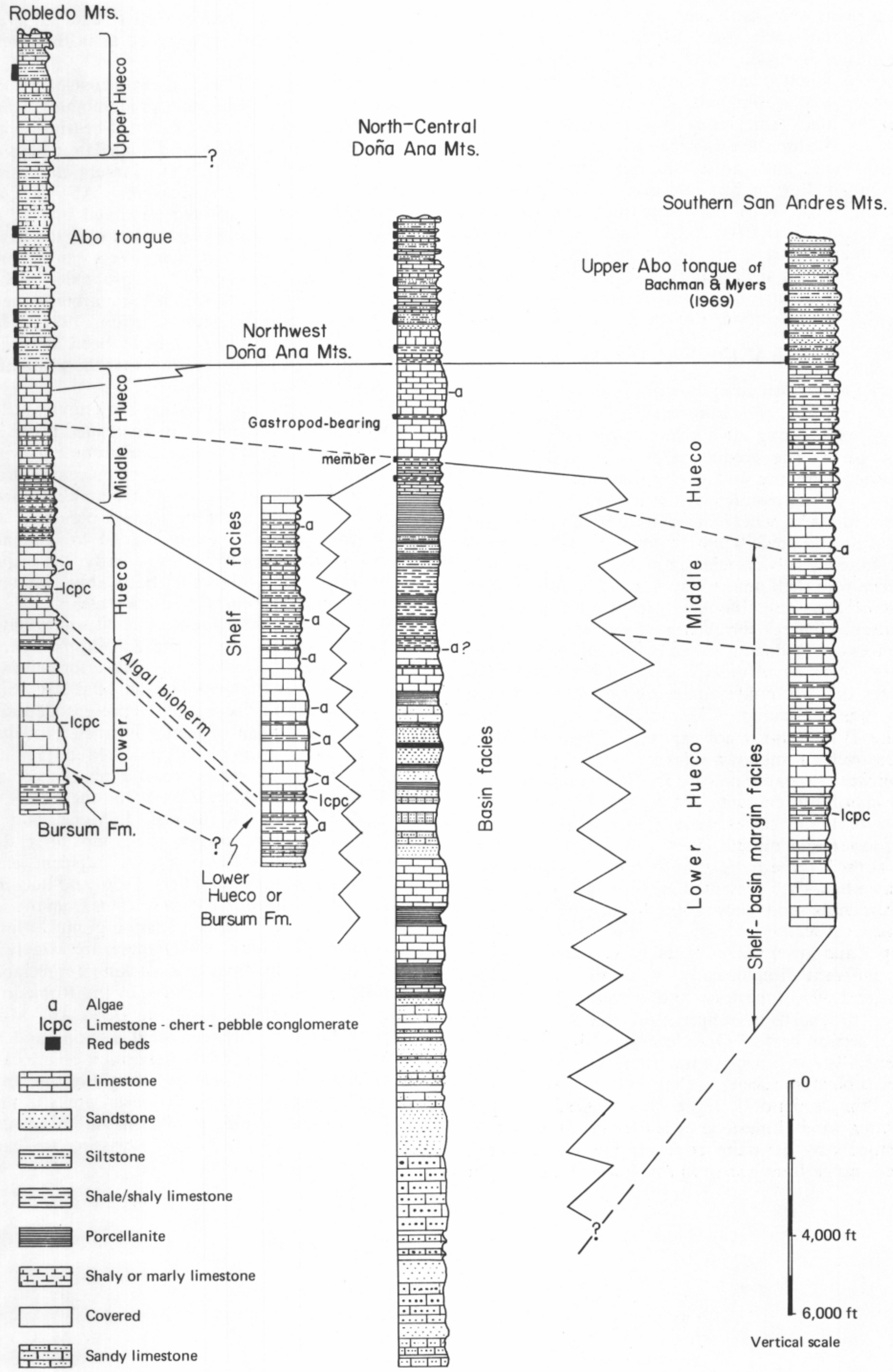


FIGURE 6—CORRELATION OF WOLFCAMPIAN ROCKS (ROBLEDO MOUNTAINS TO SOUTHERN SAN ANDRES MOUNTAINS).

contain plant remains. Hueco limestone units are typically medium- to light-colored micritic rocks, locally containing a profusion of ostracods. A restricted fauna of whole or slightly broken gastropods, echinoid spines and plates, and scaphopods is common in some beds. Green to black calcareous shale, marly beds, and calcareous siltstone are interbedded in the sequence. The lithologies and fauna and flora clearly indicate oscillating shallow marine and marginal to nonmarine conditions. Abo beds may represent deposition on broad coastal tidal flats and in tidal channels, while Hueco marine strata are interpreted as forming in shallow restricted shelf waters, and probably lagoons. LeMone (1971) arrived at a similar conclusion from studies of Abo-Hueco strata in the Robledo Mountains.

BASIN FACIES

East of a north-trending line bisecting Grande dome, Hueco strata are of a different facies, interpreted as having formed along the northwestern edge of the Orogrande basin. The predominantly non-sandy, fossiliferous shelf sequence west of this line changes abruptly eastward to unfossiliferous, sandy and silty limestones, laminated calcareous sandstone and quartzite, black shale and porcellanite. In outcrops east of Grande dome, lithologically correlating in detail any part of the sequence with shelf units to the west is impossible; some sandstone beds resemble Abo, except for a lack of red coloration. General correlation of the shelf and basin sequences can be demonstrated by simple lateral tracing of the major shelf units around the northern and southern rim of Grande dome. About 2,250 ft of basin facies was measured. This thickness is minimum because 1) the base is not exposed, 2) reverse faulting has removed an unknown thickness, and 3) parts of the section were probably omitted in the attempt to assemble a composite column. The basin rocks clearly are thicker than the corresponding shelf sequence (Bursum?, lower and middle Hueco), which is only about 875+ ft thick (base not exposed). Measured sections of the basin facies are presented in sections A, C and D in the Appendix and shown graphically in the stratigraphic cross section.

Upper and lower halves of the basin facies are somewhat different lithologically. Cyclically interbedded sandy and silty limestone and calcareous sandstone grading to quartzite comprise the lower half of the basinal section east of Grande dome. Limestone beds are generally marbleized or otherwise recrystallized, but scattered bioclastic zones are recognizable, as are occasional thin stromatolitic algae beds suggestive of shallow water. Many limestone beds are laminated micrite. Sandstone and quartzite beds are laminated to thin bedded, range from coarse to fine grained, and exhibit only parallel stratification. Calc-silicate mineralization is common in these beds as well as in the more sandy limestone beds.

Porcellanite and black shale increase in the upper part of the basin facies, and predominate at the top of the section beneath the gastropod-bearing member of the shelf sequence. Shale and porcellanite beds up to 60 ft thick alternate with thin, largely nonfossiliferous micrite units and an occasional Abo-like siltstone. About 50 to 60 ft of coarse-grained marble forms a conspicuous, persistent marker bed near the base of the upper half of the basin facies. Very poorly preserved *Triticites* and *Schwagerina* of probable Bursum age occur in a silty micrite within the marble sequence (W. E. King, personal communication, 1975). However, these fusulinids appear to have been reworked and transported, and it seems likely that the strata are lower Hueco rather than Bursum.

The lithologies, sedimentary structures and general lack of either an abundant or diversified fauna indicate deposition in a low energy environment with poor circulation of water and lack of currents. Occasional algal beds indicate shallow water at least part of the time but deeper water may have prevailed at other times as suggested by thin-bedded to laminated micrites, sandstones and shales. Clearly, the sequence is related to the Orogrande basin but what specific environments are represented is not clear.

Kottlowski (1960b) suggested that somewhat similar beds of Virgilian age in the San Andres Mountains (Panther Seep Formation) may have formed in a shallow deltaic environment and on tidal flats. Similarly, the Hueco basin facies may represent deposition on the basinward edge of gently inclined prodelta strata that extended from the Caballo Mountain–northern San Andres area, where coastal plain sedimentation predominated, southeastward to the floor of the Orogrande basin (Kottlowski, LeMone, and Seager, 1975). Such a delta, or perhaps groups of small deltas, would allow clastics to bypass adjacent carbonate shelves. Kottlowski and others (1956) and Bachman and Myers (1969) describe Hueco sections from the southern San Andres Mountains containing much limestone. According to Jordan (1971) these are largely normal shelf, bioherm or shoal types lacking appreciable sand. Similar shelf rocks are present in the Robledo Mountains. The basinal facies of the Doña Ana Mountains occurs, therefore, between shelf sections and may be interpreted as delta foreset deposition on a local downwarp across the northwestern margin of the Orogrande basin. Clastics derived from coastal areas to the north were transported into the basin via this route (and probably other routes), thus bypassing the carbonate shelves on either side (fig. 7).

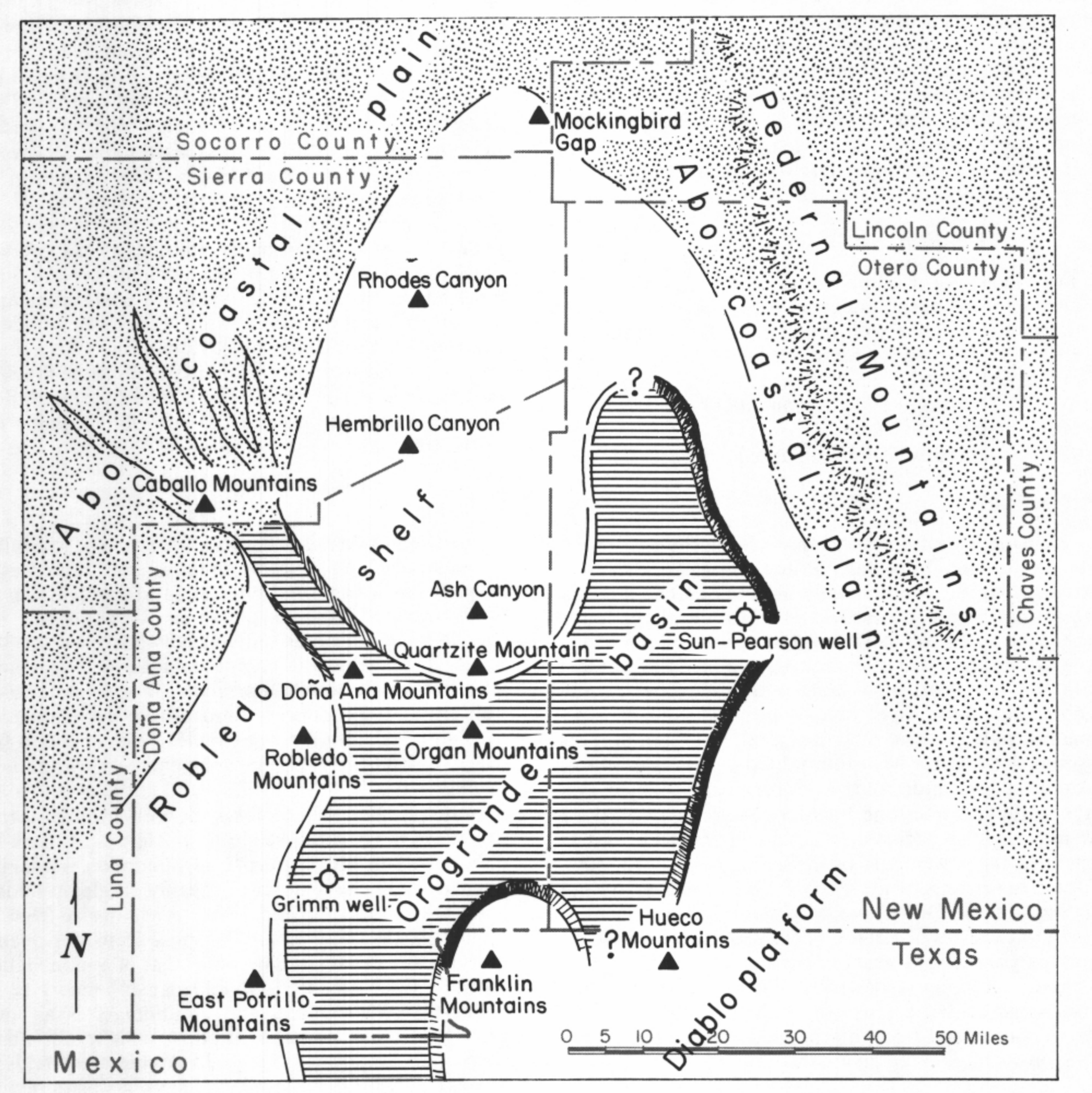


FIGURE 7—OROGRANDE BASIN AND ADJOINING AREAS IN WOLFCAMPIAN TIME.

Tertiary Stratigraphy

Tertiary rocks record two episodes of volcano-plutonic activity within the Doña Ana Mountain area: 1) andesitic volcanism and pluton emplacement during the late Eocene, and 2) comagmatic rhyolite ash-flow tuff eruption and intrusive activity during middle Oligocene time. The vent areas of the two eruptive cycles appear to coincide, at least in part, suggesting that the same plumbing system was utilized during both magmatic cycles.

EOCENE ROCKS

Two facies of Eocene rocks were mapped: 1) a sequence of epiclastic andesitic rocks and interbedded lava flows correlative with the Palm Park Formation of the Caballo Mountains, Sierra de las Uvas, and Selden Canyon area (Kelley and Silver, 1952; Clemons and Seager, 1973; Seager and Clemons, 1975), and 2) thick, massive hornblende andesite porphyry, probably both intrusive and extrusive, herein named Cleofas Andesite.

PALM PARK FORMATION

The Palm Park Formation crops out in the northwestern part of the Doña Ana Mountains and, to a lesser extent, along the southern side. Where basal contacts of the formation are exposed, it overlies middle or lower Hueco beds. In the northwestern corner of the Doña Ana Mountains, Palm Park beds are in fault contact with the Abo Formation and presumably overlie the Abo in the subsurface there. The basal contact is an unconformity with several hundred ft of relief. This erosion surface has been interpreted to be the result of erosion of Laramide folds in Eocene time (Seager and others, 1971). Limestone boulder conglomerate derived from these folds occurs as a basal conglomerate and as lenses in the lower part of the Palm Park Formation. Complete sections of the Palm Park Formation are not exposed in the Doña Ana Mountains. However, minimum thicknesses of 1,200 ft and 1,950 ft were measured from partial sections west of Grande dome and south of Wagner Canyon, respectively. Potassium-argon ages from small andesite porphyry plutons associated with the formation and from interbedded flows in the Selden Canyon-Robledo area give dates ranging from 42 to 51 m.y.

Most of the Palm Park Formation comprises andesitic epiclastic rocks of various origins. Laharic breccia is conspicuous as are deposits of purple, brown, and maroon mudstone and sandstone. Textural and mineralogical immaturity is typical of all lithologies. Clasts include several varieties of hornblende andesite porphyry, some of which resembles Cleofas Andesite and various flow units within the Palm Park. Lava flows of andesite to 200 ft thick are interbedded with laharic breccias south of Wagner Canyon. The flows become numerous in areas adjacent to the outcrops of Cleofas Andesite that form the central part of the range, but they do not comprise a significant percentage of the Palm Park in outlying parts of the Doña Ana Mountains or in ranges beyond. The andesite flows are dark-gray to purplish-gray porphyritic rocks containing oligoclase-andesine, hornblende, and biotite as phenocrysts 2 to 4 mm long. Hornblende and biotite crystals are largely replaced by magnetite, hematite, calcite and chlorite. The groundmass is generally microcrystalline with trachytic texture formed by laths of sanidine(?) and andesine(?). Nearby laharic breccias contain numerous similar rocks as clasts. Mineralogically, the flows are nearly identical with the Cleofas Andesite, except that flows generally are finer grained, darker colored, and contain smaller phenocrysts.

The Palm Park probably formed as an epiclastic apron on the flanks and in the lowlands around one or more andesitic volcanic centers. Lava flows in the apron become more numerous toward exposures of Cleofas Andesite in the Doña Ana Mountains. Clasts in the laharic breccias are derived partly from these flows and partly from the Cleofas Andesite. The Cleofas Andesite may represent the source of part of the Palm Park Formation.

CLEOFAS ANDESITE

The Cleofas Andesite forms a wide area of low hills in the central Doña Ana Mountains, and underlies an extensive pediment on the eastern and southeastern side of the range. The unit is named for exposures near Cleofas well in Cleofas Canyon, SE¼NE¼ sec. 22, T. 21 S., R. 1 E., where it comprises massive, structurally homogeneous andesite porphyry. Based on lithologic similarities, the Cleofas is almost surely correlative with the Palm Park (late Eocene). It clearly is separated from overlying middle Oligocene volcanic rocks by an unconformity.

Lithologically, the Cleofas Andesite comprises porphyritic rocks ranging from light tan, pale purple, dark reddish purple to bluish purple. Groundmass is generally fine grained; phenocrysts of creamy to glassy feldspar and dark hornblende and biotite range in size from 2 to 7 mm. Locally, phenocrysts comprise 75 to 80 percent of the rock and the texture becomes that of a monzonite or diorite. In thin section feldspar phenocrysts are oligoclase-andesine and the groundmass is an intergrowth of oligoclase and sanidine with minor quartz, clays, chlorite and magnetite. In altered areas feldspars are saussuritized, replaced by clays, chlorite, epidote and clinozoisite. Mafic minerals are altered to mixtures of chlorite and magnetite, with magnetite altering to hematite. Trachytic texture, locally developing into flow banding, occurs in a few places, but the unit is generally structureless.

Contact relations with older rocks and with the Palm Park Formation are not easy to determine. North of Wagner Canyon the contact with Hueco Limestone is basically a fault (Wagner Canyon fault) that contains a latite or monzonite porphyry dike. Local remnants of Hueco south of the fault appear to be intruded by the Cleofas Andesite as indicated by ragged, embayed contacts, metamorphism of the Hueco, and variable epidote-chlorite-clay alteration of the andesite. In this area the andesite approaches monzonite or diorite in texture. Pervasive chlorite-epidote-clay alteration of the

Cleofas covers about 1 square mile near Wagner well and discontinuous alteration extends beyond for another half mile (Sheet 1). Similar alteration is not associated with younger intrusives in the area, and is interpreted to be hydrothermal alteration related to emplacement of the andesite as a stock or sheet in this area.

Contact relations with Palm Park strata are more ambiguous. In Cleofas Canyon, Palm Park beds strike squarely into the Cleofas yet contacts are not well enough exposed to determine whether the Cleofas is intrusive, or simply a thick, lenticular flow within the Palm Park. Palm Park beds are not altered. Evidence supporting the Cleofas as intrusive comes from the SE corner of sec. 21, T. 21 S., R. 1 E. Here an isolated mass of Cleofas exhibits steep contacts with surrounding Palm Park beds, has steep, well-defined foliation, and contains xenoliths of Palm Park laharic breccia. Elsewhere unaltered, scattered, isolated Palm Park breccias are within the Cleofas, and occasional hills of Cleofas suggest south-dipping cuestas. Consequently part of the Cleofas may represent thick southward dipping flows containing an occasional lahar interbed. Alternatively, the scattered Palm Park outcrops may be engulfed, and the cuestas merely a topographic form resulting from the weathering of a joint set within a stock or south-dipping sheet.

Probably the Cleofas is mostly intrusive. On the basis of a few clear intrusive relations, hydrothermal alteration, and the massive homogeneous character of the Cleofas, it probably is intrusive in the central part of the range and in the areas adjacent to Wagner well. Flows may occur elsewhere locally but this cannot be established with certainty. It seems likely that the Cleofas pluton represents a source of many of the Palm Park flow and epiclastic units in the area.

OLIGOCENE ROCKS

Unconformably overlying Eocene rocks is a sequence of more acidic flows and associated intrusives and epiclastic rocks. In ascending order these are: 1) Doña Ana Rhyolite, a thick ash-flow tuff unit; 2) unnamed sequence of volcanic strata, including some rhyolite flows, ash-flow tuffs, air-fall tuffs, minor basaltic andesite, volcaniclastic beds and landslide breccias; 3) flow-banded rhyolite intrusives; 4) monzonite porphyry and associated intrusives. Mafic dike rocks, generally younger than the monzonite, are a fifth subdivision. While crosscutting relations can be demonstrated among most rocks of the five subdivisions, they are considered to be comagmatic, representing essentially one cycle of volcanic activity during the Oligocene. Table 1 shows chemical similarities between rocks of the first 4 groups. Petrologic similarities are also clear. Field relations indicate monzonite and flow-banded rhyolite to be nearly coeval and to be somewhat younger than the Doña Ana Rhyolite. Potassium-argon ages of 33.0 m.y., 37.3 m.y., and 33.7 m.y. were obtained for the Doña Ana Rhyolite, flow-banded rhyolite, and monzonite porphyry, respectively. Although the absolute dates do not correspond with relative stratigraphic ages, they do indicate the general age of the intrusive-extrusive activity.

The great thickness and relatively local extent of the Doña Ana Rhyolite and associated rocks, as well as the distribution of structural features and intrusive masses demand that the sequence be interpreted in terms of a cauldron model. The cauldron, named Doña Ana cauldron, clearly resulted from eruption of Doña Ana Rhyolite, but subsequent history of cauldron subsidence and filling, as well as extensive intrusive activity, is indicated by the younger rocks. The cauldron appears to be about 7 to 8 miles in diameter with boundaries defined partly by structurally high pre-cauldron rocks, partly by belts of intrusive rocks and partly by the distribution of thick Doña Ana Rhyolite as indicated by outcrops and by aeromagnetic data (fig. 8). A smaller cauldron centered on Dagger Flat is only about 2 miles in diameter and nearly surrounded by a concentric system of monzonite dikes; this small cauldron is nested within the larger cauldron.

TABLE 1—CHEMICAL ANALYSES OF DOÑA ANA RHYOLITE AND RELATED ROCKS, DOÑA ANA MOUNTAINS

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Loss	Total
Monzonite porphyry SE¼ SW¼ sec. 23, T. 21 S., R. 1 E.	68.0	.312	17.0	1.0	.052	.10	.08	5.3	5.8	.05	1.18	98.87
Doña Ana Rhyolite SE¼ NW¼ sec. 31, T. 21 S., R. 1 E. (densely welded facies)	77.9	.04	12.9	1.0	.013	.27	.06	4.0	4.6	<.05	1.38	102.213
Doña Ana Rhyolite SE¼ NW¼ sec. 31, T. 21 S., R. 1 E. (pumiceous facies beneath welded facies)	73.5	.08	12.9	1.0	.021	.10	.11	4.0	4.8	<.05	1.43	97.99
Flow-banded rhyolite SE¼ NE¼ sec. 28, T. 21 S., R. 1 E.	73.5	.20	14.1	.71	.034	.03	.08	4.3	5.5	.05	.87	99.374

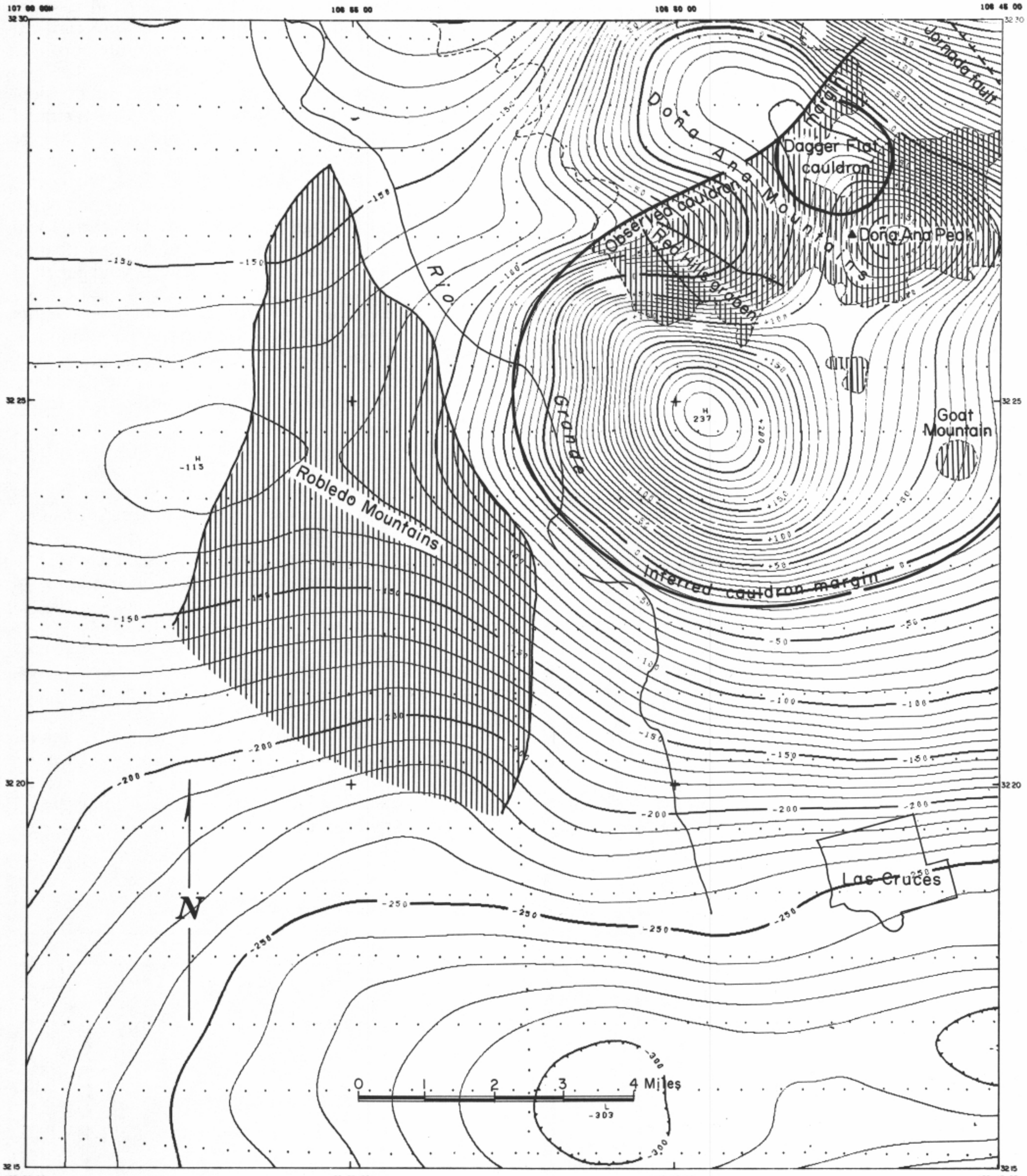


FIGURE 8—Aeromagnetic map, Doña Ana Mountains area.

Doña Ana Rhyolite

The Doña Ana Rhyolite is a rhyolitic ash-flow tuff sequence that comprises the main rock unit within the Doña Ana cauldron (fig. 9); its eruption initiated subsidence of the cauldron. The ash-flow tuff is at least 2,500 ft thick near the center of the cauldron, and the unit now forms most of the southern one-third of the mountain range. Its present distribution appears to be largely, if not wholly, restricted to the cauldron. It is not present in the Bell Top Formation in the Sierra de las Uvas-Cedar Hills area, nor has it been recognized in the Organ Mountains. Northwest of Dagger Flat, the Doña Ana Rhyolite is not present above structurally high Cleofas Andesite that probably represents the northwestern rim of the cauldron.

For mapping purposes, the Doña Ana Rhyolite was subdivided into 3 units. The basal unit comprises a discontinuous sequence of well-bedded rhyolitic air-fall tuffs and breccias not more than 100 ft thick (Tdt). These clearly represent explosive activity preceding emplacement of the ash-flow sequence. The main body of the Doña Ana Rhyolite was subdivided into two laterally and vertically gradational facies on the basis of welding characteristics. A densely welded facies comprising a compound cooling unit and containing structures formed by laminar flow was mapped in the central, upper part of the cauldron (Tdr). A more widespread facies characterized by less dense welding and exhibiting a simple cooling zonation was mapped elsewhere (Tda).

The bulk of the Doña Ana Rhyolite comprises the later facies (Tda). It is well exposed in the lower slopes beneath Doña Ana Peak and in the hills and ridges to the west (figs. 10, 11). Light brownish gray to medium gray are dominant, although a distinctive pale-red to grayish-pink subfacies forms the Red Hills 1.5 miles northeast of Hill. The formation is massive and weathers to barren, rounded hills or smooth slopes. No evidence of bedding, suggestive of multiple flows or a compound cooling history was observed, but crude platy foliation is locally developed enough to determine structural attitude. Foliation is expressed both by the alignment of scattered large collapsed pumice fragments and by eutaxitic textures. Abundant lithic fragments to 5 cm in diameter are common, as are crystals. Locally, pumice occurs to the exclusion of other fragments, especially near the top of the unit, while elsewhere either crystals or lithic fragments may predominate. The ash-flow tuff is highly magnetic; this property allows subsurface distribution of the formation to be estimated from aeromagnetic maps. The cauldron walls were inferred partly on the basis of such maps (fig. 8).

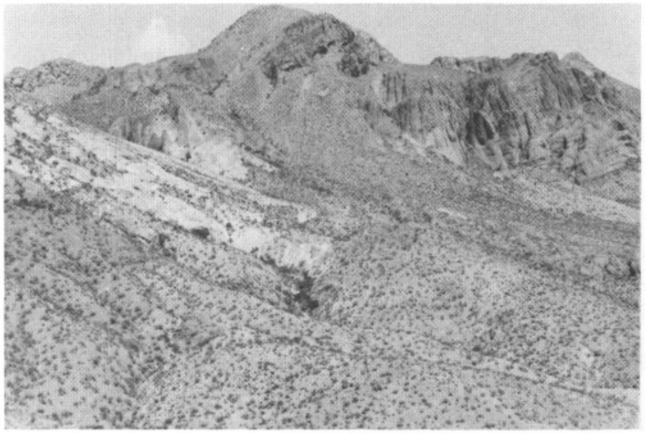


FIGURE 10—Doña Ana Rhyolite in southern escarpment of Doña Ana Mountains. Rhyolite dips northward (left) into Dagger Flat. Light areas are altered ash-flow tuff. Monzonite porphyry forms Doña Ana Peak (elevation 5829 ft).

In thin section quartz and sanidine are seen to comprise most of the phenocrysts. Commonly the crystals are broken and embayed, less commonly euhedral. Phenocrysts of euhedral sanidine are white, equant crystals 1 to 2 mm in diameter that locally are numerous and conspicuous in hand specimens. Lithic fragments of latite, andesite porphyry and rhyolite also are common as are devitrified pumice fragments in various stages of collapse. Pumice cavities are filled with anhedral mosaics of quartz, sanidine, chalcedony, magnetite and unidentified microlites. Aggregates of quartz, chalcedony and K-feldspar, formed by devitrification of glass shards, comprises the groundmass. Various alteration products like calcite, chlorite, hematite and clays generally cloud the groundmass. In specimens where hematite and magnetite dust in the matrix is abundant,

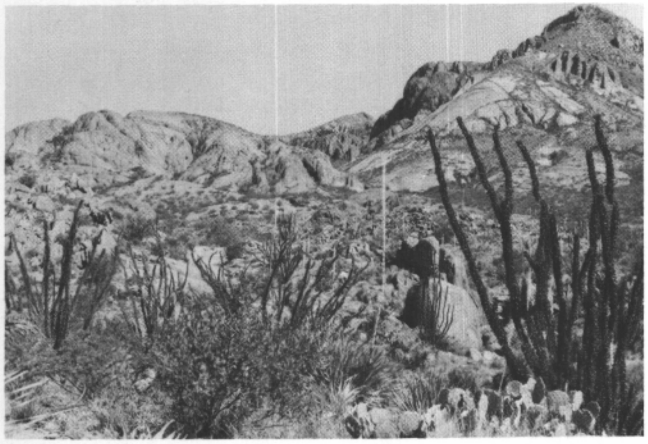


FIGURE 9—Doña Ana Rhyolite along southern escarpment of Doña Ana Mountains. Monzonite porphyry in foreground.

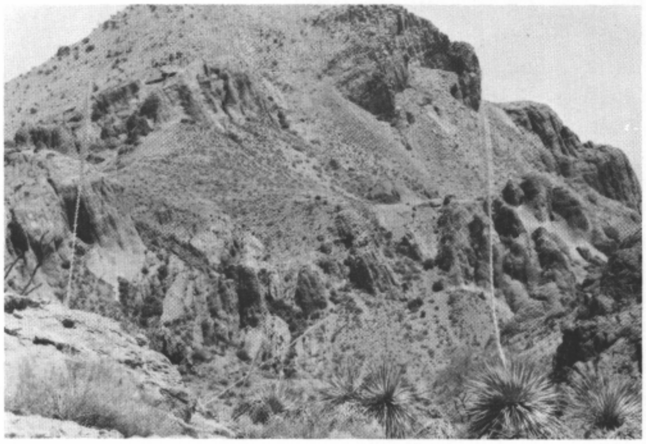


FIGURE 11—Doña Ana Rhyolite in south slopes beneath Doña Ana Peak. Crude layering dips north into Dagger Flat.

the rock is pale red and highly magnetic. Eutaxitic texture, formed by subparallel shards, pumice fragments and other elongated fragments, is common. Biotite, anorthoclase, and tridymite are accessory minerals.

The densely welded facies forms the upper half of the thickest section of Doña Ana Rhyolite adjacent to Dagger Flat. Crude stratification within this facies probably is indicative of multiple eruptions separated by enough time for partial cooling; columnar jointing is present at the base of some of these cooling units. Sharp contacts between cooling units cannot be distinguished in outcrops nor can the layering be traced horizontally for more than a few hundred yards. The facies probably comprises a multiple flow, compound cooling unit apparently restricted to areas adjacent to Dagger Flat.

The welded facies has many of the aspects of porphyritic rhyolite flows, including local weak- to well-developed flow-banding and the absence of megascopically visible pumice or shards. Contact relations with the main body of ash-flow tuffs are entirely gradational, both vertically and laterally, and occasional areas of facies mixtures occur. The tiny white equant sanidine crystals and various lithic fragments, so typical of the main body of the ash-flow tuff, also are conspicuous in the welded part of the formation. Pumice fragments, always highly collapsed and devitrified, were found in some thin sections of the welded facies together with ghosts of eutaxitic texture and shards. These observations indicate that the welded rock is gradational into, and of the same origin as, the main body of the ash-flow tuff. The dense welding and great thickness of the Doña Ana Rhyolite near Dagger Flat suggest a nearby source, possibly the dike-filled fractures concentric about Dagger Flat. These dikes include intrusive ignimbrite masses of Doña Ana Rhyolite. The ash flows are most numerous and thickest near Dagger Flat; therefore, heat was retained longer, resulting in dense welding and laminar flow.

Although most of the Doña Ana Rhyolite is inferred to have issued from fractures now occupied by monzonite or rhyolite dikes, other vents are present. Two ignimbrite intrusives were mapped near Dagger Flat. The first, in the southwestern corner of section 25, T. 21 S., R. 1 E., is an elliptical mass of Doña Ana Rhyolite about 350 yards long (Tdai) surrounded by altered Palm Park beds. The intrusive consists of pumice and lithic-rich ignimbrite, also considerably altered especially adjacent to contacts with enclosing andesitic rocks. No foliation was noted. Spherulitic bodies 4 to 6 inches in diameter are common near contacts. A second ignimbrite intrusive was mapped along the northwestern side of Dagger Flat. This intrusive is dikelike in form, trends northeast, and exhibits steep eutaxitic foliation. Texturally and mineralogically it is similar to the welded zones of nearby Doña Ana Rhyolite. The two masses probably represent feeder vents for parts of the Doña Ana Rhyolite.

UNNAMED YOUNGER CAULDRON FILL

The Doña Ana Rhyolite is overlain by a variable thickness of rhyolitic to andesitic sedimentary rocks, landslide breccias, siliceous air-fall tuff and breccia, and one or two thin ash-flow tuffs that represent continuing volcanic activity and sedimentation on the floor of the cauldron. Comparatively little of the unit remains today, although it once probably was an extensive deposit within the cauldron. Small isolated remnants occur as septa and xenoliths in younger intrusive rock or as small grabens in Doña Ana Rhyolite, but the bulk of the formation is confined to 3 separate structurally low areas.

The thickest section is exposed about 1 mile northeast of Doña Ana Peak. At this locality the unit is about 1,100 ft thick. The lower 800 ft comprises steeply dipping tuffaceous rhyolitic sandstone, mudstone and pebbly conglomerate that were deposited on Doña Ana Rhyolite. The contact is probably a minor disconformity. The epiclastic strata are fine to medium grained, light gray, light tan or pale lavender, laminated to medium bedded, and exhibit a rhythmic alteration of coarse- and fine-grained sediment. They appear to be lake deposits that formed within the cauldron. Occasional conglomerate lenses contain mostly rounded Palm Park or Cleofas Andesite clasts. The upper 300 ft of the unit is massive light-gray air-fall pumice grading upward into ash-flow tuff.

A second outcrop of the unnamed unit forms part of the erosional outlier between Doña Ana Peak and Goat Mountain. About 200 ft is exposed and this gradationally overlies Doña Ana Rhyolite. Yellowish- to light-green silicic tuffs and breccias, as well as pale-purple to gray sandstone and mudstone are typical lithologies. A distinctive pinkish-gray vitric ash-flow tuff forms the stratigraphically highest exposures here. This tuff was found elsewhere in the range and proved to be a useful marker. It is composed largely of devitrified, collapsed pumice fragments up to 3 cm long in a matrix of glass shards. Abundant biotite crystals were found in all outcrops of the tuff. Two dikes of this ash-flow tuff were mapped, one in the southwest corner and one in the northwest corner of section 25, T. 21 S., R. 1 E. The dikes are 100 to 300 yards long, 10 to 30 yards wide, trend northwest, and exhibit steeply dipping foliation formed by collapsed pumice fragments and eutaxitic banding. Biotite occurs as phenocrysts. These ignimbrites are clearly dikes, and probably represent two of the vents through which the ash flow was erupted.

The third major exposure of the unnamed unit is within the Red Hills graben. No sequence of lithologies could be established here because the unit is highly disturbed due to explosive vent activity and emplacement of nearby rhyolite intrusives. Sandstone, conglomerate and mudstone as well as tuffs and breccias, generally similar to those already described, comprise much of the unit in the graben. The distinctive ash-flow tuff is present locally. Fine-grained, dark-grayish-purple andesite (Tca) appears to be associated with the unit in the graben but it is not clear whether it is intrusive or extrusive, or whether it is younger than or contemporaneous with the epiclastic and air-fall strata.

Megabreccia beds comprise an important aspect of the unnamed sequence in the Red Hills graben. Slabs and blocks the size of cars or houses and blocks of various volcanic rocks are mixed within the softer epiclastic strata and consequently weather in relief as monoliths. Most are probably of landslide origin, presumably sliding into the graben from their source in adjacent graben walls. Doña Ana Rhyolite in blocks up to 100 yards long is conspicuous along the northeastern margin of the graben. Other scattered blocks are types of siliceous flows and tuffs that no longer are present within the cauldron or its walls. Erosion of perhaps 1,000 ft of such volcanics is suggested by coarse-grained monzonite porphyry dikes now forming the highest peaks in the range. The dikes must have cooled at least 1,000 ft beneath the cauldron surface. The only possible remnants of the vanished rocks are the landslide blocks within the Red Hills graben. Flow-banded rhyolite bodies also are mixed with landslide blocks. Some of these are sills or dikes while others may be tilted flows. The chaotic melange is clearly the product of intrusive-extrusive activity and contemporaneous landsliding into an active graben within the Doña Ana cauldron.

FLOW-BANDED RHYOLITE

Flow-banded rhyolite forms notable intrusive masses in the Red Hills graben and adjacent to Dagger Flat. In the Red Hills graben the rhyolite (and lesser amounts of vitrophyre) are in the form of plugs, dikes and sills that have intruded the chaotic graben fill, the faults bordering the graben, and to a lesser extent, the Doña Ana Rhyolite. Adjacent to Dagger Flat the rhyolite forms steeply dipping discontinuous bodies whose present outcrop is roughly concentric about Dagger Flat and inside a circular zone of monzonite porphyry dikes. Monzonite porphyry cuts the rhyolite at one locality showing the monzonite to be somewhat younger.

Lithologically, the flow-banded rhyolite is quite variable, especially in color. Light gray to dark brown is typical, with flow banding represented either by a platy foliation or by alternating light- to dark-gray layers. All of the rhyolite is characterized by the abundance of equant feldspar phenocrysts 1 to 2 mm long; these are similar in appearance and composition to those of the Doña Ana Rhyolite, and to those within the chilled margins of monzonite porphyry plutons. A chemical analysis of rhyolite from the Red Hills graben is presented in table 1.

MONZONITE PORPHYRY AND RELATED ROCKS

Monzonite porphyry forms a major group of northeast, east-west, and north-south trending dikes, some of which are arcuate in shape, roughly concentric about Dagger Flat (fig. 12). A second group of poorly exposed intrusives occurs along the southern margin of the cauldron. The monzonite clearly is somewhat younger than both Doña Ana Rhyolite and flow-banded rhyolite. The monzonite and related dikes, together with part of the flow-banded rhyolite, appear to occupy subsidence fracture systems bordering the major cauldron as well as filling a fracture system concentric about Dagger Flat. The thick dike at the northeastern corner of Dagger Flat appears connected beneath alluvium to the large monzonite mass forming Summerford Mountain. The Summerford Mountain pluton is semiconcordant within Hueco strata and is essentially laccolithic in geometry. Smaller dikes and sills of monzonite are scattered elsewhere in the range.

The monzonite porphyry is typical of middle Tertiary monzonitic rocks in the region. The porphyry is a pale-yellowish-brown to light-gray rock ranging from coarsely porphyritic to subequigranular phaneritic in texture. Very pale tan to pale-orange phenocrysts of K-feldspar up to 1 cm long are most conspicuous, although plagioclase, biotite, and green augite also are common crystals. Mafic phenocrysts generally are altered to limonite or to clots of chlorite, calcite and epidote. The monzonite is structureless except along chilled contacts, where flow-banding may be developed. Locally, large areas of the monzonite porphyry are light colored and aphanitic, but still contain numerous K-feldspar phenocrysts. Facies with this texture were mapped as latite porphyry (Tlf) on the geologic map, but may range in composition through trachyte porphyry. The various facies of the monzonite porphyry are similar mineralogically, differing only in percentage of phenocrysts and groundmass grain size. In texture, color, and phenocryst composition the chilled margin facies and latite porphyry facies (Tlf) resemble the flow-banded rhyolite masses and better welded parts of the Doña Ana Rhyolite. Chemical similarities between the monzonite, flow-banded rhyolite, and Doña Ana Rhyolite are shown in table 1. These data, together with field relations and similar ages, indicate that all of these units are part of one cauldron cycle.

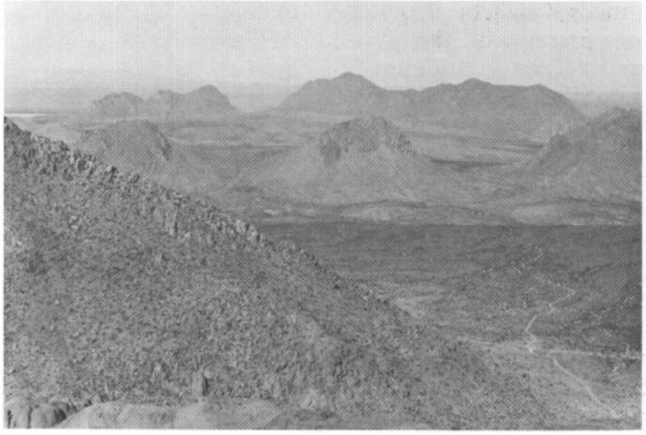


FIGURE 12—DAGGER FLAT IN LOWER FOREGROUND BORDERED BY PEAKS OF MONZONITE PORPHYRY. THE PEAKS ARE FORMED ON LINEAR TO ARCUATE DIKES THAT NEARLY SURROUND DAGGER FLAT. SUMMERFORD MOUNTAIN LACCOLITH IS THE HIGH RIDGE IN THE MIDDLE DISTANCE.

Thin sections show the monzonite porphyry to range in composition from monzonite to syenite, with local areas of alkalic syenite. The more alkalic rocks are indicated by an abundance of albite occurring as perthitic intergrowths in orthoclase, and as anhedral matrix grains. Between 18 and 60 percent of the monzonite is comprised of orthoclase or perthitic orthoclase phenocrysts, often altered to mixtures of clays, sericite, and calcite. Albite-oligoclase phenocrysts, also variably altered, comprise 12 to 42 percent of the rock. Smaller crystals of biotite, diopsidic augite, and magnetite total less than 20 percent of the monzonite. Mafic minerals are usually more or less altered to mixtures of calcite and limonite, with chlorite, epidote, and hematite. Groundmass is generally hypidiomorphic granular to felty, consisting mostly of a mesh of variably altered feldspar crystals spotted with magnetite, limonite cubes, and various other alteration products. Some larger anhedral quartz, magnetite, augite, and apatite grains are present in the groundmass as well as sphene, epidote, zircon, and ilmenite.

Various kinds of silicic dikes are identified on the geologic map. Most of the dikes are probably fine-grained equivalents of the monzonite porphyry, and locally some dikes can be seen to merge into monzonite masses. On the other hand, some of the dikes are melanocratic, although they contain large K-feldspar phenocrysts and have a monzonitic to syenitic composition (Tlp; Tla). These probably belong to the main cycle of monzonite intrusion, but their specific relation to the monzonite is not clear. Several silicic dikes cut the Summerford Mountain laccolith and are therefore younger than the monzonite. These are mainly nonporphyritic latite-trachyte and may be analogous to aplite dikes in quartz-bearing plutons.

The largest number of dikes transect the Hueco Limestone and Cleofas Andesite. The dikes are seldom more than 50 ft thick and consist of light-gray to light-yellow, slightly porphyritic felsite mapped as *Tf* on the geologic map. Locally the dikes become coarse grained, approaching monzonite or monzonite porphyry in texture. Much of the felsite is spotted with limonite formed by alteration of mafic minerals or disseminated pyrite. In thin sections the dikes are mostly latite-trachyte. Fine-grained hypidiomorphic-granular matrix of feldspar and minor quartz and mafic minerals is typical. Limonite alteration noted above is clearly seen in thin section.

Along the northwestern edge of the Doña Ana Mountains pink to cream rhyolite porphyry is exposed in several gullies. The rhyolite is intrusive into Palm Park and Hueco beds. It is identical to the rhyolite porphyry forming Lookout Peak in the Robledo Mountains, named Robledo Rhyolite by Seager and Clemons (1975) and dated 35 m.y. old by Kottlowski and others (1969). The rhyolite is a high potash variety that contains conspicuous white feldspar crystals 2 to 4 mm long as well as clear quartz phenocrysts. It probably is not related to the Doña Ana Mountain cauldron cycle.

MAFIC OR MELANOCRATIC DIKES AND PLUGS

Five groups of mafic or melanocratic dikes were mapped in the Doña Ana Mountains. Two of these groups have already been described, one associated with the unnamed younger cauldron fill in the Red Hills graben (Tca), and the other associated with monzonite porphyry and flow-banded rhyolite adjacent to Dagger Flat (Tlp). A third group, represented by only 3 small pluglike intrusives, was mapped along the southern edge of the range (Tba). This rock is fine-grained, medium-light-gray basaltic andesite containing considerable jarositic limonite and calcite as disseminated blebs. The basaltic andesite transects Doña Ana Rhyolite, but age relations with younger rock units are not known.

Several dark-greenish-gray porphyritic dikes cut Hueco Limestone south of Summerford Mountain. These comprise the fourth group of melanocratic dikes and are shown on the geologic map as latite porphyry (Tla). The relative age of these dikes also is not clear; they are younger than Cleofas Andesite, and may represent a fine-grained melanocratic facies of the monzonite porphyry. Conspicuous phenocrysts are mostly plagioclase up to 7 mm long, largely altered to chlorite, epidote, calcite and sericite. Lesser amounts of blocky tan K-feldspar also are present as phenocrysts. The matrix is a microcrystalline felty intergrowth of plagioclase laths, also considerably altered. Disseminated magnetite comprises 2 to 5 percent of the rock. Round amethyst grains to 3 mm in diameter are scattered through some of the rock, especially in the dike occupying the Wagner Canyon fault.

The fifth group of dark-colored rocks include numerous fine- to medium-grained, dark-greenish-gray andesite dikes that crop out west and north of Dagger Flat. They are shown by the symbol *Ta* on the geologic map. The source of many of these dikes apparently was a plug of the same rock located two-thirds of a mile southeast of Cleofas well. The dikes are younger than monzonite porphyry as indicated by crosscutting relations. They are presumed to represent a final stage within the Oligocene igneous cycle in the Doña Ana Mountains. In thin section the andesites are porphyritic, phenocrysts with andesine-sodic labradorite up to 3 mm long, generally altered and replaced by clays, sericite, and calcite. Magnetite also occurs as scattered crystals. Irregular to lath-shaped mafic relics are masses of calcite, fibrous antigorite, and quartz. The felty to trachytic groundmass comprises andesine laths in a matrix of calcite, chlorite, antigorite, magnetite, quartz, clay and limonite. Apatite and sphene are accessory minerals. Feldspar composition suggests that the rock may more properly be termed basaltic andesite.

BASALT AND BASALT PORPHYRY

Several dark gray to black basalt dikes and small plugs transect various rock units in the northern half of the range. These dikes and plugs are lithologically identical to numerous small plutons in the Robledo Mountains dated 13 m.y., therefore are probably younger than rocks of the Oligocene cauldron cycle. Thin sections show beautiful pilotaxitic texture formed by labradorite laths 1 to 2 mm long. Olivine crystals, altered to iddingsite in places, fill spaces between feldspar laths and comprise 10 to 15 percent of some thin sections. Up to 20 percent enstatite is present in other sections. Matrix is a cryptocrystalline mixture of magnetite, olivine, and tiny feldspar laths, considerably altered locally to hematite, clay, antigorite, chlorite, and calcite. Veinlets of quartz, chalcedony and opal are secondary, as are the calcite-filled gas cavities seen in some sections.

Quaternary Stratigraphy

Quaternary map units are summarized in table 2. Piedmont-slope deposits underlie broad constructional surfaces flanking the northern and eastern Doña Ana Mountains. In and adjacent to the mountains a relatively thin mantle of fan and terrace alluvium caps erosion surfaces on bedrock or fills inner valleys of arroyos. However, basin-fill thickness may exceed 300 ft north of the Jornada fault (Seager, 1975). Along the western and southern sides of the range in the Mesilla Valley, piedmont and valley-fill deposits are generally less than 100 ft thick, but are locally much thicker. Several generations of piedmont-slope and valley-border deposits are delineated, including fluvial deposits related to the ancestral and present Rio Grande systems. Undifferentiated arroyo alluvium and colluvium were also mapped.

Camp Rice units were first described by Strain (1966) south of El Paso and subsequently recognized in the Las Cruces-Hatch area by Hawley and others (1969) and Seager and others (1971). Camp Rice and younger units were also described by Seager and Hawley (1973) near Rincon, Seager and others (1975) in Sierra Alta quadrangle, and Seager (1975) along Selden Canyon. The Quaternary history of the area has recently been reviewed by Hawley (1975).

TABLE 2—QUATERNARY MAP UNITS, DOÑA ANA MOUNTAINS

Age	Maximum Thickness (ft)	Map Symbol	Map Name		Description
Middle Pleistocene to Holocene	10	Qvs;Qps			Alluvial-eolian complex; sandy deposits
	10 10	Qca Qpa			Colluvium and alluvium of small upland valleys. Undifferentiated piedmont-slope alluvium
	10 50	Qpy Qvy	Younger alluvium		Arroyo channel, terrace and fan deposits; nonindurated bouldery to sandy deposits graded to the Jornada Basin floor (Qpy), or to local base levels close to that of the Rio Grande flood plain (Qvy)
	10	Qpo	Older alluvium	Jornada del Muerto	Fan deposits, fills of shallowly incised drainage ways, and erosion surface veneers; generally very coarse gravel with well-developed soil-carbonate within 2 to 3 ft of the surface
	50	Qvou		Rio Grande valley	Intertonguing river and fan deposits from 10 to 120 ft above modern drainage; mostly gravel and sand with soil-carbonate accumulations
	100	Qvo			Major arroyo terrace and fan deposits and minor veneers on erosion surfaces; 10 to 120 ft above modern drainage; mostly gravel with soil-carbonate accumulations as in Qpo
			UNCONFORMITY		
Early(?) to Middle Pleistocene	10 60	Qcrj Qcrp	Camp Rice Formation (basal Camp Rice probably upper Pliocene)		Piedmont-slope alluvium with paleosols; generally loamy to gravelly, and locally conglomeratic (Qcrp); usually capped by loamy surficial deposits with well-developed soil-carbonate horizons (Qcrj)
	200	Qcrf			Fluvial deposits of the ancestral Rio Grande; generally are well sorted; variably cemented sand containing reddish silt and/or clay lenses that represent flood plain or alluvial flat deposits; rounded clasts of resistant rock types from upstream sources are common in pebbly sands
	200	Qcrc			Carbonate-cemented fanglomerate derived from limestone in the northwestern part of the range and from volcanic rocks in the southern part
			WIDESPREAD UNCONFORMITY		

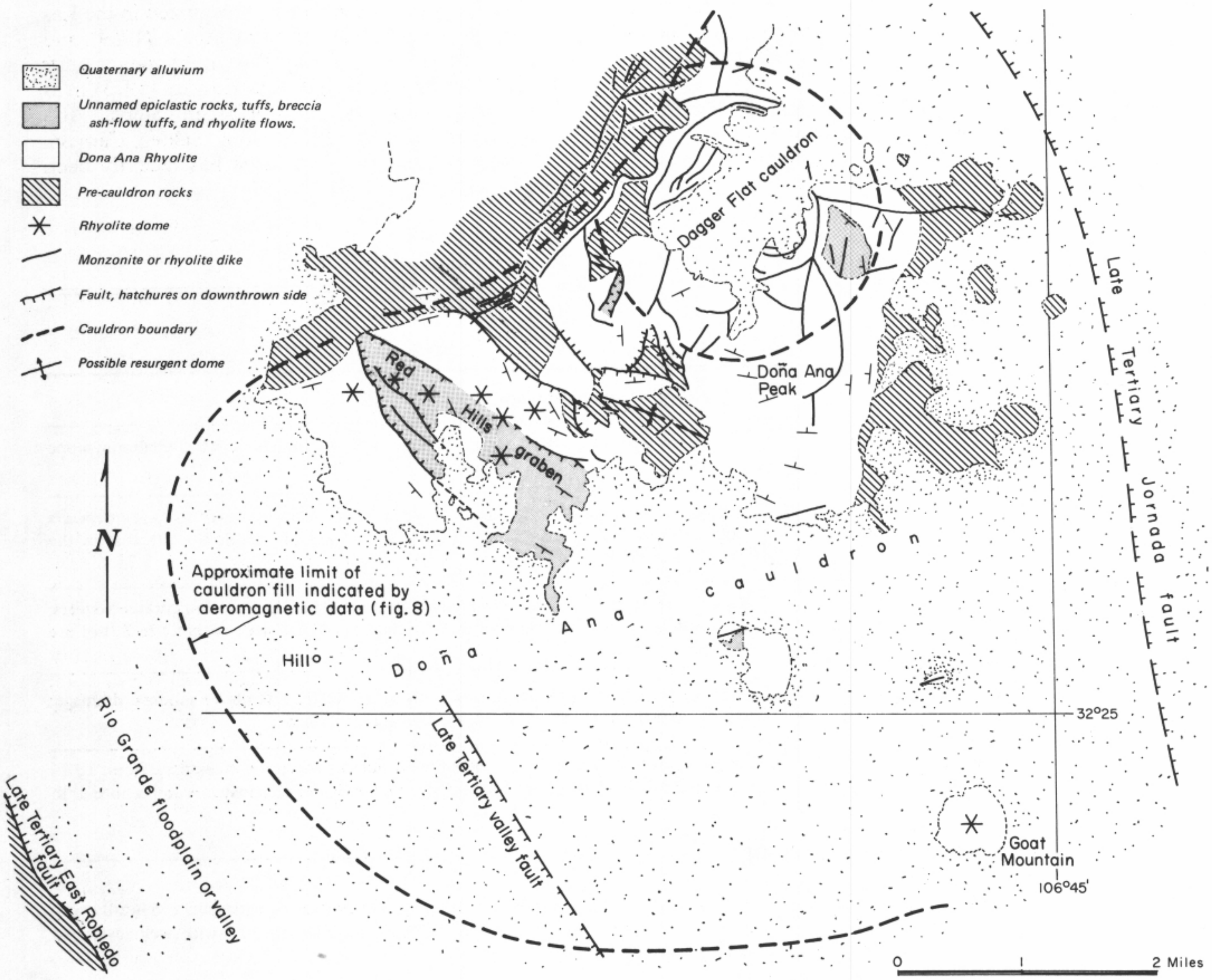


FIGURE 13—TECTONIC MAP OF DOÑA ANA CAULDRON.

Structural Geology

Most of the structural features in the Doña Ana Mountains are of volcano-tectonic origin. Among these, the Doña Ana cauldron and its smaller nested satellite, Dagger Flat cauldron, are the main concern of this section of the report. Related to the cauldrons but described separately is the Summerford Mountain laccolith.

Volcano-tectonic structures associated with the Cleofas Andesite are not as clear. The problem of the intrusive or extrusive nature of the andesite was discussed in the section on stratigraphy. Structural features bearing on the character of the Cleofas Andesite near Wagner Well are considered briefly. These include the Wagner Canyon fault and folds in Hueco Limestone. Although the folds are thought to have formed through emplacement of the Cleofas Andesite, they now comprise the roof of the Summerford Mountain laccolith. A discussion of the Cleofas Andesite pluton follows description of the laccolith.

DOÑA ANA AND DAGGER FLAT CAULDRONS

The Doña Ana cauldron formed contemporaneously with and was consequent on eruption of Doña Ana Rhyolite. Continuing subsidence and volcanic activity is indicated by the great thickness of epiclastic strata, chaotic landslide breccias, flows, and intrusive rocks that overlie or intrude the Doña Ana Rhyolite within the cauldron. These younger rocks are similar to moat deposits and related intrusives reported in other cauldrons (Deal, 1971). In the Doña Ana cauldron, a resurgent dome and subjacent moat is either absent or weakly developed, so that the deposits merely represent fill on the floor of the cauldron or within intracauldron grabens.

Only the northern margin of the cauldron is exposed. Structurally high pre-cauldron Cleofas Andesite outside the cauldron is separated from cauldron rocks by a swarm of monzonite, flow-banded rhyolite, and related dikes (fig. 13; section *A-A′*, *B-B′*). The intrusives trend northeast, but arcuate offshoots near the Dagger Flat cauldron contribute to the semi-concentric dike system marginal to that feature. The rest of the cauldron margin is covered by Pleistocene and younger fan deposits; consequently the dimensions of the cauldron are uncertain. Unpublished aeromagnetic maps prepared by the U.S. Geological Survey in cooperation with the New Mexico Bureau of Mines & Mineral Resources show the distribution of the magnetic Doña Ana Rhyolite beneath bolson and valley fill (fig. 8). This distribution suggests the western and southern boundaries of the cauldron are beneath the Rio Grande flood plain curving eastward to Goat Mountain (figs. 8, 13). The eastern margin of the cauldron probably is transected by the late Tertiary Jornada fault and concealed beneath bolson fill of the Jornada del Muerto. The pre-cauldron floor, formed of Cleofas Andesite, is exposed on the eastern side of the range as a result of late Tertiary uplift by movement along the Jornada fault, westward tilting of the cauldron fill, and subsequent erosion.

The Red Hills graben appears to be a major northwest-trending intracauldron structure (fig. 13; Sheet 1; section *C-C′*, *D-D′*). The graben is filled with epiclastic strata as well as rhyolitic flows and landslide breccias (younger cauldron fill unit) all younger than Doña Ana Rhyolite. Many of the landslide blocks clearly were derived from the walls of the graben, and several flow-banded rhyolite intrusives are located along border faults. This indicates contemporaneous volcanic activity and rather chaotic sedimentation in an active volcano-tectonic graben. The roots of large flow-banded rhyolite domes and dikes also are present within the graben as is chaotic tuffisite and vitrophyre. The assemblage is typical of moat deposits that develop near cauldron margins following major cauldron collapse and resurgence. Yet the Red Hills graben appears to be developed within the cauldron facies of the Doña Ana Rhyolite. Other thick outcrops of the younger cauldron fill also appear to be in downfaulted blocks within the cauldron and seem unrelated to a cauldron margin. The lack of exposures of much of the cauldron margin makes interpretation of these moat-like deposits difficult. Probably the deposits simply indicate continuing subsidence and deposition of epiclastic, landslide, and volcanic rocks on the cauldron floor and in intracauldron grabens, as well as continuing intrusive activity along various fracture systems of subsidence origin.

The smaller Dagger Flat cauldron, only 2 to 3 miles in diameter, is nested within the larger cauldron (fig. 13, section *B-B′*). It is defined primarily by linear to arcuate sets of monzonite and rhyolite dikes that are crudely concentric about the cauldron. The dip of most dikes appears to be nearly vertical but several dip inward toward Dagger Flat. Dips measured from foliation in adjacent outcrops of Doña Ana Rhyolite are roughly centroclinal toward Dagger Flat and range from 10 to 60 degrees. This structural basin probably formed by cauldron subsidence, and the concentric rhyolitic to monzonitic dike system probably occupies tensional fractures formed by subsidence. Similar dikes extend northeast and southwest of the Dagger Flat cauldron and apparently occupy the northwestern margin of the Doña Ana cauldron. Occasional ignimbrite dikes of Doña Ana Rhyolite in both dike systems suggest some of these fractures are old and were used initially to erupt Doña Ana ash flows within the cauldrons.

There is no obvious resurgent dome in the Doña Ana cauldron. Yet some evidence suggests the cauldron floor was arched by magma pressures during later stages of evolution of the cauldron. Doña Ana Rhyolite is generally structurally higher than the younger cauldron fill. This is partly a result of deposition of the younger deposits in graben settings, as well as due to late Tertiary uplift of the east side of the range where Doña Ana Rhyolite is thickest and most extensive. On the other hand, part of the structural relief of the Doña Ana Rhyolite may be accounted for by doming. The unit appears to dip quaquaversally away from an exposure of pre-cauldron rocks in secs. 25 and 26, T. 21 S., R. 1 E. (Sheet 1; sections *C-C′*, *D-D′*). The pre-cauldron rocks are complexly faulted and intruded by various types of flow-banded rhyolite, monzonite, felsite, and basaltic andesite over an area of about 1 square mile. The area may represent the summit of a very deeply eroded resurgent dome.

The deep erosion of the Doña Ana cauldron is significant. Most other known cauldrons in the southwest or Rocky Mountain region are now exposed at significantly higher levels of erosion. Assuming the monzonite dikes, which form the highest peaks in the range, crystallized 1,000 ft below the surface, the present level of erosion is 1,000 to 3,000 ft below the original cauldron surface. At this level, the foundation of the cauldron as well as parts of the cauldron walls are exposed. The dike systems represent crudely developed ring dikes, the roots of feeder vents that may have produced rhyolitic or trachytic ring domes or flows at the surface. The 1,000 ft or more of flows and other rocks that must have covered the Doña Ana Rhyolite above these monzonite peaks is now almost entirely gone. Some of it probably is represented by down-faulted blocks of the younger cauldron fill and some may be represented by landslide blocks of unfamiliar (mostly siliceous) rock types found within the sedimentary and volcanic fill of the Red Hills graben.

SUMMERFORD MOUNTAIN LACCOLITH

The thick dikelike mass of monzonite porphyry north of Dagger Flat appears to be continuous beneath thin alluvium with the Summerford Mountain laccolith. This relation suggests that the source of the laccolith was a shallow magma chamber beneath the Doña Ana cauldron.

Actually, only part of the laccolith is exposed in the northern Doña Ana Mountains. The northern and eastern parts are faulted off by movement on the Jornada fault that separates the Jornada del Muerto graben from the Doña Ana Mountains (fig. 4). Presumably the down-faulted sections of the laccolith are deeply buried beneath gravels in the Jornada del Muerto basin. The exposed southern part of the laccolith comprises a thick south-dipping sheet intruded into Hueco Limestone. Both the floor and roof of the laccolith are exposed (Sheet 1 and section *A-A′*, Sheet 2). The floor is almost entirely concordant and dips 15° to 60° beneath the monzonite. Only about 50 percent of the length of the roof contact with the laccolith is concordant, however, and in several places the upper surface of the laccolith cuts sharply across the limbs and axes of folds in the roof (section *B-B′*).

Clearly folding of the Hueco is related to emplacement of the laccolith and Cleofas Andesite. Fold axes generally are parallel with contacts of both plutons. Fold shapes are a function of proximity to the plutons, being tight, locally isoclinal adjacent to igneous contacts, but changing to broad, open structures, like Grande dome, away from contacts. Determining which folds formed through emplacement of the Cleofas Andesite and which resulted from intrusion of the laccolith was resolved by fold geometries. Folds formed by intrusion of the laccolith are open, symmetrical structures preserved in the floor of the laccolith and along the axis of the laccolith where it plunges southwestward beneath sedimentary rocks (Sheet 1). In both cases folds die out away from the laccolith, and trend parallel to the laccolith contact or to the laccolith axis.

In contrast, folds in the southern flank of the laccolith, which forms the septa between Cleofas Andesite and the laccolith, are tight structures that are locally isoclinal and overturned to the north (section *A-A′ B-B′*, *E-E′*). Amplitudes range from several hundred to a few ft. Longitudinal faults associated with the folds probably are reverse or thrust faults; drag features indicate movement toward the north. Accounting for these folds by intrusion of the laccolith is difficult. The geometry of overturning and thrusting demand horizontal compression directed from south to north. How that compression could be generated in a laccolith roof that was being raised vertically by magma pressure is hard to visualize. On the other hand, emplacement of the Cleofas Andesite pluton could have provided the necessary compression as suggested in the following section on Cleofas Andesite pluton. If the roof folds antedate emplacement of the laccolith, it is not surprising that so much of the roof is discordant, nor unusual that monzonite both intrudes and truncates the limbs and axes of many of the folds. However, these folds probably were modified somewhat in trend by emplacement of the laccolith, especially in the area where the northeast trending axis of the laccolith intersected the east-northeast trending older folds (Sheet 1).

CLEOFAS ANDESITE PLUTON AND WAGNER CANYON FAULT

The asymmetric to overturned folds in the roof of the Summerford Mountain laccolith probably predate intrusion of the laccolith. They were likely formed by the emplacement of Cleofas Andesite as a laterally spreading stock or as a northward intruded sheet. Evidence for a floor beneath the Cleofas is lacking because erosion has not yet progressed to the level of the Permian strata. The possibility of a floor is suggested by the nature of the Wagner Canyon fault which separates folded Hueco strata from Cleofas Andesite near Wagner Canyon.

The Wagner Canyon fault and the Cleofas Andesite pluton may represent a trapdoor structure. In this interpretation the Cleofas would be a floored intrusive, sheetlike or laccolithic in geometry, that dipped south and that was bordered on the north by the Wagner Canyon fault (section *A-A′ B-B′*). Movement on the fault would accommodate the vertical rise of the Cleofas intrusive and consequent arching of the roof. Hueco strata have been removed by erosion from the roof, but their down-faulted, buckled extension north of the Wagner Canyon fault forms the southern flank of the laccolith. The fault dips steeply northward and transects bedding and fold axes in the Hueco; it clearly formed after or during the compression that generated the folds. On the other hand, the fault is intruded by latite porphyry (Tla) that is similar in mineralogy and probably related to the middle Oligocene monzonite porphyry. Thus, the fault probably predates the Summerford

Mountain laccolith and most likely formed during emplacement of the Cleofas Andesite pluton.

Intrusion of the Cleofas Andesite pluton may have progressed in the following way. Initial northward injection of the andesite as a sheet compressed Hueco strata into folds generally overturned to the north but locally to the south. Continuing magma injection resulted in increasing magma pressure that lifted the roof trapdoor style by movement along the Wagner Canyon fault. Folding in the relatively down-dropped block may have continued as magma pressures continued to build against the fault surface. Alternatively, the Wagner Canyon fault may be a simple fault-intrusive boundary between a cylindrical stock of Cleofas Andesite and adjacent country rock. In either case the east-northeast-trending tight folding of Hueco strata as well as the Wagner Canyon fault are a consequence of emplacement of Eocene Cleofas Andesite, rather than due to younger events.

LATE TERTIARY STRUCTURES

The main late Tertiary structures in the Doña Ana Mountains are the range boundary faults, movement on which has elevated the range (fig. 4). Both the Jornada fault and the Valley fault, which bound the range on the northeast and southwest respectively, are inferred from unpublished gravity and magnetic maps. Thus, the range is essentially a horst, although between Hill and Fort Selden it may be a simple west tilted fault block. Westward tilt of the range is indicated by the general 10- to 20-degree dip of various rock units along the western side of the range. The interior of the range is remarkably free of late Tertiary faulting, one notable exception being the west-northwest-trending normal fault east of the Ft. Selden interchange on I-25 (Sheet 1). This fault borders the large block of Abo-Hueco strata and may be viewed as a minor range boundary fault in that area.

A major consequence of late Tertiary uplift is the tilting of the whole Doña Ana Cauldron complex to the west 10 to 20 degrees. This has resulted in deeper levels of erosion along the eastern side of the cauldron complex so that the cauldron foundation as well as monzonitic roots of ring dike systems are exposed. In contrast, erosion along the western side of the cauldron has revealed features formed at somewhat shallower levels, such as flow-banded rhyolite domes, and the upper levels of intracauldron graben fill.

Summary of Middle Tertiary Volcanic-Plutonic-Tectonic Activity

Volcanism in the Doña Ana Mountain area began in late Eocene time. Thick sequences of lahars and interbedded andesite lava flows that are widespread in northern Doña Ana County originated in part from a volcanic center in the Doña Ana Mountains. The Cleofas Andesite, which is similar in mineralogy to many of the nearby flows and to some of the laharic clasts, may represent an unroofed shallow magma chamber, the possible source of some flows and lahar clasts. The Cleofas probably is mostly a stock, but parts of the pluton may be a concordant trapdoor structure, whose roof was raised by normal faulting. Intrusion of the stock and/or trapdoor pluton compressed Hueco Limestone beds into tight, locally faulted folds now exposed in the northern part of the range. Five to eight million years of erosion followed emplacement of the Cleofas Andesite. During this time roof rocks above the pluton were largely removed.

In middle Oligocene time volcanism was renewed. Eruption of the Doña Ana Rhyolite was accompanied by cauldron collapse. Multiple, densely welded flows with a compound cooling history accumulated to at least 2,500 ft thick within the cauldron; no outflow sheets are known but may exist beneath the extensive areas of bolson fill in the region. Continuing subsidence of the cauldron is indicated by at least 1,000 ft of younger epiclastic strata, including local lake beds and chaotic landslide blocks, as well as siliceous to intermediate lavas, ash-flow and air-fall tuffs, and breccias, all deposited on the floor of the cauldron and in intracauldron grabens. Emplacement of silicic intrusives along ring fracture systems and within intracauldron grabens was contemporaneous with and followed deposition of the younger volcanic sequence. From the magma chamber inferred beneath the cauldron, a semiconcordant laccolithic sheet of monzonite porphyry spread northward, intruded Hueco Limestone and produced new folds in the limestone while modifying those that were already there. Resurgence of the cauldron floor is suggested by structurally high, faulted and intruded pre-cauldron rocks near the center(?) of the cauldron. Numerous, but volumetrically minor, andesite plugs and dikes represent the last igneous activity in the cauldron cycle.

Uplift and westward tilting of the cauldron complex in late Tertiary time resulted in deep dissection so that the present level of erosion is probably at least 1,000 to 3,000 ft below the cauldron surface. The intrusive roots of the complex, its foundation and cauldron walls, as well as part of its volcanic fill are exposed at this level. Basaltic dikes of middle to late Miocene age cut the complex but are related to the late Tertiary rifting.

Economic Geology

Only two areas of mineralization were found in the Doña Ana Mountains. Malachite staining in fractured Cleofas Andesite is present in the NW¼NE¼ sec. 20, T. 21 S., R. 2 E., about 2 miles east of Dagger Flat. The mineralization was explored by two shafts, one about 50 ft deep, the other about 25 ft deep, without encountering primary mineralization. Gold and silver were reported by Dunham (1935) from prospects along a rhyolite dike between Wagner and Cleofas wells SE¼SE¼ sec. 15, T. 21 S., R. 1 E. Mineralization is in altered Cleofas Andesite and silicified rhyolite. Considerable massive quartz is associated with the silicified rock. Several prospects and cuts have been made along the dike, and two assayed samples averaged about 13 ounces of gold and 1,675 ounces of silver per ton (Dunham, 1935). Although the 4-ft-wide dike extends for several hundred yards along strike, alteration appears to be limited to about 150 ft along the dike and only a few ft out from it. Opencuts and shafts have explored the altered zone.

References

Bachman, G. O. and Myers, D. A., 1969, Geology of the Bear Peak area, Doña Ana County, New Mexico: U.S. Geol. Survey, Bull., 1271-C, 46 p.

Chapin, C. E., 1971, The Rio Grande rift, part 1: modifications and additions: New Mexico Geol. Soc., Guidebook 22nd field conf., p. 191-201

Clemons, R. E. and Seager, W. R., 1973, Geology of Souse Springs quadrangle: New Mexico Bureau Mines Mineral Resources, Bull. 100, 31 p.

Deal, E. G., 1973, Geology of the northern part of the San Mateo Mountains, Socorro County, New Mexico: A study of a rhyolite ash-flow tuff cauldron and role of laminar flow in ash-flow tuffs: Ph.D. dissert., Univ. New Mexico, Albuquerque, New Mexico, 136 p.

Dunham, K. C., 1935, The geology of the Organ Mountains: New Mexico Bureau Mines Mineral Resources, Bull. 11, 272 p.

Elston, W. E., Damon, P. E., Coney, P. J., Rhodes, R. C., Smith, E. I., and Bikerman, M., 1973, Tertiary volcanic rocks, Mogollon-Datil province, New Mexico, and surrounding region: K-Ar dates, patterns of eruption and periods of mineralization: Geol. Soc. America, Bull., v. 84, p. 2259-2274

Gile, L. H., 1967, Soils of an ancient basin floor near Las Cruces, New Mexico: Soil Science, v. 103, p. 265-276

Gile, L. H., Hawley, J. W., and Grossman, R. B., 1971, The identification, occurrence and genesis of soils in an arid region of southern New Mexico: Soil Survey Inv., Soil Conserv. Service, unpub. training bull., Desert Soil-Geomorphology Project, 117 p.

Hawley, J. W., 1975, Quaternary history of Doña Ana County region, south-central New Mexico: New Mexico Geol. Soc., Guidebook 26th field conf., p. 191-201

Hawley, J. W., Kottlowski, F. E., Strain, W. S., Seager, W. R., King, W. E. and LeMone, D. V., 1969, The Santa Fe Group in the south-central New Mexico Border region, *in* Border Stratigraphy Symposium: New Mexico Bureau Mines Mineral Resources, Circ. 104, p. 52-79

Jordan, C. F., Jr., 1971, Lower Permian stratigraphy of southern New Mexico and west Texas: Ph.D. thesis, Rice Univ., Houston, Texas, 136 p.

Kelley, V. C., 1952, Tectonics of the Rio Grande depression of central New Mexico: New Mexico Geol. Soc., Guidebook 3rd Ann. field conf., p. 93-105

———, 1955, Regional tectonics of south-central New Mexico: New Mexico Geol. Soc., Guidebook 6th field conf., p. 96-104

Kelley, V. C. and Silver, C., 1952, Geology of the Caballo Mountains: Univ. New Mexico, Geol. Ser. No. 4, Univ. New Mexico Press

Kottlowski, F. E., 1953, Road log from Las Cruces to near Caballo: New Mexico Geol. Soc., Guidebook 4th field conf., p. 27-41

———, 1960a, Reconnaissance geologic map of Las Cruces thirty-minute quadrangle: New Mexico Bureau Mines Mineral Resources, Geol. Map 14

———, 1960b, Summary of Pennsylvanian sections in southwestern New Mexico and southeastern Arizona: New Mexico Bureau Mines Mineral Resources, Bull. 66, 187 p.

Kottlowski, F. E., Flower, R. H., Thompson, M. L. and Foster, R. W., 1956, Stratigraphic studies of the San Andres Mountains, New Mexico: New Mexico Bureau Mines Mineral Resources, Mem. 1, 132 p.

Kottlowski, F. E., LeMone, D. V., and Seager, W. R., 1975, Marginal marine and continental facies of the Lower Permian in central New Mexico, *in* Permian exploration, boundaries, and stratigraphy: West Texas Geol. Soc. and Permian Basin Sec. Soc. Econ. Paleontologists and Mineralogists Symposium, p. 119-124

Kottlowski, F. E., Weber, R. H., and Willard, M. E., 1969, Tertiary intrusive-volcanic-mineralization episodes in the New Mexico region (abs.): Geol. Soc. America, Program, 1969 Ann. Mtg., p. 278

LeMone, D. V., Klement, K. W., and King, W. E., 1971, Abo-Hueco facies of the upper Wolfcampian Hueco Formation of the southeastern Robledo Mountains, Doña Ana County, New Mexico: Permian Basin Sec. Soc. Econ. Paleontologists and Mineralogists, Guidebook 1971 field conf., Robledo Mountains, New Mexico, and Franklin Mountains, Texas, p. 137-174

Lloyd, E. R., 1949, Pre-San Andres stratigraphy and oil-producing zones in southeastern New Mexico: New Mexico Bureau Mines Mineral Resources, Bull. 29, 79 p.

Pray, L., 1959, Stratigraphic and structural features of the Sacramento Mountains escarpment, New Mexico: Roswell Geol. Soc. and Permian Basin Sec. Soc. Econ. Paleontologists and Mineralogists, Guidebook, Sacramento Mountains, p. 86-130

Ruhe, R. V., 1962, Age of the Rio Grande valley in southern New Mexico: Jour. Geology, v. 70, p. 151-167

———, 1967, Geomorphic surfaces and surficial deposits in southern New Mexico: New Mexico Bureau Mines Mineral Resources, Mem. 18, 65 p.

Seager, W. R., 1973, Resurgent volcano-tectonic depression of Oligocene age, south-central New Mexico: Geol. Soc. America, Bull., v. 84, p. 3611-3626

———, 1975, Geology of south half San Diego Mountain quadrangle, New Mexico: New Mexico Bureau Mines Mineral Resources, Geol. Map 35

Seager, W. R. and Clemons, R. E., 1975, Geology of the Cedar Hills-Selden Hills area, Doña Ana County, New Mexico: New Mexico Bureau Mines Mineral Resources, Circ. 133

Seager, W. R., Clemons, R. E., and Hawley, J. W., 1975, Geology of Sierra Alta quadrangle, Doña Ana County, New Mexico: New Mexico Bureau Mines Mineral Resources, Bull. 102, 56 p.

Seager, W. R. and Hawley, J. W., 1973, Geology of the Rincon quadrangle, New Mexico: New Mexico Bureau Mines Mineral Resources, Bull. 101, 42 p.

Seager, W. R., Hawley, J. W., and Clemons, R. E., 1971, Geology of the San Diego Mountain area, Doña Ana County, New Mexico: New Mexico Bureau Mines Mineral Resources, Bull. 97, 36 p.

Strain, W. S., 1966, Blancan mammalian fauna and Pleistocene formations, Hudspeth County, Texas: Texas Memorial Museum, Austin, Bull. 10, 55 p.

Thompson, M. L., 1954, American Wolfcampian fusulinids: Kansas Univ., Paleontologists Contr., n. 14, Protozoa, art. 5, 226 p.

Wilpolt, R. H., Macalpin, A. J., Bates, R. L., and Vorbe, G., 1946, Geologic map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro Counties, New Mexico: U.S. Geol. Survey, Oil and Gas Inv. Prelim. Map 1-61

Appendix—Measured Sections

SECTION A—GRANDE DOME—BASIN SECTION

North flank of Grande dome in NE¼NE¼ sec. 17, T. 21 S., R. 1 E. Section begins in canyon bottom and proceeds northward uphill and up section. Measured by W. R. Seager and C. W. O'Brien.

Unit	Lithology	Thickness (ft)
	Algal limestone cliff-forming marker bed (base? of Hueco)	
	Bursum? or *lower Hueco* basin facies (total thickness exposed)	317
39	Porcellanite, light- to medium-gray, weathers buff to rust; siliceous, dense, hard	8
38	Micrite, medium-gray; rust-weathering siliceous laminae in lower 3 ft; 1 ft of siliceous sandstone in upper part	11
37	Micrite, medium-gray, weathers blue gray; minor intraclasts, oolite or pellets about 1 mm in diameter; single bed	2
36	Covered	5
35	Calcarenite, medium-gray, weathers blue gray; well-sorted oolites?, pellets? or micrite grains?; coarse-grained quartz abundant	2
34	Quartz sandstone, tan, coarse-grained	1.5
33	Micrite, medium-gray to light-gray; siliceous, sandy laminae	4
32	Covered	11
31	Like unit 33	8
30	Micrite, medium-gray; medium-bedded	5
29	Micrite, medium- to dark-gray, weathers blue gray, and siliceous sandy, light-tan porcellanite containing siliceous, sandy laminae weathering rust	30
28	Micrite, medium-gray, weathers blue gray; siliceous laminae scattered throughout; scattered fossil fragments and whole fossils	10
27	Porcellanite, siliceous, laminated, light-grayish-green	5
26	Sandstone, tan to rust, siliceous	1
25	Micrite, medium- to dark-gray, siliceous, and laminated porcellanite; 40 percent of unit is siliceous, laminated porcellanite; epidote on joints; thin- to medium-bedded; weathers to ledgy slopes	34
24	Micrite, medium to dark-gray, weathers buff, siliceous?; thin- to medium-bedded	10
23	Covered. Shale?	3
22	Micrite, siliceous, dark-gray, weathers rust	2
21	Covered. Shale?	2
20	Micrite, medium-gray, weathers tan; siliceous; contains micrite intraclasts or burrow fillings 1 to 10 mm long	2
19	Micrite, light-gray to greenish-gray; shaley, laminated; shale interbedded; minor siliceous, laminated micrite at base. Forms slope	14
18	Micrite, gray, weathers light gray; 50 percent of unit is siliceous laminae and thin beds that weather rust; single bed	2.5
17	Micrite, dark-gray, weathers blue gray; laminated in lower half; minor tan siliceous streaks and laminae in upper half	7
16	Micrite, medium- to dark-gray, weathers blue gray; scattered siliceous streaks and laminae; single bed	2
15	Porcellanite, light-gray, weathers rust; siliceous, laminated	7
14	Micrite, medium-gray to tan; siliceous, sandy; porcellanitic and laminated in upper 16 ft, medium-bedded at base; small scale crossbedding in lower half	24
13	Micrite, medium-gray, weathers tan; sandy, siliceous; small scale crossbedding; thin- to medium bedded	5
12	Black shale	1
11	Same as unit 13	10
10	Calcarenite, medium-bluish-gray, weathers tan, sandy; 1 ft of laminated micrite at top	9
9	Algal biomicrite, medium-gray, weathers cream; algal laminations and disrupted algal clasts	3
8	Sparite, medium-gray; tan, sandy laminations; medium-bedded; thin porcellanite and shale interbeds	6
7	Covered	45
	Offset 45 ft up arroyo	
6	Micrite, black- to medium-gray; siliceous blebs that weather to granular texture; porcellanitic zones in unit; single bed	3
5	Micrite, medium-gray; single bed	2
4	Micrite, grayish-green; contains dark-gray limestone nodules or cobbles; thin- to medium-bedded; becomes porcellanitic and laminated toward top; small scale crossbedding; epidote on fractures	8
3	Micrite, medium-gray; sandy laminations at top; single bed	2
2	Porcellanite, light-gray; laminated; minor thin beds of micrite; thin monzonite sill at base	4
1	Micrite, medium-gray to light-gray; minor laminations and chert nodules; beds 6 inches to 3 ft thick	6

SECTION B—GRANDE DOME—SHELF SECTION

West flank of Grande dome, Bursum? or lower Hueco units measured near crest of dome in SW¼NE¼ sec. 17, T. 21 S., R. 1 E. Lower and middle Hueco units measured on SW flank of dome in S½ sec. 17, T. 21 S., R. 1 E. Measured by W. R. Seager and D. V. LeMone.

Unit	Lithology	Thickness (ft)
	Fault contact with black gastropod limestone member of Hueco	
	Middle Hueco (total thickness)	242
38	Micrite, pale-red (5R6/2) pale-brown (5YR5/2), weathers grayish orange pink (5YR7/2); thin-bedded; jointed; partly covered	10
37	Micrite, pale-yellow-brown (10YR6/2), weathers yellow gray (5YR7/2); conspicuous brown-weathering sparry blebs; thin-bedded	7
36	Covered	4
35	Biomicrite, medium-light-gray (N6), weathers grayish orange (10YR7/4); spar streaks and blebs disseminated; thin-bedded to laminated; fossil fragments unidentified	1
34	Allochemical micrite, medium-light-gray (N6), weathers light gray (N7); unidentified sand size allochems; scattered siliceous blebs at top; occasional whole high-spired gastropods; thin-bedded	1
33	Covered	3
32	Allochemical micrite, medium-gray (N5); allochems unidentified, fine sand size; intraclastic zone 2 to 3 inches thick at top; calcite vugs; thin- to medium-bedded	10
31	Ostracod biomicrite, medium-gray (N5), weathers pale orange (10YR8/2); single bed	0.5
30	Covered	4
29	Ostracod biomicrite, pale-yellow-brown (10YR6/2), weathers yellow gray (5Y7/2); foraminifera?; thin-bedded	6
28	Covered	6

Unit	Lithology	Thickness (ft)
27	Pelmicrite or oomicrite, brownish-gray (5YR2/1), weathers moderate yellow brown (10YR5/4); fine sand size allochems; single bed	0.5
26	Covered	2
25	Micrite, pale-brown (5YR5/2), weathers grayish orange (10YR7/4); highly jointed; single bed	1
24	Covered	4
23	Micrite, "birdseye" micrite, and biomicrite from base to top; light-gray (N7) to pale-red (10R6/2), weathering light olive gray (5Y6/1) to pale yellow brown (10YR6/2); calcite blebs; occasional silicified braciopods; thick- to medium-bedded in lower half; laminated at top	10
22	Mostly covered; some micrite, pale-yellow-brown (10YR6/2), pale-red (10R6/2), to light-olive-gray (5Y6/1), weathering grayish orange (10YR7/4), pinkish gray (5YR8/1), to yellowish gray (5Y8/1), is present in slope; few siliceous blebs	20
21	Allochemical micrite, olive-gray (5Y4/1) weathers light olive gray (5Y6/1); unidentified fine allochemical sand; intraclasts near base; ropy brown chert at top; massive, forms ledge	2
20	Biomicrite (fine bioclastic sand), dark-gray (N3), weathers very pale orange (10YR8/2); rust-weathering chert bed 2 inches thick near middle; medium-bedded, laminated in part; poorly preserved brachiopods and ostracods	7
19	Biomicrite (very fine skeletal sand), medium-dark-gray (N4), weathers moderate orange pink (5YR8/4); nodular, ropy chert and blebs; upper half, single massive beds; some bioturbation	2
18	Covered, except for 1 ft of bioturbated biosparite at middle, medium-dark-gray (N4), weathering pale yellow orange (10YR8/2)	6
17	Micrite, pale-brown (5YR5/2) to medium-gray (N5), weathering medium gray (N5) to dark yellow orange (10YR7/4); silty laminae; 1 inch siliceous rusty limestone at top; single bed; distinctive marker bed	1
16	Covered	11
15	Biomicrite, dark-gray (N3), weathers light olive gray (5Y6/1); bioturbated; medium-bedded; silty?, partly covered	3
14	Covered	10
13	Biomicrite, dark-gray (N3), weathers olive gray (5Y4/1), bioturbated; massive, ledge former	2
12	Banded allochemical micrite, and micrite, light-brownish-gray (5YR6/1), weathers light olive gray (5Y6/1); limestone intraclasts and pellets?, and fossil hash; medium-bedded, forms ledge	8
11	Covered	23
10	Biomicrite, dark-gray (N3), weathers light gray (N7), and micrite, grayish-orange (10YR7/4); thin- to medium-bedded, poor exposures	8
9	Micrite, very pale orange (10YR8/2), weathers grayish orange (10YR7/4); abundant spar blebs and streaks gives "birdseye" effect; thin- to medium-bedded, forms ledge	3
8	Shale, dark-gray to tan, fissile, calcareous; 6-inch bed of light-brown micrite 5 ft below top	15
7	Covered	3
6	Micrite, medium-gray (N5), weathers medium light gray (N6); some very fine allochems-oolites?, minor gastropod and crinoid fragments; mottled appearance probably due to bioturbation; medium-bedded	8
5	Micrite, yellow-gray (5Y7/2), weathers yellow gray (5Y7/2), in lower half, light-brown (5YR6/4), weathering grayish orange (10YR7/4) in upper half; small chert nodules and blebs ¼ inch to ½ inch long; thin-bedded	2
4	Covered	6
3	Biomicrite, olive-gray (5Y4/1), weathers yellow brown (10YR6/2-10YR4/2); unidentified skeletal sand in crude laminae; rust-weathering chert nodules and beds 1 to 2 inches thick; stylolitic; thin- to medium-bedded; marker bed in Robledos	3
2	Mostly covered; minor siliceous light-gray to yellow-gray micrite with rust-staining outcrops in slope	15
1	Mostly covered; 25 percent of unit is light-gray (N7) micrite weathering yellow gray (5Y7/2), with occasional siliceous vugs and rust stains; thin- to medium-bedded	14

	Lower Hueco (total thickness)	422
47	Micrite, medium-gray, weathers rusty orange; sandy, siliceous; marker bed, forms ledge	4
46	Micrite gray, sandy, weathers rust; and interbedded blue-gray, thin-bedded micrite; soft medium-gray micrite weathering yellow to buff; yellow and light-bluish-gray mottled micrite; and shale; irregular rusty siliceous blebs and streaks are common; thin- to medium-bedded	24
45	Covered	3
44	Micrite, greenish-gray, weathering mottled buff to bluish gray; siliceous streaks weathering rust are common	4
43	Algal biomicrite dark-gray, weathering medium gray; medium-bedded	3
42	Covered	3
41	Micrite, dark-gray, weathers medium to blue gray; siliceous streaks, single bed	4
40	Micrite, brownish-gray, weathers cream	5
39	Micrite, medium- to dark-gray, weathering buff to light gray; siliceous streaks and laminae in some beds; top bed contains fine sand; beds are 6 to 17 inches thick separated by shale? or marly limestone	12
38	Mostly covered; nodular white quartz, and medium-gray micrite float	4
37	Micrite, medium-gray, weathers light gray, single bed	3
36	Micrite, medium- to brownish-gray, weathering buff to pale orange; 3 beds 6 inches to 1 ft thick separated by shale? or marly limestone?	15
35	Micrite, brownish-gray to tan, weathers buff to brown to light orange; siliceous laminae and streaks; medium-bedded	5
34	Biointramicrudite, dark-gray, weathers medium gray; thin, nodular beds interbedded with soft marly limestone; some intraclastic zones; algae, gastropods, brachiopods, bryozoans; thick- to medium-bedded	25
33	Micrite, tan, weathers buff; medium-bedded	11
32	Covered; soft, cream-colored micrite as float	7
31	Micrite, light-gray, weathers buff to rust or orange; discontinuous siliceous layers to 1 ft thick, weather dark brown	6
30	Covered	4
29	Biopelmicrite, dark-gray, weathers medium gray; siliceous streaks, scattered quartz grains; nodular, thin beds	2
28	Mostly covered, nodular, soft argillaceous biomicrite inferred from float	12
27	Micrite, moderate-red, weathering orange and buff	1
26	Micrite, tan, weathers light gray; nodular, soft, siliceous streaks and blebs	5
25	Micrite, moderate-red, weathers orange, single bed	1
24	Covered	4
23	Intramicrudite, olive-gray, weathering mottled buff and gray	1
22	Micrite, tan, weathers buff, siliceous streaks, eyes, irregular blebs; thin-bedded	3
21	Covered. Shale or marly, nodular limestone inferred from float	5
20	Biopelmicrite and biopelmicrudite, light- to medium-gray, weathers light gray to blue gray; some intraclastic zones; beds are 6 inches to 1 ft thick, separated by soft nodular limestone and/or shale	11
19	Covered	20
18	Sparite, light- to medium-gray, weathers light gray; scattered fossil fragments, siliceous streaks and grains; medium-bedded; interbedded with soft, poorly exposed limestone	10
17	Algal biomicrudite, medium-gray, weathers light gray;	

Unit	Lithology	Thickness (ft)
	fetid, scattered chert; local zones of fossils (corals, bryozoans, echinoids, brachiopods, crinoids, fusulinids. *Schwagerina andresensis, Pseudoschwagerina*) form crest of hogback and dip slope	51
16	Micrite and intraclastic biomicrite, medium-gray, weathers light gray; 2 ft of algal biomicrudite at top; thin-bedded, soft, nodular bedding in part; unit only 50 percent exposed; marly limestone? or shale? forms unexposed part; forms saddle	22
15	Algal biomicrite, medium-gray, weathers light gray; pelsparite? or biosparite? in upper 8 ft; medium-bedded	28
14	Covered. Shale? or soft, marly limestone?	8
13	Algal biomicrudite, medium-gray, weathers light gray; cherty and sandy zones weather buff to rust; thin-bedded; 50 percent covered	4
12	Covered. Shale?	4
11	Algal biomicrudite, medium-gray, weathers mottled light to medium gray; medium- to thin-bedded	11
10	Covered	4
9	Algal biomicrudite, medium-gray, single bed	3
8	Covered, shale?	3
7	Intrasparite, chert pebble conglomerate, medium- to dark-gray; occasional chert granules or pebbles scattered throughout, and chert pebble conglomerate in lens form; locally fetid; some sandy layers; medium- to thick-bedded	14
6	Covered	3
5	Micrite and allochemical sparite, medium- to dark-gray, weathers dark gray to blue gray; calcarenite (bio-intrapelsparite?) constitutes 50 percent of section; scattered chert nodules; thick- to medium-bedded	16
4	Covered	3
3	Micrite, medium- to dark-gray, weathers light gray to tan; sandy; conspicuous chert or siliceous beds 4 to 5 inches thick (chert is best developed on north flank of Grande Dome), beds 6 inches to 1 ft thick; forms slope or saddle; marker bed	13
2	Biomicrudite; medium-gray, weathers light brownish gray; echinoids, crinoids, gastropods; 50 percent covered	10
1	Algal biomicrudite, mottled light- to medium-gray, scattered chert nodules; single massive bed (algal bank?), thickens and thins along strike, forms cliff; marker bed	8

Unit	Lithology	Thickness (ft)
	Lower part of *lower Hueco* or *Bursum?* (total thickness)	205.5
42	Mostly covered. Few inches of medium-gray micrite exposed 1 ft above base	15
41	Micrite, medium-dark-gray (N4), weathers medium light gray (N6), laminated, silty	1
40	Mostly covered. Very fine grained calcarenite, medium-dark-gray (N4), weathering light olive gray (5Y6/1) at base; allochems unidentified	7
39	Micrite, medium-dark-gray, weathering light gray (N7); siliceous streaks and fretwork (penecontemporaneous solution?); chert (black) nodules and lenses	1.5
38	Interbedded sandy oosparite, phylloidal algal biomicrite, calcarenite-limestone pebble conglomerate, allochemical micrite, and marly limestone and shale, olive-gray (5Y4/1-5Y4/2) and medium-gray (N5), weathers to medium light gray (N6), yellow gray (5Y7/2), to light gray (N7); limestone beds are massive, medium-bedded alternating with soft slope-forming units	14
37	Covered. Occasional soft green marl beds exposed	5
36	Limestone, medium-gray (N6-N5), weathers grayish orange (10YR7/4) to medium gray (N5); very sandy; fine quartz sand at base, very fine sand at top; sand is frosted, subrounded; medium-bedded, small scale crossbedding	2.5
35	Covered	7
34	Micrite, brownish-gray (5YR4/1), weathers pinkish gray (5YR8/1) to medium light gray (N6); few gastropods, algae?; single bed, forms ledge	1
33	Covered	4
32	Sparite, mottled olive-gray (5Y4/1) to dark-yellow-orange (10YR6/6), weathers light gray (N7); scattered siliceous flakes and nodules; ghost digitate algae?; cut and fill, minor load structures, small scale crossbedding; massive bed, forms cliff	7.5
31	Covered	8
30	Interbedded fissile gray to black shale, with thin micrite layers, and medium-gray faintly laminated, medium-bedded micrite	10
29	Micrite, medium-gray (N5), weathers yellow gray (5Y8/4); faint laminae, medium-bedded, forms ledge	2
28	Shale, medium-dark-gray (N4), fissile, nodular, calcareous; few ½-inch thick micrite beds	3
27	Micrite, dark-gray, weathers yellow gray (5Y8/1) to light gray (N7); thin-bedded	.5
26	Shale, like unit 28	2.5
25	Algal biomicrite, and intraclastic laminated micrite, medium-dark-gray (N4) to medium-yellow-brown (10YR5/4), weathering yellow gray (5Y7/2) to pale orange (10YR8/2); 2 cycles of laminated micrite at base grading up to phylloidal algae or thin-bedded micrite at top	4
24	Mostly covered; brown sandy calcarenite (quartz and unidentified limestone sand); very thin bedded	4
23	Micrite, medium-gray (N4-N6), weathers olive gray (5Y4/1) to yellow gray (5Y8/1); sandy streaks and laminae with load structures; sandy limestone pebble conglomerate lenses; some algae?; unit thin-bedded, partly covered; forms slope with thin ledges	11
22	Micrite and biomicrite, medium-dark-gray (N4), weathers light gray (N7); rugose corals, crinoids, gastropods in lower few ft; few thin intraclastic zones with scattered very fine pellets and oolites; thin- to medium-bedded, forms ledge	7
21	Covered	3
20	Algal? biolithite, dark-gray (N3-N4), weathers pale yellow brown (10YR4/2-10YR6/2); laminated, single bed, forms ledge	1
19	Covered. Some light-olive-gray laminated micrite at base	4
18	Laminated micrite at base grading upward through medium-bedded micrite to intrasparite and oosparite at top, medium-dark-gray (N4) to yellow-gray (5Y7/2) to brownish-gray (5YR4/1)	3
17	Mostly covered. Some laminated micrite, medium-gray (N5), weathering medium light gray (N6) at base; yellow-gray (5Y8/1) thin-bedded micrite outcrop near middle; forms slope	10
16	Oosparite and intramicrudite in lower half, medium-light-gray (N6), weathers light gray, sandy; laminated algal biomicrite in upper half	1
15	Mostly covered. Few inches of laminated medium-gray (N5) micrite weathering olive gray (5Y4/1); forms slope	4
14	Oosparite, medium-gray (N5), weathering olive gray (5Y4/1); some quartz sand; current deformed oolite laminae; algal micrite in top 6 inches, with occasional laminated micrite intraclasts; forms ledge	1.5
13	Covered	2
12	Algal? biolithite, dark-gray (N3) to medium-light-gray (N6), weathers light medium gray (N7-N5); possible soft sediment deformation of laminae or of possible algal origin; some siliceous laminae; weathers to concentric, circular forms; marker bed	.5
11	Covered	4
10	Micrite, mottled light- and dark-gray (N7-N4), sandy	1
9	Covered. Thin-bedded light-gray micrite as float; silicified wood	10
8	Micrite, medium-dark-gray (N4), weathers medium gray (N5), laminated; some laminae show soft sediment deformation; sandy; few siliceous streaks and flakes in upper 6 inches; prominent ledge	1.5

Unit	Lithology	Thickness (ft)
7	Covered	7
6	Micrite, medium-gray (N5), weathers medium light gray; laminated to thin-bedded; very fine silt laminae	1
5	Mostly covered. Six inches of light-brown (5YR6/4), silty, calcareous shale near middle	4
4	Micrite, medium-dark-gray (N4), weathers light gray (N7); silt laminae; 1- to 2-inch thick beds	1
3	Covered	23
2	Micrite, medium-gray (N5), weathers mottled light olive gray (5Y6/1) and pale yellow orange (10YR8/6); mottled and burrowed; silt or fine allochemical laminae; fetid	2.5
1	Micrite, dark-gray (N4), weathers light gray (N7); hackly fractures; thin to medium bedded; interbedded black calcareous shale	3

SECTION C—NORTH RIDGE

About 1 mile north of north flank of Grande dome, along ridges produced by west dipping Hueco and Abo strata. Section begins in upper (?) beds of lower Hueco and continues westward without structural break into middle (?) Abo strata. SE¼ sec. 8, SW¼ sec. 9, T. 21 S., R. 1 E. Measured by W. R. Seager and D. V. LeMone.

Unit	Lithology	Thickness (ft)
	Top of exposed *Abo* Tongue	
	Abo Tongue (total thickness of partial section)	267
39	Ostracod biosparite and/or biomicrite, medium-dark-gray (N4), weathers greenish gray (5GY6/1); highly bioturbated; small gastropods; forms stripped surface at top of mesa	1
38	Covered; probably silty shale and/or siltstone at base; rusty-brown siltstone 3 ft below top	12
37	Sandstone, pale-red (10R6/2); crossbedded, ripple laminated in ½-inch sets; 2 beds	2
36	Ostracod-bearing micrite, light-gray (N7), weathers light olive gray (5Y6/1); very fine silt; single bed	2
35	Like unit 37	2
34	Covered	9
33	Biomicrite, medium-gray (N5), weathers moderate yellow brown (10YR5/4); bioturbated, abundant skeletal sand; occasional whole gastropods; silty; single bed; massive	1
32	Covered	10
31	Dolomite?, grayish-orange (10YR7/4); very fine grained; fine-grained unidentified allochems; thin, wavy, crinkly beds	5.5
30	Mostly covered. Greenish-gray-shale exposed about 2 to 3 ft from top; thin-bedded, cream-colored micrite exposed near middle	8
29	Micrite, very pale orange (10YR8/2); soft, nodular, vuggy, thin-bedded; appears like caliche; ostracods; poorly exposed	2
28	Ostracod biomicrite, gray (N3 to N6), weathers pale yellow brown (10YR6/2) to yellow gray (5Y8/1); bioturbated; beds 6 inches to 1 ft thick; fetid; forms ledge	4
27	Covered. Green fissile shale exposed near top	23
26	Ostracod? biomicrite, medium-light-gray (N6) to dark-yellow-orange (10YR6/6), weathers grayish orange (10YR7/4) to pale-yellow orange (10YR8/6); grades up to coarsely crystalline, vuggy limestone; beds 6 inches thick; forms ledges	1.5
25	Mostly covered; calcareous siltstone grading up to red sandstone at middle of unit; crossbedding, lamination present in sandstone; typical Abo lithologies	15
24	Biomicrudite, with minor biosparite, medium-dark-gray (N4), weathers light olive gray (5Y6/1); gastropods, bryozoans, echinoids, skeletal sand; beds 1 ft thick separated by 2 to 3 ft thick shale breaks	16
23	Micrite, medium-gray (N5), weathers light olive gray (5Y6/1), occasional fine skeletal sand and burrows; intraclastic at top; light-gray marker bed on hillside; single bed, forms ledge	2.5
22	Covered; yellow soft marl exposed 3 ft below top; probably silty shale at base	14
21	Sandstone, pale-yellow-brown (10YR6/2), weathers moderate yellow brown (10YR5/4); fine- to medium-grained, small scale trough crossbedding; laminated; prominent red ledge	1
20	Covered	2
19	Biomicrite and biomicrudite in lower 4 ft and upper 1 ft, medium-gray (N5-N4), weathers medium light gray (N6) to light olive gray (5Y6/1); silty; current transported skeletal sand, locally burrowed; whole echinoid spines, ostracods, gastropods; beds 1 to 2 ft thick; forms ledges; black shale in middle of unit	8
18	Covered; black calcareous shale exposed in upper 6 ft	9
17	Like unit 21	3
16	Siltstone and silty shale, medium-gray (N5-N6), weathers yellow gray (5Y8/1) to pale yellow brown (10YR6/2); very calcareous; small scale ripple crossbedding; thin-bedded; unit grades up to unit 17	14
15	Biomicrite, medium-gray (N5), weathers light olive gray (5Y6/1); current-transported skeletal sand; burrowed; silty; ostracods, algae?; single bed	1
14	Micrite, grayish-yellow (5Y8/4), weathers same; thin-bedded, nodular; poorly exposed	7
13	Biosparite and biomicrudite, medium-dark-gray (N4-N5), weathers grayish orange (10YR7/4); fetid, burrowed, silty?; whole ostracods, sponges, gastropods, fossil hash; forms ledge	7
12	Covered	2
11	Sandstone, light-brownish-gray (5YR6/1), weathers grayish orange (10YR7/4); very fine grained, calcareous; small scale crossbedding; plant remains	0.5
10	Covered	6
9	Biomicrite and biomicrudite, medium-dark-gray (N4), weathers medium light gray (N6); large gastropods, scaphopods, sponges, ostracods, echinoids, fine skeletal sand transported and burrowed; double bed	1.5
8	Covered	6
7	Quartzite, very light gray (N8), weathers medium light gray (N6); fine-grained, calcareous, load structures, crossbedding; single bed	0.5
6	Covered; soft yellow-brown, poorly cemented calcareous siltstone	10
5	Sandstone, very pale orange (10YR8/2) to light-gray (N7), weathers pale yellow brown (10YR6/2); fine-grained, micaceous calcareous, ripple crosslaminations	5
4	Covered; probably silty shale	4
3	Sandstone, light-gray (N7-N8) to yellow-gray (5Y8/1-5Y6/1), weathers pale yellow brown (10YR6/2-10YR7/4) to moderate yellow brown (10YR5/4); coarse at base to finer-grained quartz sand toward top; calcareous; low angle crossbeds in sets 1 inch to 3 ft thick; fossiliferous at base (gastropods) rill marks and ripple marks, plant remains; channel form	40
2	Siltstone and fine-grained sandstone, pale-red (5R6/2), weathers grayish red (10R4/2); laminated to ripple cross-laminated	4
1	Covered	5

Unit	Lithology	Thickness (ft)
	Base of Abo Tongue	
	Dark-gray *gastropod limestone member* (total thickness)	405
34	Biomicrudite, dark-gray (N3), weathers dark yellow orange (10YR6/6); silty; crinoids, large gastropods, echinoids, brachiopods, single bed	1
33	Covered; probably brown silty shale and siltstone; forms prominent saddle	5

Unit	Lithology	Thickness (ft)
32	Biomicrite, medium-dark-gray (N4-N5), weathers medium dark gray (N4) to light olive gray (5Y6/1); largely skeletal sand but occasional whole gastropod, echinoid, brachiopod lenses; interbedded shale forms saddles within sequence; scattered chert nodules; beds 1 to 2 ft thick	35
31	Mostly covered; about 1 ft of dark-gray biomicrite containing gastropods, scaphopods, intraclastic debris near middle, and silty fissile shale at top	9
30	Biomicrite, medium-dark-gray (N4), weathers light olive gray (5Y6/1); intraclastic at top; brachiopods, gastropods, scaphopods; single bed	2
29	Covered; probably shale	5
28	Biomicrite, medium-dark-gray (N4), weathers gray orange (10YR7/4); silty; skeletal sand mostly, burrowed; some large brachiopods	3
27	Poorly exposed silty shale and siltstone, calcareous	13
26	Algal biolithite, medium-dark-gray (N4-N5), weathers grayish orange (10YR7/4) to medium dark gray (N4); marker bed	2
25	Partly covered; thin-bedded medium-gray (N5), biomicrite at base containing gastropods, brachiopods, echinoids	10
24	Gastropod biomicrudite, and biomicrite, medium-gray (N4-N5), weathers light gray (N7), light olive gray (5Y6/1) to light gray (N7-N6); minor biosparite; fetid, bioturbated; occasional echinoid, crinoid, bryozoan, scaphopods, algae, sponges; beds 1 to 2 ft thick, forms ledgy dip slope	65
23	Siltstone (Abo), light-olive-gray (5Y6/1), weathers moderate brown (5YR4/4); siliceous, laminated, ripple crosslaminated	8
22	Covered; shale?	5
21	Gastropod biomicrite, medium-gray (N4-N5), weathers moderate brown (5YR4/4) to medium gray (N5); slightly silty; abundant skeletal sand; brachiopods, scaphopods?, maclurid gastropods, echinoids	2
20	Covered, probably shale	11
19	Biosparite and biomicrite, medium-dark-gray (N4), weathers light olive gray (5Y6/1) to medium dark gray (N4); skeletal sand except for occasional lenses of unbroken gastropods and echinoid spines; beds 1 to 2 ft thick	20
18	Covered; probably shale	5
17	Echinoid biosparrudite and biosparite, medium-dark-gray (N4), weathers olive gray (5Y4/1), grayish orange (10YR7/4-10YR6/2) to medium gray (N5); coarsely crystalline, fetid; fossils as skeletal sand and whole (echinoids and gastropods); scattered chert, some burrows; beds 1 to 2 ft thick, forms ledges	5
16	Shale	3
15	Like 17; 2 ft of Abo siltstone 20 ft above base	63
14	Covered; shale?	4
13	Siltstone, pale-yellow-brown (10YR6/2); siliceous, ripple crosslaminations; grades to channel locally; typical Abo lithology	2
12	Covered; silty shale?	20
11	Like unit 13	7
10	Mostly covered; porcellanitic shale?	22
9	Biosparite, medium-gray, weathers light olive gray (5Y6/1); fine-grained, laminated, locally bioturbated; single bed	1.5
8	Mostly covered; mostly shale? Very fine grained allochemical limestone near middle	21
7	Micrite, allochemical micrite and near top, biosparite and micrite in graded beds, medium-gray (N4-N5), weathers light olive gray (5Y6/1) to light brown (5YR6/4); whole brachiopods, crinoids, gastropods sorted into layers; beds 1 to 3 ft thick separated by shale units 1 to 4 ft thick; silty at top; forms ledgy slopes	16
6	Covered, shale?	4
5	Ostracod biomicrite, medium-light-gray (N6), weathers light gray (N7); unbroken fossils including gastropods, single bed, forms ledge	3.5
4	Shale, greenish-gray, fissile	4
3	Micrite, medium-gray (N5) to light-green-gray (5G8/1), weathers gray orange (10YR7/4) to light brown (5YR5/6); silty; grades up to 5 ft of calcareous Abo siltstone at top that contains small scale ripple crosslaminations	11
2	Gastropod biomicrudite, medium-light-gray (N6), weathers light gray (N7); silty laminae locally; brown chert; gastropods and unidentified fossil fragments; medium-bedded	12
1	Gastropod biomicrudite, medium-light-gray, weathers light gray (N7); recrystallized in part; fossils whole (gastropods, echinoids, crinoids); scattered siliceous streaks; beds 1 to 3 ft thick	5

Base of dark-gray gastropod limestone member

	Undifferentiated *middle* and *lower Hueco* basin facies (total thickness of partial section)	447
42	Mostly covered; light-gray (N7) Abo siltstone, weathering pale yellow brown (10YR6/2), gradational to porcellanite crops out in middle third of unit; upper third is black shale	15
41	Biomicrudite, medium-gray (N5), weathers moderate orange pink (5YR8/4) to light gray (N7); rusty, siliceous streaks; unbroken planispiral gastropods, echinoids, crinoid fragments	2
40	Porcellanite	2
39	Biosparite?, medium-gray (N5), weathers light gray (N7); skeletal sand, single bed	5
38	Porcellanite, silty, grading to siliceous Abo siltstone; moderate-red-orange (10R6/6) to greenish-gray (5GY6/1); some 1 to 2 ft thick Abo siltstone interbeds	10
37	Siltstone, light-gray (N7), weathers moderate brown (5YR4/4); Abo type lithology, siliceous, laminated, crosslaminations; grades up to porcellanite of unit 38	3
36	Porcellanite, yellow-gray (5Y8/1) to gray-yellow-green (5GY7/2), weathers light gray (N7) to pale yellow brown (10YR6/2); 5 ft of gray shale at top	20
35	Biomicrite, medium-dark-gray (N4), weathers gray orange (10YR7/2); skeletal sand; single bed	1
34	Micrite, dark-gray with rusty sand/silt layers and laminae; very sandy; lower 6 ft covered	8
33	Allochemical micrite, medium-gray (N4-N5); allochems unidentified; recrystallized?; single bed	1
32	Porcellanite grading to siltstone; medium-gray (N5), gray-orange (10YR7/4), light-gray (N7), grayish-green (10GY5/2), weathers yellow orange (10YR6/6), yellow gray (5Y8/1), gray orange pink (5YR7/2); occasional thin beds of silty micrite; thin-bedded, forms slope	23
31	Biomicrite, medium-gray (N5), weathers light gray (N7); siliceous layer ½ inch thick at top; single bed, forms ledge	1.5
30	Upper 25 ft is black shale with thin medium-gray micrite beds and porcellanite; 1 ft of buff micrite near middle; lower 20 ft is Abo siltstone like unit 25; basal Abo is channel form and grades laterally into porcellanitic shale	46
29	Biomicrudite, medium-dark-gray (N4), weathers medium light gray (N6); unbroken gastropods; recrystallized; single bed	0.5
28	Porcellanitic siltstone and shale, gray-yellow-green (5GY7/2), moderate-orange-pink (5YR8/4), medium-gray (N5), weathers light brown (5YR6/4), to medium light gray (N6); thin rust-colored Abo siltstone tongues interbedded as well as 3- to 4-inch thick silty, laminated biomicrite beds with algae?, conodonts?; epidote on joints	20
27	Siltstone and fine sandstone, yellow-gray (5Y8/1), weathers grayish orange pink (5YR7/2); horizontal laminations and ripple crosslaminations; typical Abo; grades upward to unit 28	5

Unit	Lithology	Thickness (ft)
26	Black shale	4
25	Siltstone, gray-yellow-green (5GY7/2), weathers light brown (5YR6/4); calcareous; ripple crosslaminations (Abo?, lowest Abo-like bed)	1
24	Black shale, with porcellanitic shale	20
23	Micrite and biomicrite, medium- to light-gray (N5-N7), weathers pale orange (10YR8/2-10YR8/6), yellow gray (5Y8/1), medium light gray (N6); vertical worm burrows filled with skeletal sand at base with laminated biomicrite above showing soft sediment deformation; massive micrite at top	3
22	Black shale, partly covered	23
21	Recrystallized limestone, pale-yellow-brown (10YR6/2) to yellow-orange (10YR8/6), weathers same; vuggy, quartz in vugs; siliceous streaks and blebs	1
20	Interbedded black fissile shale and procellanitic shale; shale units 5 to 10 ft thick, porcellanite ½ to 1 ft thick	61
19	Biomicrite, medium-dark-gray (N4), weathers medium gray (N5) to moderate brown (5YR4/4); recrystallized, algae? silty, siliceous laminae at top; single bed	3
18	Siliceous shale grading up to porcellanite, light-olive-gray (5Y6/1) to medium-light-gray (N6), weathers yellow gray (5Y8/1) to gray orange (5YR7/2); laminated, hard, fissile	12
17	Black shale	8
16	Marble, pale-yellow-brown (10YR6/2)	1
15	Partly covered; probably black shale; few thin-bedded, recrystallized micrite and biomicrite at base	8
14	Limestone, medium-gray (N5) to olive-gray (5Y4/1), weathers medium dark gray (N4) to olive gray (5Y6/1); recrystallized; medium-bedded	3
13	Shale, greenish-gray to black; fissile, fractured	8
12	Interbedded micrite and biomicrite, medium-gray (N5) to medium-yellow-brown (10YR5/4), weathers medium gray (N5-N6) to gray orange (10YR7/2); silty laminae; shale partings; ostracods and/or foraminifera, gastropods, algal? fragments; thin- to medium-bedded	10
11	Micrite, yellow-gray (5Y7/2), weathers yellow orange (10YR8/6); rust-weathering siliceous streaks; single bed; may be top of lower Hueco	1
10	Covered	20
9	Micrite, medium-gray, weathers very light gray (N8) to pale yellow brown (10YR6/2); rusty siliceous laminae; stylolites; single bed	1
8	Marly soft limestone and recrystallized micrite, light-gray, weathers pale yellow orange (10YR8/6); poorly exposed; minor pyrite	18
7	Like unit 8	10
6	Shale, gray, calcareous	2.5
5	Micrite, medium- to light-gray (N4-N7), weathers yellow gray (5Y8/1), pale yellow orange (10YR8/6), medium light gray (N6), light brown (5YR5/6); much recrystallized?, some marbleized zones; few thin beds of recrystallized biomicrite (gastropods, echinoids, brachiopods); stylolite; N. 20-30° E. trending lineation on upper bedding planes of some beds; minor chert and siliceous streaks; beds 1 to 2 ft thick, forms ledges	47
4	Covered	8
3	Micrite or very fine grained recrystallized limestone, medium-gray (N5), weathers pale yellow brown (10YR6/2); single bed	0.5
2	Covered	8
1	Recrystallized limestone, medium-gray (N5), weathers pale blue (5PB7/2); possible fossil fragments; disseminated pyrite; massive; incomplete exposure	2

SECTION D—HUECO BASIN FACIES

Measured northward across north-dipping hogbacks about 1 mile east of the center of Grande dome in NE¼ sec. 16, and SE¼ sec. 9, T. 21 S., R. 1 E. Measured by W. R. Seager and D. V. LeMone

Unit	Lithology	Thickness (ft)
	Axis of syncline	
	Hueco basin facies (total thickness of partial section)	1,476
124	Porcellanite, light-greenish-gray (5GY8/1), weathers pale yellow brown (10YR6/2); thin- to medium-bedded, internal laminations; hard, dense	18
123	Mostly covered; few outcrops of grayish-orange weathering marble (10YR7/4)	6
122	Marble, light-gray (N7), weathers grayish orange (10YR7/4); single prominent bed near synclinal axis	2
121	Micrite, medium-gray (N5), weathers medium light gray (N6); recrystallized, sandy; possible recrystallized skeletal debris scattered through unit; occasional siliceous layers and laminae; beds 1 to 3 ft thick	12
120	Marble, light-gray (N7-N8); weathers very light gray (N8) with tan cast due to sand and chert nodules; single bed	2
119	Porcellanite, like unit 124	10
118	Micrite, recrystallized, like unit 121	18
117	Porcellanite, like unit 124	3
116	Micrite, recrystallized, like unit 121	20
115	Porcellanite, like unit 124	5
114	Mostly covered; thin-bedded limestone?	10
113	Micrite and marble, medium-dark-gray (N4-N5) with reddish cast (10R6/2), weathers light gray (N7-N8); sandy, silty; some siliceous laminae, scattered small chert nodules; beds 1 to 3 ft thick, forms ledgy dip slope; unit 70 percent exposed	20
112	Sandstone and porcellanite, light-greenish-gray (5GY8/1) to light-gray (N7) to brownish-gray (5YR4/1), weathers moderate brown (5YR4/4) to pale yellow brown (10YR6/2); siliceous to slightly calcareous; laminated to thin-bedded; porcellanite in upper half	22
111	Biomicrite, recrystallized, medium-light-gray (N6), weathers light gray (N7), pinkish gray (5Y8/1), light brown (5YR6/4); sandy laminae and thin irregular beds within limestone; unidentified recrystallized skeletal debris; beds 1 to 2 ft thick	22
110	Covered	9
109	Marble, medium-gray (N5), weathers pinkish gray (5YR8/1) to light gray (N7); sandy; siliceous at top; marker bed	2
	Offset 100 *Yards east for better exposures to ridge crest*	
108	Quartzite, sandstone, and porcellanite, light-gray (N7); weathers pale yellow brown (10YR6/2) to pale brown (5YR5/2-5YR3/2); laminated to thin-bedded; siliceous to very calcareous ($CaCO_3$ on microfractures?); porcellanitic in upper 12 ft	34
107	Covered	4
106	Sandstone, light-gray (N7), weathers light brown (5YR6/4); siliceous, hard	1
105	Covered	3
104	Micrite, recrystallized, medium-dark-gray (N4), weathers light gray (N7); silty, fine sand; beds 6 inches to 1 ft thick; forms top of ridge together with upper half of unit 103	4
103	Porcellanite, sandstone, siltstone, light-gray (N7) to light-greenish-gray (5G8/1), weathers light brown (5YR6/4) to moderate brown (5YR3/4) to pale brown (5YR5/2); ranges from siliceous to slightly to very calcareous; bedding ranges from laminated to 3 ft thick; minor thin marble beds interbedded; unit 70 percent exposed	52
102	Covered	8
101	Micrite, recrystallized; medium-gray (N5-N6), grayish-red (5R5/2), weathers light gray (N7) to light brown (5YR6/4); very sandy, silty; scattered siliceous streaks and nodules; sandy laminae; beds 2 to 3 ft thick	13

Unit	Lithology	Thickness (ft)
100	Mostly covered; 3 ft of slightly calcareous porcellanite exposed near middle of unit	13
99	Sandstone or sandy marble; very light gray (N8), weathers moderate brown (5YR4/4-5YR3/4); very calcareous; grades down to unit 98; massive, internally laminated sand	4
98	Marble, light-gray (N7); very sandy laminae, weathers dusky brown (5YR2/2) to pale brown (5YR5/2); sandstone bed ½ to 2 ft thick near middle of unit; beds ½ to 2 ft thick	21
97	Covered	12
96	Marble, medium-dark-gray to pale-brown (5YR5/2), weathers pale yellow brown (10YR6/2) to grayish orange pink (5YR7/2); beds 3 ft thick	8
95	Covered; thin- to medium-bedded silty, sandy limestone?	15
94	Micrite, recrystallized?, medium-light-gray (N6), weathers light gray (N7); siliceous laminae; unidentified spar-replaced skeletal? debris; single bed	3
93	Sandstone-siltstone, light-gray (N7), weathers light brown (5YR6/4); fine- to medium-grained sand; calcareous; laminated in part; soft sediment deformation; beds 6 inches to 1 ft thick	5
92	Mostly covered; occasional outcrop of sandy limestone beds 6 inches to 1 ft thick	18

NOTE—Several black shale beds 6 inches to 1 ft thick are exposed in canyon to east of section in the interval between units 124 and 92, probably occurring in the covered intervals noted above.

Unit	Lithology	Thickness (ft)
91	Marble, yellow-brown (10YR7/2), weathers light brownish gray (5YR6/1); very coarse grained; massive beds 3 to 4 ft thick; conspicuous marker bed forms light band on south slope of E-W trending ridge	30
90	Covered	6
89	Biomicrite, marbleized, medium-gray (N5), weathers medium light gray (N6); very sandy, silty zones weather dark yellow brown (10YR4/2); unidentified skeletal sand; local zones of poorly preserved, reworked? fusulinids (collected 1 mile west) and identified by W. E. King as *Triticites* and *Schwagerina;* beds about 2 ft thick	16
88	Biomicrite, recrystallized, medium-gray (N5), weathers medium light gray (N6); silty, occasional siliceous laminae and abundant chert nodules at top; unidentified skeletal sand debris; beds 6 inches to 2 ft thick	3
87	Covered	4
86	Like unit 85; dark-gray marker bed below light-gray marble	12
85	Marble, yellow-gray, (5Y8/1), weathers pale orange (10YR8/2); very coarse grained, massive, no visible bedding	17
84	Marble, medium-dark-gray (N4), weathers medium gray (N5); coarse-grained, sandy, base not exposed, poorly exposed; 1 to 2 ft thick beds	2
83	Marble, very light gray (N8), weathers pale yellow brown (10YR7/2); very coarse grained, massive, thick-bedded	11
82	Poorly exposed; porcellanite, light-gray (N7), weathers light brown (5Y6/4) to pale yellow brown (10YR6/2); abundant epidote; hard, dense; may be silicified	42
81	Like unit 83	54
80	Covered. Inferred major reverse fault in this interval; unknown amount of section omitted	30
79	Marble, very light gray (N8), weathers pale yellow brown (10YR6/2 to 10YR4/2); coarse-grained; very sandy thin beds and laminae; single bed	11
78	Covered	12
77	Marble, medium light-gray (N6), weathers light gray (N7); sandy laminae; single bed	1
76	Covered	4
75	Partly covered. Porcellanite, medium-light-gray (N6), weathers moderate yellow brown (10YR5/4-10YR4/2); pyrite disseminated, epidote, limonite on fractures	27
74	Marble, light-gray (N6-N7), coarse-grained; 10 percent sandy laminae; thin-bedded	3
73	Covered	9
72	Marble, light-gray (N7-N8); sandy, silty in many beds; medium-grained; beds 1 to 2 ft thick; distinct light colored unit	13
71	Quartzite and porcellanite, light-gray (N7) to light-greenish-gray (5G8/1), weathers pale yellow brown (10YR6/2) to very pale orange (10YR8/2); coarse to very fine grained sand; massive to laminated, abundant calc-silicate minerals, especially epidote	24
70	Covered	5
69	Micrite, recrystallized, light-gray, weathers pale yellow brown (10YR6/2) to dark yellow brown (10YR4/2); very sandy, parallel sand laminae; single bed	2
68	Covered	5
67	Micrite, recrystallized, medium-dark-gray (N4), weathers light gray (N7) at base to pale yellow brown (10YR6/2), very sandy limestone at top; uppermost 4 ft like unit 65	20
66	Covered	4
65	Micrite, recrystallized, and marble, medium-light-gray (N6) to light-gray (N7), weathers mottled light gray (N7), grayish orange (10YR7/4) and moderate orange pink (10R7/4); very sandy, silty laminae, siliceous flakes and veinlets; recrystallized biosparrudite lenses, fossils not identified; beds 1 to 2 ft thick	6
64	Quartzite, very light gray (N8), weathers very pale orange (10YR8/2), with desert varnish; calcareous; massive to thin-bedded; occasional lens of gray marble	7
63	Covered	9
62	Marble, medium-gray (N5), weathers mottled light gray (N7) to very pale orange (10YR8/2); coarse-grained, silty laminae	2
61	Covered	5
60	Like unit 64	16
59	Micrite, recrystallized, medium-light-gray (N6), weathers same; silty laminae and siliceous laminae; single bed	1
58	Quartzite, very light gray (N8), weathers very pale orange (10YR8/2); calcareous; muscovite on fractures; thin-bedded to laminated; fine- to medium-grained	11
57	Covered	3
56	Quartzite, like unit 58	1
55	Covered	4
54	Marble	2
53	Covered	5
52	Sandstone, light-green-gray (5GY8/1), weathers yellow gray (5Y8/1); very calcareous; coarse- to fine-grained, laminated to thin-bedded; possible arkose at top (feldspar altered to clay); calc-silicate alteration	26
51	Limestone, medium-light-gray (N6); marbleized; possible fossil fragments (algae?); single bed	1
50	Covered; 2-inch thick silty limestone in middle of unit	17
49	Limestone, medium-light-gray (N6), weathers light gray (N7); silty, laminated	8
48	Algal? biolithite, medium-gray (N5), weathers medium light gray (N6), with gray-orange (10YR 7/4) laminae; recrystallized stromatolitic algae?	1
47	Sandstone, yellow-gray (5Y8/1); fine-grained; calcareous; calc-silicate alteration; laminated to thin-bedded	16
46	Covered	5
45	Marble, moderate-red (5R4/6), weathers gray red (5R4/2); laminated sand layers; soft sediment deformation	2
44	Covered; distinctive very thinly laminated light- and dark-gray limestone that looks varved exposed in middle of unit	18

Unit	Lithology	Thickness (ft)
43	Marble, light-gray (N6-N8) to dark-reddish-brown (10YR3/4) to pale-orange (10YR8/2), weathers light gray (N7-N8) to pinkish gray (5YR8/1); massive with internal siliceous and silty laminae at base becoming laminated with fine sand at top	10
42	Marble, pale-red-purple (5RP6/2) to gray-orange (10YR7/4), weathers light brown (5YR6/4) to light gray (N7); patches of laminated siltstone within marble	2
41	Covered	13
40	Limestone, fine- to coarse-grained marble, medium-gray (N5) to medium-dark-gray (N4), weathers light gray (N7) to light brownish gray (5YR6/1); laminated, silty, especially at top; silt and fine sand laminae; beds 1 ft thick	21
39	Covered	2
38	Sandstone, and siltstone, medium-gray (N5-N6) to yellow-gray (5Y8/1), weathers very pale orange (10YR8/2) to gray orange (10YR7/4); very calcareous; laminated to thin-bedded; extensive calc-silicate alteration and disseminated pyrite; flaggy weathering	35
	Offset 100 yards to west across fault; may be a few ft cut out	
37	Like unit 38	74
36	Limestone, marbleized to very finely recrystallized, medium-gray (N5) weathers gray orange pink (5YR7/2); sandy and silty laminae and zones 1 to 2 inches thick within beds 4 inches to 1 ft thick; 50 percent sand	23
35	Limestone, medium-gray (N5) weathers yellow gray (5Y8/1); very sandy, grades to calcareous sandstone at top; horizontal laminations, local cross-beds?; massive beds	11
34	Micrite, medium-gray (N5), weathers mottled medium light gray (N6) and moderate yellow brown (10YR5/4); slightly sandy, metamorphic? mineral in upper 2 to 3 inches; beds 1 ft thick; marker bed	2
33	Limestone, light-gray (N7-N5), weathers gray orange (10YR7/4) to light gray with dark yellow orange (10YR6/6) laminae; finely recrystallized to marbleized, sandy laminae; some ½-inch porcellanite layers; soft sediment deformation; minor intraclastic zones; beds 4 inches to 2 ft thick	8
32	Siltstone and sandstone, medium-dark-gray (N4) to light-gray (N7), weathers gray orange pink (5YR7/2) to moderate brown (5YR3/4); noncalcareous; fine-grained; laminated; grades up to overlying limestone	7
31	Like unit 33	20
30	Covered	8
29	Limestone, finely recrystallized to marbleized, medium-light-gray (N6) weathers light olive gray (5Y6/1); sandy streaks and laminae; minor chert or porcellanite beds 1 to 2 inches thick; upper part of unit is very sandy, massive, coarse-grained and not laminated	16
28	Quartzite, yellowish-gray (5Y8/1) weathers moderate brown (5YR3/4) and light brown (5YR5/6); slightly calcareous, laminated within massive beds; calc-silicate alteration	6
27	Marble, pale-yellow-brown (10YR6/2), weathers pale orange (10YR8/2); thin-bedded to laminated	2
26	Covered	6
25	Like unit 28, except very calcareous	4
24	Limestone, recrystallized, medium-dark-gray (N4), weathers medium gray (N5), sandy, single bed	1
23	Like unit 28	3
22	Covered	7
21	Limestone, medium-dark-gray (N4), weathers medium light gray (N6); finely recrystallized	1
20	Quartzite and porcellanite, light-olive-gray (5Y6/1), weathers light brown (5YR6/4) alternating with dusky brown (5YR2/2); laminated to thin-bedded; cyclic coarse- to fine-grained; calc-silicate and carbonate secondary minerals	9
19	Quartzite and sandstone light-gray (N7); calcareous, very fine grained grading locally to sandy limestone; some beds of limonite-stained shale near middle of unit	5
18	Covered	21
17	Quartzite and porcellanite, light-greenish-gray (5GY 8/1) to light-gray (N8), weathers gray yellow pink (5YR7/2) to dark yellow brown (10YR2/2); laminated to thin-bedded; mica on bedding planes, calcareous; epidote	11
16	Covered	10
15	Limestone, recrystallized, medium-gray (N5), weathers pale yellow brown (10YR6/2) with laminae of medium gray (N5), and siliceous zones gray brown (5YR3/2); abundant sandy laminae and beds ½ to 2 inches thick; 50 percent sand	20
14	Limestone at base grading to sandstone at top; limestone is medium-light-gray (N6), weathering moderate yellow brown (10YR5/4) with dusky-red (10R2/2) laminae; upper sandstone is dark-greenish-gray (5GY4/1) to light-greenish-gray (5GY8/1), weathering dark greenish gray (5GY4/1); limestone is massive, sandy containing sandstone lenses; recrystallized; sandstone at top is very calcareous, laminated, fine to medium grained, and contains calc-silicate minerals	5
13	Covered	16
12	Marble, pale-yellow-brown (10YR6/2), weathers same; ghosts of intraclasts visible; sandy laminae, some recrystallized fossil fragments; single bed	5
11	Mostly covered; some laminated to thin-bedded quartzite and porcellanite with calc-silicate alteration present	16
10	Quartzite, light-gray (N7), weathers dusky red (10R2/2) to pale yellow brown (10YR6/2); thin-bedded to laminated, locally massive; very calcareous, much calc-silicate alteration; recrystallized limestone and porcellanite lenses in upper 7 ft	44
9	Quartzite-like unit 10 containing 1- to 5-inch beds of pale-yellow-brown (10YR6/2) to light-gray (N7) porcellanite weathering light brown (5YR6/4); no limestone lenses	22
8	Marble, medium-dark-gray (N4) to light-gray (N7), weathers light gray (N7) to medium gray (N5) and light brown (5YR6/4); scattered sandy laminae becoming sandier toward top; beds 1 to 3 ft thick; grades into overlying unit	22
7	Limestone, recrystallized, light-gray (N7); very sandy; sand present as laminae and lenses, weathering brown; calc-silicate minerals in sandy zones; thin- to medium-bedded	8
6	Covered	6
5	Sandstone grading to quartzite at top, light-olive-gray (5Y6/1), weathers yellow gray (5Y7/2); laminated to thin-bedded; calc-silicate minerals	15
4	Covered	2
3	Marble, medium-light-gray (N6), weathers light gray (N7); sandy, silty laminae; single bed	6
2	Covered	8
1	Sandstone grading to quartzite, light-gray (N7), weathers dusky red (10R2/2); very calcareous; contains recrystallized limestone lenses; laminated to thin-bedded; calc-silicate alteration	11
	Fault along axis of anticline; base of exposed section	

CONTENTS OF POCKET

Sheet 1–Geologic Map
Sheet 2–Structure sections and fig. 5
Sheet 3–Columnar sections

Type faces: Text–10pt. Times Roman, leaded one-point
Appendix–8pt. Times Roman, leaded one-point
Display heads–24pt. Times Roman, letterspaced

Presswork: Text–38" Miehle Offset
Cover–20" Harris Offset

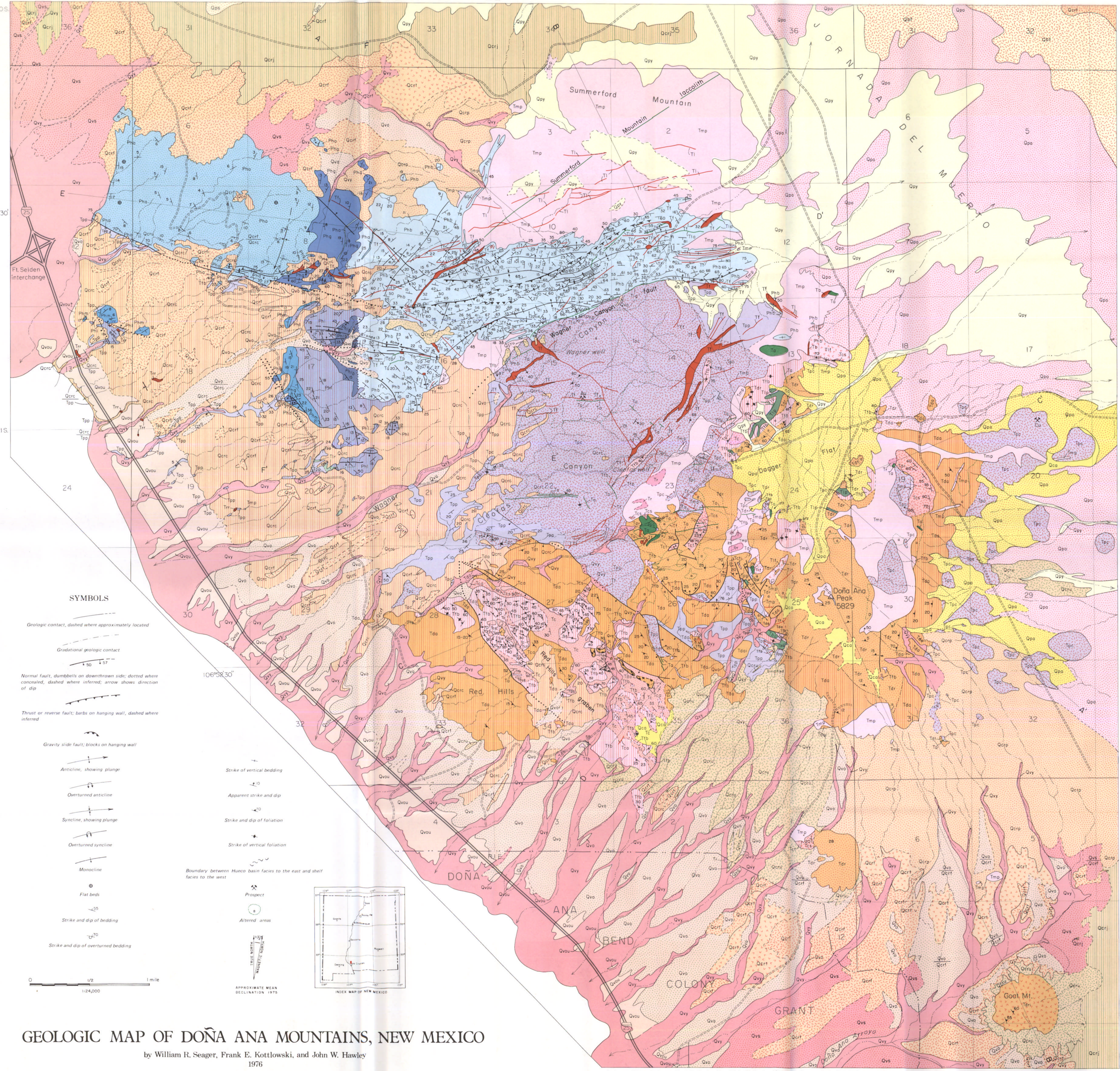
Binding: Saddlestitched

Stock: Text–70 lb. White Matte
Cover–65 lb. Hopsack

Inks: Text–Cal Mira-jet Black
Cover–Cal PMS

NEW MEXICO BUREAU OF MINES & MINERAL RESOURCES A DIVISION OF NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

CIRCULAR 147 SHEET 1



SYMBOLS

Geologic contact, dashed where approximately located

Gradational geologic contact

Normal fault, dumbbells on downthrown side; dotted where concealed, dashed where inferred; arrow shows direction of dip

Thrust or reverse fault; barbs on hanging wall, dashed where inferred

Gravity slide fault; blocks on hanging wall

Anticline, showing plunge

Overturned anticline

Syncline, showing plunge

Overturned syncline

Monocline

Flat beds

Strike and dip of bedding

Strike and dip of overturned bedding

Strike of vertical bedding

Apparent strike and dip

Strike and dip of foliation

Strike of vertical foliation

Boundary between Hueco basin facies to the east and shelf facies to the west

Prospect

Altered areas

GEOLOGIC MAP OF DOÑA ANA MOUNTAINS, NEW MEXICO

by William R. Seager, Frank E. Kottlowski, and John W. Hawley
1976

Geology by William R. Seager, Frank E. Kottlowski, and John W. Hawley, 1975 Cartography by Neila M. Pearson, 1976

EXPLANATION

QUATERNARY

MIDDLE PLEISTOCENE TO HOLOCENE

Valley fill

Qvy: *Younger channel, terrace, and fan alluvium of valley border; coarse to medium grained*

Qvs: *Alluvial-eolian complex of valley border; sandy deposits on Camp Rice fluvial facies* (Qcrf)

Qvo, Qvou: **Qvo:** *Older terrace and fan alluvium of valley border; coarse to medium grained, with thin, partly indurated zones of carbonate accumulation.* **Qvou:** *river deposits intertonguing with older alluvium* (**Qvo**)*; coarse to fine grained*

Basin fill

Qpy: *Younger piedmont-slope alluvium; like* Qvy

Qps: *Alluvial-eolian complex of piedmont slopes; sandy deposits on Camp Rice Formation* (Qcrj)

Qpo: *Older piedmont-slope alluvium; like* Qvo

Qbf: *Basin-floor sediments; fine-grained alluvial-flat and playa deposits on Camp Rice fluvial facies* (Qcrf)

Undifferentiated units

Qca, Qpa: **Qca:** *Colluvium on steep slopes, and alluvium of small upland valleys; coarse to medium grained.* **Qpa:** *complex of alluvial deposits on upper piedmont slopes; comprises a discontinuous cover of younger and older* (**Qpy** *and* **Qpo**) *alluviums inset against and burying Camp Rice* (**Qcrp** *and* **Qcru**) *alluvium; coarse to medium grained*

UNCONFORMITIES

LATE PLIOCENE TO MIDDLE PLEISTOCENE

Upper Santa Fe Group

Qcru, Qcrp, Qcrj, Qcrt, Qcrc, Qcrf

Camp Rice Formation

Qcrp: *Piedmont-slope alluvium, with paleosol zones; coarse to medium grained, with thin (<1m) zones of carbonate cementation.* **Qcrc:** *fanglomerate, carbonate-cemented, with local nonindurated zones.* **Qcru:** *piedmont alluvium and fanglomerate, undifferentiated.* **Qcrf:** *fluvial facies, ancestral river deposits; coarse to medium grained, generally nonindurated with local sandstone bodies.* **Qcrt:** *transition zone from fluvial to piedmont facies; fine to medium grained, toeslope deposits.* **Qcrj:** *sediments of relict Jornada Basin surface (La Mesa and Jornada I geomorphic surfaces); medium to fine grained, with thick (to 3m) zones of soil-carbonate accumulation that are partly indurated*

UNCONFORMITY

TERTIARY

MIOCENE

Tb: *Basalt porphyry*

OLIGOCENE

Mafic Intrusives

Ta: *Andesite dikes and plugs, central Doña Ana Mountains*

Tlp: *Melacratic latite porphyry dikes adjacent to Dagger Flat*

Tba: *Basaltic andesite plugs, south edge Doña Ana Mountains*

Tla: *Amethyst-bearing latite porphyry dikes, northern Doña Ana Mountains*

Tap: *Andesite porphyry dikes, Grande dome area (may be Cleofas Andesite)*

Felsic intrusives

Tl: *Rhyolite-trachyte porphyry dikes cutting* Tmp

Tf: *Felsite and fine-grained monzonite porphyry dikes; northern half of Doña Ana Mountains*

Trr: *Rhyolite porphyry (Robledo rhyolite), northwest Doña Ana Mountains*

Doña Ana cauldron fill

Tmp, Tlf: **Tmp:** *Monzonite porphyry.* **Tlf:** *latite porphyry facies*

Tfb: *Flow-banded rhyolite; includes small masses of vitrophyre*

Tc, Tcs, Tca, Tct, Tcti: **Tc:** *Younger cauldron fill; chaotic megabreccia and volcaniclastic sedimentary rocks associated with flow-banded rhyolite intrusions.* **Tcs:** *rhyolitic volcaniclastic sedimentary rocks and tuffs, including lithic ash-flow tuff* (**Tct**, *flow;* **Tcti**, *intrusive) and andesite flows and/or intrusions* (**Tca**)

Tdr, Tda, Tdai, Tdt, Tdri

Doña Ana Rhyolite

Tdt: *Basal air-fall tuff.* **Tda:** *lithic-crystal ash-flow tuff, moderately welded.* **Tdr:** *densely welded ash-flow tuff facies.* **Tdai:** *intrusive ignimbrite.* **Tdri:** *rhyolite-microsyenite plug-dome of Goat Mountain*

Tr: *Undifferentiated rhyolite*

UNCONFORMITY

EOCENE

Tpp, Tpc, Tlr

Palm Park Formation (Tpp); Cleofas Andesite (Tpc); Love Ranch Formation (Tlr)

UNCONFORMITY

PERMIAN

WOLFCAMPIAN

Shelf facies

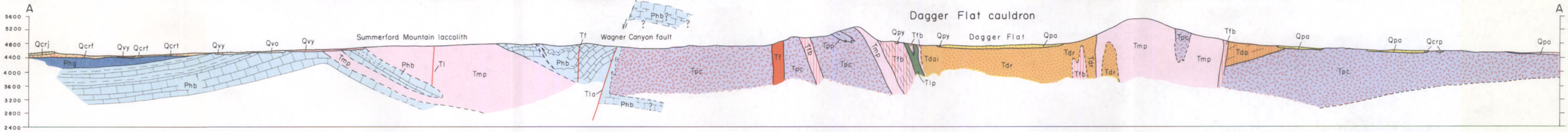
Pha
Phg
Phm
Phl
Phlb

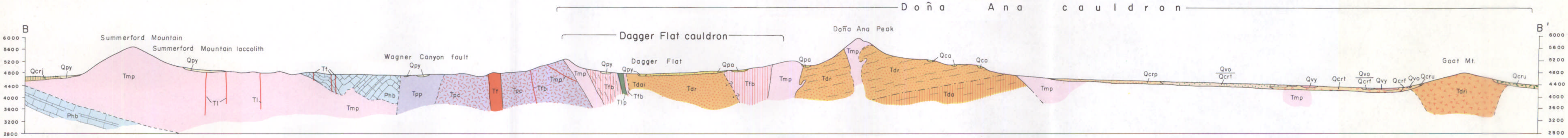
Basin facies

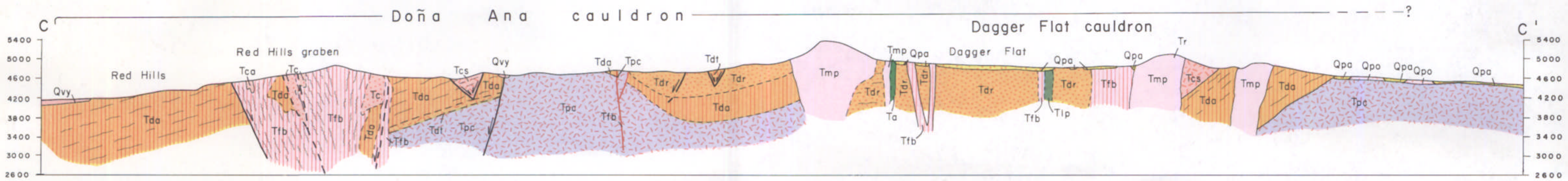
Pha
Phb

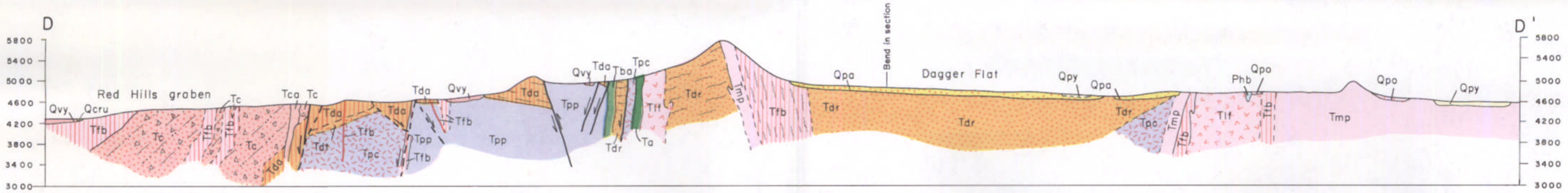
Hueco-Abo Formations

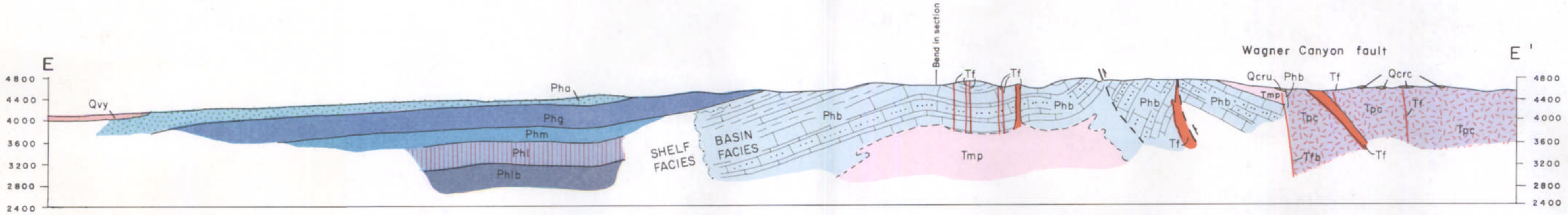
Pha: *Abo tongue.* **Phg:** *dark-gray, gastropod-bearing member.* **Phm:** *middle Hueco.* **Phl:** *lower Hueco.* **Phlb:** *lower Hueco or Bursum equivalent.* **Phb:** *Hueco basin facies*

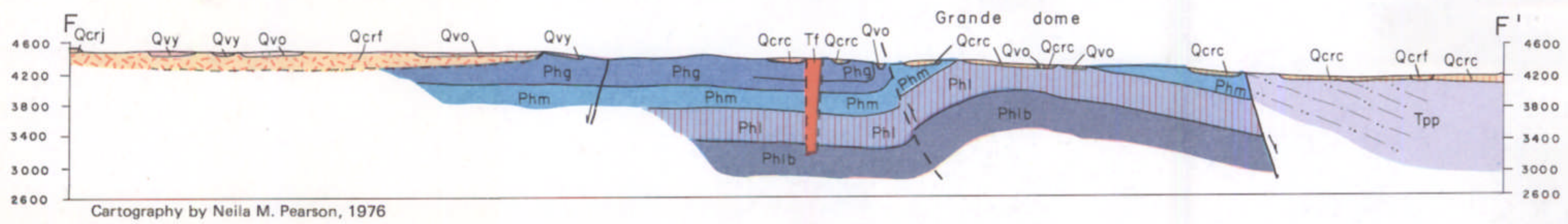




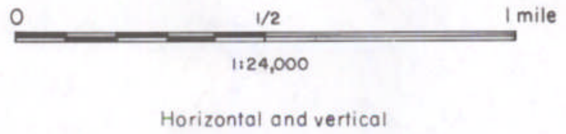








Cartography by Neila M. Pearson, 1976



STRUCTURE SECTIONS OF DOÑA ANA MOUNTAINS, NEW MEXICO

by William R. Seager, Frank E. Kottlowski, and John W. Hawley
1976

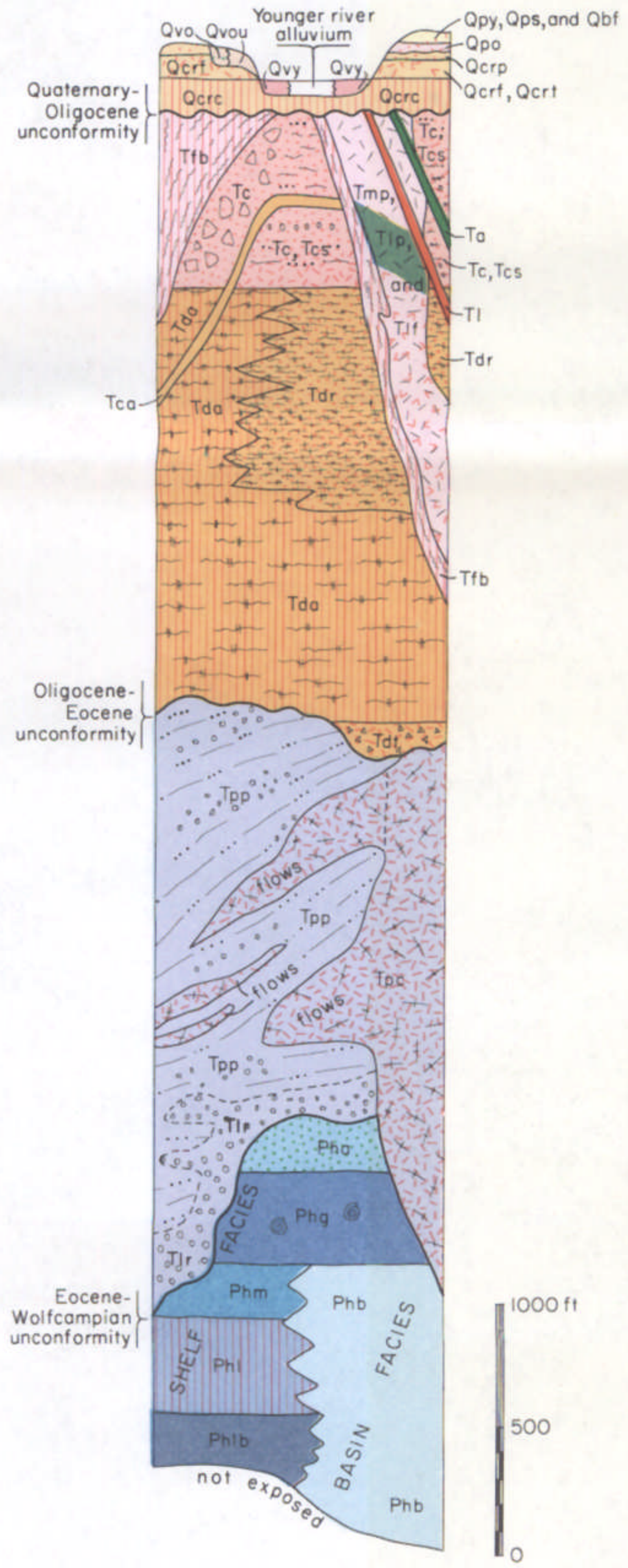


Fig. 5
COMPOSITE COLUMNAR SECTION
OF DOÑA ANA MOUNTAINS

COLUMNAR SECTIONS OF HUECO, ABO, AND BURSUM(?) FORMATIONS, DOÑA ANA MOUNTAINS, NEW MEXICO

by William R. Seager, Frank E. Kottlowski, and John W. Hawley

1976

Cartography by Neila M. Pearson, 1976